INTERNATIONAL RICE RESEARCH INSTITUTE

Annual Report for 1985

1986
INTERNATIONAL RICE RESEARCH INSTITUTE
Los Baños, Laguna, Philippines
P. O. Box 933, Manila, Philippines

Contents

TRUSTEES **vi**
PERSONNEL **vii**
ABOUT THIS REPORT **xiv**
ABBREVIATIONS AND ACRONYMS **xvi**
GENETIC EVALUATION AND UTILIZATION (GEU) PROGRAM
Genetic resources program **1**
Agronomic and physiological characteristics **7**
Grain quality and nutritional value **23**
Disease resistance **35**
Insect resistance **55**
Drought tolerance **67**
Adverse soils tolerance **81**
Deep water and flood tolerance **91**
Adverse temperature tolerance **99**
Innovative breeding methods **103**
Computerized data management **119**
Seed technology **123**
Integrated GEU program **125**
CONTROL AND MANAGEMENT OF RICE PESTS
Diseases **143**
Insects **155**
Weeds **177**
IRRIGATION WATER MANAGEMENT **193**
SOIL AND CROP MANAGEMENT
Soil characterization **211**
Management of soil and fertilizer nitrogen **217**
Nitrogen fixation and azolla management **239**
Management of organic manures **255**
Management of other nutrients **261**

Rice crop cultural practices 273
Tillage and management of soil physical conditions 279
CLIMATIC ENVIRONMENT AND RICE 305
CONSTRAINTS ON RICE YIELDS 321
CONSEQUENCES OF NEW TECHNOLOGY 345
CROPPING SYSTEMS PROGRAM
Analysis of the physical and biological environment 361
Analysis of the social and economic environment 365
Pest control in rice-based cropping systems 369
Design and evaluation of cropping patterns 381
Selecting and testing varieties for rice-based cropping systems 397
Agronomic management in rice-based cropping systems 401
Preproduction testing of improved cropping systems 429
MACHINERY DEVELOPMENT AND TESTING 433
TRAINING PROGRAMS 445
COOPERATIVE PROGRAMS
International Rice Testing Program 465
International Network on Soil Fertility and Fertilizer Evaluation for Rice 479
Asian Rice Farming Systems Network 489
Cooperative country projects 500
Communication and publications 519
Technology sharing 523
RESEARCH SUPPORT SERVICES 530
PUBLICATIONS AND SEMINARS 536
FINANCES 550
STAFF CHANGES 551
WEATHER SUMMARY 553

Trustees

DR. FORREST F. HILL
Chairman of the Board Emeritus
701 The Parkway
Ithaca, New York 14860, USA

DR. KENZO HEMMI
Chairman of the Board
1-12-42 Utsukushigaoka
Midoru-ku, Yokohama-shi
Japan 227

MIN. SALVADOR H. ESCUDERO III
Vice Chairman
Minister of Agriculture and Food
Ministry of Agriculture and Food
Diliman, Quezon City
Metro Manila
Philippines

MEMBERS

DR. M.S. SWAMINATHAN
Director General
International Rice Research Institute
P.O. Box 933
Manila, Philippines

MRS. TAHRUNNESSA A. ABDULLAH
4-B Amynabad Co-operative Housing Society
Siddheswari, Dhaka 17
Bangladesh

ATTY. EDGARDO J. ANGARA
President
University of the Philippines System
Diliman, Quezon City
Metro Manila, Philippines

DR. ALMIRO BLUMENSCHEIN
Director
Centro Nacional de Pesquisa-Arroz Feijão
Caixa Postal 179
Goiania, Goias, Brazil

DR. NORMAN R. COLLINS
Program Officer-in-Charge
The Ford Foundation
320 East 43rd Street
New York, N.Y. 10017, USA

DR. ROBERT K. CUNNINGHAM
35 Clarence Road
Harpenden
Harts ALS 4AH
England

DR. LLOYD T. EVANS
Division of Plant Industry
Commonwealth Scientific and Industrial Research Organization
P.O. Box 1600
Canberra City, ACT 2601
Australia

DR. JAAP J. HARDON
Director for Agricultural Research
Ministry of Agriculture and Fisheries
Wageningen Office
Mansholtlaan 4, Wageningen
The Netherlands

DR. LETITIA E. OBENG
56 West Park Avenue
Kew, Surrey
United Kingdom

DR. IDA NYOMAN OKA
Bogor Research Institute for Food Crops (BORIF)
Jalan Merdeka 99
Bogor, Indonesia

DR. M.V. RAO
Deputy Director General
Indian Council of Agricultural Research
Krishi Bhavan, New Delhi
India

MR. YOOKTI SARIKAPHUTI
Director General
Department of Agriculture
Ministry of Agriculture and Cooperatives
Bangkok, Thailand

DR. XU GUAN-REN
Director General Emeritus
Institute for Application of Atomic Energy in Agriculture
Chinese Academy of Agricultural Sciences
P.O. Box No. 5109, Beijing, China
or Ma-Lian-Wa, Beijing, China

Personnel

OFFICE OF THE DIRECTOR GENERAL

M. S. Swaminathan, *Ph D, director general*
Marcos R. Vega, *Ph D, deputy director general*
Dennis J. Greenland, *D Phil, deputy director general*
Mano D. Pathak, *Ph D, director, research and training*
Hugh T. Murphy, *MBA, director, administration*[1]
Faustino M. Salacup, *BS, CPA, director, protocol and liaison*
Paul A. Cooper, *BA, director, budget and accounts*
J. Ritchie Cowan, *Ph D, consultant*[1]
Yoshiko Yamamoto, *MA, consultant*[1]
R. Vaidyanathan, *Cert. Accountancy, consultant*[4]

ADMINISTRATIVE AND PROFESSIONAL STAFF

Rebecca C. Pascual, *MS, manager, food and housing services*
Zosimo Q. Pizarro, *LLB, manager, personnel and legal offices*
Pedro G. Banzon, *LLB, manager, security and purchasing/shipping offices*
Purita M. Legaspi, *BBA, CPA, manager, accounting office*

LIAISON SCIENTISTS

Manuel J. Rosero, *Ph D, IRRI liaison scientist, Latin America*
Walter C. Tappan, *BS, IRRI liaison scientist, Indonesia and Malaysia*
Dioscoro L. Umali, *Ph D, IRRI liaison scientist, China (consultant)*
Kaung Zan, *Ph D, IRRI liaison scientist, Africa*[1]
S. M. H. Zaman, *Ph D, IRRI liaison scientist, Africa*[1]

COOPERATIVE RESEARCH STAFF

AFRICA

Kaung Zan, *Ph D, IRRI liaison scientist*[1]
S. M. H. Zaman, *Ph D, IRRI liaison scientist*[4]

BANGLADESH

Frank W. Sheppard, Jr., *D Ed, research systems specialist/IRRI representative*
C. Thomas Brackney, *MS, rice production specialist*[1]
Dwight G. Kanter, *Ph D, plant breeder*
Noel P. Magor, *M Agr, associate agronomist*[4]

BURMA

Malcolm M. Hammond, *Dip. Agr. E., agricultural engineer*[1]
Pedro B. Escuro, *Ph D, plant breeder*[1]
Rosendo K. Palis, *Ph D, agronomist*[1]

CHINA

Dioscoro L. Umali, *Ph D, IRRI liaison scientist (consultant)*

EGYPT

Ebrahimali A. Siddiq, *Ph D, plant breeder*
Leo Dale Haws, *Ph D, rice production training specialist*[1]
Salvador C. Labro, *MS, mechanization specialist*[1]

INDIA

Fred E. Nichols, *BS, agricultural engineer*

INDONESIA

Walter C. Tappan, *BS, IRRI liaison scientist*
Jerry L. McIntosh, *Ph D, agronomist*
Venkat R. Reddy, *MS, agricultural engineer*[1]

JAPAN

Y. Takahashi, *D Agr, part-time IRRI representative*

LATIN AMERICA

Manuel J. Rosero, *Ph D, IRRI liaison scientist*

MALAGASY

B. B. Shahi, *Ph D, plant breeder*
James R. Hoopper, *Ph D, agronomist*
Michael Loevinsohn, *Ph D, consultant*[1]

PHILIPPINES

Robert E. Stickney, *Ph D, agricultural engineer*
Dennis M. Wood, *Ph D, crop production specialist*[1]

THAILAND

Donald W. Puckridge, *Ph D, agronomist*
H. David Catling, *Ph D, entomologist*[1]
Billy J. Cochran, *Ph D, agricultural engineer*[1]

SENIOR SCIENTIFIC STAFF

Agricultural economics

John C. Flinn, *Ph D, agricultural economist and head*
Cristina C. David, *Ph D, agricultural economist*
J. Bart Duff, *MS, agricultural economist*
Leonardo A. Gonzales, *Ph D, agricultural economist*
Edwin C. Price, *Ph D, agricultural economist*[1]
Marlin G. van der Veen, *Ph D, agricultural economist*
Gelia T. Castillo, *Ph D, visiting scientist*[4]
Harold C. Conklin, *Ph D, honorary visiting research associate*
Robert E. Huke, *Ph D, visiting scientist*[1]
Albert Polak, *Ph D, visiting anthropologist*
Joyotee Smith, *Ph D, visiting associate agricultural economist*[1]
Amanda Te, *Ph D, visiting associate agricultural economist*[1]
Laurian J. Unnevehr, *Ph D, visiting associate agricultural economist*[1]
Jennie Dey *Ph D, consultant*[1]
Violeta Cordova, *MS, assistant scientist*
Abraham Mandac, *MS, assistant scientist*
Pedro Bueno, *MS, assistant scientist*
Piedad Moya, *MS, senior research assistant*
Nicostrato Perez, *MS, senior research assistant*
Thelma Paris, *MS, senior research assistant*
Nicanor Roxas, *MS, senior research assistant*[1]
Gloria Umali, *MS, senior research assistant*[1]
Lourdes Velasco, *MS, senior research assistant*
Ernesto Bautista, *MS, senior research assistant*[6]
Ricardo Guino, *MS, senior research assistant*
Mary Jane Novenario, *MS, senior research assistant*[4]
Anita Frio, *BS, research assistant*
Adelita Palacpac, *BS, research assistant*
Estrella Antonio, *BS, research assistant*
Raymundo Gonzaga, *BS, research assistant*

Julius Feraren, *BS, research assistant*
Vivencio Marfori, *BS, research assistant*
Constancia Maranan, *MS, research assistant*
Leonida Yambao, *BS, research assistant*
Luisa Bambo, *BS, research assistant*
Vivencio Marciano, *BS, research assistant*
Policarpio Masicat, *BS, research assistant*
Fe Gascon, *BS, research assistant*
Cresencia Bantilan, *BS, research assistant*
Gloria Mañoza, *BS, research assistant*
Agnes S. Arante, *BS, research assistant*[7]
Mary Jean Lim, *BS, research assistant*[4]
Leonarda Ebron, *MS, research assistant*[7]
Fleurdeliz Juarez, *MS, research assistant*[7]
Celerina Maranan, *BS, research assistant*[7]
Leticia Pua, *MS, research assistant*[1,6]
Leah Aceña, *BS, research assistant*[1,6]
May Mercado, *BS, research assistant*[7]
Clemen Gonzales, *MS, research assistant*[6]
Lolita Garcia, *BS, research aide*[6]
Esther Marciano, *BS, research aide*[2]
Aida Papag, *BS, research aide*
Milagros Obusan, *BS, research aide*
Venancio Acebedo, *BS, research aide*[6]
Celia Opeña, *BS, research aide*[7]
Macario Genesila, *BS, research aide*[6]
Cristina Austria, *BS, research aide*[4,6]
Cristina Carpio, *BS, research aide*[4,6]
Myra Gina Palacpac, *BS, research aide*[6]

Agricultural engineering

Clarence W. Boekhop, *Ph D, agricultural engineer and head*
Makoto Ariyoshi, *MS, agricultural engineer*[1]
Amir U. Khan, *Ph D, agricultural engineer*
Billy J. Cochran, *Ph D, agricultural engineer*[1,5]
Malcolm M. Hammond, *Dip Agr. E., agricultural engineer*[1,5]
Fred E. Nichols, *BS, agricultural engineer*[5]
Venkat R. Reddy, *MS, agricultural engineer*[1,5]
Robert E. Stickney, *Ph D, agricultural engineer*[5]
M. A. Choudhary, *Ph D, visiting associate scientist*[1]
Yong Woon Jeon, *Ph D, visiting associate agricultural engineer*[6]
Salvador C. Labro, *MS, mechanization specialist*
Ignacio C. Manalili, *BS, assistant engineer*
Alejandro L. Caballes, *MS, senior research assistant*
Lawrence C. Kiamco, *BS, senior research assistant*
Pilar C. Lim, *MS, senior research assistant*[1]
Godofredo C. Salazar, *MS, senior research assistant*[6]
Mamerto M. Aban, *MS, research assistant*
Agnes S. Arante, *BS, research assistant*[7]
Eulito U. Bautista, *MS, research assistant*
Rustico C. Bautista, *BS, research assistant*[6]
Alexis T. Belonio, *BS, research assistant*[6]
Edwin J. Calilung, *MS, research assistant*
Miguelito S. Diestro, *BS, research assistant*
Leonarda Z. Ebron, *MS, research assistant*[7]
Leonides S. Halos, *MS, research assistant*
Fleurdeliz S. Juarez, *MS, research assistant*[7]
Herbert T. Manaligod, *BS, research assistant*[6]
Celerina L. Maranan, *BS, research assistant*[7]
Alfredo M. Mazaredo, *BS, research assistant*
Artemio B. Vasallo, *BS, research assistant*
Arnold R. Elepaño, *BS, research aide*[4]

Agronomy

Surajit K. De Datta, *Ph D, agronomist and head*
Cezar P. Mamaril, *Ph D, agronomist*
Keith Moody, *Ph D, agronomist*
Keith T. Ingram, *Ph D, associate agronomist*[4]
Donald W. Puckridge, *Ph D, agronomist*[5]
Roland J. Buresh, *Ph D, visiting scientist*
P. C. Gupta, *Ph D, visiting scientist*[1]
Robert L. Zimdahl, *Ph D, visiting scientist*[1]
Jose A. Malabuyoc, *MS, assistant scientist*
Ernesto L. Aragon, *MS, assistant scientist*
Wenceslao P. Abilay, Jr., *MS, senior research assistant*[5]
Serafin T. Amarante, *MS, senior research assistant*
Paul C. Bernasor, *MS, senior research assistant*
Alfredo N. Calendacion, *MS, senior research assistant*
Felipe V. Garcia, *MS, senior research assistant*[5]
Wilma N. Obcemea, *MS, senior research assistant*
Jovencio M. Alcantara, *BS, research assistant*[5]
Jenny C. Calabio, *MS, research assistant*
Ernesto G. Castillo, *MS, research assistant*
Eduardo M. Castin, *BS, research assistant*
Rebecca Salome C. Chavez, *BS, research assistant*
Teresita T. Chua, *BS, research assistant*[4]
Bernabe S. Cia, *BS, research assistant*
Rolando T. Cruz, *MS, research assistant*
Marilou del Rosario, *BS, research assistant*[1]
Josue P. Descalsota, *BS, research assistant*
Patricio C. Elliot, *MS, research assistant*[5,6]
Rowena C. Evangelista, *MS, research assistant*
Evelyn V. Flordeliz, *MS, senior research assistant*
Carmelene M. Gorostiza, *BS, research assistant*[4]
Joel D. Janiya, *MS, research assistant*
Eufrocino V. Laureles, *MS, research assistant*
Rosario T. Lubigan, *BS, research assistant*
Maxima O. Mabbayad, *MS, research assistant*
Manolo A. Maguling, *BS, research assistant*
Teodoro R. Migo, *BS, research assistant*
Domingo C. Navarez, *BS, research assistant*
Ricardo P. Novero, *BS, research assistant*
Paquito P. Pabico, *MS, research assistant*
Jaime L. Padilla, *MS, research assistant*
Joselito G. Real, *BS, research assistant*
Cristoti A. Redulla, *BS, research assistant*
Rogelio T. Rosales, *MS, research assistant*
Marianne I. Samson, *BS, research assistant*
Elizabeth B. Yambao, *MS, research assistant*
Leopoldo F. Estorninos, Jr., *MS, research assistant*
Victoria N. Caenio, *M Agr, research assistant*[4]
Marian A. Flagas, *MS, research assistant*[6]
Rodolfo R. Villapando, *BS, research assistant*[1]
Ferdinand F. Fajardo, *BS, research aide*[5,6]
Rodrigo M. Gusto, *BS, research aide*
Isabel C. Reyes, *BS, research aide*[6]
Marilyn S. Cabiera, *BS, research aide*[6]

Cereal chemistry

Bienvenido O. Juliano, *Ph D, chemist and head*
Consuelo M. Perez, *MS, assistant scientist*
Milagros R. Momongan, *MS, senior research assistant*[1]
Corazon P. Villareal, *MS, senior research assistant*
Ma. Luisa Francisca C. Balasta, *BS, research assistant*
Ma. Gracia B. Ibabao, *MS, research assistant*
Susan F. Villanueva, *BS, research assistant*[4]

Communication and publications

Thomas R. Hargrove, *Ph D, editor and head*
William H. Smith, *BS, editor*
Edwin A. Tout, *MA, associate editor*
Lloyd R. Bostian, *Ph D, visiting editor*[1]
Ian Montagnes, *MA, visiting editor*[4]
Ramiro C. Cabrera, *BFA, assistant manager*
Marcelo B. Pamulaklakin, *BS, administrative assistant*
Corazon V. Mendoza, *MS, assistant editor*[1]
Gloria S. Argosino, *MA, assistant editor*
Emerita P. Cervantes, *M Ed, assistant editor*
Urbito T. Ongleo, *BS, photography supervisor*
Edito S. Rufon, *senior printing supervisor*
Benedict P. Nadal, *BFA, audiovisual supervisor*
Fidelito E. Manto, *graphics supervisor*[1]
Arturo V. Africa, *graphics supervisor (typesetting)*
Victoria L. Cabanilla, *MS, senior research assistant*
Conrado G. Regala, *senior graphics assistant (typesetting)*
Melita Q. Magsino, *AB, senior graphics assistant*
Ma. Elena P. Dayrit, *BFA, senior graphics assistant*
Patricio O. Mamon, *BS, senior graphics assistant*
Edgardo M. Delfino, *BS, senior illustrator*
Gladys T. Balacuit, *BFA, senior illustrator*
Rafael Ma. Salvador T. Isberto, *BFA, illustrator*[1]
Cecilio L. Palacpac, Jr., *senior printer*
Rogelio M. Alfonso, *senior printer*
Erlie E. Putungan, *BS, graphics assistant (typesetting)*
Ma. Lourdes V. de Guzman, *AB, graphics assistant*[4]
Celso Amutan, *AB, graphics assistant*[4]
Philip Ch. Flores, *audiovisual assistant*[6]
Marieta Manza, *BS, audiovisual assistant*
John B. Figarola, *senior illustrator*[6]
Simeon N. Tapiz, *senior photographer*
Lingkod C. Sayo, *BS, senior photographer*
Jose E. Reyes, Jr., *photographer*
Bartolome B. Vibal, *photographer*
Danilo N. Antonio, *senior printer*
Eduardo F. Palisoc, *printer*
Justiniano R. Acosta, *printer*
Reynaldo Stevens, *printer*

Computer center

Sean E. O'Connor, *BS, consultant*
Angelito G. Bernardo, *BS, senior research assistant*
Flora Marinela D. Gamo, *BS, research assistant*
Celeste L. Saludo, *BS, research assistant*[1]
Ma. Fe Dei M. Maguyon, *BS, research assistant*[4]
Luisa C. Tiongco, *BS, research assistant*[4]
Wenceslao C. Alimagno, *BS, research assistant*
Amor A. Lazaro, *BS, research aide*[4]

Entomology

Elvis A. Heinrichs, *Ph D, entomologist and head*[1]
B. Merle Shepard, *Ph D, entomologist and head*
James A. Litsinger, *Ph D, entomologist*
Osamu Mochida, *D Agr, entomologist*
Ramesh C. Saxena, *Ph D, entomologist*
H. David Catling, *Ph D, entomologist*[1,5]
Daniel Dale, *Ph D, visiting scientist*
Earl H. Tryon, *Ph D, visiting associate scientist*[8]
Michael Loevinsohn, *Ph D, consultant*[1,5]
Filomeno Medrano, *MS, assistant scientist*
Gerardo Aquino, *MS, assistant scientist*
Remedios Aguda, *MS, senior research assistant*
Carlos Vega, *MS, senior research assistant*
Herminia Rapusas, *MS, senior research assistant*
Edralina Baldos-Medina, *MS, senior research assistant*
Angelita Romena, *MS, senior research assistant*
Gertrudo Arida, *MS, senior research assistant*
Alberto Barrion, *MS, senior research assistant*
Jovito Bandong, *MS, senior research assistant*[5]
Vicente Viajante, *MS, senior research assistant*
Salvador Valencia, *MS, senior research assistant*
Lourdes Sunio, *BS, senior research assistant*
Patrocinio Pantua, *MS, research assistant*
Isaias Domingo, *BS, research assistant*
Lilia Fabellar, *MS, research assistant*
Crispin dela Cruz, *MS, research assistant*[5]
Virginia Magalit, *MS, research assistant*
Eleanor Ferrer, *MS, research assistant*
Jesusa Crisostomo, *MS, research assistant*[4]
Alfonso Dulay, *BS, research assistant*
Ruperto Basilio, *BS, research assistant*
Nora Peña, *BS, research assistant*
Hilario Justo, Jr., *BS, research assistant*[6]
Serapio de Sagun, *BS, research assistant*
Jose Soriano, Jr., *BS, research assistant*
Maria Austria, *BS, research assistant*
Belen Rueda, *BS, research assistant*[6]
Rodelio Macatula, *BS, research assistant*
Kristian Manalili, *BS, research assistant*
Elisa Camañag, *BS, research assistant*
Bernard Canapi, *BS, research aide*[5,6]
Danilo Dimaano, *BS, research aide*[1,6]
Dominiciano Estano, *BS, research aide*
Macario Parducho, *BS, research aide*[5,6]
Myrth Velasco-Soriano, *BS, research aide*[6]
Edgar Libetario, *BS, research aide*[5,6]
Elsa Rubia, *BS, research aide*
Rodolfo Apostol, *research aide*[1]
Hazel Tababa, *BS, research aide*[4,6]

Integrated experimental farm and grounds

Federico V. Ramos, *MS, farm superintendent*[1]
Orlando G. Santos, *MPS, farm and grounds superintendent*
Juan M. Lapis, *MS, assistant farm superintendent*
Filomeno O. Tanting, *MS, senior farm supervisor*
Reynaldo C. Aranda, *BS, farm supervisor*
Celso C. Salamatin, *BS, farm supervisor*

Edwin B. Nuevo, *BS, farm supervisor*
Zacarias D. Dacula, *BS, farm supervisor*
Jose R. Tagaro, Jr., *BS, farm supervisor*
Loreto B. Aclan, *BS, junior farm supervisor*
Eladio M. Baradas, *MS, senior grounds supervisor*
Nestor C. Gonzales, *grounds supervisor*
Fabian B. Alcantara, *grounds supervisor*
Florencio D. Revilleza, *grounds supervisor*

International rice germplasm center

Te-Tzu Chang, *Ph D, principal geneticist and head*
Liwayway M. Engle, *Ph D, visiting scientist*[4]
Genoveva C. Loresto, *MS, assistant scientist*
Mercedes B. Parker, *MS, assistant scientist*
Oscar O. Tagumpay, *BS, senior research assistant*
Flora Credo, *MS, research assistant*
Rogelio Parreño, *BS, research assistant*
Rizalino Portes, *BS, research assistant*
Verena Tolentino, *BS, research assistant*
Carina Zuño, *BS, research assistant*
Ma. Socorro Almazan, *BS, research aide*
Tomas Clemeno, *BS, research aide*
Myrna Diaz, *BS, research aide*[4]
Marcelo Espiritu, *BS, research aide*
Julie Godilano, *BS, research aide*
Margarito Obien, *BS, research aide*
Renato Reaño, *BS, research aide*

International rice testing program

V. Seshu Durvasula, *Ph D, plant breeder and global coordinator*
Muhammad Akbar, *Ph D, plant breeder*[4]
Dennis P. Garrity, *Ph D, associate agronomist*[9]
Anwar A. Khan, *Ph D, visiting scientist*[4]
Keung Zan, *Ph D, visiting scientist*[3,5]
Torcito T. Ebron, Jr., *BS, senior research assistant*
Mario M. Movillon, *MS, research assistant*
Patricio C. Agustin, *MS, research assistant*[9]
Edilberto D. Redona, *MS, research assistant*[4]
Victoria C. Lopez, *BS research assistant*
Paul Cornelio T. Maturan, *BS, research assistant*
Frisco M. Malabanan, *BS, research assistant*
Imelda P. Malabanan, *BS, research assistant*
Evelyn A. Torres, *BS, research assistant*

Library and documentation center

Lina M. Vergara, *MS, librarian and head*
Y. Takahashi, *D Agr, part-time IRRI representative*[5]
Milagros C. Zamora, *MS, assistant librarian*
Mila M. Ramos, *MLS, assistant librarian*
Carmelita S. Austria, *MLS, senior library supervisor*
Elaine H. Enriquez, *BLS, library supervisor*
Editha S. Lantican, *MLS, library supervisor*
Kazuko Morooka, *BA, indexer (in Japan)*
Yuko Tasajima, *BS, indexer (in Japan)*

Multiple cropping

Richard A. Morris, *Ph D, agronomist and head*
Dennis P. Garrity, *Ph D, associate agronomist*[9]
O. P. Meelu, *Ph D, visiting scientist*
Leonard R. Oldeman, *Ph D, visiting scientist*[1]
Chirtchart Smitobol, *Ph D, visiting scientist*[5]
Wilhelmino A.T. Herrera, *MS, assistant scientist*
Hermenegildo C. Gines, *MS, senior research assistant*
Manuel M. Tamisin, *MS, senior research assistant*
Roberto T. Bantilan, *MS, senior research assistant*
Benigno T. Samson, *MS, senior research assistant*
Teresita S. Laudet, *MS, senior research assistant*
Rogelio D. Magbanua, *MS, senior research assistant*
Romulo E. Furoc, *MS, senior research assistant*
Samuel P. Liboon, *BS, research assistant*
Rolando O. Torres, *MS, research assistant*
Cecilia H. Reyes, *BS, research assistant*
Anacorita N. Villegas, *MS, research assistant*
Patricio C. Agustin, Jr., *MS, research assistant*[9]
Victor A. Quimsing, *MS, research assistant*[10]
Bienvenido P. Garrote, *MS, research assistant*[6]
Maridelle A. Dizon, *BS, research aide*
Zenaida P. Pascual, *BS, research aide*
Rogelio G. Pernito, *BS, research aide*[6]
Narciso A. Edillo, *BS, research aide*[6]
Anastacia P. Aclan, *BS, research aide*
Helen-Grace S. Centeno, *BS, research aide*
Bettina R. Santos, *BS, research aide*[6]
Reynaldo C. Rodriguez, *BS, research aide*

Pesticide residue laboratory

Bienvenido O. Juliano, *Ph D, cereal chemist*
Redentor A.R. Natividad, *BS, research assistant*
Elizabeth F. Acedo, *BS, research assistant*[4]
Aurora M. Argente, *MS, research assistant*
Jocelyn V. Uichanco, *BS, research assistant*[1]

Phytotron

Benito S. Vergara, *Ph D, plant physiologist*
Celestino T. Rivera, *MS, assistant scientist*
Bienvenido B. Manimtim, *BS, research assistant*

Plant breeding

Gurdev S. Khush, *Ph D, plant breeder and head*
Derk HilleRisLambers, *Ph D, plant breeder*
Sant S. Virmani, *Ph D, plant breeder*
David J. Mackill, *Ph D, associate plant breeder*
Tsugufumi Ogawa, *D Agr, associate plant breeder*[3]
D. Senadhira, *Ph D, associate plant breeder*
Pedro B. Escuro, *Ph D, plant breeder*[1,5]
Dwight G. Kanter, *Ph D, plant breeder*[5]
B. B. Shahi, *Ph D, plant breeder*[5]
Ebrahimali A. Siddiq, *Ph D, plant breeder*[5]
Michel A. Arraudeau, *MS, visiting scientist*
Chung Ik-Cho, *Ph D, visiting scientist*
R. N. Kaw, *Ph D, visiting scientist*
R. Thakur, *Ph D, visiting scientist*[4]
Jean-Christophe Glaszmann, *Ph D, visiting associate scientist*[4]
Rodolfo C. Aquino, *MS, assistant scientist*[2]
Eleuterio M. Mendoza, *MS, assistant scientist*[1]
Jose C. de Jesus, Jr., *MS, assistant scientist*
Rizal M. Herrera, *BS, assistant scientist*

Vicente T. Librojo, Jr., *MS, senior research assistant*
Regina D. Dalmacio, *MS, senior research assistant*
Enrique R. Angeles, *MS, senior research assistant*
Normita M. de la Cruz, *BS, senior research assistant*
Felipe B. Lasala, *BS, senior research assistant*
Heraldina R. Salonga, *BS, research assistant*[11]
Alicia V. Alzona, *BS, research assistant*[6]
Emmanuel N. Sison, *BS, research assistant*[6]
Esperanza H. Bacalangco, *BS, research assistant*
Presquito A. Aurin, *MS, research assistant*
Benito U. Romena, *BS, research assistant*
Antonio A. Evangelista, *BS, research assistant*
Modesto M. Amante, *BS, research assistant*
Alicia A. Capiral, *BS, research assistant*
Nestor R. Baraoidan, *BS, research assistant*
Alma L. Librojo, *MS, research assistant*
Georgina V. Vergara, *MS, research assistant*[4,6]
Rodolfo S. Toledo, *BS, research assistant*[4,6]
Carlos L. Casal, Jr., *BS, research aide*
Norvie L. Manigbas, *BS, research aide*
Alvaro M. Pamplona, *BS, research aide*
George A. Busto, Jr., *BS, research aide*
Paulino D. Tenorio, Jr., *BS, research aide*
Oscar D. Edralin, *BS, research aide*[4]
Silvino B. Calvero, *BS, research aide*[4,6]
Jose P. Roxas, *BS, research aide*[4]

Plant pathology
Twng-Wah Mew, *Ph D, plant pathologist and head*
Hiroyuki Hibino, *D Agr, plant pathologist*
J. Michael Bonman, *Ph D, associate plant pathologist*
Lina L. Ilag, *Ph D, visiting scientist*[4]
Arcadio J. Quinto, *Ph D, visiting scientist*[4]
P. Vidyasekaran, *Ph D, visiting scientist*[1]
Sang-Won Ahn, *Ph D, visiting associate plant pathologist*[4]
Fausto L. Nuque, *MS, assistant scientist*
Jose M. Bandong, *MS, assistant scientist*
Bienvenido A. Estrada, *MS, assistant scientist*
Francisco A. Elazegui, *MS, assistant scientist*
Emmanuel R. Tiongco, *MS, assistant scientist*
Vladimarte M. Aguiero, *MS, senior research assistant*
Pepito Q. Cabauatan, *MS, senior research assistant*
Casiana M. Vera Cruz, *MS, senior research assistant*
Rogelio C. Cabunagan, *MS, research assistant*
Claro Q. Torres, *MS, research assistant*
Renato C. Reyes, *MS, research assistant*
Marietta R. Baraoidan, *MS, research assistant*
Teresita I. Vergel de Dios, *MS, research assistant*
Emerlito S. Borromeo, *MS, research assistant*
Byron L. Candole, *MS, research assistant*
Teodoro C. Aballa, *MS, research assistant*
Avelita M. Rosales, *MS, research assistant*
Alita O. Mackill, *MS, research assistant*
Edna Y. Ardales, *MS, research assistant*[4]
Guillermo Z. Salamat, Jr., *BS, research assistant*
Ricardo D. Daquioag, *BS, research assistant*
Sonia P. Ebron, *BS, research assistant*
Nestor G. Fabellar, *BS, research assistant*
Zenaida M. Flores, *BS, research assistant*
Filomena C. Sta. Cruz, *BS, research assistant*
Leandro M. Sanchez, *BS, research assistant*
Marichu E. Alvenda, *BS, research aide*
Gilda B. Jonson, *BS, research aide*
Robert C. de la Peña, *BS, research aide*

Plant physiology
Benito S. Vergara, *Ph D, plant physiologist and head*
Shigemi Akita, *D Agr, plant physiologist*
Genshichi Wada, *D Agr, plant physiologist*[4]
Francisco J. Zapata, *Ph D, associate plant physiologist*
D. S. Brar, *Ph D, visiting scientist*[1]
S. T. Mercy, *Ph D, visiting scientist*
B. Venkateswarlu, *Ph D, visiting scientist*
Francisco T. Parao, *MS, assistant scientist*
Romeo M. Visperas, *MS, assistant scientist*
Victoria P. Coronel, *MS, senior research assistant*
Aurora M. Mazaredo, *MS, research assistant*
Gloria S. Cabuslay, *MS, research assistant*
Ma. Rebecca C. Laza, *MS, research assistant*[4]
Evangeline S. Ella, *MS, research assistant*[12]
Librada Blanco, *BS, research assistant*
George Pateña, *MS, research assistant*
F. Sherwin Lopez, *BS, research aide*
Annabelle U. Novero, *BS, research aide*[12]

Rice farming systems program
Virgilio R. Carangal, *Ph D, agronomist and head*
Ram K. Pandey, *Ph D, agronomist*
James R. Hoopper, *Ph D, agronomist*[5]
Jerry L. McIntosh, *Ph D, agronomist*[5]
Rosendo K. Palis, *Ph D, agronomist*[1,5]
Noel P. Magor, *M Agr, associate agronomist*[4,5]
Arsenio D. Calub, *Ph D, visiting scientist*
Rolando V. Labios, *MS, senior research assistant*[4,6]
Antonio C. Morales, *MS, senior research assistant*
Ramon A. Oliveros, *MS, senior research assistant*[6]
Nicasio G. Punto, *MS, senior research assistant*[1,6]
Edward A. Barlaan, *MS, research assistant*[6]
Esteban C. Godilano, *BS, research assistant*
Leonila A. Lantican, *BS, research assistant*[6]
Eleuterio T. Rebancos, Jr., *BS, research assistant*[6]
Conrado M. Siota, *BS, research assistant*[4,6]
Primitivo L. Tengco, *BS, research assistant*[4,6]
Raymundo G. Tibayan, *BS, research assistant*[1,6]
Cesar C. Maligalig, *BS, research aide*

Soil chemistry/physics
Felix N. Ponnamperuma, *Ph D, principal soil chemist and head*[1]
Heinz-Ulrich Neue, *Ph D, soil chemist and acting head*
Terence Woodhead, *Ph D, physicist*
Shah Muhammad, *Ph D, visiting scientist*
Nagarajah Subramanian, *Ph D, visiting scientist*[4]
Gerhild Boje-Klein, *Ph D, visiting associate soil chemist*[1]
Ruby U. Castro, *MS, assistant scientist*
Rhoda S. Lantin, *MS, assistant scientist*
Corinta C. Quijano, *MS, assistant scientist*
Bernardita E. Mandac, *MS, senior research assistant*

Myrna R. Orticio, *BS, senior research assistant*
Ma. Theresa C. Cayton, *MS, senior research assistant*
Alma Ma. B. Capati, *MS, senior research assistant*
Rodolfo Y. Reyes, *MS, research assistant*
Victor A Quimsing, *MS, research assistant*[10]
Nida B. Uy, *MS, research assistant*
Josefina L. Solivas, *BS, research assistant*
Jocelyn B. Ballesteros, *BS, research assistant*
Ma. Carmelita G. Robielos, *BS, research assistant*
Cynthia M. Chavez, *BS, research assistant*
Virgilio Q. Gaddi, *BS, research assistant*
Roberto P. Bautista, *BS, research assistant*
Ricardo F. Capistrano, *BS, research assistant*
Nancy Urriza, *BS, research assistant*[6]
Delfina R. Valencia, *BS, research assistant*
Susana G. Maghari, *BS, research assistant*
Edna A. de San Agustin, *BS, research assistant*
Celeste C. Pateña, *BS, research aide*
Adonna M. Robles, *BS, research aide*
Roberto Oficial, *BS, research aide*
Rene R. Diocares, *BS, research aide*
Nenita B. Fortuno, *BS, research aide*
Mary Ethel C. Tenedora, *BS, research aide*

Soil microbiology

Iwao Watanabe, *D Agr, soil microbiologist and head*
Jagdish K. Ladha, *Ph D, associate soil microbiologist*
Pierre A. Roger, *D Pedologie, visiting scientist*
Ian F. Grant, *Ph D, visiting associate soil microbiologist*[1]
Wilbur B. Ventura, *MS, assistant scientist*
Agnes C. Tirol-Padre, *MS, senior research assistant*
Benjamin C. Padre, Jr., *research assistant*
Corazon R. Espinas, *MS, research assistant*
Teresita Santiago-Ventura, *BS, research assistant*
Susan Santiago-Ardales, *BS, research assistant*
Reynaldo T. Oliveros, *MS, research assistant*[6]
Ma. Luisa G. Daroy, *BS, research assistant*
Grace Buenaventura-Mascariña, *BS, research assistant*[6]
Rosario Remulla-Jimenez, *BS, research assistant*
Ma. Theresa B. Lapis, *BS, research assistant*[6]
Gloria Caldo-Punzalan, *BS, research assistant*[6]
Rolando B. So, *MS, research assistant*

Statistics

Kwanchai A. Gomez, *Ph D, statistician and head*
David J. Finney, *Ph D, consultant*[1]
Nora Epifania N. Nano, *BS, senior research assistant*
Grace L. Reyes, *BS, senior research assistant*
Violeta I. Bartolome, *BS, research assistant*
Joselice B. Caballes, *BS, research assistant*[4]
Urbana B. Cadiz, *BS, research assistant*
Victoria M. Claveria, *BS, research assistant*[4]
Anabella B. Cruz, *BS, research assistant*
Romel E. Ferido, *BS, research assistant*[1]
Annabelle Teresita B. Fernandez, *MS, research assistant*
Joel Rizaldy G. Flor, *BS, research assistant*[4,6]
Dolores R. Ledesma, *MS, research assistant*
Leonardo P. Lopez, *BS, research assistant*
Adelina Nenette C. Mendoza, *BS, research assistant*
Ruben T. Palabasan, *BS, research assistant*[4]
Thelma H. Parado, *BS, research assistant*
Priscilla A. Piguing, *BS, research assistant*
Rise D. Ronquillo, *BS, research assistant*[6]
Heraldina R. Salonga, *BS, research assistant*[11]
Julie D. Zamora, *BS, research assistant*
Dennis A. Benigno, *BS, research aide*[6]
Susan V. Fernandez, *BS, research aide*[1,6]
Lynn Corazon M. Mulimbayan, *BS, research aide*
Augusto C. Rivera, *BS, research aide*[1,6]

Tissue culture

Francisco J. Zapata, *Ph D, associate plant physiologist*
S. T. Mercy, *Ph D, visiting scientist*
Lina B. Torrizo, *MS, senior research assistant*
Manuel S. Alejar, *BS, research assistant*[4]
Evangelina S. Ella, *MS, research assistant*[12]
Gemma D. Encarnacion, *BS, research assistant*
Editha M. Abrigo, *BS, research assistant*
Rhodora R. Aldemita, *BS, research assistant*
Leonardo B. Magaling, *BS, research assistant*
Annabelle U. Novero, *BS, research aide*[12]
Della C. de Castro, *BS, research aide*[4,6]

Training and technology transfer

Dan R. Minnick, *Ph D, training specialist and head*
B. R. Tripathi, *Ph D, visiting scientist*
Glenn L. Denning, *Ph D, visiting associate field specialist*
Earl H. Tryon, *Ph D, visiting associate training specialist*[8]
Julian A. Lapitan, *MS, visiting associate field specialist*[1]
C. Thomas Brackney, *MS, rice production specialist*[1,5]
Leo Dale Haws, *Ph D, rice production training specialist*[1,5]
Dennis M. Wood, *Ph D, crop production specialist*[1,5]
Alfredo A. Domingo, *MS, assistant scientist*
Rizalino T. Dilag, Jr., *BS, senior research assistant*
Emerito V. Tipa, *MS, senior research assistant*
Noemi M. Yapit, *MS, senior training assistant*
Ernesto G. Perez, *BS, senior training assistant*
Oscar A. Garcia, *BS, training assistant*
Salvador I. Yabes, *MS, training assistant*
Cristina M. Bajet, *MS, training assistant*[1]
Orlando N. Magistrado, *MS, training assistant*
Josefa L. Gonzales, *MS, training assistant*
Alberto C. Aduna, *BS, training assistant*
Enrique L. Navarro, *MS, training assistant*
Rosela I. Gementiza, *BS, training assistant*
Rebecca H. Patalen, *M Agr, training assistant*
Jose V. del Carmen, *MS, training assistant*[4]
Jose S. Nicolas, *MS, research assistant*
Rodolfo R. Saledo, *MS, research assistant*
Regalado M. Aseron, *BS, research assistant*
Romarico S. Necesario, *BS, research assistant*[6]
Arsenio R. Samiano, *BS, research assistant*
Ramon M. Cu, *BS, research assistant*[4]
Remedios A. Escobin, *BS, research assistant*
German O. Turija, *BS, research aide*[6]

Water management

Sadiqul I. Bhuiyan, *Ph D, agricultural engineer and head*
D. Hammond Murray-Rust, *Ph D, associate agricultural engineer*
Domingo F. Tabbal, *MS, assistant scientist*
Tolentino B. Moya, *MS, senior research assistant*
Geronimo E. Dozina, Jr., *MS, senior research assistant*[1]
Manuel M. Alagcan, *MS, research assistant*
Danilo M. Cablayan, *MS, research assistant*[1]
Marius M. Agua, *MS, research assistant*
Valeriana B. Gloria, *BS, research assistant*
Gloria S. Bumanlag, *MS, research assistant*
Abel R. Sumayao, *MS, research assistant*
Maximina A. Lantican, *BS, research assistant*
Ambrosio R. Castañeda, *BS, research assistant*
Oliver G. Coroza, *BS, research assistant*[5]
Wenceslao C. dela Viña, *MS, research assistant*
Alejandro L. Galang, *BS, research assistant*

---

[1] Left during the year.
[2] On leave.
[3] Joined and left during the year.
[4] Joined during the year.
[5] Cooperative research staff.
[6] On project appointment.
[7] Transferred from Agricultural Engineering to Agricultural Economics.
[8] Transferred from Training and Technology Transfer to Entomology.
[9] Transferred from International Rice Testing Program to Multiple Cropping.
[10] Transferred from Soil Chemistry Physics to Multiple Cropping.
[11] Transferred from Statistics to Plant Breeding.
[12] Transferred from Plant Physiology to Tissue Culture.

About this report

This 24th annual report reviews research conducted by institute staff during 1985. Some experiments are summarized completely. Others are ongoing, and interim results are reported. In all cases, further information can be obtained from the departments identified in section and subsection headings, as this volume is necessarily abbreviated. IRRI scientists also report their results in *IRRI highlights*, the *International rice research newsletter* (IRRN), the *IRRI research paper series* (IRPS), conference proceedings, monographs, and technical journals.

Each year, the institute intensifies its cooperative work with national and international agencies, based on priorities expressed at work plan meetings. Although almost every section of this report mentions this collaboration, it is covered specifically in the Cooperative Programs section. Three programs that are predicated on international cooperation — the International Rice Testing Program (IRTP), the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), and the Asian Rice Farming Systems Network (ARFSN) — are discussed under Cooperative Programs. Other sections that include a particularly strong international focus are Machinery Development and Testing, and Training Programs.

The volume of detail requires many abbreviations, which are listed on the following pages. In addition, we have spelled out all names and terms on first use in each subsection and have used abbreviations thereafter.

This report refers to four fundamental types of rice culture. Upland culture means rice grown without irrigation in unbunded fields. Rainfed lowland culture means rice grown without irrigation but in fields that are bunded to impound water. Irrigated culture means rice grown with irrigation in bunded fields. Deep water culture means rice grown in unbunded fields that become submerged under 50 cm or more of water. The adjectives upland and lowland describe rice and rice-growing soils.

The report uses the International System of Units (SI), with a few exceptions. Monetary units are usually in U.S. dollars ($); if not, exchange rates are provided. Control or check normally means an untreated control. Grain yield is calculated as rough rice at 14% moisture, and protein content as a percentage of brown rice at 14% moisture. Yield refers to grain yield unless otherwise noted. Fertilizer amounts are given in terms of the elements (N, P, K, Zn, etc.) and not in the older conventional oxide formulation (P_2O_5, K_2O, etc.).

To derive the real costs of production in energy-terms, we have developed a table of energy equivalences of inputs for rice production. This is given and discussed in the section Consequences of New Technology under the heading Energy and Rice Production.

Pedigrees are indicated by a slant bar (/) rather than by a multiplication sign (×). For example, PTB33 × IR30 is written PTB33/IR30. The sequence of crosses is illustrated by the number of slant bars: (PTB33 × IR30) × IR36 is written PTB33/IR30//IR36. Fourth and further crosses are designated /4/, /5/, and so on. Backcrosses are indicated by a superscript numeral.

Unless otherwise noted, scoring of morphological characters and of damage attributed to rice pests and physiochemical stresses is based on scales in the *Standard evaluation system for rice* (SES), 2d ed., 1980. Copies are available from the IRTP, IRRI.

A single asterisk (*) means difference at the 5% level of significance, and a double asterisk (**) means a significant difference at the 1% level; ns means not significant. Unless otherwise stated, separation of means in table columns is by Duncan's multiple range test at the 5% level.

This report normally uses generic names for chemicals. Use of a commercial or brand name does not constitute endorsement.

A thumb index on the back cover provides access to each section. To use it, bend the book slightly and follow the margin index to the page with the black edge marker.

Abbreviations and acronyms

AARD = Agency for Agricultural Research and Development, Indonesia
ABA = abscisic acid
AC = amylose content
ACIAR = Australian Centre for International Agricultural Research
ADB = Asian Development Bank
ADF = acid detergent fiber
ai = active ingredient
ARA = acetylene-reducing activity
ARFSN = Asian Rice Farming Systems Network
AU = animal unit
AVRDC = Asian Vegetable Research and Development Center
AW = armyworm

Bak = bakanae
BARI = Bangladesh Agricultural Research Institute
BB = bacterial blight
BB&I = basal, broadcast and incorporated
BC = backcross
B:C = benefit-cost ratio
BGA = blue-green algae
B&I = broadcast and incorporated
Bl = blast
BPH = brown planthopper
BPI = Bureau of Plant Industry, Philippines
BR = broadcast seeded rice
BRP = brown rice protein
BRRI = Bangladesh Rice Research Institute
BS = best split
BWDB = Bangladesh Water Development Board

CAAMS = Chinese Academy of Agricultural Mechanization Sciences
CAAS = Chinese Academy of Agricultural Sciences
CAI = cellulolysis adequacy index
CCC = chlormequat chloride
CFU = colony-forming unit
CGIAR = Consultative Group on International Agricultural Research
CIMMYT = Centro Internacional de Mejoramiento de Maiz y Trigo
CIP = International Potato Center
CIPR = Christmas Island phosphate rock
CMS = cytoplasmic male sterile
C:N = carbon to nitrogen ratio
CNRRI = China National Rice Research Institute
CRIFC = Central Research Institute for Food Crops, Indonesia
CRPS = continuous rice production system
CSIRO = Commonwealth Scientific and Industrial Research Organization
CV = common variance, coefficient of variation
CW = caseworm
CWSI = crop water stress index
CY = crop year

DAI = days after inoculation
DAP = days after planting
DAPI = days after panicle initiation
DAS = days after seeding, days after sowing
DAT = days after treatment
DBPI = days before panicle initiation
DBS = days before seeding, days before sowing
DE = days after emergence
DEI = distribution equity index
DI = days after infestation
DM = dry matter
DMRT = Duncan's multiple range test
DNA = deoxyribonucleic acid
DP = deep placed, deep placement
DPRK = Democratic People's Republic of Korea
DS = dry season
DSC = differential scanning calorimetry
DSR = dry seeded rice
DT = days after transplanting
DTF = days to flowering

ELISA = enzyme-linked immunosorbent assay
EMC = equilibrium moisture content
EMS = ethyl methane sulfonate
ER = effective rainfall
ES = elemental sulfur

fb = followed by
FCRI = Field Crops Research Institute, Thailand
FMP = fused magnesium phosphate
FRT = floating rototiller
FTM = fertilizer testing model
FYM = farmyard manure

GB = germplasm bank, germplasm computer data bank
GBIRET = Germplasm Bank Information Retrieval system
GBSRI = Gunn-Bellani solar radiation integrator
GC = gel consistency
GCA = general combining ability
GEU = genetic evaluation and utilization
G-K = Ganges-Kabodak Irrigation System, Bangladesh
GLH = green leafhopper
GMRC = Grain Marketing Research Center, Manhattan, KS, USA
GSV = grassy stunt virus
GT = gelatinization temperature

HI = harvest index
HRP = highly reactive rock phosphate
ht = height
HW = hand weeded

IARC = international agricultural research center
IAS = Institute of Animal Science, UPLB
IBE = isobutyl ester
IBPGR = International Board for Plant Genetic Resources
ICAR = Indian Council of Agricultural Research
ICRISAT = International Crops Research Institute for the Semi-Arid Tropics
IFDC = International Fertilizer Development Center
IFPRI = International Food Policy Research Institute
IFRON = International Floating Rice Observational Nursery
IITA = International Institute of Tropical Agriculture
INSFFER = International Network on Soil Fertility and Fertilizer Evaluation for Rice
IPB = Institute of Plant Breeding, UPLB
IPE = isopropyl ester
IRAT = Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres, France
IRBBN = International Rice Bacterial Blight Nursery
IRBN = International Rice Blast Nursery
IRBPHN = International Rice Brown Planthopper Nursery
IRCTN = International Rice Cold Tolerance Nursery
IRDWON = International Rice Deep Water Observational Nursery
IRGC = International Rice Germplasm Center
IRON = International Rice Observational Nursery
IRR = internal rate of return
IRRI = International Rice Research Institute
IRRSWON = International Rice Rainfed Shallow Water Observational Nursery
IRRSWYN = International Rice Rainfed Shallow Water Yield Nursery
IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery
IRSBN = International Rice Stem Borer Nursery
IRSTYN = International Rice Salinity Tolerance Yield Nursery
IRT = infrared thermometer
IRTN = International Rice Tungro Nursery
IRTP = International Rice Testing Program
IRUSS = International Rice Ufra Screening Set
IRWBPHN = International Rice Whitebacked Planthopper Nursery
IRWIT = International Rice - Wheat Integrated Trials
IRYN-E = International Rice Yield Nursery -- Early
IRYN-M = International Rice Yield Nursery -- Medium
IRYN-VE = International Rice Yield Nursery -- Very Early
ITPRON = International Tide-Prone Rice Observational Nursery
IURON = International Upland Rice Observational Nursery
IURYN-E = International Upland Rice Yield Nursery -- Early
IURYN-M = International Upland Rice Yield Nursery -- Medium
IV = improved variety

LAI = leaf area index
LCPIS = Libmanan-Cabusao Pump Irrigation System, Philippines
LF = leaffolder
LRP = less reactive rock phosphate
LSc = leaf scald
LSD = least significant difference
LSS = line source sprinkler

MAF = Ministry of Agriculture and Food, Philippines
MBCR = marginal benefit-cost ratio
MLE = maximum likelihood estimate
MLR = multiple linear regression

MRIFC = Maros Research Institute for Food Crops, Indonesia
MRM = multifertilizer response model
MRRTC = Maligaya Rice Research and Training Center, Philippines
MV = modern variety

NDF = neutral detergent fiber
NIA = National Irrigation Administration, Philippines

OC = organic carbon
OLS = ordinary least squares estimate
OM = organic matter
O&M = operation and maintenance
OSP = ordinary superphosphate
OYT = observational yield trial

PAR = photosynthetically active radiance
PARC = Pakistan Agricultural Research Council
PFA = paraformaldehyde
P+H = plow and harrow
PI = panicle initiation
PMC = pollen mother cell
PPD = phenyl phosphorodiamidate
PR = percolation rate
PSU = Pangasinan State University, Philippines
PU = prilled urea

RA = *Rice abstracts*
RAVC = return above variable costs
RB = rice bug
RCBD = randomized complete block design
RDA = Rural Development Administration, Korea
RF = rainfall
RGA = rapid generation advance
RH = relative humidity
RRL = relative root length
RSV = ragged stunt virus
RTBV = rice tungro bacilliform virus
RTSV = rice tungro spherical virus
RTV = rice tungro virus, tungro
RWM = rice whorl maggot
RWS = relative water supply
RYT = replicated yield trial

SB = stem borer
SCA = specific combining ability
SCU = sulfur-coated urea
SD = standard deviation
SES = *Standard evaluation system for rice*
ShB = sheath blight
SMT = soil moisture tension
SMU = soil mapping unit
SR = solar radiation
SRT = skid-supported power rototiller
SSAc = salicylic-sulfosalicylic acid
SSB = striped stem borer
SWCB = southwestern corn borer

Ta = air temperature
TARC = Tropical Agriculture Research Center, Japan
Tc = canopy temperature
TDMY = total dry matter yield
TMA = thermomechanical analysis
TPR = transplanted rice
TSP = triple superphosphate

UPLB = University of the Philippines at Los Baños
UPN = Upland Pedigree Nursery
URYT = upland rice yield trial
US = urea sulfur
USDA = United States Department of Agriculture
USG = urea supergranules

VAM = vesicular-arbuscular mycorrhizal fungi
VISCA = Visayas State College of Agriculture, Philippines

WA = wild aborted
WAI = weeks after inoculation
WARDA = West Africa Rice Development Association
WAS = weeks after seeding, weeks after sowing
WBPH = whitebacked planthopper
WE = weeks after emergence
WRRC = Western Regional Research Center, USDA
WS = wet season
WSR = wet seeded rice
wt = weight
WT = weeks after transplanting
WUE = water use efficiency

YSB = yellow stem borer

ZLF = zigzag leafhopper

Genetic evaluation and utilization (GEU) program

Genetic resources program

International Rice Germplasm Center, Statistics Department, and Tissue Culture Facility

FIELD COLLECTION 2
INSTITUTIONAL EXCHANGES 3
INVENTORY, CHARACTERIZATION, AND DATA PROCESSING 3
SEED INCREASE, REJUVENATION, AND DISTRIBUTION 4
SEED PRESERVATION 4
RESCUE OF NONVIABLE SEEDS BY TISSUE CULTURE 5
STUDIES ON SEED VIABILITY 5

FIELD COLLECTION

International Rice Germplasm Center (IRGC)

Collaborative efforts with national and state centers in canvassing and collecting indigenous rice varieties continued in the first half of 1985 with financial assistance from the International Board for Plant Genetic Resources (IBPGR). Joint efforts with Sabah State of Malaysia resulted in the acquisition of 227 traditional varieties and 4 samples of wild rices. During the remainder of the crop season, local staff gathered 49 samples. A third mission to Madagascar collected 112 varieties; local workers sustained the collection efforts during the staggered planting seasons at different altitudes.

During the second half of the year, efforts were directed to prepare some of the germplasm-rich countries in Southeast Asia to continue the momentum of field exploration and sampling on their own. Short-term training courses for field collectors of national and provincial centers were held in Indonesia, Burma, and Vietnam. The courses included field trips to practice varietal identification and sampling methods. The field collectors trained by the IRRI-IBPGR field collector numbered 30 in Indonesia, 51 in Burma, and 42 in Vietnam. On the island of Kalimantan, Indonesian workers and IRRI staff collected 48 local varieties. The training course emphasis was on the collection of wild species, which had not been adequately sampled in the past.

Since the collaborative and coordinated field collection of rice germplasm was initiated in 1971, more than 40,000 seed samples were collected in 14 Asian countries, of which about 13,000 were gathered with IRRI's direct participation. Financial inputs from IBPGR accounted for 14,614 seed samples collected from 1978 to 1985 (Table 1). A large proportion of the samples came from remote areas, where small rice farms face various edaphic or biotic stresses.

A number of institutions continued field activities, either with IBPGR assistance or on their own. Duplicate seed samples were received from the International Institute of Tropical Agriculture (IITA) in Nigeria, Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (IRAT) in France, West Africa Rice Development Association (WARDA) in Liberia, Agricultural Research Institute of Burma, Centro Nacional de Pesquisa - Arroz y Feijão of Brazil, Agricultural Research Council of Pakistan, Rice Research Institute of Thailand, and University of Kenya.

Participants in the first Genetic Resources Conservation and Management Training Course coming from Burma, China, Ethiopia, Ghana, India, Indonesia, Malaysia, Philippines, Sri Lanka, and Vietnam also implemented field collections in their countries before coming to IRRI in 1986.

Table 1. Rice seed samples collected under collaborative arrangements with IBPGR funding, 1978-85.

Country	Seed samples (no.)								
	1978	1979	1980	1981	1982	1983	1984	1985	Total
Bangladesh	276[a]	246	57		139	95	103	–	916
Bhutan	–	–	–	–	102	83	66	–	251
Burma	13	183	263	62	–	–	–	2	523
Indonesia	590	688[b]	387	534		46	193[c]	49	2,487
Malagasy	–	–	–	–	–	–	98	123	221
Malaysia (Sabah)	–	–	–	–	–	–	–	276[c]	276
Nepal	9	16	720	297	–	–	–	–	1,042
Pakistan	–	–	–	–	4	–	–	100	104
Sri Lanka	402	236[d]	145	–	–	–	122[e]	–	905
Thailand	804	121	218	1,140	666	1,943	2,996[f]	–	7,888
Vietnam	–	–	–	–	–	–	–	1[g]	1
Total	2,094	1,490	1,790	2,033	911	2,167	3,578	551	14,614

[a]Including 20 wild rices. [b]Including 7 wild rices. [c]Including 4 wild rices. [d]Including 16 wild rices. [e]Including 14 wild rices. [f]Including 123 wild rices. [g]Wild rice.

INSTITUTIONAL EXCHANGES

International Rice Germplasm Center

During 1985, 24 state, national, and international centers deposited 4,300 seed samples of *Oryza sativa*, 83 strains of *O. glaberrima* (from IITA), and 242 wild species in the IRGC. The major donors were

- Hunan, Hubei, Yunnan, and Guangdong Provincial Academies of Agricultural Sciences through the Chinese Academy of Agricultural Sciences — 992 varieties and 15 wild rices
- Department of Agriculture, Thailand — 565 varieties and 162 wild species
- IITA, Nigeria — 570 varieties and 83 strains of *O. glaberrima*
- Centre National de la Recherche Appliquee au Developpement Rural, Malagasy — 460 varieties and 8 wild rices
- IRAT, France — 426 varieties
- Sabah State, Malaysia — 425 varieties
- WARDA staff in Liberia and Sierra Leone — 205 varieties
- Zonal Agricultural Research Station, Madhya Pradesh, India — 202 varieties
- University of Kenya, Nairobi — 181 varieties and 4 wild rices
- Agricultural Research Council, Pakistan — 163 varieties
- National Rice Research Institute, Cuba — 107 varieties, 1 wild rice, and 13 breeding lines
- Malaysian Agricultural Research and Development Institute — 100 varieties
- Agricultural Research Institute, Burma — 99 varieties
- Centro Nacional de Pesquisa - Arroz y Feijão, Brazil — 95 varieties
- Instituto de Investigación Agropecuaria, Panama — 91 varieties
- National Institute of Genetics, Japan — 7 varieties and 30 wild taxa
- National Institute of Agrobiological Resources, Japan — 54 varieties
- Central Research Institute for Food Crops, Indonesia — 49 varieties
- Tamil Nadu Agricultural University, India — 43 varieties
- Centre National de la Recherche Scientifique, France — 33 *Oryza* species and 9 varieties
- Bureau of Plant Industry, Philippines — 30 varieties
- Rural Development Administration, Republic of Korea — 28 varieties
- United States Department of Agriculture — 10 varieties

IRRI also initiated the first seed exchange with the Democratic People's Republic of Korea, in which seven commercial varieties were provided by its Rice Research Institute.

INVENTORY, CHARACTERIZATION, AND DATA PROCESSING

International Rice Germplasm Center and Statistics Department

At the end of the year, IRGC holdings were 71,621 accessions of *O. sativa*, 2,970 strains of *O. glaberrima*, 2,142 populations of wild species, and 695 genetic testers and mutants. Another 4,500 recently received seed samples of *O. sativa* were sown in November or December, which reduced the number of newly received and unplanted samples to about 900.

For initial seed increase and characterization, 3,100 samples were grown. Another 4,484 accessions were grown for characterization, resulting in 4,867 accessions being completely characterized both in the field and in the laboratory. These efforts brought the total number of accessions completely characterized to 57,047. For the other categories of rice, characterization was completed on 700 wild rices and 1,245 *O. glaberrima* strains. The characterization of wild rices was difficult, because many annual wild forms were hybrids between *O. sativa* and its wild relatives.

Microcomputer programs were initiated in 1985 to speed up the recording and processing of various forms of information that require continuous IRGC staff inputs. Such programs will store the huge backlog of information acquired during field collection, data on acquisitions of different categories, changes in name of donor agencies, and records of seed samples distributed.

With the acquisition of an IBM-PC XT in 1985, a system analysis was undertaken to computerize the various manual operations from the time seeds of a given entry are received until they are planted

and the data recorded, as well as to link these operations to the centralized mainframe-based GEU Data Management System. Such computerization is expected to markedly improve the speed and efficiency of record-keeping operations, reduce labor, and enhance the precision of data handling.

The system is divided into three parts according to the type of activity: preplanting, planting, and postplanting. The preplanting component of the system was implemented during the last quarter of 1985.

SEED INCREASE, REJUVENATION, AND DISTRIBUTION

International Rice Germplasm Center and Statistics Department

The land area devoted to seed production inside and outside IRRI totaled 33 ha, which surpassed the 1984 area by 2.2 ha. Unfortunately, seed production in a rented field at Dayap, Laguna, suffered from severe Zn deficiency in dry season and from flooding shortly after transplanting in wet season (WS). Subsequently, the amounts of seed harvested in both seasons were below average. Since plots (12,801) planted for seed rejuvenation were much more than those planted for initial seed increase (3,098) and for characterization (4,484), the number of accessions that were canned for medium- and long-term storage and for duplicate storage in the U.S. was proportionally reduced.

The IRGC also grew special seed increase plots for older accessions that have been determined by GEU teams to have resistance to or tolerance for one or more biotic or edaphic stresses. These accessions were provided to other GEU teams for screening of additional GEU traits. In 1985, 889 such accessions were grown.

The construction of a headhouse for seed processing and a double screened area for wild rices and difficult-to-grow accessions was completed in August. During the remainder of the year, 860 wild rices were grown in pots for seed increase and re-identification, while 960 *O. sativa* accessions were planted for maintaining the small but invaluable seed stocks.

Seed distribution to researchers at IRRI and in other countries continued to be a major service of the IRGC. A total of 30,709 packages of *O. sativa* (306 requests) and 1,138 wild rices and *O. glaberrima* strains (24 requests) were supplied to scientists, research fellows, and scholars of IRRI, while foreign researchers requested and obtained 4,736 *O. sativa* accessions (172 requests) and 1,174 samples of wild species and *O. glaberrima* strains (36 requests). Although the number of *O. sativa* accessions supplied by IRRI remained about the same for 7 yr, the demand for wild rices significantly increased.

Many novel resistances to or tolerances for pests and diseases have been identified by IRRI scientists in recent years. The markedly large number of seed requests for exotic materials from molecular geneticists, cellular biologists, and other biotechnologists may account for a large proportion of the foreign requests. The IRGC staff had to plant special seed increase plots to meet the demands for exotic germplasm.

In the early 1970s, a file of original seeds coming from every source was set up. It has proved to be an invaluable check on the identity of numerous samples through comparison of seed characters. In recent years, we have been referring to the original seeds in the file before storage, rejuvenation, and distribution. It is one of the most effective quality control measures that a genebank can have.

SEED PRESERVATION

International Rice Germplasm Center

Because of the problems encountered in seed production in rented fields, only 3,491 accessions were canned and stored in the medium- and long-term rooms, and a duplicate package of each was sent to the National Seed Storage Laboratory in the U.S. for safekeeping. The number is much below the average of 5,500 accessions canned during 1983-84. At the end of 1985, 23,901 accessions were so preserved.

Since many of the new accessions came from farmers' fields, mechanical mixtures posed serious strains on the hand-picking operation prior to canning and thus lowered the rate of canning the rejuvenated accessions. Beginning in WS and prior to threshing, harvested accessions were initially selected panicle by panicle, each of which contained more than 100 seeds. This new control

measure speeded up the subsequent seed selection operation in the laboratory.

RESCUE OF NONVIABLE SEEDS BY TISSUE CULTURE

International Rice Germplasm Center and Tissue Culture Facility

We continued to use the tissue culture technique to grow plants from the nonviable seeds of accessions that had lost seed viability sooner than expected during cold storage. Fifty-eight accessions were thus restored to our collection. Some of these accessions were no longer available elsewhere.

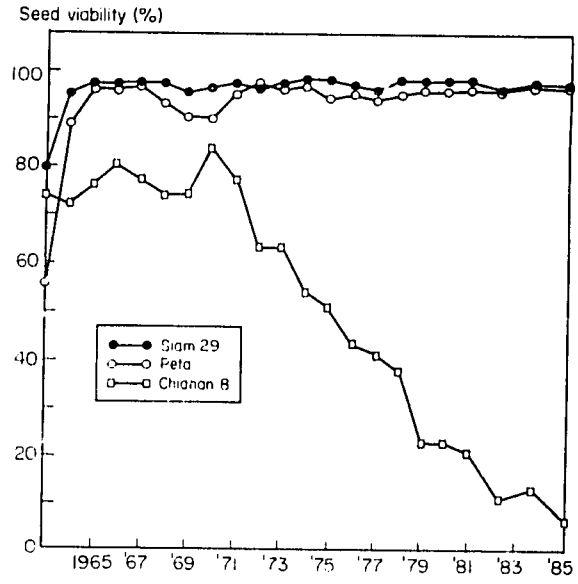
STUDIES ON SEED VIABILITY

International Rice Germplasm Center

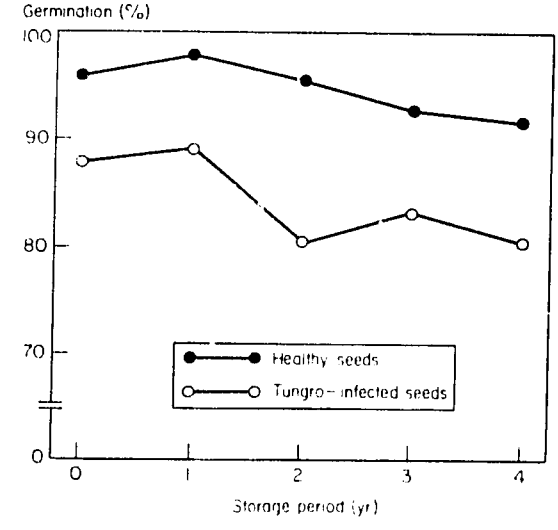
In a study on seed hygroscopicity and longevity, glutinous and nonglutinous varieties were found to differ more in equilibrium moisture content than varieties of the two ecogeographic races, indica and sinica. Correlation between equilibrium moisture content and amylose content was found to be positive ($r = 0.88$) at 80% relative humidity (RH); however, this relationship may not be entirely linear, because no cultivar with 5-6% amylose was available in the experiment.

Under simulated seed aging conditions (35 °C, 80% RH), tropically based indica varieties generally showed a greater viability retention rate than temperate varieties, which agreed with our seed longevity studies covering a period of 22 yr (Fig. 1). However, amylose content did not show any association with viability loss and seedling vigor at different sampling dates.

A comparison of fully protected IR varieties and lines and the same set of 4 varieties infected with tungro virus and grown in 1981 showed that the infected seeds had an initially lower viability level (88 vs 96%) in healthy seeds; after 2 yr storage in the medium-term room (2 °C, 8% moisture content), the viability level of the infected seeds began to drop. After 4 yr of storage, the mean viability levels of the IR varieties and lines differed by 11% (Fig. 2). The findings justified our time-consuming efforts in discarding the distinctly discolored seeds



1. Seed viability of 3 rice varieties maintained at 2 °C, 8% moisture content, 1984-85.



2. Percentage germination of healthy and tungro-infected rice seeds at 2 °C, 8% moisture content, IRRI, 1985.

from virus-infected plants prior to canning and preservation.

A comparative study of different seed packing materials showed that seeds with 12% moisture content that are stored in paper envelopes lose their viability in less than 2 yr under very damp and warm conditions (24-32 °C, 80-100% RH) and in a

deep-freeze locker (−20 °C). Aluminum foil envelopes preserved seed viability up to 3 yr in the same damp room, 4.5-6 yr in the short-term room (19 °C, 50% RH), and with no appreciable loss after 7.5 yr in a deep freezer. Among different varieties, the strongly dormant H4 showed a slower loss in viability than the weakly dormant IR34 and nondormant IR36 under different storage conditions, except in the deep freezer. Again, this observation agreed with our 22-yr storage experiment (Fig. 1).

Genetic evaluation and utilization (GEU) program

Agronomic and physiological characteristics

Agronomy and Plant Physiology Departments

MAXIMUM YIELD EXPERIMENT 8
IRRI 8
Farmer's field 8
LODGING RESISTANCE 8
YIELD PERFORMANCE OF HYBRID RICE 10
YIELD PERFORMANCE AND NITROGEN RESPONSE OF VARIETIES AND BREEDING LINES 11
Irrigated rice 11
IRRI 11
Farmer's field 12
BPI stations 13
Rainfed rice 14
IRRI 14
Farmer's field 14
QUALITY GRAIN AND YIELD POTENTIAL 14
Sink size 15
Milling recovery 15
Potential yields 15
Growth duration 16
Location 17
High density grain index 18
Heritability 18
VARIETAL DIFFERENCES IN DARK RESPIRATION RATE 19
EFFECT OF DEEP PLACEMENT FERTILIZATION AT LATER GROWTH STAGE ON SPIKELET FORMATION 20

MAXIMUM YIELD EXPERIMENT

Agronomy Department

IRRI. Ten rices of early, medium, and late maturities received varying N rates. Urea supergranules were deep-placed, followed by a top-dressing of prilled urea as required. Planting dates were staggered for uniform ripening at two IRRI sites (old and new).

In dry season (DS), IR21820-154-3-2-2-3 yielded the highest (7.1 t/ha) at medium N rate at the old site (Fig. 1). Other late maturing rices gave comparable yields at the same rate and site. At the new site, IR29723-143-3-2-1 yielded the highest (6.8 t/ha). Early maturing IR32429-47-3-2-2 yielded higher than IR58 at both sites. Among the medium maturing rices, the highest yielders were IR18348-36-3-3 (named IR64 by the Philippine Seed Board) at the new site and IR31868-64-2-3-3-3 at the old site.

Yields obtained were generally lower in 1985 DS than in 1983 DS because solar radiation at the ripening stage was low. Using 35-d-old seedlings of late maturing rices might have also affected yield. Lodging was more severe at high N doses.

In wet season (WS) late maturing IR29723-143-3-2-1 (6.1 t/ha) and medium maturing IR35546-52-3-3-2 consistently gave highest yields at both sites (Fig. 2). Insect pests and diseases affected susceptible rices in both seasons. In general, maximum yields usually came from the medium N rate.

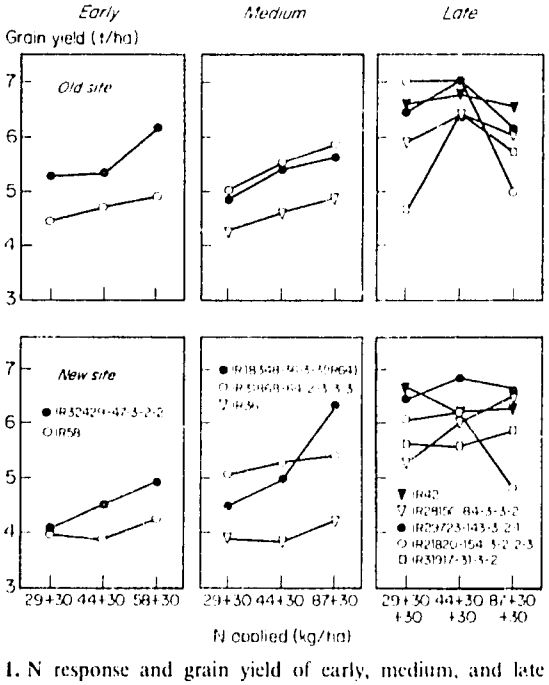
Farmer's field. In a farmer's field during DS, IR29723-143-3-2-1 and IR31917-31-3-2 of the late maturing group gave the highest yields (Fig. 3). In the medium maturing group, IR18348-36-3-3 (IR64) had the best performance. Among the rices tested, only the early maturing IR32429-47-3-2-2 responded up to the highest level of N application, while IR58 had no significant yield response to N. Two rices had their maximum yield at the lowest level of N.

During WS, a typhoon devastated the crop during the reproductive stage. IR42 gave the highest grain yield of 5.2 t/ha (Fig. 4). However, the maximum grain yield in the farmer's field was 1 t/ha lower than at IRRI.

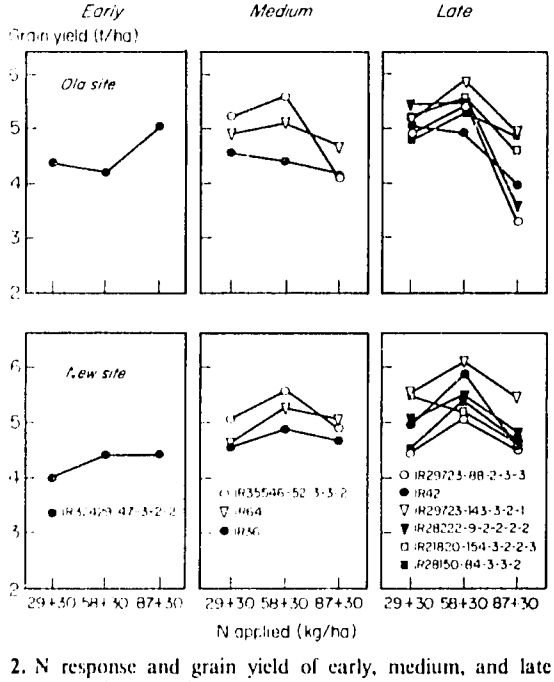
LODGING RESISTANCE

Agronomy Department

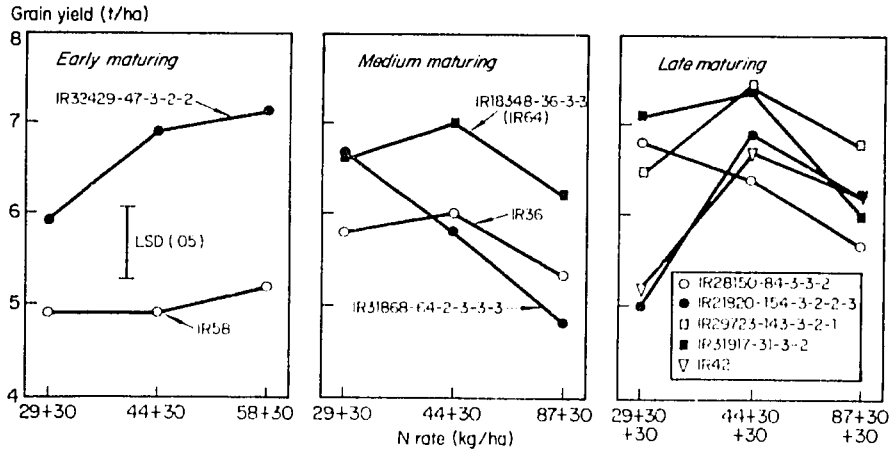
Lodging reduced grain yield even in modern semidwarf rices. In a field study, IR64 and IR32429-47-3-2-2 did not lodge, whereas lodging



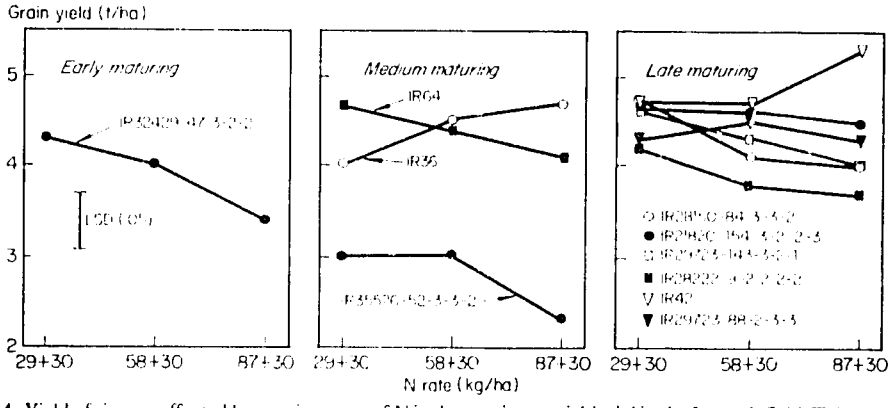
1. N response and grain yield of early, medium, and late maturing rices at 2 sites. IRRI, 1985 DS.



2. N response and grain yield of early, medium, and late maturing rices at 2 sites. IRRI, 1985 WS.

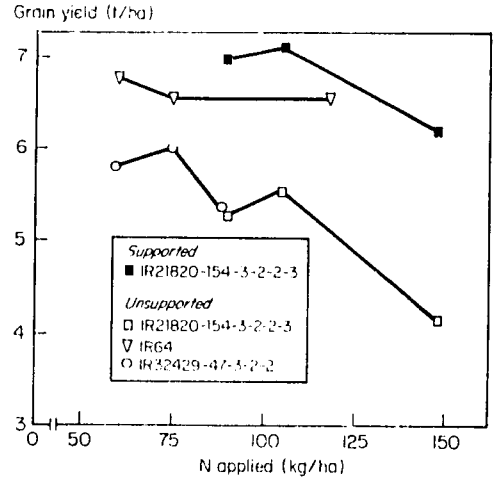


3. Yield of rices as affected by varying rates of N in the maximum yield trial in the farmer's field. Talavera, Nueva Ecija, Philippines, 1985 DS.

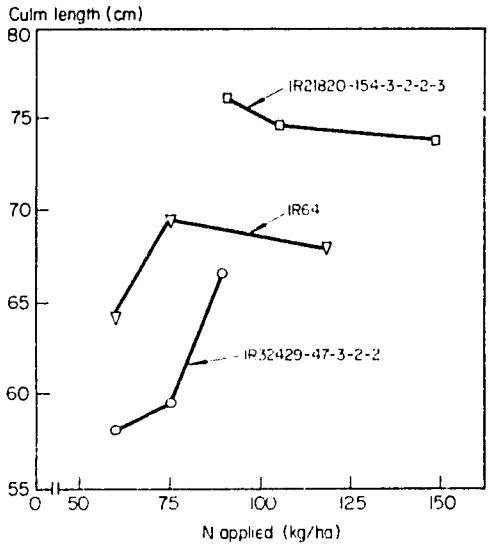


4. Yield of rices as affected by varying rates of N in the maximum yield trial in the farmer's field. Talavera, Nueva Ecija, Philippines, 1985 WS.

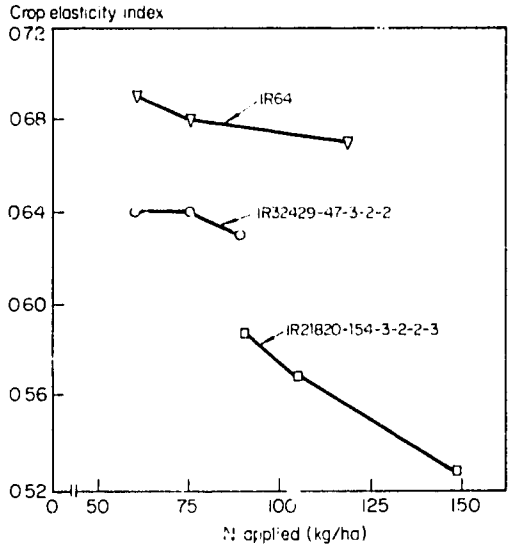
of IR21820-154-3-2-2-3 increased in direct proportion to applied N. Lodging occurred at ripening and involved bending of the whole plant with no stem breakage. Based on yields in a supported treatment (Fig. 5), lodging reduced grain yield of IR21820-154-3-2-2-3 by about 1.7 t/ha for a yield of about 7.0 t/ha at 89 and 104 kg N/ha when lodging was prevented. That line showed the highest culm length, followed by IR64 and IR32429-47-3-2-2 (Fig. 6); however, the response of culm length to N was not clear. IR64 and IR32429-47-3-2-2 had a higher crop elasticity index while IR21820-154-3-2-2-3 showed a linear decrease in crop elasticity index with increasing N (Fig. 7). N amounts and crop characteristics could have interacted to cause lodging in IR21820-154-3-2-2-3. Knowledge of culm properties, i.e., node and internode physiological characteristics, root dis-



5. Yield of 3 rice genotypes in unsupported treatment and of IR21820-154-3-2-2-3 in supported treatment. A 3- × 3-m nylon net was installed in one-half of the test plot to prevent lodging. IRRI, 1985 DS.



6. Culm length of 3 rice genotypes measured in the unsupported treatment. IRRI, 1985 DS.



7. Crop elasticity index (CEI), or ability to recover from an applied horizontal push, of 3 rice cultivars in the unsupported treatment. IRRI, 1985.

tribution, and soil moisture condition, is essential in developing appropriate selection criteria.

$$CEI = 1 - \left(\frac{\text{initial angle} - \text{final angle}}{\text{initial angle} - 30^\circ} \right)$$

YIELD PERFORMANCE OF HYBRID RICE

Agronomy Department

During DS, four hybrid rices, their high yielding parents (IR36, IR50, IR13429-75-3-1-1-3-2, and IR13429-150-3-2-1-2), two early maturing varieties (IR60 and IR62), and two medium maturing varieties (IR8 and IR42) were tested at three N rates. The hybrids were badly affected by bacterial leaf blight, sheath rot, sheath blight, and Cercospora leaf spot. Thus without applied N, their yields were lower than those of their parents and other test rices.

At intermediate N (75 kg/ha), yields of hybrid rices except MR365A/IR36 were comparable to those obtained with most of the test rices (Table 1).

The highest yield recorded among the hybrid rices — 6.4 t/ha for IR747B$_2$-6-3A/IR50 at 150 kg N/ha — was 0.6 t/ha lower than that of IR8 at the intermediate N rate.

The hybrid rices had unproductive tillers and a high percentage of unfilled spikelets.

Because of their disease susceptibility, the four hybrid rices were not further evaluated in WS. Instead, another hybrid rice, IR21845-90-3A/IR54, was tested. Its high yielding parents, KAU1727, and seven other IR varieties were included in the study.

Without N, the hybrid rice yield was similar to those of its parents and most of the test varieties (Table 2).

IR64 at high N application had the highest grain yield (5.3 t/ha). Except for this variety, optimum

Table 1. Yields of hybrid rices and their high yielding parents at 3 N levels in an irrigated field. IRRI, 1985 DS.

Variety	Yield (t/ha)		
	0 kg N/ha	75 kg N/ha	150 kg N/ha
IR36	3.9 abc	5.2 de	6.0 ab
MR365A/IR36	2.7 de	4.1 f	4.4 d
IR50	4.1 ab	6.4 ab	4.8 d
IR747B$_2$-6-3A/IR50	3.4 bcde	5.6 bcde	6.4 ab
IR13429-75-3-1-1-3-2	3.6 bcd	6.1 abcd	5.8 bc
MR365A/IR13429-75-3-1-1-3-2	3.0 de	6.2 abc	5.1 cd
IR13429-150-3-2-1-2	4.6 a	5.4 cde	6.3 ab
MR365A/IR13429-150-3-3-1-2	2.5 e	5.0 e	5.8 bc
IR8	3.5 bcd	7.0 a	6.7 ab
IR42	4.5 a	5.9 bcde	6.8 a
IR60	4.1 ab	5.8 bcde	6.2 ab
IR62	3.1 cde	6.4 ab	6.2 ab

Table 2. Yields of hybrid rices and high yielding parents at 3 N levels in an irrigated field. IR II, 1985 WS.

Variety	Yield (t/ha)		
	0 kg N/ha	60 kg N/ha	120 kg N/ha
IR8[a]	–	–	–
IR36	2.7 c	4.1 bcd	4.1 cde
IR42	3.4 ab	4.4 abcd	4.6 bc
IR50	2.9 bc	4.4 abcd	3.9 de
IR60	2.8 bc	4.3 abcd	4.9 ab
IR62	3.1 abc	4.7 ab	4.2 cde
IR64	3.2 abc	4.5 abc	5.3 a
IR21845-90-3B (P_1)	3.2 abc	4.1 bcd	3.8 e
IR54 (P_2)	2.9 bc	4.0 cd	3.9 de
IR21845-90-3A/ IR54 (F_1)	3.6 a	4.9 a	4.5 bcd
KAU1727	3.2 abc	3.8 d	4.2 cde

[a]Completely damaged by RTV.

yields of hybrid and all test rices were at 60 kg N/ha. IR8 was severely damaged by tungro, and no yields were obtained.

YIELD PERFORMANCE AND NITROGEN RESPONSE OF VARIETIES AND BREEDING LINES

Agronomy Department

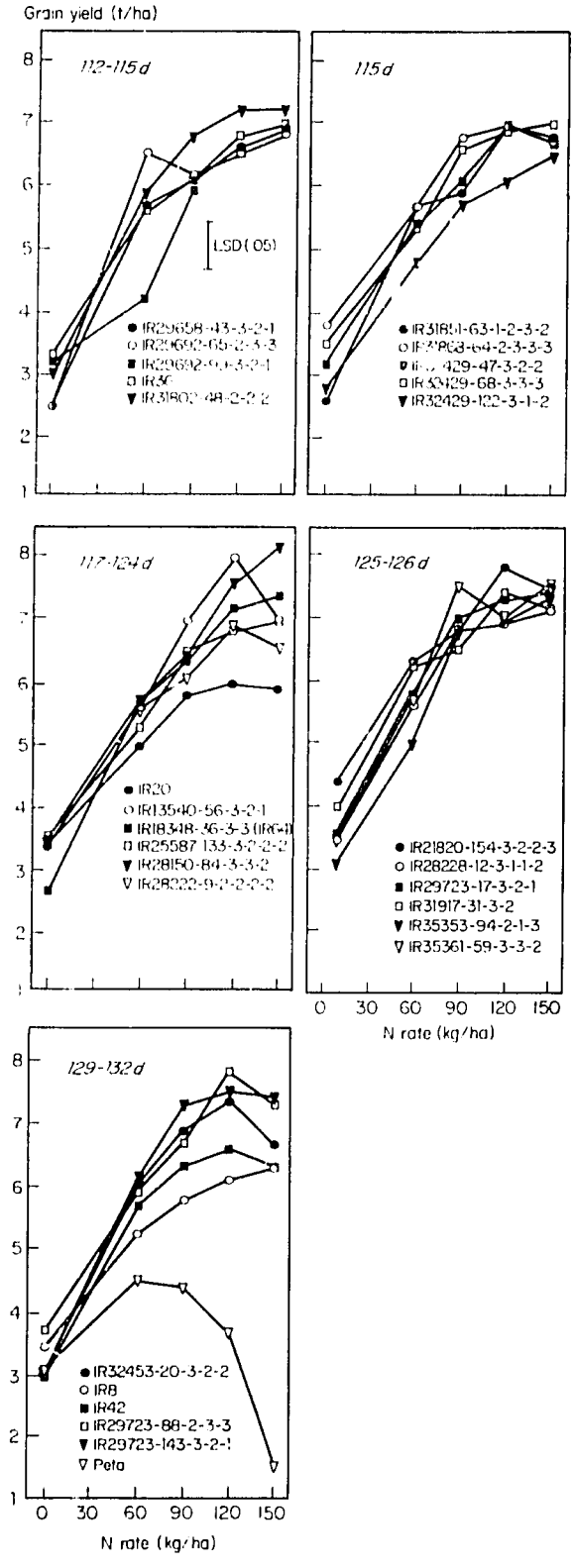
Irrigated rice. Yield performance and responsiveness to N of IR varieties and promising breeding lines were evaluated at IRRI, in farmers' fields, and at three Philippine Bureau of Plant Industry (BPI) stations. N rates during DS were higher than during WS.

IRRI. The 28 rices tested in irrigated plots with 5 N levels during DS consisted of 10 early (≦115 d), 12 medium (116-126 d), and 6 medium-late varieties. A medium maturing line, IR28150-84-3-3-2, gave the highest yield of 8.2 t/ha at 150 kg N/ha. Without N, another medium maturing line, IR21820-154-3-2-2-3, yielded 4.4 t/ha. IR29692-65-2-3-3 had the best yield response of about 4.0 t/ha to the first increment of 60 kg N/ha; however, it had the lowest yield at zero fertilizer N.

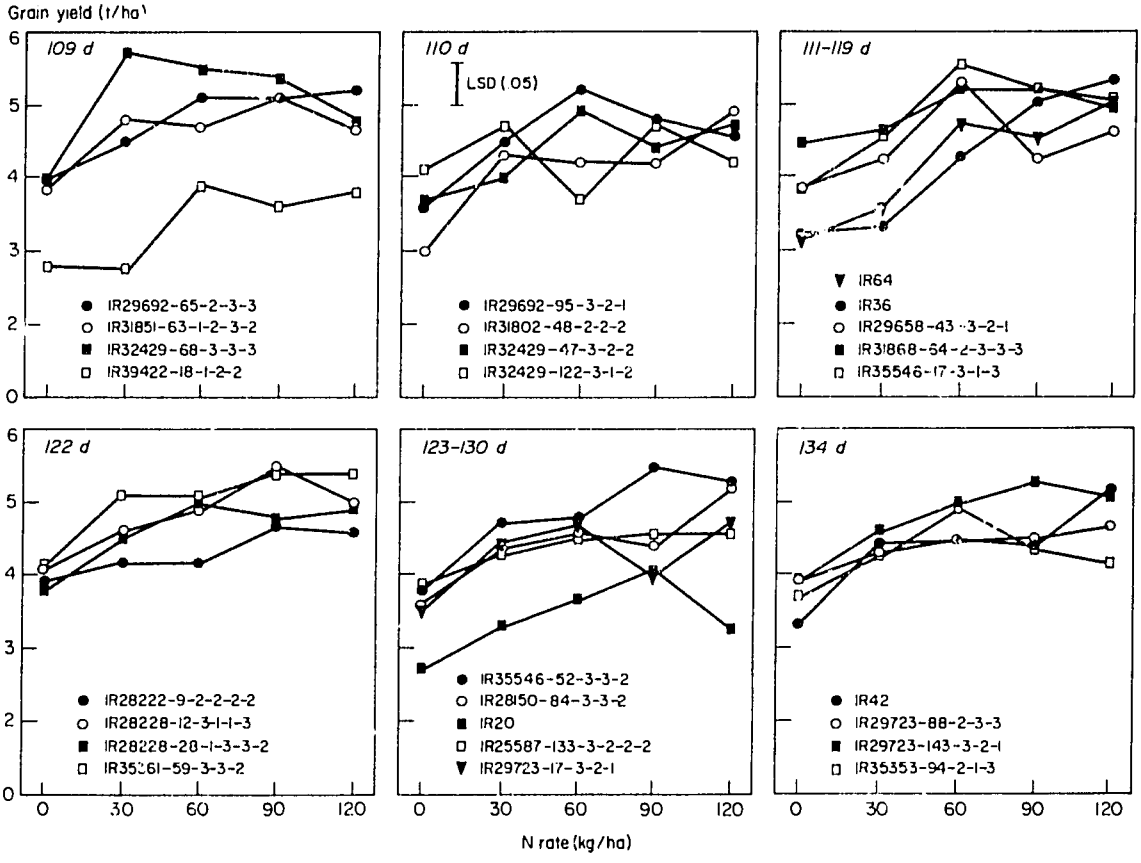
Twelve rices reached their maximum yield. The rest did not — an indication that the highest rate of N application was not enough for the other test rices to express their yield potential.

WS yields were considerably lower than DS yields when N was applied. Only 7 rices failed to reach their maximum yield, even at 120 kg N/ha.

Figures 8 and 9 show the actual yields of rices



8. Yield of rices at 6 N rates. IRRI, 1985 DS.



9. Yield of rices at 5 N rates. IRRI, 1985 WS.

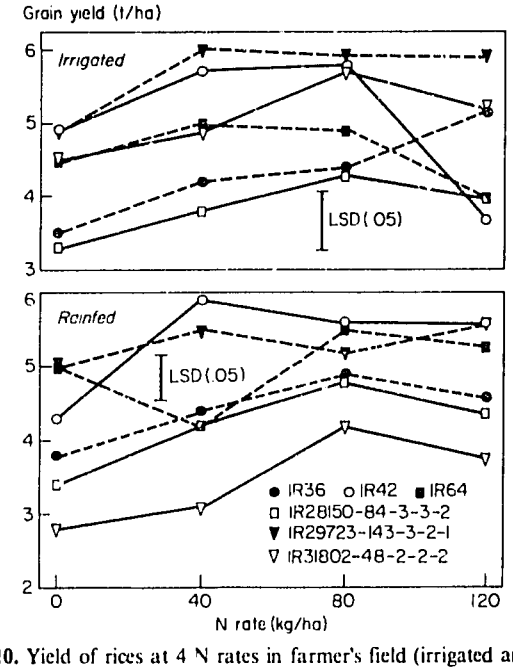
with varying levels of N in DS and WS under irrigated conditions.

Farmer's field. The promising breeding line IR29723-143-3-2-1, which outyielded all test rices in the same field during the previous DS (Annual report for 1984), also gave the highest yield at all levels of N in 1985 DS (Table 3). Although yields of

Table 3. Yields of IR varieties and promising breeding lines at 4 N levels (0-150 kg N/ha) in irrigated farmer's field, 1985 DS.

Variety	Duration (d)	Grain yield[a] (t/ha)			
		0	50	100	150
IR36	111	3.1	3.9	6.0	7.1
IR42	142	6.2	7.1	7.8	8.2
IR18348-36-3-3	111	4.0	5.6	7.6	8.5
IR28150-84-3-3-2	123	5.5	6.2	7.6	8.2
IR29723-143-3-2-1	142	6.7	8.3	8.6	8.6
IR31868-64-2-3-3-3	111	4.3	5.3	7.0	7.4
IR32429-47-3-2-2	101	3.2	3.3	4.5	5.8

[a]Av of 3 replications. LSD (0.05) = 0.8 t/ha.



10. Yield of rices at 4 N rates in farmer's field (irrigated and rainfed). Cabuyao, Laguna, Philippines, 1985 WS.

test rices increased with increasing N rate, responses to N application were not spectacular, as yields without fertilizer N were high (6.7 t/ha from IR29723-143-3-2-1).

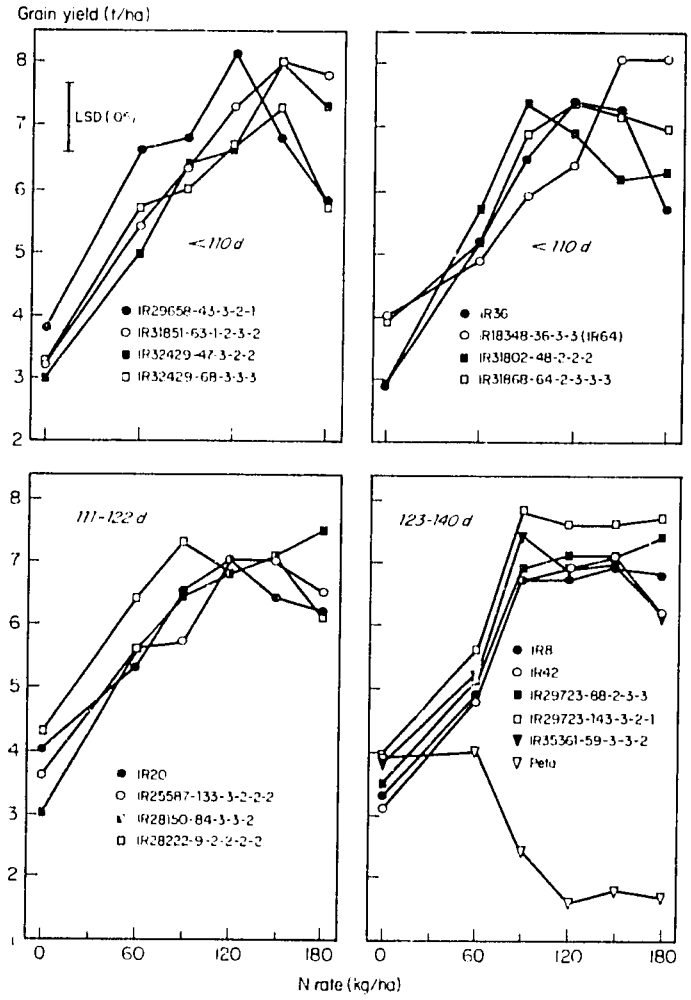
During WS, application of 40-80 kg N/ha appeared to be optimal (Fig. 10). The medium-late maturing line IR29723-143-3-2-1 had better yield at all N levels.

BPI stations. The optimum rate of N in Maligaya during DS seemed to be 120 kg N/ha (Fig. 11). Three rices, however — IR18348-36-3-3 (IR64), IR28150-84-3-3-2, and IR29723-88-2-3-3 — had increasing yield up to 180 kg N/ha. With the exception of IR18348-36-3-3 and IR29658-43-3-2-1, test rices had high yields less than 8.0 t/ha. Without N, the breeding line IR28222-9-2-2-2-2 outyielded the rest with 4.3 t/ha.

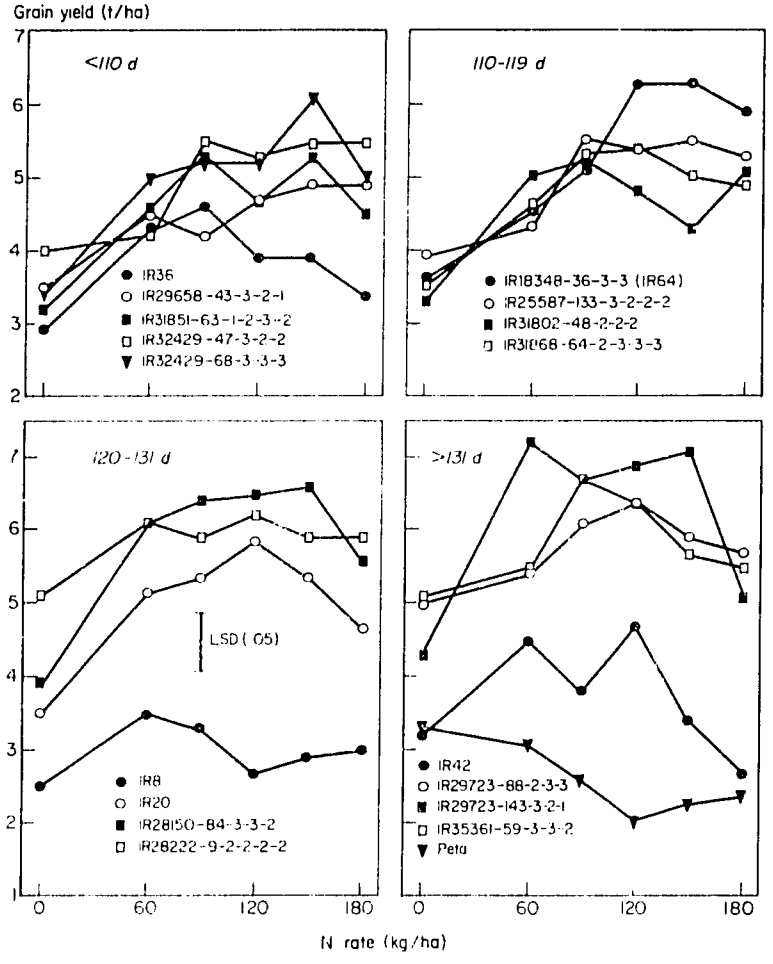
In WS a typhoon devastated the crop. Test rices generally lodged, and shattering was heavy. Maximum yields were below 5 t/ha.

DS planting in Bicol showed that rices maturing in 120 d or longer generally yielded higher than the early maturing rices (Fig. 12). Water supply was insufficient during the reproductive stage; hence, yields were relatively lower than those at IRRI and Maligaya. Only IR29723-143-3-2-1 yielded more than 7.0 t/ha.

As in Maligaya, the Bicol area was also affected by a typhoon during WS. Maximum yields were 5-6 t/ha.



11. Yield of rices at 4 N rates. Maligaya, Muñoz, Nueva Ecija, Philippines, 1985 DS.



12. Yield of rices at 4 N rates. Bicol Experiment Station, Pili, Camarines Sur, Philippines, 1985 DS.

Figure 13 summarizes the yields obtained from the Visayas when N was applied during DS. IR18348-36-3-3 (IR64), IR29723-143-3-2-1, and IR35361-59-3-3-2 had higher yields than the rest. Without fertilizer N, only the breeding line IR29723-88-2-3-3 produced more than 4.0 t/ha. The optimum rate of N application at the Visayas station was about 120 kg N/ha.

At the Visayas station, WS yields were comparable to DS yields and generally higher than those in Maligaya and Bicol during WS (Fig. 14). IR64 again outyielded all test rices. IR32429-47-3-2-2, IR29723-143-3-2-1, and IR35546-52-3-3-2 were found to increase yields with increasing N rate up to 120 kg N/ha. Most rices had their highest yield at 60-90 kg N/ha.

Rainfed rice. *IRRI.* Twelve rices were tested in IRRI rainfed plots. IR64 gave the highest yield (5.1 t/ha) at 120 kg N/ha (Table 4). Without fertilizer N, however, IR46 and IR28150-84-3-3-2 produced grain yields of 4.0 t/ha.

Farmer's field. Application of 40-80 kg N/ha appeared to be optimal under rainfed conditions and gave yields similar to those under irrigated conditions (Fig. 10).

QUALITY GRAIN AND YIELD POTENTIAL

Plant Physiology Department

High density or quality grains are heavier. The standard IR8 grain weighs 28 mg, and a high

density grain is 31 mg. The rice grain yield is heterogeneous, and the lower density grains comprise the major proportion of the yield in IR8. Yield could be increased by 35% if the low density grains could be changed into quality grains.

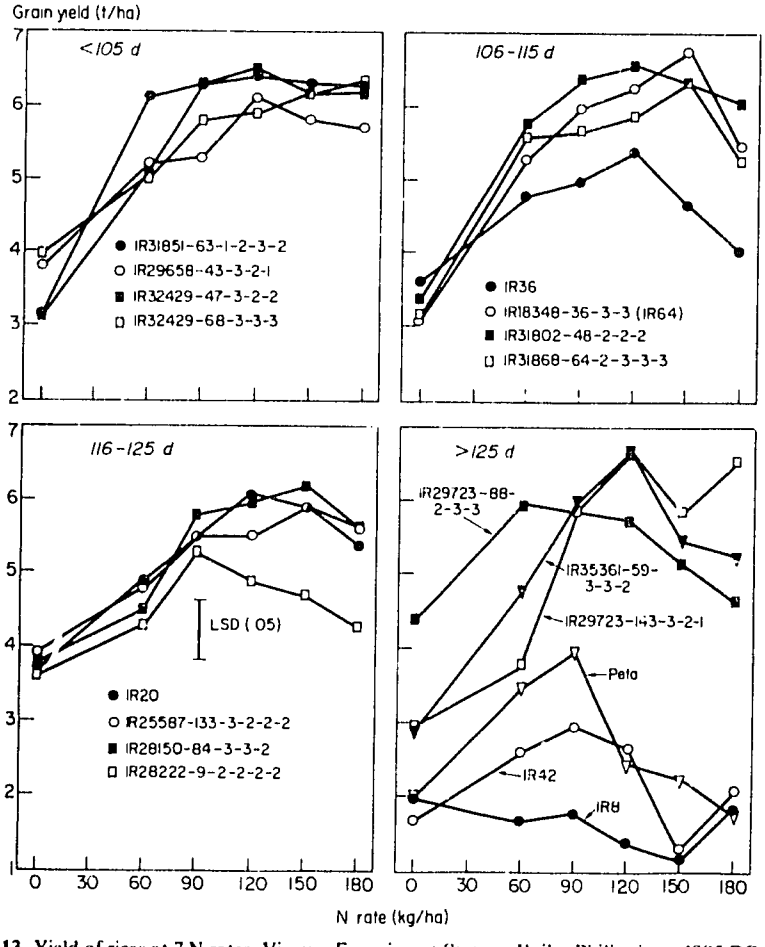
Sink size. Potential grain weight is higher for any given variety than the reported standard (Table 5). In IR8, improvement of grain weight could increase the yield from 7.0 to 7.8 t/ha.

IR29725 has a very high percentage of high density grains. The varietal differences are large and suggest vast scope for improvement of this character.

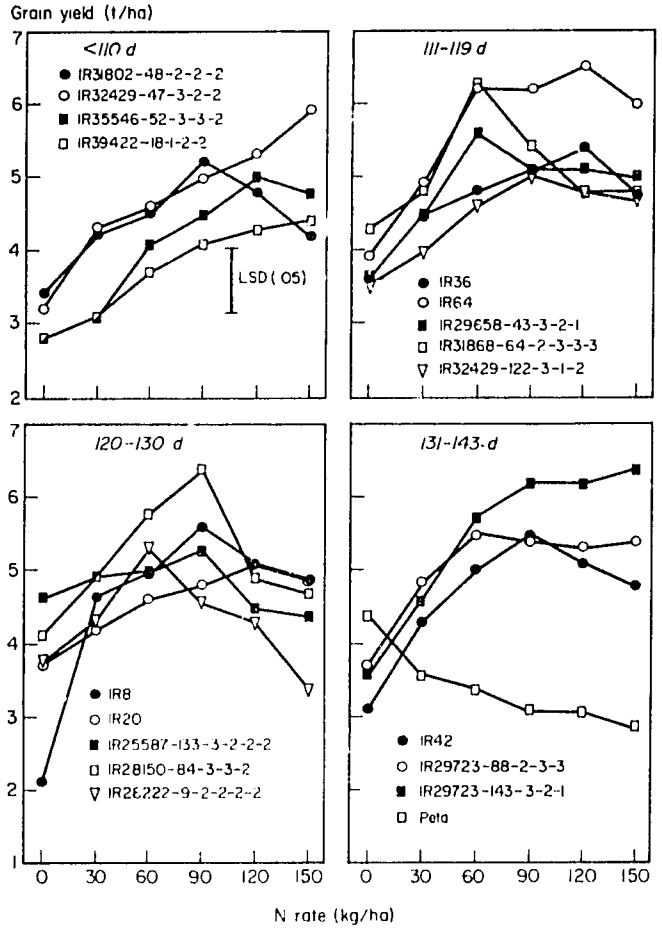
Milling recovery. Different grades of grain were obtained by using the full spectrum of the seed blower opening, i.e., from 0.6 to 7.6 cm (0.25 to 3.0 in) at intervals of 0.6 cm (0.25 in), to vary the air pressure. Air velocity increases with larger opening, and causes collection of heavier grains. Milling recovery and head rice recovery showed a linear relationship [$r = 0.969^{**}$, $Y = 26.62(X) - 2.47$] with blower opening (Fig. 15). At the widest opening (6.4 cm or 2.5 in), milling recovery was high (70%) and head rice recovery was 64%; it was 91% based on milled rice. Besides indicating higher grain yield, selecting varieties with high percentage of high density grains would also give higher milling and head rice yields.

Potential yields. Potential grain yield could be determined for a cultivar by multiplying total spikelet number by the individual grain weight of high density grain.

Potential yield = total spikelets produced/m^2 × 1,000-grain weight of high density grain



13. Yield of rices at 7 N rates. Visayas Experiment Station, Iloilo, Philippines, 1985 DS.



14. Yield of rices at 6 N rates. Visayas Experiment Station, Iloilo, Philippines, 1985 WS.

Table 4. Yields of IR varieties and promising breeding lines at 5 N levels (0-120 kg N/ha). IRRI rainfed farm, 1985 WS.

Variety	Duration (d)	Grain yield[a] (t/ha)				
		0	30	60	90	120
IR36	112	2.5	3.2	3.6	3.6	3.2
IR42	136	3.2	3.7	3.9	4.2	4.0
IR46	127	4.0	4.5	4.4	4.0	3.6
IR64	127	3.5	3.5	3.9	4.3	5.1
IR25587-133-3-2-2	136	3.7	3.4	3.2	3.3	3.3
IR28150-84-3-3-2	136	4.0	4.0	3.9	4.5	4.0
IR28228-12-3-1-1-2	136	3.5	3.8	3.9	3.7	3.9
IR29723-88-2-3-3	136	3.3	3.1	3.7	4.2	3.4
IR29723-143-3-2-1	136	3.2	3.8	3.6	4.4	4.1
IR31802-48-2-2-2	112	2.9	2.9	3.9	3.8	3.3
IR31868-64-2-3-3-3	112	2.8	3.8	3.6	3.5	3.6
IR32429-122-3-1-2	112	2.6	2.8	2.8	3.0	3.6

[a]Av of 3 replications. LSD (0.05) = 0.8 t/ha.

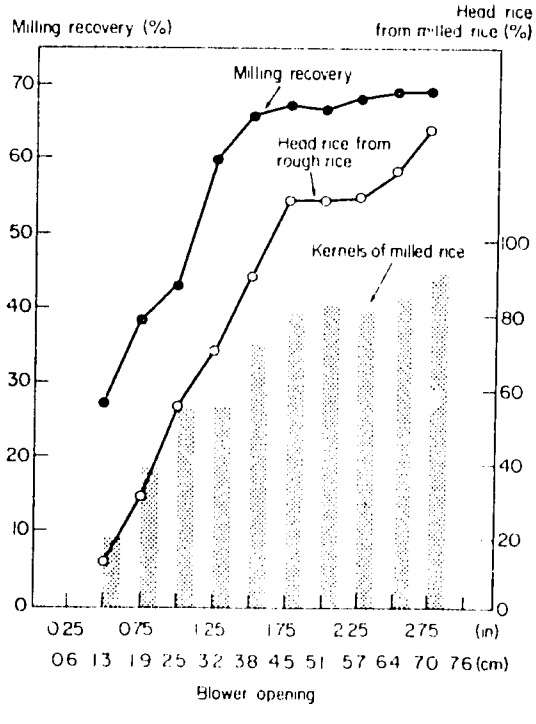
In these studies the potential yield is 10.4 t/ha for IR8, 8.8 t/ha for Peta, 8.3 t/ha for IR58, and 7.6 t/ha for Binato. But the actual yields realized were only 7.9, 5.9, 7.0, and 4.8 t/ha, respectively. In some field experiments, the spikelet number realized was as high as 48.2×10^3, which amounts to a potential yield of 14.9 t/ha.

Growth duration. The duration of vegetative growth in BPI-76 was varied by photoperiod treatments from 45 to 105 d at 20-d intervals to examine the relationship between growth duration and quality grain. Although a higher shoot dry weight was advantageous for the production of a larger sink, high density grain production was not related to shoot weight at all growth durations. It should be possible to put the high density grain

Table 5. Distribution of different grades of grains.[a] IRRI, 1985.

Variety	Distribution (%)				
	Chaff	Poor 1.00-1.06	Average 1.08-1.14	Good 1.16-1.20	Quality or high density >1.20
IR29725	18.4	7.3 (17.0)	3.0 (19.4)	8.6 (22.3)	63.0 (25.3)
IR42	8.0	8.7 (11.8)	10.8 (15.5)	15.0 (18.7)	57.4 (20.6)
IR28222	15.1	12.7 (17.6)	5.5 (21.8)	12.5 (24.5)	54.1 (27.9)
IR28178	23.8	13.1 (15.2)	4.6 (17.6)	8.5 (19.8)	49.8 (22.9)
IR29744	16.1	15.5 (12.3)	5.8 (14.2)	15.4 (15.4)	47.3 (18.4)
Peta	19.5	12.7 (16.7)	8.4 (21.5)	15.6 (24.6)	43.7 (28.0)
IR58	9.9	11.0 (15.3)	8.5 (18.7)	30.3 (21.6)	40.3 (24.0)
IR8	11.5	17.0 (22.5)	7.0 (25.9)	26.0 (29.1)	39.0 (31.0)
Binato	20.0	12.3 (16.9)	12.0 (21.5)	23.9 (25.0)	32.0 (26.5)

[a]Figures in parentheses are weight (mg) of a single grain.



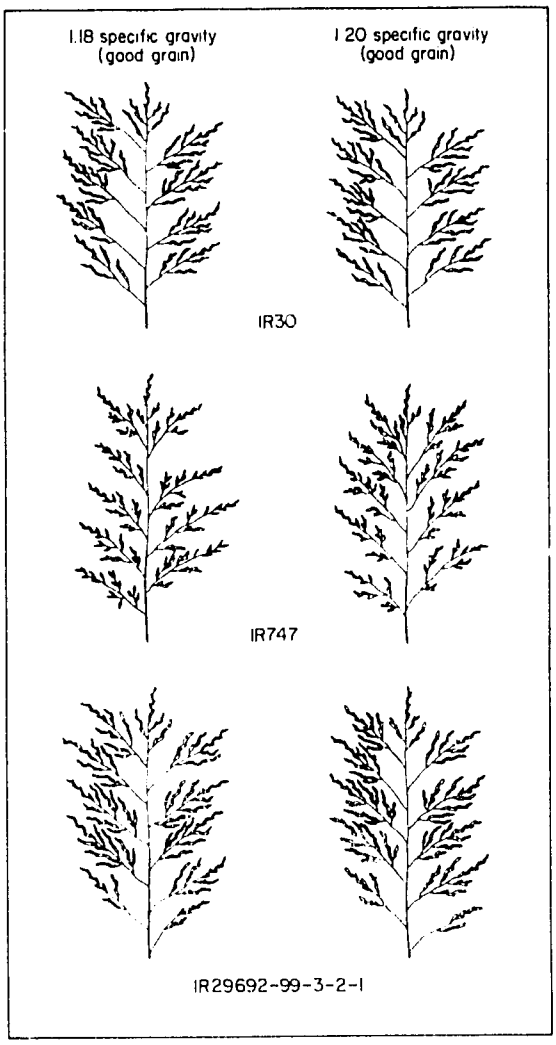
15. Milled rice and head rice at different openings of the seed blower. IRRI, 1985.

character in the background of a variety of any growth duration.

Location. Eleven rice cultivars with grain sizes varying from 15 to 40 g 1,000 grains were examined for the occurrence of medium (submerged at 1.18 specific gravity) and high density (submerged at 1.20 specific gravity) grains. Medium and high density grains were concentrated on the primary axis, followed by the secondaries; tertiaries did not have any (Fig. 16). The order of appearance of medium and high density grains was always basipetal in a branch. It was hypothesized that 1) the rice panicle is an assemblage of small, independent sinks (spikelets), 2) the topmost sink in each branch is the first one to become active, and 3) this creates a translocation gradient for the assimilates, which flow toward the terminal sink and fill it to its potential size. This terminal sink influences the subsequent sink that will be filled.

These studies indicate the following possibilities for enhancing yield potential:

- Combine high grain number with high proportions of intermediate and high density grains.



16. Location of good and quality grain in 3 rice varieties. IRRI, 1985 DS.

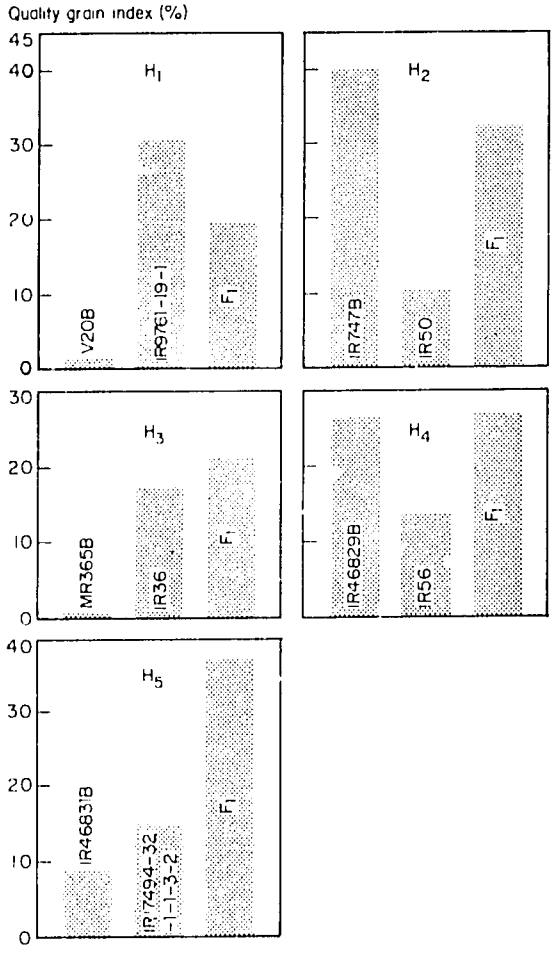
- Combine varieties with high density grains on primaries with those possessing higher number on the secondaries so that both types of branches receive the advantage.
- Tailor new varieties to minimize secondary and tertiary branches so that the number of primaries increases.

High density grain index. A high density grain is a manifestation of certain vital physiological processes such as assimilation, translocation, conversion, and low respiration. An increased proportion of high density grain as such, or increasing the same at a given grain or spikelet number, would enhance yield potential. Furthermore, it would ensure higher milling and kernel recoveries. This trait might be useful in screening varieties for high yield potential; it could be calculated as follows:

$$\text{High density grain index} = \frac{\text{number of quality grains/m}^2 \times 100}{\text{total number of spikelets/m}^2}$$

From this formula, the high density grain index is 47% in Peta, 39% in IR8, 30% in IR58, 40% in Binato, and 57% in IR42. IR29275 registered 63%.

Heritability. The possibility of attaining an increased high density grain index in the progeny of crosses is of great significance. Five hybrid combinations with their respective parents were examined. The character was found at a lower level in the F_1 of the H_1 cross (Fig. 17). In crosses H_2, H_3,



17. Quality grain in parents and hybrids. IRRI, 1985.

H_4, and H_5, F_1s showed a higher proportion of high density grains than their respective superior parents. Cross H_5 showed the highest heterosis for this character. High density grain index is heritable and heterotic, which means it is amenable to manipulation for higher yield potential.

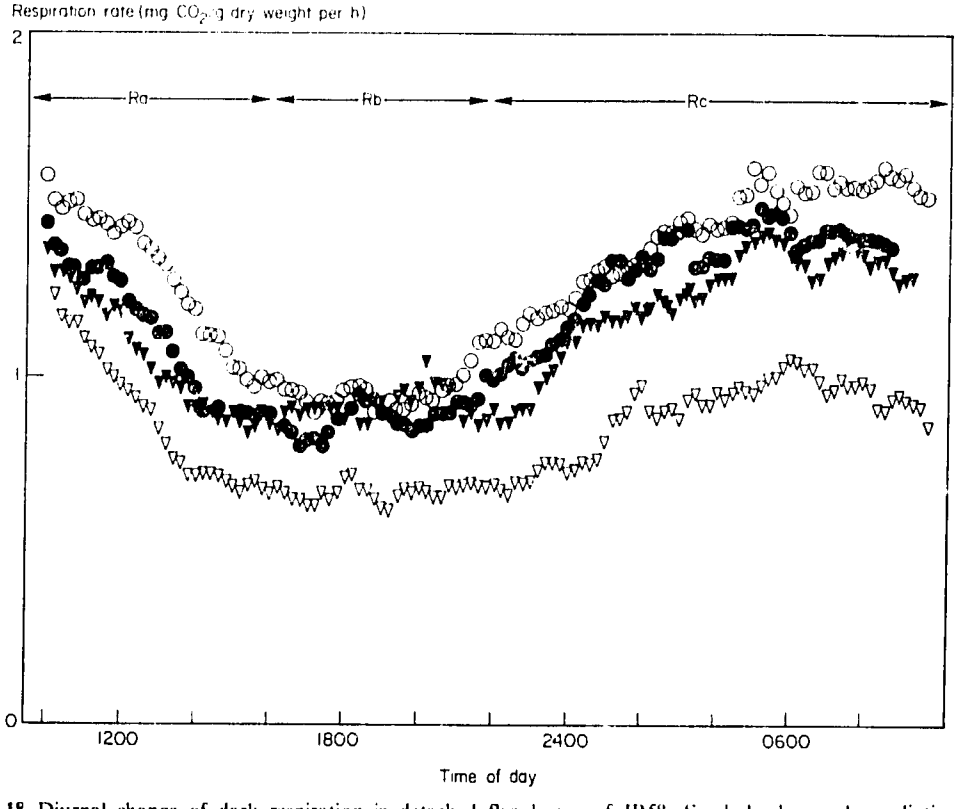
VARIETAL DIFFERENCES IN DARK RESPIRATION RATE

Plant Physiology Department

Low dark respiration rate at later growth stages has been considered a contributory factor in improving crop growth rate. Identifying rice varieties with low maintenance dark respiration is one way of improving crop growth rate. Dark respiration is affected by both environmental factors and physiological factors.

The diurnal pattern of dark respiration in 16 field-grown rice varieties was studied. The materials were sown on 15 Aug and transplanted on 30 Aug. Forty kg N/ha as urea was applied basally. The dark respiration rate at heading of detached flag leaves sampled early in the morning was measured. After enclosing the leaves in a temperature-regulated chamber (24 ± 0.5 °C), the rate of CO_2 evolution was measured by infrared gas analyzer (Fig. 18). The rate decreased during the first 6 h (Ra) and was almost constant for the next 6 h (Rb). After 12 h, it increased again, and eventually leveled off (Rc). Little varietal difference was found in the diurnal pattern.

In comparing dark respiration rate among varieties, it is desirable to find the rate that is stable for a certain period and is little affected by preceding environmental conditions. Dark respiration rate in Rb showed a quite constant rate for about 6 h and was only slightly affected by the solar radiation of the preceding day, except with extremely low solar radiation (Fig. 18). Thus, Rb is a suitable phase for comparing varietal differences. The relationships



18. Diurnal change of dark respiration in detached flag leaves of IR58. Symbols show solar radiation (mWh/cm²) of the day before sampling: • = 475, O = 445, ▼ = 355 ▽ = 155.

Table 6. Average dark respiration rate, N content, plant height, and days to heading of 16 rice varieties. IRRI, 1985.

Variety	Days (no.) from seeding to heading	N content (%)	Plant height at heading (cm)	Average dark respiration rate (mg CO_2/g dry weight per h)		
				Ra	Rb	Rc
ADT28	66	3.99	119	1.58	1.12	1.45
IR58	69	3.83	92	1.36	1.21	1.80
TKM6	70	3.69	134	2.16	1.63	1.94
IR36	72	3.90	91	1.34	1.07	1.28
Azucena	73	3.66	139	1.77	1.41	1.73
Nona Bokra	76	3.33	152	2.31	2.00	2.31
Zenith	77	3.55	125	2.04	1.81	2.09
Basmati	78	3.19	130	1.23	1.20	1.50
IR52	79	3.52	105	1.23	0.96	1.30
IR8	80	2.81	86	1.18	0.69	0.93
20A	83	3.19	168	1.17	0.89	1.23
ER10	84	3.02	103	1.02	0.72	1.02
H5	86	2.36	159	0.95	0.74	0.96
Milfor	87	2.57	118	1.00	0.87	1.24
Mahsuri	90	2.21	126	1.16	0.89	1.09
Peta	91	2.42	145	1.07	0.73	0.86

among the Rbs of 16 varieties and various plant factors were examined. The Rb was not related to plant height (Table 6) and was negatively correlated with duration from seeding to heading (r = -0.568*), partly because of the lower N content of leaves of longer growth duration (r = 0.557*). N content was highly and negatively correlated with growth duration (r = -0.937**).

EFFECT OF DEEP PLACEMENT FERTILIZATION AT LATER GROWTH STAGE ON SPIKELET FORMATION

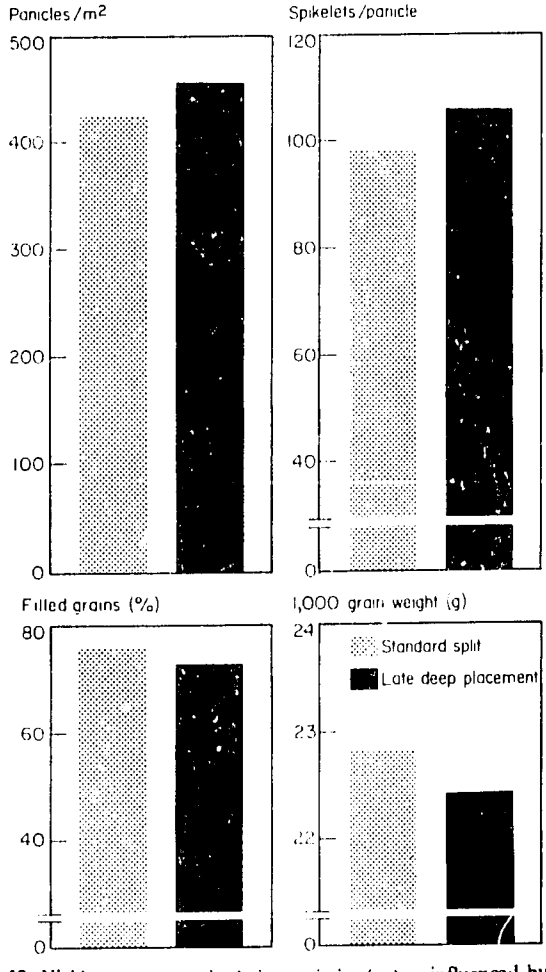
Plant Physiology Department

Experiments in 1985 DS evaluated the influence of late deep placement of N on plant growth, yield components, and grain yield. The fertilizer method and rate are shown in Table 7.

Table 7. Fertilizer application. IRRI, 1985 DS.

Variety	N rate[a] (kg/ha)				
	Standard split			Deep placement at later growth stage	
	Basal	5 DBPI	5 DBF	Basal	5 DBPI[b]
IR36	110	40	0	40	110
Peta	60	40	0	40	100
IR8	110	40	40	40	150
IR42	110	40	40	40	150

[a]Source: complete fertilizer (12-12-12). DBPI = days before panicle initiation, DBF = days before flowering.
[b]Deep-placed at 10-15 cm.



19. Yield components in 4 rice varieties (av) as influenced by standard split and late deep placement of N. IRRI, 1985 DS.

Compared with the standard split method of fertilization (av of four varieties), deep placement of N at later growth stages suppressed the growth of unproductive tillers, increased the percentage of effective tillers, and reduced the leaf area index. The first three elongated internodes were significantly shortened. Crop growth rate during the reproductive phase and dry matter efficiency in producing spikelets were higher. Growth after heading in deep placement plants was also faster.

Late deep placement prompted more panicles and higher spikelet number per panicle but reduced filled grain ratio and 1,000-grain weight slightly (Fig. 19).

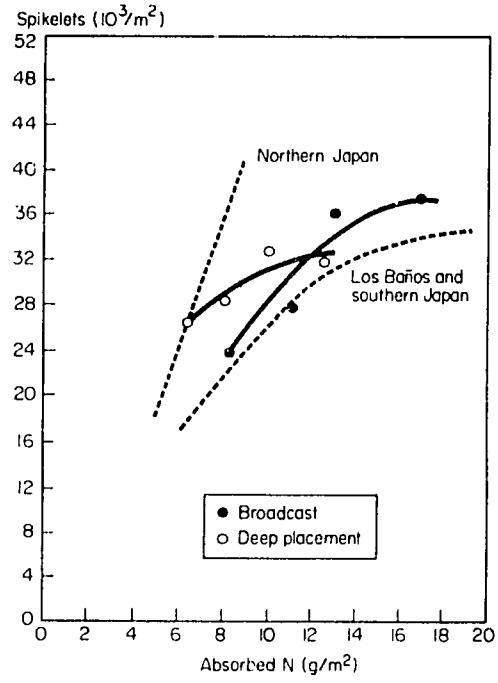
All varieties showed better yields under standard split than under late deep placement (Table 8). The lower yield in the deep placement plot may have been due to slower growth at the earlier growth stages because of lower N level. With deep placement, the comparatively better yield of IR8 seemed to indicate a varietal difference in grain yield response to late N deep placement.

Another field trial was conducted to compare the effect of broadcast and deep-placed N at later growth stage on spikelet formation using IR21850-84-3-3-2 and different rates of N. The N fertilizer treatment consisted of 40 kg N/ha applied basally in all plots and 25-200 kg N/ha either broadcast or deep-placed.

Table 8. Yield response of 4 rice varieties of different maturity to method of N fertilization. IRRI, 1985 DS.

Variety	Maturity (d)	Yield (t/ha)		
		Standard split	Deep placement at later stage	Difference
IR36	107	6.3	5.9	0.4
IR8	132	7.4	7.2	0.2
IR42	132	7.7	6.8	0.9
Peta[a]	141	3.5	2.2	1.3
Av		6.2	5.5	

[a]Lodged.



20. Relation between spikelet number and absorbed N by heading of IR21850-84-3-3-2 with deep-placed and broadcast N at later growth stage. IRRI, 1985.

The spikelet number correlated with the amount of absorbed N by heading for both broadcast and deep-placed N (Fig. 20). This association declined at higher N rates. Up to 11 g/m^2 of absorbed N, deep-placed N produced more spikelets/m^2 than broadcast N, meaning the efficiency of N used to produce spikelets is higher in deep-placed than in broadcast N at low to moderate N levels. The efficiency of spikelet production per unit of absorbed N by deep placement was higher than in Los Baños, Philippines, and southern Japan, but still lower than in northern Japan.

Genetic evaluation and utilization (GEU) program

Grain quality and nutritional value

Cereal Chemistry, Plant Breeding, Agronomy, Entomology, Statistics, Multiple Cropping, and Soil Microbiology Departments, Tissue Culture Facility, and International Rice Testing Program

BREEDING PROGRAM AND EVALUATION **24**
- Intermediate-amylose lines **24**
- Milling quality studies **24**
- Quantitative analysis of aroma **25**
- Oxygen uptake of developing grains **25**
- Protein screening of yield trials **25**
- Identification of rice varieties **26**

GRAIN QUALITY AND NUTRITIONAL FACTORS **27**
- Country samples **27**
- Nonstarch and starch lipids of milled rice **28**
- Thermal properties of rice starch **28**
- Processed rice products **29**
  - Puffed rice **29**
  - Layer cake **30**
  - Rice noodles **30**
  - Rice wine (*tapuy*) **31**
- Lysine content of anther culture and mutant grains **31**
- Distribution of types of protein bodies **31**
- Sulfur amino acids and sulfur-deficient soils **32**
- Energy and protein yield of nonrice crops **32**

BY-PRODUCTS AND RESIDUES **32**
- Epicuticular wax of rough rice **32**
- Rice straw properties **32**

Cereal Chemistry, Plant Breeding, Agronomy, and Statistics Departments

Intermediate-amylose lines (*Cereal Chemistry and Plant Breeding*). With intermediate amylose content (AC) and intermediate gelatinization temperature (GT) rices being developed and selected in the breeding program, it was observed that AC and GT (indexed by alkali spreading value) were no longer significantly correlated among elite lines (Table 1). AC correlated significantly with Instron cooked rice hardness and Amylograph consistency in the wet season (WS) crop but not in the dry season (DS) crop. However, cooked rice hardness and Amylograph consistency were correlated with each other in both crops. Gel consistency (GC) using the standard 100 mg rice flour was more significantly correlated with cooked rice hardness and Amylograph consistency than was GC using 90 mg flour. IR64 had a cooked-rice hardness value of 6.8 kg in the WS crop and 7.7 kg in the DS crop; values for IR28150-84-3 were 7.4 kg for the WS crop and 7.7 kg for the DS crop. Additional quality parameters besides GC would be desirable to discriminate among samples of similar starch properties, such as intermediate-AC, intermediate-GT lines.

Milling quality studies (*Cereal Chemistry and Plant Breeding*). A screening procedure for moisture adsorption tolerance (fissuring resistance) was developed based on an actual micromilling test.

An infrared moisture balance was used to reduce the weight (moisture) by 1% for 5.00 g brown rice in 45 s or 2% for 8.00 g rough rice in 90 s. The dried grains were then stressed by overnight exposure to ambient conditions of temperature and humidity, and 5 g brown rice was milled in a Kett Pearlest mill for 30 s. The friction micromill gave similar results and sample ranking as a McGill mill. A stress study on brown rice revealed differences in endosperm stress tolerance, whereas the data on rough rice reflected differences in hull tightness and endosperm stress tolerance. Rough rice data are more relevant in the tropics, where it is mainly rough rice that is stored.

Application of this method to elite lines gave generally higher head rice yield for stressed rough rice than for stressed brown rice. IR64 and IR28150-84-3 with intermediate AC and intermediate GT had better head rice yields from stressed rough rice than IR42, but had comparable head rice yields from stressed brown rice (Table 2). The Indian variety Halubbulu was found to be stress tolerant and to have high AC and intermediate GT.

Field grain samples of IR varieties were harvested in 1985 WS at normal maturity and at 1 wk later, oven-dried at 38-40 °C in the laboratory, aged in sealed jars for 2 mo, and then subjected to

Table 1. Range of values and correlation coefficients among quality characteristics of intermediate-amylose elite lines, IRRI, 1984 WS and 1985 DS.

Property	Range of values	Correlation coefficients with			
		Alkali spreading value	Gel consistency	Cooked rice hardness	Amylograph consistency
1984 WS (n = 17)					
Amylose content (%)	20.6- 24.7	0.37	-0.63**	0.82**	0.86**
Alkali spreading value	3.0- 6.0		-0.49*	0.48	0.34
Gel consistency (mm)	29 - 53			-0.69**	-0.64**
Cooked rice hardness (kg)	5.8- 8.5				0.71**
Amylograph consistency (BU)	80 -410				
1985 DS (n = 17)					
Amylose content (%)	17.5- 25.0	-0.04	-0.71**	0.28	0.35
Alkali spreading value	3.5- 7.0		-0.28	0.28	0.58*
Gel consistency (mm)	31 - 54			-0.49*	-0.51*
Cooked rice hardness (kg)	6.7- 9.4				0.58*
Amylograph consistency (BU)	80 -380				

Table 2. Typical responses of IR42, IR36, IR64, IR28150-84-3, and Halubbulu rice to moisture-adsorption stress test for milling quality. IRRI, 1985 DS and WS.

Variety or line	Season	Head milled rice yield[a] (% of rough rice)		
		Unstressed	Stressed rough rice[b]	Stressed brown rice[c]
IR42	DS	52 ± 1.5	42 ± 4.5	44 ± 1.5
IR36	DS	43 ± 1.0	44 ± 1.0	27 ± 2.3
IR64	DS	59 ± 0.5	55 ± 2.2	41 ± 4.7
IR28150-84-3	DS	59 ± 0.5	59 ± 0.5	43 ± 5.0
Halubbulu	–	57 ± 1.0	56 ± 3.6	43 ± 4.2
IR42	WS	67 ± 0.4	43 ± 9.1	51 ± 3.2
IR36	WS	52 ± 0.4	54 ± 3.3	27 ± 0.4
IR64	WS	63 ± 1.6	54 ± 2.3	45 ± 3.5
IR28150-84-3	WS	66 ± 1.7	63 ± 4.0	45 ± 3.3

[a]Mean ± SD. [b]Removal of 2% moisture using infrared moisture meter. [c]Removal of 1% moisture using infrared moisture meter.

milling tests with and without stressing of brown and rough rice. Lodging contributed to poor head rice yield. Total milled rice recovery ranged from 69 to 73% of rough rice; head rice yield was 46-71% (mean 61%) at normal harvest and 47-70% (mean 60%) with 1-wk delayed harvest. Head rice yield was 19-54% (mean 39%) for stressed brown rice and 28-64% (mean 50%) for stressed rough rice. With 1 wk delay in harvest, head rice yield was 17-54% (mean 38%) for stressed brown rice and 15-63% (mean 48%) for stressed rough rice. Thus, delaying harvest for 1 wk in WS was not relevant in screening for fissuring resistance. A fixed artificial stress, such as drying to remove a constant moisture content and then exposing to a humid condition, was a more sensitive method.

Quantitative analysis of aroma (*Cereal Chemistry*). In a cooperative study, chemists at the United States Department of Agriculture (USDA) Western Regional Research Center (WRRC), Albany, California, developed a relatively simple method for the quantitative analysis of the aroma principle of rice, 2-acetyl-1-pyrroline. The method uses 2-h atmospheric pressure steam distillation-continuous extraction of 200 g rice in 6 liters water (with an internal standard collidine) with an acid-phase (82 ml 0.46 M sulfuric acid) 120 ml diethyl ether solvent extraction. The aqueous layer covered with diethyl ether is then neutralized with $NaHCO_3$ and shaken thoroughly, and the ether layer is concentrated prior to gas-liquid chromatography at 90 °C and 0.4 kg/cm^2 He using a 1.2 m × 3 mm Pyrex column of 80-100 mesh Chromosorb G coated 10% by weight with Carbowax 20-M. Retention time was 22 min for 2-acetyl-1-pyrroline and 26 min for collidine. Collidine recovery was 28%; this factor was used to correct for 2-acetyl-1-pyrroline content.

Oxygen uptake of developing grains (*Cereal Chemistry*). Immature grains contribute to poor milling recovery and may also contribute to high respiration rates of unthreshed panicles. A study of the O_2 uptake using a Clark O_2 electrode of fresh grains of the relatively nondormant variety IR62 about 15, 20, 25, and 30 d after flowering in 1985 WS showed similar values (12.0, 11.4, 11.4, and 10.5 nmol O_2/h per grain, respectively). Thus, wet immature and mature grains have similar respiration rates.

Protein screening of yield trials (*Cereal Chemistry, Plant Breeding, Agronomy, and Statistics*). Brown rice protein (BRP) continued to correlate negatively with growth duration in both crops of the 1984-85 replicated yield trials, as did rough rice yields (Table 3). In contrast, the correlation between growth duration and yield was negative and significant only in WS; it was positive in DS, as was reported in 1984. A few entries showed higher protein content than the check varieties IR36 and IR42 in either season, but not in both seasons. IR29658-69-2 (10.6% BRP) had higher yield (4.8 t/ha) than IR36 (10.5% BRP, 4.0 t/ha) and higher yield and protein than IR42 (9.6% BRP, 4.2 t/ha) in 1984 WS. IR28228-119-2 had higher yield (7.0 vs

Table 3. Range and correlation between growth duration, brown rice protein (BRP), and rough rice yield in replicated yield trials.[a] IRRI, 1984 WS and 1985 DS.

Property	1984 WS (n = 416)			1985 DS (n = 367)		
	Range	Correlation coefficient with		Range	Correlation coefficient with	
		Growth duration	Rough rice yield		Growth duration	Rough rice yield
BRP (%)	6.8- 13.9	-0.39**	-0.30**	6.4- 10.7	-0.49**	-0.12*
Growth duration (d)	98 -134		-0.76**	102 -135		0.15**
Rough rice yield (t/ha)	1.5- 5.7			3.9- 7.8		

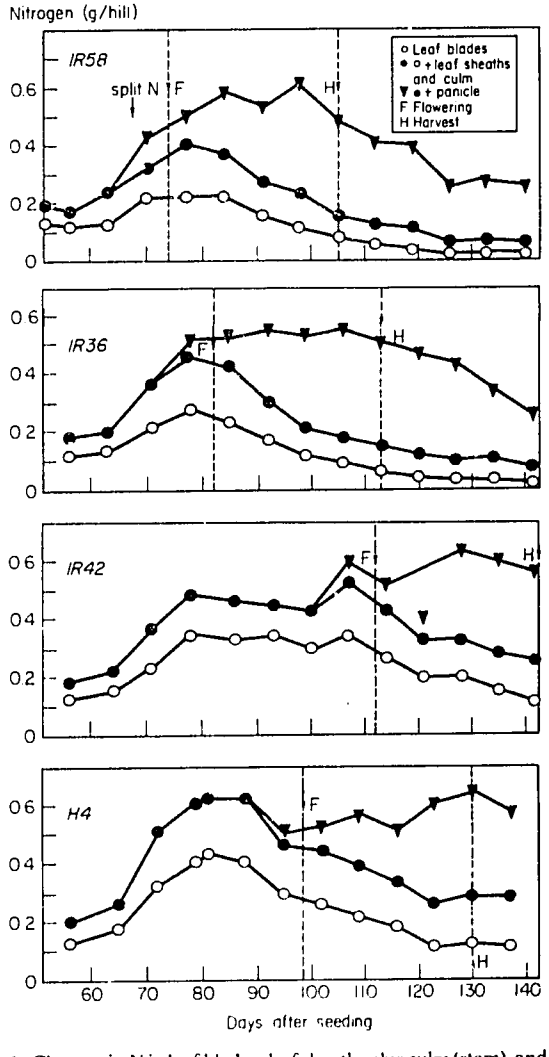
[a]IR36 and IR42 check varieties. Interactions between checks and trial plots were significant in 1985 DS.

6.3 t/ha) and BRP (9.6 vs 8.7%) than IR36 in 1985 DS.

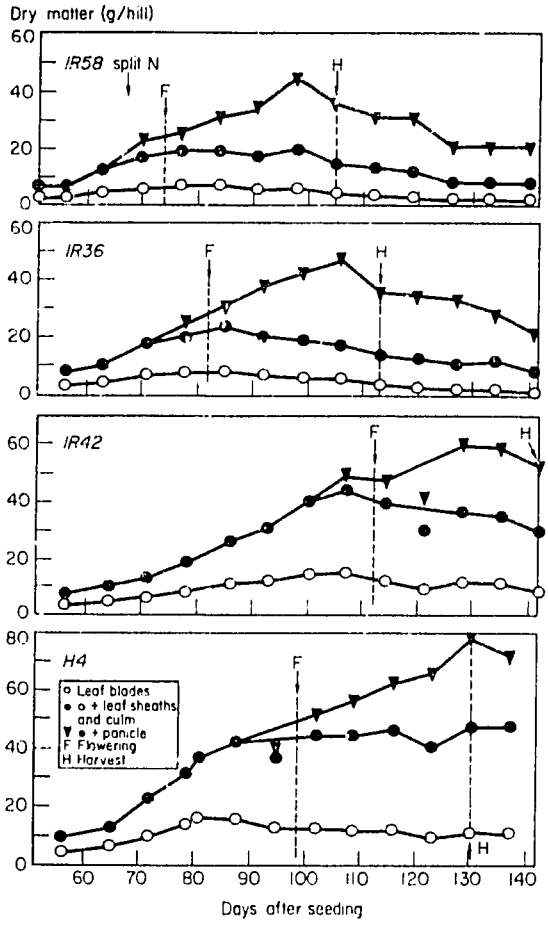
Flowering in IR58 and IR36 occurred around the period of maximum N uptake per hill from applied N fertilizer (Fig. 1), which may explain the higher N harvest index (HI) and higher grain protein in these varieties compared with IR42 and H4 (Annual report for 1984). In contrast, dry matter accumulation rates of the four varieties were similar (Fig 2). Confirmation of the results in 1985 DS in experimental plots involving three methods of urea fertilizer application showed higher protein and N HI only for IR58 (Table 4). IR36 had surprisingly low protein content, comparable to IR42, in contrast to the higher values in replicated yield trials.

Among 29 IR varieties grown in the 1985 WS demonstration plot, growth duration was 100-142 d, HI ranged from 0.38 to 0.58, and N HI was 0.38-0.71. HI was 0.57 for IR36, 0.57 for IR58, and 0.42 for IR42; N HI was 0.70 for IR36 and IR58, and 0.60 for IR42. Highest N HIs (0.69-0.71) were obtained from 5 IR varieties with highest HI (0.57-0.60) and growth duration of 100-112 d. Similar results were obtained for IR36, IR58, and IR42 in 1984 WS.

Identification of rice varieties (*Cereal Chemistry*). Electrophoresis of alcohol-soluble endosperm proteins (prolamin) has become a recognized method for identifying varieties of wheat, rye, and triticale. However, the prolamin content of rice protein is less than 5%. In a cooperative study with the Department of Plant Science, University of Manitoba, Canada, milled rice from



1. Changes in N in leaf blades, leaf sheaths plus culm (stem), and panicles of 3 IR varieties and H4. IRRI, 1984 WS.



2. Changes in dry weight in leaf blades, leaf sheaths plus culm (stem), and panicles of 3 IR varieties and H4. IRRI, 1984 WS.

six varieties with diverse properties was subjected to electrophoretic screening. Proteins were extracted with 5 *N* acetic acid and subjected to polyacrylamide flat gel electrophoresis in pH 3.1 aluminum lactate buffer. The six varieties could be distinguished on the basis of their electrophoretic protein banding pattern, making this method potentially useful for variety identification.

GRAIN QUALITY AND NUTRITIONAL FACTORS

Cereal Chemistry, Agronomy, and Multiple Cropping Departments and Tissue Culture Facility

Country samples (*Cereal Chemistry*). Rice samples were received from eight countries (Table 5). Rices

Table 4. Mean rough rice protein, harvest index, and N harvest index of 4 rice varieties that received 116 kg urea N/ha. IRRI, 1985 DS.

Variety	Growth duration (d)	Rough rice protein (%)	Harvest index	N harvest index
IR58	101	7.4	0.60	0.74
IR36	111	5.9	0.54	0.65
IR8	124	6.0	0.49	0.64
IR42	125	6.2	0.48	0.67

from Argentina showed a shift in selections to low and intermediate AC and to soft GC. Most of the selections had low AC and intermediate GT, or intermediate to high AC and low GT. The check rices all had low GT. The combination low AC and intermediate GT was uncommon except for Australian long-grain rices.

The Burmese rices were either of intermediate AC, of low AC, or waxy. The intermediate-AC rices had either intermediate or low GT, but the low-AC and waxy rices had low GT. Nonwaxy rices had all three types of GC values, but waxy rices had soft GC.

The six Chinese rices had the typical high AC for indica and low to intermediate AC for japonica rices. Protein content and cooked rice hardness values were higher for the indicas than the japonicas.

The Greek rices had low AC and intermediate to low GT, or intermediate AC and intermediate GT. GC values were either soft or medium, and the intermediate-AC sample had the hardest cooked rice. Protein content of the samples was low.

Korean samples showed similar properties for japonica and indica/japonica rices. However, japonicas tended to have lower length-width ratios (1.8) than indica/japonica rices (1.9-2.7). Japonicas had more homogeneous milled rice lengths of 4.7-4.9 mm and widths of 2.7-2.8 mm, whereas the indica/japonica grains were 4.7-5.9 mm long (mean 5.4 mm) and 2.2-2.5 mm wide. The shortest-grain indica/japonica rice, Chilseongbyeo (4.7 mm), was narrower (2.4 mm) than the japonicas.

Pakistani fine-grain selections were high-AC rices, and one intermediate-AC, intermediate-GT rice. GC was either medium or hard. The selections had higher protein content and harder cooked rice

Table 5. Range of milled rice properties of country samples, IRRI, 1985.

Source	Sample	Amylose content[a]	Gelatinization temperature[b]	Gel consistency[c]	Protein (%)	Cooked rice hardness[d] (kg)
Argentina	21 selections	L, I>H	L>I	S>M>H	–	–
	9 varieties	H>I>L	L	M>H>S	–	–
Burma	14 nonwaxy	I>L	L>I	H>S,M	5.6- 8.1	–
	11 waxy	Wx	L	S	5.1- 8.2	–
China	3 indica	H	L, I	H, M	9.7-11.8	8.2- 9.6
	3 japonica	I, L	L	M	6.2- 8.4	7.4- 9.1
Greece	3 varieties	L>I	I>L	S>M	5.2- 6.0	5.1- 8.2
Korea	6 indica/japonica	L	L	S	7.8- 9.3	5.4- 6.6
	4 japonica	L	L	S	7.3- 8.3	6.1- 6.8
Pakistan	3 varieties	I	L	M, H	–	7.8- 8.7
	6 selections	H>I	L>I	H>M	–	8.5-11.9
Suriname[e]	2 varieties and 10 selections	I>L	I>L, HI	M,S>H (R) S>M (P)	– 6.0- 9.3	7.7-11.4(R) 8.4-13.4(P)
United States	4 medium grain	L	L	S	5.0- 8.6	6.7- 8.1
	10 long grain	I>L>H	I>L, H	S>M	6.6- 8.0	7.1- 9.4

[a]H = high (>25%), I = intermediate (20-25%), L = low (10-20%), Wx = waxy. [b]Based on alkali spreading value: L = low (6-7), I = intermediate (4-5), HI = high intermediate (3). [c]S = soft (61-100 mm), M = medium (41-60 mm), H = hard (27-40 mm). Boiling time 8 min R, 15 min P. [d]Cell area of 6.5 cm². [e]R = raw, P = parboiled.

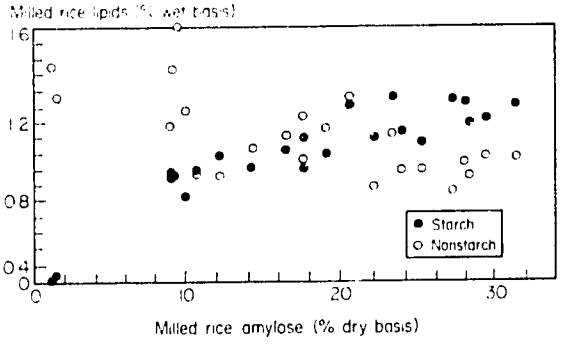
than the 3 Basmati check varieties and on cooking gave elongation ratios of 1.7-2.0 that were comparable to the 1.8-1.9 ratios of the Basmati checks.

The Surinam raw and parboiled milled rices showed a wider range of AC, GT, and GC for selections than for the check varieties Diwani and Eloni (intermediate AC, intermediate GT, medium GC). Parboiled rices gave softer GC values than raw rice, despite the longer boiling time of 15 min to allow for slower dispersion rate. They also gave harder cooked rice than did raw rices. The preferred variety Diwani had 20% AC compared with 22% for Eloni. Cooked parboiled Diwani was also 1 kg softer by the Instron hardness test.

The U.S. medium-grain rices showed typical AC, GT, and GC. The variation in properties among long-grain rices was due to the inclusion of specialty rices Toro 2 and Century Patna 231 (low AC) and Newrex (high AC). Newrex had the hardest cooked rice.

Nonstarch and starch lipids of milled rice (*Cereal Chemistry*). Although starch lipids (complexed with amylose) are important in texture properties of cooked rice, nonstarch lipids are probably the fractions that undergo rancidity during storage of milled rice. The content of nonstarch lipids is influenced not only by the degree of milling but also by AC. Accumulated data, supplemented in 1985 with those on low-AC lines and mutants from breeding programs, showed higher nonstarch lipids in waxy and very low-AC than in intermediate- and high-AC rices (Fig. 3). In contrast, waxy milled rices had lower starch lipid levels than intermediate- and high-AC rices. The wider scatter of nonstarch lipids data may have been due to differences in degree of milling, which had little effect on starch lipid content.

Thermal properties of rice starch (*Cereal Chemistry*). Thermal properties of eight alkaline-protease prepared rice starches were investigated at General Foods, Inc., Cobourg, Ontario, Canada, using thermomechanical analysis (TMA) and differential scanning calorimetry (DSC). Total TMA area and volume expansion at 90 and 95 °C correlated negatively with AC (Table 6), verifying



3. Relation between AC and nonstarch and starch lipids of milled rices. IRRI, 1981-85.

Table 6. Range of physicochemical and thermal properties of 8 rice starches prepared by alkaline-protease treatment of milled rice. General Foods, Inc., Canada, and IRRI, 1985.

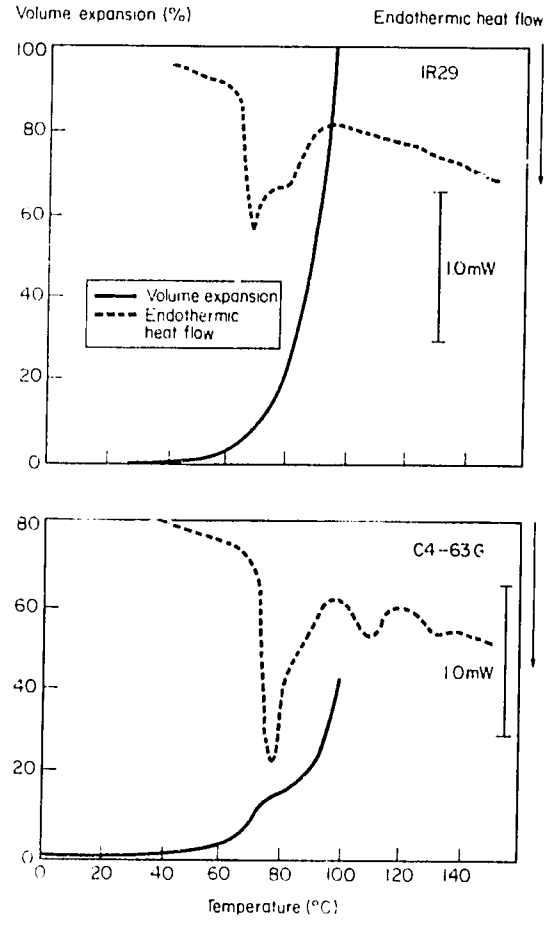
Property	Range of values	Correlation coefficients[a] with	
		AC	Final GT
Amylose content (%)	2.1 - 31.2	1.00	-0.30
Final GT (°C)	60 77	-0.30	1.00
Total lipids (%)	0.24- 1.65	0.91**	-0.35
TMA analysis (50% starch in water)			
Volume expansion at 90°C (%)	18.7 - 64.1	-0.93**	0.06
Volume expansion at 95°C (%)	20.7 -108.7	-0.97**	0.18
Total area under TMA curve (arbitrary units)	34.8 - 86.2	-0.85**	-0.18
DSC data (20% starch in water)			
Temperature $_{peak}$ (°C)	61.5 - 79.4	-0.36	0.98**
ΔH^b $_{gelatinization}$ (J/g)	8.6 - 17.1	-0.81*	0.63 (0.84**)[c]
ΔH^b $_{amylose\text{-}lipid}$ (J/g)	0 - 2.8	0.82*	-0.64 (-0.94**)[c]

[a]Significant at the 5% (r = 0.707) and 1% (r = 0.834) levels. [b]Enthalpy. [c]Excluding the 2 waxy starches (n = 6).

the stabilizing role of amylose in starch gels. DSC peak transition temperature correlated positively with final GT. Correlation coefficients between GT and enthalpies of gelatinization and amylose-lipid complex melting were not significant for all samples, but were significant for nonwaxy samples. AC correlated negatively with gelatinization enthalpy and positively with enthalpy of amylose-lipid complex melting. At intermediate to low water content, the DSC thermal curve was not representative of the initial starch crystallite profile but reflected the composite thermal effects of several processes that occurred simultaneously during heating in DSC: melting, annealing, and crystallization, particularly of the amylose-lipid complex. Amylose-lipid complex crystallization can explain the negative correlation between gelatinization enthalpy and AC.

The TMA volume expansion curves of nonwaxy starch (from variety C4-63G) exhibited a two-stage swelling pattern (Fig. 4), the first associated with the onset of gelatinization phenomena (glass transition and partial melting) and the second with the melting of starch crystallites. The profile of IR2071-137-5 provided evidence for both the thermally activated processes of glass transition and crystallite melting. In contrast, waxy starch (from IR29) showed mainly the second phase of volume expansion after the glass transition region.

Processed rice products (*Cereal Chemistry*). *Puffed rice*. Puffed volume of milled rice from steeped rough rice previously dry-parboiled at 0 kg/cm^2 steam pressure and puffed by heating the



4. Thermomechanical analysis (125 mg) and differential scanning colorimetry (5 mg) of thermal curves of protease-prepared waxy (IR29) and nonwaxy (C4-63G) rice starches in 50% water. Heating rate: 2 °C/min for TMA and 10 °C/min for DSC. General Foods, Inc., Canada, and IRRI, 1985.

parboiled milled rice in oil at 210-220 °C correlated negatively with AC (Annual report for 1972). Indian scientists recently reported that, with increasing severity of parboiling conditions, puffed volume is optimal for nonwaxy rices with increasing AC. Puffed rice may also be obtained from raw milled rice by prior cooking, drying, and then gun puffing. IR rices differing in AC and GT were processed into puffed rice by both methods of gelatinization, and the properties of the product were compared.

Parboiling of steeped rough rice for 10 min at 100 °C and wet steam pressure of 0 kg/cm^2 was verified to produce higher puffed volume (volume expansion ratio 2.8-3.2) in waxy and low-AC rices with low GT than in intermediate- and high-AC rices with low or intermediate GT (expansion ratio 1.8-2.4). Since the grains were not completely parboiled at 100 °C, steeped rough rices were also parboiled at steam pressure 1.5 kg/cm^2 (127 °C) for 10 min. Intermediate- and high-AC rices showed higher water uptake during parboiling at 127 °C (30-37%) than at 100 °C (23-29%), whereas waxy and low-AC rices showed similar water uptake values of 29-34% at 100 °C and 29-35% at 127 °C. Volume expansion ratio on puffing increased to 5.4-5.9 for waxy and low-AC rices and to 4.0-5.8 for intermediate- and high-AC rices. Puffed rice hardness was lower for the more expanded products parboiled at 127 °C (1-2 kg) than at 100 °C (2-9 kg). IR29 (waxy), IR841-85-1 (low AC), and IR64 (intermediate AC) nad the highest volume expansion ratios, but IR841-85-1 had the crunchiest grain and lowest hardness value. Degree of parboiling as indexed by water uptake seems to determine volume expansion ratio and hardness of puffed rice. Whiteness of milled parboiled rice decreased with increasing parboiling temperature.

Boiling of milled rice in excess water gave a more homogeneous puffed product than steaming of steeped milled rice at 0 kg/cm^2 (100 °C) until cooked. A 10-min boiling time was inadequate to cook the grain core, and 13-22 min boiling was required to completely cook 9 rices. Cooking time was influenced by starch GT and grain thickness. IR42 showed excessive grain cracking during cooking, which could reflect its susceptibility to moisture adsorption stress. Puffed volume expansion ratio improved for most samples, particularly the intermediate-GT rices, from 3.3-5.1 after 10-min cooking to 4.8-5.8 after complete cooking. Puffed rice hardness of nonwaxy rices dropped from 1.6-2.9 kg/grain to 1.6-2.1 kg/grain, whereas mean waxy rice hardness remained lowest at about 1 kg/grain with longer cooking time. Two high-protein (11%) samples tended to have lower puffed volume. Thus, under conditions of complete gelatinization of rice grains (similar water uptake) by parboiling of rough rice or cooking of milled rice in excess water, nonwaxy rice and waxy rice gave similar volume expansion.

Layer cake. Low-AC U.S. rice flours produced better layer cakes than intermediate-AC, long-grain rice flours in studies at WRRC. The cake used 80 g sugar, 7 g baking powder, 15 g vegetable oil, and 80 ml water/100 g rice flour. The batter was baked at 177 °C for 32 min. Since the U.S. rices also differed in GT, the relative importance of AC and GT on the quality of layer cake was reassessed using IR varieties. The low-AC, low-GT variety IR24 produced very good layer cake. In contrast, another low-AC, low-GT variety, IR43, required more water to allow mixing of the batter with a cake mixer. More water was also required for intermediate-AC IR48 and high-AC IR42 (Table 7). All these low-GT rices produced good quality cake crumb, and cake volume was directly related to AC.

High-AC, intermediate-GT IR36 and low-AC, high-GT Century Patna 231 produced a completely collapsed cake. The IR36 batter was also more fluid than that of IR42. Reduction of water to 80 ml and sugar to 40 g to ensure starch gelatinization improved the cake, but expansion was lower and the cake more grainy and harder than that of IR42 (Table 7). Similar results were earlier reported for intermediate-AC, intermediate-GT U.S. rices. Evidently, higher GT and not higher AC is the major cause of the harder, grainy texture of cakes from long-grain rices compared with medium-grain U.S. rices.

For greater volume expansion during baking, sheeting of the IR43 batter five times in a pasta maker roller, after prehydrating the rice flour with the water ingredient, was slightly superior to mixing with a cake mixer (Table 7).

Rice noodles. Samples obtained from commercial production of flat noodles in Sydney, Australia, and flat and extruded noodles in

Table 7. Effect of variety and sheeting on the water requirements, height, and hardness of rice layer cake.[a] IRRI, 1985.

Sample	Amylose content[b]	Gelatinization temperature[c]	Water-rice ratio	Mean height (mm) of cake	Instron hardness (kg) of aged cake
IR24	L	L	0.80	49	0.48
IR43	L	L	0.93	50	0.50
IR43 (sheeted)	L	L	0.93	52	0.50
IR48	I	L	1.00	53	0.58
IR42	H	L	1.13	60	0.40
IR36[d]	H	I	0.80	42	1.1

[a]100 g rice flour, 80 g sugar, 7 g baking powder, 15 g vegetable oil, and water. [b]H = high (>25%), I = intermediate (20-25%), L = low (10-20%). [c]Based on alkali spreading value: L = low (6-7), I = intermediate (4-5). [d]Sugar reduced to 40 g/100 g rice flour.

Bangkok, Thailand, were characterized for physicochemical properties. The imported Thai milled rice used in Sydney had high AC with hard GC. The Thai rice used in Bangkok also had high AC but had intermediate GT and medium-soft GC. Wet milling resulted in a drop in Amylograph pasting viscosity of the flour. Gel viscosity in 0.2 *N* KOH decreased progressively during wet milling, mixing, molding, and extrusion into fine noodles.

Rice wine (tapuy). RD4 (waxy) and seven IR varieties differing in AC were studied for rice wine production by food microbiologists at the Institute of Food Science and Technology, University of the Philippines at Los Baños. The process involves washing and steaming milled rice, incubation with *Rhizopus oryzae* followed by *Saccharomycopsis capsularis* to hydrolyze starch to glucose, and fermentation in jars with *Saccharomyces cerevisiae*. Waxy and low-AC rices gave the highest volume (280 ml/100 g rice) and alcohol content (12-13%) of rice wine and the lowest weight of unfermented residue. Intermediate- and high-AC rices generally had lower wine yield (250 ml/100 g rice) and alcohol content (10-12%).

Waxy rices had the fastest rate of wine production. Alcohol content leveled off within 6 d of fermentation in 6 of the 8 rices, but wine production was complete in 6 of the samples within 12 d of fermentation.

Four rices used in traditional *tapuy* making were characterized. Three were waxy and had low GT and soft GC. The fourth sample was a red rice with 25% AC, low GT, and hard GC.

Lysine content of anther culture and mutant grains (*Tissue Culture and Cereal Chemistry*). Anther culture-derived lines from the cross IR9752-71-3-2/IR19792-15-2-3-3-3 (n = 26) and its parents and from Taipei 309 (n = 22) and Taipei 177 (n = 1) were analyzed for BRP by Kjeldahl and biuret analyses, and for relative lysine content by dye binding capacity of Acilane Orange G dye. Brown rice samples with high dye binding capacity for their protein level were analyzed for lysine content by ion-exchange chromatography. Lysine among the anther culture samples was no higher than that of their parents. Brown rice properties of one high-lysine mutant each from Assam 5 and Calrose 76 from the USDA Beltsville Agricultural Research Center were compared with those of their parent. Only the Calrose 76 mutant 397C-R4C-7 had higher lysine content of protein than its parent (4.5 vs 4.0%) and higher BRP (9.9 vs 7.8%). However, the mutant had lighter opaque grain (1.8 vs 2.3 mg/grain) and thus only 11% higher lysine content/grain.

Distribution of types of protein bodies (*Cereal Chemistry*). Japanese scientists recently reported that spherical and crystalline protein bodies are present not only in the subaleurone layer but also in the inner endosperm of japonica rices such as Kinmaze. In earlier collaborative studies with scientists at the U.S. Grain Marketing Research Center (GMRC), Manhattan, Kansas, and the University of Durham, England, crystalline protein bodies were observed to be confined mainly to the subaleurone or outer layer. Confirmatory observation on Kinmaze mature endosperm by light microscopy in bright and dark fields at GMRC showed that the protein bodies in the inner endosperm are mainly spherical. Transmission electron microscopy of the Kinmaze subaleurone layer confirmed the presence of all three protein body types: large spherical, small spherical, and crystalline. Thus Kinmaze has the same endosperm

protein body distribution as indica and japonica rices previously observed at GMRC and Durham: only large spherical protein bodies in the inner endosperm and all three types in the subaleurone layer.

Sulfur amino acids and sulfur-deficient soils (*Cereal Chemistry and Agronomy*). Studies on Bangladesh and Indonesian rices in 1981 suggested that soil S deficiency does not reduce the content of the S amino acids, cysteine and methionine, in BRP (Annual report for 1981). Analysis of field samples from the Bangladesh Rice Research Institute (BRRI) and the Maros Research Institute for Food Crops (MRIFC, Indonesia) showed normal total S amino acids in the zero-S plots (Table 8). Pot experiments, however, showed low levels of brown rice S amino acids in 1 ppm S samples and normal values for 10 ppm S samples. The difference can be explained in part by the higher protein content of the S-deficient grains, since the lysine content difference was much less than that for cysteine plus methionine. Thus, most field samples grown in S-deficient soils would have normal levels of S amino acids in the grain protein, whereas low S amino acid levels can be obtained in pot experiments with S-deficient soils. Amino acid S accounted for 92% of total brown rice S in the BRRI samples, 68% in MRIFC samples, and 74% in IRRI samples. The mean value was 76% of total S compared with 85% in 1981 samples.

Energy and protein yield of nonrice crops (*Cereal Chemistry and Multiple Cropping*). A comparison of the energy and protein yields of cereals and legumes in rice farming systems showed higher dry matter yields for maize, sorghum, and brown rice than for legumes (Table 9). Energy yields for peanut and soybean, however, were higher than those of other legumes because of their higher mean fat contents (48% for peanut, 18% for soybean, and <2% for the others). Soybean had the highest protein yield. Cowpea and bush sitao (*Vigna unguiculata* ssp. *sesquipedalis*) had the lowest protein yields because of poor dry matter yields. Soybean had the highest mean crude protein content (40%) among the crops.

BY-PRODUCTS AND RESIDUES

Cereal Chemistry, Plant Breeding, Entomology, and Soil Microbiology Departments and International Rice Testing Program

Epicuticular wax of rough rice (*Cereal Chemistry and Entomology*). Epicuticular wax was extracted with chloroform from intact rough rice of 13 IR varieties and lines for 60 s, concentrated, and weighed. Values obtained ranged from 1.9 to 6.9 mg/100 g rough rice (mean 4.1 mg/100 g). The surface wax content of hulls was not simply related to index of susceptibility and weight loss of rough rice to Angoumois grain moth.

Rice straw properties (*Cereal Chemistry and Plant Breeding*). The composition of leaf blades, leaf sheaths, and stems in harvest straw was studied on IR36, IR42, IR58, and H4 grown in 1984 WS in

Table 8. Effect of S-deficient soils on the content of S amino acids (cysteine and methionine) and lysine in brown rice protein, BRRI, MRIFC, and IRRI, 1985.

Location	Treatment		Mean rough rice yield[a] (t/ha)	Brown rice weight (mg)	Brown rice protein (%)	Contents (% in protein)	
						Cysteine + methionine	Lysine
Bangladesh (BR3)	Control		2.2	21	9.5	4.6	3.5
	NPK		3.7	23	9.5	4.6	3.4
	NPKS (30 kg S/ha)		6.6	22	9.2	5.6	3.4
Indonesia (n = 8)	0 S	Range	3.2-4.8	15-20	6.0- 9.6	4.4-5.5	4.0-4.4
		Mean	4.0	18	8.3	5.0	4.2
	50 kg S/ha	Range	5.4-7.9	17-21	7.2- 9.8	3.7-5.5	3.5-4.9
		Mean	6.3	18	8.0	5.0	4.3
IRRI (n = 6)	1 ppm S	Range	(39-105)	14-20	6.8-11.8	2.2-4.4	3.6-4.5
		Mean	(68)	17	10.4	2.9	3.9
	10 ppm S	Range	(95-245)	15-22	6.9- 9.8	5.0-6.3	3.9-4.6
		Mean	(152)	19	8.1	5.2	4.3

[a]Values in parentheses are yield data in g/hill.

Table 9. Mean dry matter, energy, and protein yields of various crops in rice farming systems compared with IR58 in replicated yield trial. IRRI, 1984-85.

Crop	Season	Varieties (no.)	Dry matter yield (t/ha)	Energy yield (10^3 mJ/ha)	Protein yield (kg/ha)
Maize	1984 DS	5	2.2	37.5	248
Sorghum	1984 DS	5	3.3	60.0	307
Cowpea	1984 WS	5	0.8	14.5	199
Mungbean	1984 WS	5	1.2	22.6	324
Peanut	1984 DS	5	1.1	33.3	307
Pigeonpea	1984 DS	5	1.5	26.7	313
Bush sitao	1985 WS	5	0.5	7.2	110
Soybean	1984 DS	5	1.9	42.9	792
Brown rice (IR58)	1984 WS	1	3.2	57.8	355
Brown rice (IR58)	1985 DS	1	4.1	75.3	435

cooperation with animal nutritionists at the Institute of Animal Science (IAS), UPLB. The plots received 50 kg N/ha basally and 25 kg N/ha as topdressing. A greater fraction of straw N than straw dry weight was removed during grain development of modern rices, particularly from leaf blades (Fig. 1, 2). Leaf blades accounted for 75% of mean N decrease and 48% of mean weight loss of the vegetative portion of productive tillers from flowering to harvest. A contributing factor was the higher protein content of leaf blades relative to leaf sheaths plus stem.

During grain development, N translocation from straw to developing grain in IR rices was accompanied by an increase in percentage of neutral detergent fiber (NDF, cell wall content), acid detergent fiber (ADF), lignin, and silica in both leaf blades and leaf sheaths plus stem. Percent hemicellulose (NDF − ADF) decreased. Leaf blades had lower cellulose content but higher lignin and ash contents than leaf sheaths plus stem. Because of weight reduction, only silica and lignin levels per hill did not decrease but remained constant.

A polysaccharide fractionation scheme was developed to complement the van Soest fiber analysis method. Straw powder was extracted in sequence with 80% ethanol, 0.3% KOH with 0.018 *M* sodium borohydride, and 10% KOH with 0.018 *M* sodium borohydride. Recovery was 70-85% of starting straw weight, probably because of mineral loss during dialysis and alkaline degradation of polysaccharides. Mainly free sugars, free amino acids, and lipids were extracted with 80% ethanol. The 0.3% KOH solvent extracted starch, β-glucans, pectins, some arabinoxylans, and a major portion of proteins and silica. The 10% KOH solvent extracted mainly (90-97%) hemicellulose that was soluble in pH 5 after acidification with acetic acid. The residue after 10% KOH extraction was mainly cellulose. The percentage of the 10% KOH fraction decreased, and that of the cellulose fraction increased in leaf blades during grain maturation. The percentage of the 0.3% KOH fraction increased near harvest in both leaf blades and leaf sheaths plus stem, probably due to accumulation of carbohydrates. The major neutral sugars were xylose, arabinose, glucose, and galactose in the 0.3% KOH fraction; xylose in the 10% KOH fraction; and glucose in the residue.

Results from the collaborative study with IAS were as follows. The whole plant (minus grains) had more ash than the harvest straw after threshing (Table 10). The dried harvest straw had a higher in vitro organic matter digestibility value than the whole dried plant. IR36 showed the highest value

Table 10. Ash content and in vitro organic matter digestibility (IVOMD), using rumen fluid, of harvest and whole plant straw of 4 varieties at grain maturity. Institute of Animal Science, UPLB, and IRRI, 1984 WS.

Variety	Ash content[a] (% dry weight)		IVOMD[a] (% of total organic matter)	
	Harvest straw[b]	Whole plant	Harvest straw[b]	Whole plant
IR36	20.1 ± 3.9	23.2 ± 1.5	50.0 ± 0.5	45.6 ± 2.7
IR42	21.1 ± 0.9	22.8 ± 0.6	47.9 ± 4.5	38.0 ± 2.4
IR58	20.7 ± 1.6	25.4 ± 1.8	45.1 ± 0.4	35.8 ± 3.9
H4	18.5 ± 0.5	22.3 ± 2.8	46.9 ± 0.5	40.5 ± 2.3

[a]Mean ± SD. [b]40-60 cm long.

Table 11. Comparison of cell wall fractions of straw components of productive tillers of traditional and modern varieties. IRRI, 1985.

Cell wall fraction	Percent (air-dry basis)					
	Leaf blades		Leaf sheaths		Stem	
	Traditional	Modern	Traditional	Modern	Traditional	Modern
Neutral detergent fiber	56-65	58-63	65-73	70-73	46-62	55-58
Acid detergent fiber	45-50	42-47	50-53	50-54	32-44	36-40
Hemicellulose	10-18	16-17	15-22	17-20	15-21	18-22
Lignin	5-6	5-6	4-5	4-5	3-6	3-4
Cellulose	18-27	22-24	29-34	32-33	24-35	28-31
Weight percent of total	19-28	28-32	27-36	31-34	36-50	35-40

among the four varieties, but the difference in harvest straw digestibility with IR42 was less than that in 1982 WS (Annual report for 1984). The harvest straw was still quite green at harvest. The results indicate that the stubble had a lower in vitro organic matter digestibility value than the harvest straw. Stem internodes had higher values (45-57%) than the leaf blades and leaf sheaths (27-45%) in both IR36 and IR42, although stems had higher cellulose content. The NDF of elongated internodes (60-64%) was less than that of leaf blades and sheaths (67-72%) for IR36 but was similar in IR42 straw (71-72% vs 67-71%).

A comparison of the chemical analysis at harvest of leaf blades, leaf sheaths, and stems of productive tillers of five traditional and four semidwarf varieties differing in lodging susceptibility showed similar composition in van Soest cell wall fractions (Table 11). IR varieties had more homogeneous composition than traditional rices. Leaf sheaths had more fiber and cellulose than leaf blades and stems. The culm of Century Patna 231 showed the highest values of NDF, ADF, lignin, and cellulose. The mean weight ratio of blade:sheath:stem was 29:33:38 for the modern varieties and 24:30:46 for the traditional rices.

Harvest straw stem of 4 brittle-stem mutants of Balilla 28 showed 53-64% NDF, 33-38% ADF, 19-26% hemicellulose, 5-6% lignin, and 20-28% cellulose, suggesting more lignin and less cellulose than in the stem of normal varieties. The mean weight ratio of blade:sheath:stem was 35:36:29.

Genetic evaluation and utilization (GEU) program

Disease resistance

Plant Pathology and Plant Breeding Departments

BACTERIAL BLIGHT **36**
- Screening, testing, and evaluatior of resistance **36**
- Resistance assessment **36**
  - Performance of IR varieties in screenhouse **36**
  - Performance of IR varieties in farmer's field **37**
  - Evaluation of resistance **38**
- Virulence shift of pathogen population **39**
- Development of near-isogenic lines **39**
- Inheritance of resistance **39**
- Varietal classification based on reactions to Philippine races **40**

BLAST **41**
- Screening **41**
- Evaluation of GEU elite lines **41**
- Evaluation of selected upland accessions **42**
- Effects of variety and plant age on partial resistance **42**
- Virulence **43**
- Genetic studies **45**
- Development of isogenic lines **46**

SHEATH BLIGHT **46**
- Screening nursery **46**
- Varietal resistance **46**
  - Evaluation at adult stage **46**
  - Assessment of resistance at tissue level **47**
  - Evaluation at seedling stage **47**
  - Severity under selected environmental factors **48**
  - Varietal resistance and inoculum dynamics **48**

NEMATODE DISEASES OF RICE **49**
- Upland rice **49**
- Lowland rice **49**

TUNGRO **50**
- IR varieties and lines in Mindanao **50**
- Reaction of selected varieties to tungro-associated viruses **50**
- Reaction of elite lines **51**
- Reaction to RTV and GLH **51**
- Field reaction of IR varieties with TKM6 gene **52**
- Reaction of green leafhopper-resistant varieties to tungro-associated viruses **52**

RAGGED STUNT **52**
- Plant height reduction and virus accumulation in ragged stunt virus-infected tolerant varieties **52**

35

Plant Pathology and Plant Breeding Departments

Screening, testing, and evaluation of resistance (*Plant Pathology*). All pedigree nurseries, replicated yield trials, observational yield trials, germplasm accessions, selected International Rice Testing Program nurseries, elite lines, and IR varieties were screened and tested for resistance to bacterial blight (BB) (Table 1, 2). Currently, resistance genes *Xa-4* and *xa-5* are used in the GEU program. Therefore, screening and tests were designed specifically to ensure their being incorporated in the breeding materials by inoculating the rice plants with race 1 (PXO 61) and race 2 (PXO 86) during the tests.

Resistance assessment (*Plant Pathology*). *Performance of IR varieties in screenhouse*. Twelve IR varieties were evaluated. One day before transplanting, inoculum was sprayed onto the plants to simulate natural infection. Plants of all varieties

Table 1. Summary of breeding materials and varieties screened for resistance to bacterial blight race 1. IRRI, 1985.

Nursery	Entries (no.) with given disease score						Not tested (no.)
	1	3	5	7	9	1/7[a]	
Hybridization block (DS)	160	19	8	102	19	8	1
Hybridization block (WS)	152	12	7	96	5	18	3
Observational Yield Trial (DS)	291	8	6	99	20	77	3
Observational Yield Trial (WS)	330	4		51		15	
Upland Observational Yield Trial (WS)	6	4	6	73		10	
Lowland Rainfed OYT (WS)	346	3	2	71		22	
Lowland Irrigated OYT (WS)	387	9	18	145		47	
Replicated Yield Trial (DS)	324	3	8	52		13	
Upland Replicated Yield Trial (WS)	80	7	13	110		86	
Germplasm bank (DS)	133	22	101	1,785	31	31	259
Germplasm bank (WS)	409	46	29	2,031		96	445
USDA	5			162		1	16
IRTP materials	663	11	12	221	6		13
Other requests	291	8	6	99	20	77	3
Pedigree nurseries[b]	56,837			10,960		7,346	1,194
Total	60,414	156	216	16,057	101	7,847	1,937

[a]Segregating. [b]Includes those of Aug, Sep, Oct, Nov, Dec 1984, and Jan, Feb, Mar, Apr, May, Jun, and Jul 1985.

Table 2. Summary of breeding materials and varieties screened for resistance to bacterial blight race 2. IRRI, 1985.

Nursery	Entries (no.) with given disease score						Not tested (no.)
	1	3	5	7	9	1/7[a]	
Hybridization block (DS)	8	20	36	220	28	4	1
Hybridization block (WS)	4	11	21	245	3	2	4
Observational Yield Trial (DS)	3	15	32	422	21	5	6
Observational Yield Trial (WS)		11	41	348			
Upland Observational Yield Trial (WS)		1	1	64		26	
Lowland Rainfed Observational Yield Trial	7	22	18	388		9	
Lowland Irrigated Observational Yield Trial	21	60	34	482		3	
Replicated Yield Trial (DS)	1	36	128	235			
Upland Replicated Yield Trial (WS)	8	3	8	244		41	
USDA	1	2	1	164			16
IRTP materials	8	42	93	494	7		11
Other requests	3	15	32	422	21	5	6
Pedigree nurseries[b]	1 809			3 669		695	56
Total	1 873	238	445	7 397	80	790	100

[a]Segregating. [b]Includes those of Dec 1984 (Rainfed Lowland), Feb (Rainfed Lowland), Mar (Pedigree), Apr (Deep water), Apr (Rainfed Lowland), May (Pedigree), Jun (Rainfed Lowland), and Jul (Irrigated).

Table 3. Performance of IR varieties against BB in the screenhouse. IRRI, 1985.

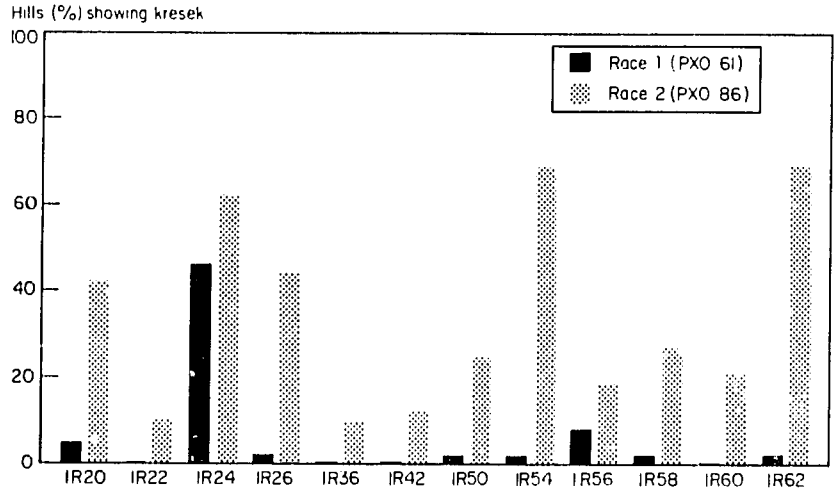
Variety	Early tillering stage				Booting stage			
	Hill infection (%)		Leaf infection (%)		Hill infection (%)		Leaf infection (%)	
	Race 1	Race 2	Race 1	Race 2	Race 1	Race 2	Race 1	Race 2
IR20	25.0	43.8	7.6	22.4	14.6	56.2	1.8	21.8
IR22	33.4	75.0	7.2	25.2	12.4	56.2	1.2	9.6
IR24	91.6	73.0	29.6	23.8	52.0	75.0	14.8	24.0
IR26	18.8	75.0	3.8	26.2	2.0	60.4	0.4	18.6
IR36	27.0	66.6	9.6	15.6	0.0	60.4	0.0	9.2
IR42	37.6	70.8	11.2	23.0	6.2	60.4	0.2	12.0
IR50	45.8	98.0	11.2	31.8	6.2	58.4	0.2	15.6
IR54	20.8	39.8	5.6	11.8	2.2	60.8	0.0	12.0
IR56	91.6	95.8	28.4	30.8	56.2	73.0	9.0	10.6
IR58	33.4	58.4	6.8	16.8	4.2	70.8	0.6	20.8
IR60	43.8	91.6	11.8	29.2	4.2	58.4	0.2	10.0
IR62	27.0	68.8	7.4	17.8	10.4	70.8	2.2	18.2

showed a higher percentage of hill and leaf infection with race 2 except IR24 at early tillering (Table 3). IR56 was as susceptible as IR24, an IR variety that is known to carry no resistance gene for BB. In all cases, the resistance gene *Xa-4* showed incomplete resistance to race 1.

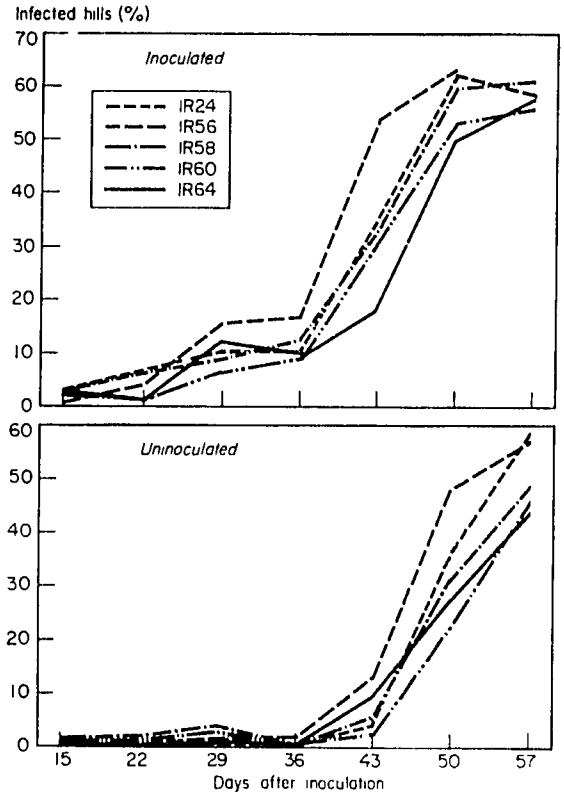
Race 2 induced a high percentage of kresek plants on IR54 and IR62, while race 1 did so on IR20 and IR56 (Fig. 1).

Performance of IR varieties in farmer's field. In 1985 wet season (WS), IR24, IR56, IR58, IR60, and IR64 were planted in a farmer's field in Mabitac, Laguna, where BB was common, to evaluate their resistance to BB. As in the screenhouse, the plants were inoculated with a low dosage 1 d before transplanting.

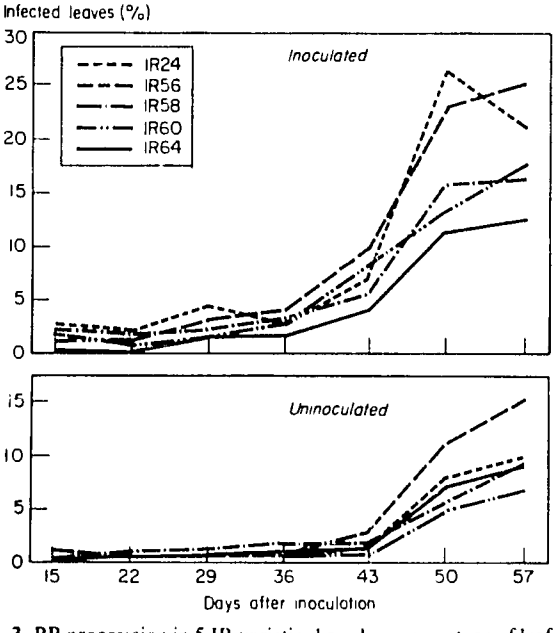
In field plots where plants were inoculated, disease on hills and leaves was significantly higher than in plots with natural infection, indicating efficiency of the treatment. IR24 and IR56 showed the highest number of infected hills and leaves, and IR64 the least. The rate of disease development indicated a significant difference among the IR varieties. Disease progression based on infected hills and leaves was most rapid on IR56 and IR24 for plots where inoculum was introduced into the plants, and only on IR56 based on natural infection (Fig. 2, 3). Infected hills was highly correlated



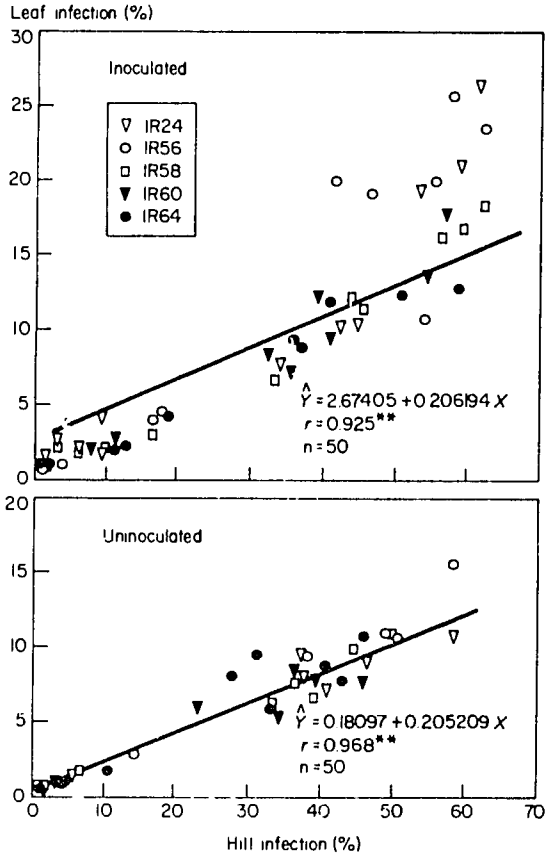
1. Incidence of kresek on 12 IR varieties in the screenhouse. IRRI, 1985 WS.



2. BB progression in 5 IR varieties based on percentage of hill infection of inoculated and uninoculated plots in a farmer's field. Mabitac, Laguna, Philippines, 1985 WS. DAI = days after inoculation.



3. BB progression in 5 IR varieties based on percentage of leaf infection of inoculated and uninoculated plots in a farmer's field. Mabitac, Laguna, Philippines, 1985 WS.



4. Relation between percentage of hill infection and percentage of leaf infection on 5 IR varieties inoculated and naturally infected in a farmer's field. Mabitac, Laguna, Philippines, 1985 WS.

with infected leaves (Fig. 4). Grain yield also reflected hill and leaf infection (Table 4). BB significantly reduced the grain yield of IR24, IR56, and IR64.

Evaluation of resistance. The IRRI breeding program has utilized the resistance gene *Xa-4* widely. There are two allelic genes reported at the *Xa-4* locus: $Xa\text{-}4^a$ and $Xa\text{-}4^b$. The differential effects of resistance conditioned by these genes were studied.

Pelita I/1, Pelita I/2, Peruim Kamppan, and Sintawati were chosen for this study, with IR24 as the susceptible check. Disease severity and lesion progression as criteria for assessing resistance showed differences in the two groups of varieties (Table 5). All four varieties exhibited some resistance to race 1 (PXO 61) from maximum tillering to booting (Fig. 5). Pelita I/1 and Pelita I/2 had higher resistance than Peruim Kamppan and Sinta-

Table 4. Grain yield of selected IR varieties inoculated and naturally infected with BB in a farmer's field. Mabitac, Laguna, Philippines, 1985 WS.

Variety	Grain yield (t/ha)		
	Inoculated	Uninoculated	Difference
IR24	2.4	2.9	0.5
IR56	3.2	3.8	0.6
IR58	3.9	4.2	0.3
IR60	4.4	4.5	0.1
IR64	3.8	4.4	0.6
Mean	3.6	3.9	0.3

LSD (0.05) 0.24433 – two treatment (inoculated and uninoculated) means.

wati at maximum tillering, but similar resistance at booting. The four showed similar susceptibility to races 2 and 3.

Virulence shift of pathogen population (*Plant Pathology*). In the Philippines, varieties with *Xa-4* have gradually replaced susceptible cultivars since the early 1970s. A shift in virulence of the pathogen population was noted in the mid-1970s. The frequency of pathogen races with virulence that matched the *Xa-4* gene was high. In 1985, BB incidence in farmers' fields was common and, in many cases, severe. Race 2 remained the most dominant, but an increase in frequency of race 1 was noted, perhaps because of widespread planting of traditional cultivars (Fig. 6).

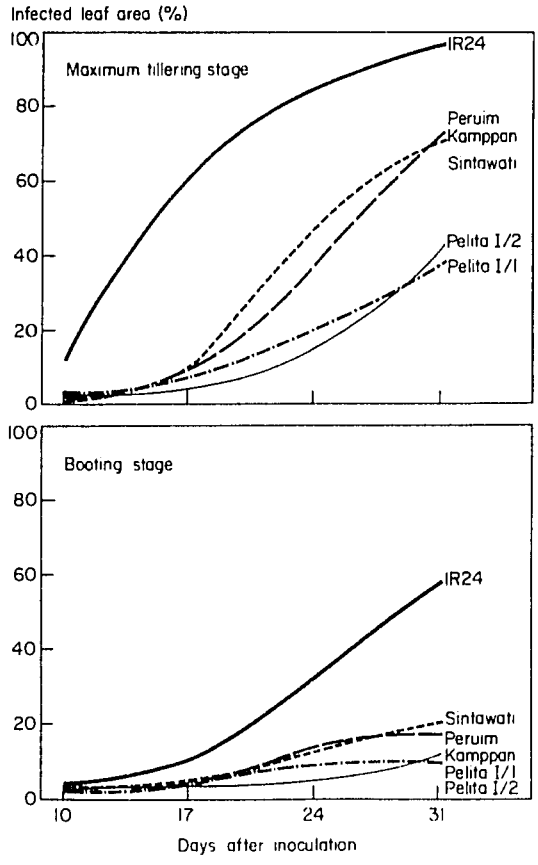
Development of near-isogenic lines (*Plant Breeding and Plant Pathology*). In collaboration with the Tropical Agriculture Research Center (TARC), Japan, we continued to develop near-isogenic lines with a monogenic basis. Using Philippine and Japanese races, BC_4F_4 progenies were developed having either the *Xa-3*, *Xa-4*, *xa-5*, *Xa-6*, *xa-9*, or *Xa-10* genes for resistance. BC_4F_2 progenies having *Xa-1*, *Xa-2*, *Xa-7*, or *Xa-11* and BC_3F_1 progeny having *xa-8* were also developed. The resistance gene of Sateng was confirmed to be dominant in the backcrossed generations.

Inheritance of resistance (*Plant Breeding and Plant Pathology*). F_2 and F_3 analyses of the cross Toyonishiki (susceptible)/Chugoku 45 (*Xa-3*) were carried out at IRRI and the F_3 analysis at TARC. The F_3 segregated into 33 homozygous resistant, 100 segregating, and 53 homozygous

Table 5. BB severity and lesion development at maximum tillering (MT) and postbooting (PB) stages on 5 cultivars, induced by 4 races of *Xanthomonas campestris* pv. *oryzae* at inoculum concentration of 1 × 10^9 cells/ml in the screenhouse. IRRI, 1985.

BB race	Rice growth stage	Variety				
		IR24	Pelita I/1	Pelita I/2	Peruim Kamppan	Sintawati
				BB severity[a]		
PXO 61	MT	32.9	11.6	13.5	24.2	21.0
	PB	24.8	8.0	9.3	11.9	10.2
PXO 71	MT	33.8	12.8	11.9	20.9	23.3
	PB	23.8	7.1	8.0	7.3	10.1
PXO 86	MT	30.3	38.6	29.7	40.9	34.1
	PB	18.0	21.5	20.4	25.9	19.9
PXO 79	MT	36.5	32.8	28.7	37.3	36.2
	PB	21.3	20.8	18.5	21.0	22.4
				Lesion development rate[b]		
PXO 61	MT	0.42	0.18	0.20	0.28	0.25
	PB	0.29	0.14	0.16	0.18	0.16
PXO 71	MT	0.39	0.18	0.22	0.24	0.24
	PB	0.25	0.16	0.10	0.21	0.17
PXO 86	MT	0.44	0.35	0.30	0.34	0.40
	PB	0.23	0.21	0.21	0.24	0.20
PXO 79	MT	0.46	0.33	0.27	0.29	0.34
	PB	0.25	0.24	0.23	0.24	0.26

[a]Percentage of infected leaf area 30 d after inoculation. [b]Percentage of increased lesion area per day.

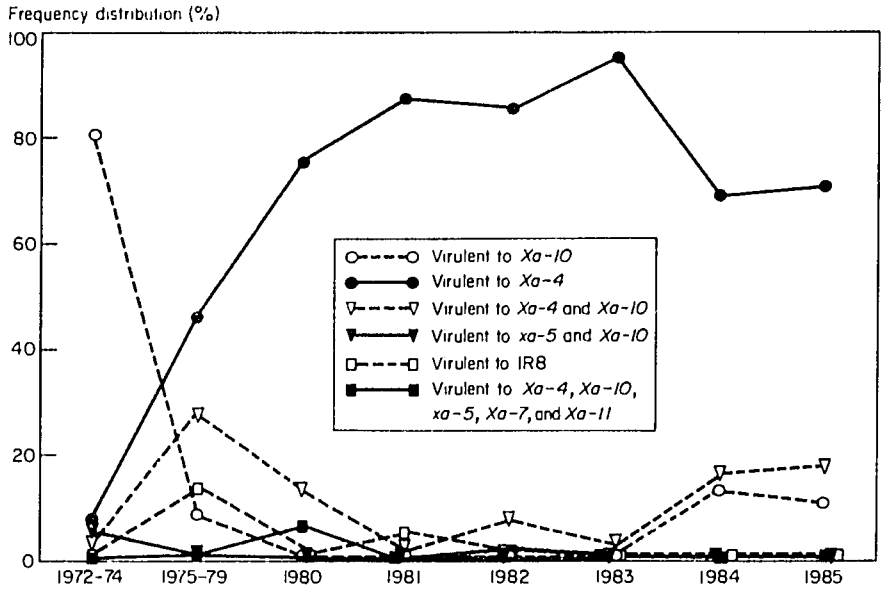


5. Lesion progression of *Xanthomonas campestris* pv. *oryzae* on 5 rice cultivars at 2 growth stages in the screenhouse. IRRI, 1985 DS.

susceptible lines. Identical results were obtained at IRRI and at TARC, confirming the results of F_2 analysis at IRRI. Therefore, the *Xa-3* gene of Chugoku 45 is effective against Philippine as well as Japanese races. Furthermore, the genetic analysis of Chugoku 45 (*Xa-3*), Zenith (*Xa-6*), and Sateng (*xa-9*) at TARC indicated that these resistant varieties have the same gene (Table 6). F_2 and F_3 analyses carried out at IRRI and TARC during the last 2 yr lead to the conclusion that *Xa-6* and *xa-9* are allelic to *Xa-3*.

Varietal classification based on reactions to Philippine races (*Plant Breeding and Plant Pathology*). We continued to inoculate resistant varieties with four Philippine races. We also crossed about 400 varieties with IR24, which is susceptible to 4 races. The reaction of F_1 hybrids with varieties of group I (resistant to four races) was similar to that of the resistant donors. The reaction of F_1 hybrids with varieties of group II (resistant to race 1, moderately resistant to race 4, and susceptible to races 2 and 3) was also similar to the reaction of resistant donors.

The varieties of groups I and II were thus confirmed to have a dominant gene for resistance to Philippine races. On the other hand, the F_1 hybrids with the varieties of group III were susceptible to all four Philippine races. Varieties of group I belong mostly to the *bulu* ecotype, while varieties of group III belong to the *aus* ecotype (Table 7).



6. Frequency distribution of field population in *Xanthomonas campestris* pv. *oryzae* in the Philippines with virulence on a set of differential varieties. IRRI, 1985.

Table 6. Reaction[a] to BB (T7133, Race IIIA) at booting to flowering stages of F_2 progenies from crosses of resistant varieties. TARC, Japan, 1985.

Cross	F_2 (no.) showing indicated reaction		χ^2 3:1	P
	R	S		
Toyonishiki/Chugoku 45 (*Xa-3*)	232	75	0.027	0.8<P<0.9
Toyonishiki/Java 14 (*Xa-3*)	275	75	2.381	0.1<P<0.2
Toyonishiki/Zenith (*Xa-6*)	306	92	0.800	0.3<P<0.5
Toyonishiki/Sateng (*xa-9*)	299	98	0.021	0.8<P<0.9
Chugoku 45 (*Xa-3*)/Sateng (*xa-9*)	356	0	0	1
Chogoku 45 (*Xa-3*)/Zenith (*Xa-6*)	398	0	0	1
Sateng (*xa-9*)/Zenith (*Xa-6*)	302	0	0	1

[a]R = resistant, S = susceptible.

Table 7. Major varietal groups based on reaction to 4 Philippine BB races. IRRI, 1985.

Varietal group	Representative variety	Major ecotype	Gene	Reaction[a]			
				Race 1	Race 2	Race 3	Race 4
I	Java 14 Zenith Sateng	bulu	*Xa-3*	R	R	R	R
II	TKM6		*Xa-4*	R	S	S	MR
III	DZ192	aus	*xa-5*	R	R	R	MS

[a]R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible.

Varieties showing reaction patterns different from these three groups were also found on the basis of continuous inoculation tests of resistant varieties.

BLAST

Plant Pathology and Plant Breeding Departments

Screening (*Plant Pathology and Plant Breeding*). During 1985 materials from the GEU program, national programs, the International Rice Germplasm Center (IRGC), and the International Rice Testing Program were tested in the IRRI blast (Bl) nursery (Table 8). The equivalent of 126,308 entries were screened, most coming from the GEU program.

Introduction and maintenance of certain specific races continued to increase the diversity of the nursery *Pyricularia oryzae* population. For example, variety UPLRi5 was previously resistant to the nursery fungus population, but in 1985 a race capable of attacking it was found and introduced into the nursery. Through continuous sowing of UPLRi5, the newly introduced race is being maintained and used for screening. Constantly increasing the number of races within the nursery may make it possible to more readily assess relative levels of partial resistance in varieties and lines.

Evaluation of GEU elite lines (*Plant Pathology*). The rice Bl pathogen can reproduce on partially

Table 8. Source and number of materials tested at the IRRI Bl nursery. 1985.

Source		Entries (no.)
F_2 populations (158)		18,848
Pedigree nurseries		87,402
Irrigated lowland	46,798	
Rainfed lowland	19,119	
Deep water	17,635	
Cold tolerance	3,320	
Upland	530	
Yield trials elite lines, hybridization block		5,008
National programs		7,135
IRGC accessions		6,178
IRTP nurseries		1,737
	Total	126,308

resistant varieties, but at a lower rate than on fully susceptible varieties. Recent evidence indicates that the partial resistance of a variety may be a good indicator of how stable its Bl resistance will be once it is grown widely by farmers. Using a Bl nursery miniplot technique, the partial resistance of the GEU elite lines was measured twice during WS. The results from both trials were highly correlated ($r = 0.96$) (Table 9). Some lines and varieties, such as IR64, were similar to IR36, the partially resistant check. However, several lines were as susceptible as or more susceptible than IR50, a variety that has suffered Bl damage at many lowland tropical sites. Further tests with these leaf Bl-susceptible lines are necessary to measure their response to panicle Bl. Also, a number of lines were completely resistant in the nursery. It will be necessary to find *P. oryzae* races compatible with these lines before their resistance relative to IR36 and IR50 can be assessed.

Evaluation of selected upland accessions (*Plant Breeding and Plant Pathology*). A group of upland accessions from the IRGC were selected for phenotypic acceptability based on several seasons of tests at IRRI and at upland sites in the Philippines. They were evaluated for Bl resistance in the IRRI Bl nursery, and those showing very few or no lesions were tested again at Caliraya, Philippines, and, with the help of Indonesian researchers, at Sitiung, West Sumatra. The best accessions from these evaluations are listed in Table 10.

Effects of variety and plant age on partial resistance (*Plant Pathology*). Resistance to *P. oryzae* infection generally increases with plant age during the vegetative stage. Ten upland varieties were stagger-planted so that plants of various ages could be exposed simultaneously to a single isolate of *P. oryzae*. After inoculation, several components of resistance were measured, including the relative infection efficiency (expressed as lesion number/100 cm^2 leaf), lesion size, latent period (expressed as days to 50% sporulation), cumulative spore production per lesion, and sporulation period.

Plant age greatly affected relative infection efficiency, and several of the varieties became completely resistant by 40 d after seeding (DAS) (Table 11). Lesion size differed with variety, but little effect of plant age was found. Latent period did not differ significantly with either variety or

Table 9. Relative blast resistance of GEU elite lines evaluated using an upland miniplot technique, IRRI, 1985.

Line	Relative ADPC[a]		Final % DLA[b]	
	Trial 1	Trial 2	Trial 1	Trial 2
IR37721-9-2-1-3	0.1	0.1	0.1	0.6
IR35546-52-3-3-2	0.2	0.1	0.5	0.7
IR39422-18-1-2-2	0.2	0.1	0.5	0.4
IR39423-124-3-3-1	0.3	0.3	0.7	0.7
IR28224-3-2-3-2	0.4	0.9	1.4	4.8
IR29658-43-3-2-1	0.4	0.2	1.0	0.8
IR29658-69-2-1	0.6	0.3	1.3	1.1
IR31868-64-2-3-3-3	0.6	0.2	1.3	0.9
IR28222-9-2-2-2-2	0.6	2.1	1.5	9.3
IR31802-48-2-2-2	1.1	0.6	2.8	2.6
IR32429-68-3-3-3	1.2	0.8	3.2	2.0
IR32429-47-3-2-2	1.3	1.2	3.2	3.6
IR33043-46-1-3	1.7	2.5	6.0	11.5
IR27078-11-2	1.9	3.5	9.3	16.2
IR28228-12-3-1-1-2	2.0	2.0	9.0	7.2
IR10011-16-3-2	2.0	2.0	6.3	6.0
IR13761-11-3	2.3	2.3	6.7	9.2
IR5931-113-1	2.3	2.5	8.7	10.3
IR31851-63-1-2-3-2	2.8	1.9	9.8	7.2
IR10147-113-5-1-1-5	2.8	2.1	12.8	6.5
IR32429-122-3-1-2	2.9	2.0	12.0	8.2
IR28228-119-2-3-1-1	3.3	2.6	14.3	10.8
IR28228-28-1-3-3-2	4.2	3.6	17.5	21.8
IR29723-143-3-2-1	4.3	4.3	20.3	22.0
IR32453-20-3-2-2	4.8	6.1	17.2	30.8
IR12979-24-1-8	4.8	3.9	15.5	17.3
IR13754-5-2	5.1	5.0	16.8	17.7
IR25587-133-3-2-2-2	5.9	5.3	19.2	21.0
IR3535[illegible]-94-2-1-3	6.0	7.7	20.0	18.3
IR46	6.2	4.2	30.3	21.2
IR64	6.3	5.6	22.3	30.0
IR29708-113-3-2-3	6.6	4.1	24.3	16.0
IR5420-1-1-2-3	6.8	6.5	22.5	20.7
IR42	7.4	5.7	29.2	30.5
IR58	8.6	6.2	40.3	29.2
IR36 (check)	9.1	6.2	34.2	26.2
IR32720-138-2-1-1-2	9.6	4.2	45.8	24.5
IR25588-7-3-2	9.8	5.5	36.3	20.0
IR6023-10-1-1	11.2	3.8	43.3	14.5
IR29725-109-1-2	11.2	7.8	39.7	34.2
IR29723-17-3-2-1	12.9	7.9	53.7	52.5
IR29692-65-2-3-3	13.7	9.1	58.3	42.8
IR35293-125-3-2-3	16.1	8.1	68.7	41.7
IR29670-15-2-3	20.7	11.7	72.7	63.0
IR32307-107-3-2-2	21.4	10.9	58.7	35.0
IR18818-87-2-2-2	21.8	13.3	70.2	65.0
IR8	22.0	12.8	77.8	62.5
IR25604-99-1-3-2-2	23.0	11.7	79.2	52.5
IR20	23.1	12.8	75.5	55.3
IR35361-59-3-3-2	23.9	19.7	76.7	75.8
IR29692-99-3-2-1	26.0	14.8	72.2	71.3
IR50 (check)	27.0	13.0	91.8	73.8
IR29725-22-3-3-3	28.8	15.0	88.8	55.5
IR29723-88-2-3-3	29.1	18.2	83.7	76.7
IR37704-98-3-2-2	30.5	15.2	85.0	56.7
IR28150-84-3-3-2	31.5	14.5	93.2	69.7
IR35546-17-3-1-3	33.2	16.3	93.3	80.8

[a]Relative area under the disease progress curve, calculated from 2 replications and 6 dates of scoring. [b]Percent diseased leaf area at the final scoring.

Table 10. Selected IRGC upland rice accessions showing Bl resistance at several upland sites. 1985.

Variety	Accession number
AP-444	10621
AUS122	28976
C	15165
Carreon	05993
Dodeng B	11826
Hao Deng	11906
IRAT104	38558
IRAT109	28563
IRAT113	28566
Jabahulo	25864
Ketang Trenggalek	17976
Khamu	23741
Khao Hae (K. Siw)	29773
Khao Hao	11911
Khao Inpong	25902
Khao Khao Kendu	29511
Khao Kinon	29793
Khao Panh	11809
Mack Kheua Hay	11822
Mak Bok	12918
Manik-Mundu	25887
M1-57	00360
Ninnoubou	16088
Padi Babarau	14393
Pah Yan 274-9-9	23768
Phe Done	11909
Saket 1	46632
Saket 1	46633
Sampopoy	26891
Sokan	24048
Sthania Shon	31621
Unnamed	51086
Y Lay	11915
62-441	15136

Table 11. Effect of plant age on lesion number/100 cm² leaf at 7 d after inoculation.[a] IRRI, 1985.

Variety	Lesion no./100 cm² at given plant age[b]			
	10 DAS	25 DAS	40 DAS	55 DAS
Kinandang Patong	10.3	1.8	0.1	0.0
C22	6.4	4.5	2.4	1.6
Kele	4.5	5.1	2.8	0.8
Iguape Cateto	3.2	0.1	0.0	0.0
Dourado Precose	3.1	1.1	0.0	0.0
IRAT112	2.8	0.5	0.0	0.0
IAC47	2.3	0.3	0.0	0.0
ARC7098	1.9	1.6	0.4	0.6
Molladiga	1.7	0.0	0.0	0.1
Denorado	1.1	0.3	0.0	0.0

[a]LSD (0.05) for comparisons between varieties within plant age and between plant age within a variety = 0.8.
[b]DAS = days after seeding.

plant age. Variety by plant age interaction was encountered. Kinandang Patong, for example, had more lesions/100 cm² than C22 at 10 DAS, but fewer than C22 at 25 and 40 DAS (Table 11).

As with relative infection efficiency, there was variety by plant age interaction for cumulative spore production per lesion. The lesions on C22, IAC47, Kele, and ARC7098 on plants inoculated at 25 DAS had a higher cumulative spore production than those inoculated at 10 DAS (Table 12). The opposite was true for Iquape Cateto.

Sporulation period increased with plant age, perhaps because older leaves remain active longer and can thus support sporulating lesions longer. The trend was particularly clear in C22 and Kele, where enough lesions occurred on plants inoculated 40 and 50 DAS to make assessment of sporulation period possible on the older plants (Table 12). There was no significant variety by plant age interaction for sporulation period.

For relative infection efficiency and cumulative spore production, there was interaction between variety and plant age. Such differential effects indicate the importance of evaluating leaf Bl resistance at various stages of plant development, not only at the early seedling stage.

Virulence (*Plant Pathology*). A 1983 study indicated that *P. oryzae* isolates from the upland rice areas of Zamboanga del Sur, Philippines, differed from isolates from South Cotabato and Nueva Ecija when tested on widely grown Philippine varieties. In 1985 more isolates from various regions in the Philippines were tested, and the Japanese, Korean, and international differential sets were included. Results were similar to those of the previous study: isolates from Zamboanga del Sur showed a higher frequency of virulence on varieties that have been grown there, such as C22 and UPLRi7, and a relatively low frequency on IR varieties (Table 13). Conversely, isolates from areas where IR varieties were grown could usually attack IR varieties, but not C22 and UPLRi7. Perhaps more important than the area of origin of an isolate was its variety of origin. For example, 2 isolates from Zamboanga del Sur, representing 11% of the total from the province (Table 13), were collected from IR varieties and showed virulence patterns similar to those of isolates from areas where IR varieties predominated.

Most pathogen samples from Batangas, Ifugao,

Table 12. Effects of plant age on cumulative spore production (CSP) and sporulation period (SP) per lesion.[a] IRRI, 1985.

Variety	10 DAS		25 DAS		40 DAS		55 DAS	
	CSP (no.)	SP (d)	CSP (no.)	SP (d)	CSP (no.)	SP (d)	CSP (no.)	SP (d)
C22	1301	6.0	2254	7.0	2210	14.0	2216	15.5
Kinandang Patong	491	6.5	598	7.0	–	–	–	–
Molladiga	468	4.0	250	4.0	–	–	–	–
Iguape Cateto	354	4.5	178	4.0	–	–	–	–
IAC47	280	3.0	552	5.5	–	–	–	–
Kele	276	5.5	763	5.0	751	13.0	584	14.5
Denorado	273	5.5	225	4.0	–	–	–	–
IRAT112	228	4.5	180	4.5	–	–	–	–
Dourado Precose	172	4.0	247	2.5	–	–	–	–
ARC7098	61	4.0	204	2.5	–	–	–	–

[a]LSD (0.05) for comparisons between varieties within plant age = 0.32 for CSP and 1.7 for SP. LSD (0.05) for comparisons between plant age within a variety = 0.28 for CSP and 1.8 for SP.

Table 13. Percentage of *Pyricularia oryzae* isolates collected from various Philippine sites virulent on Philippine rice varieties.[a] IRRI, 1985.

Variety	Isolates (%) virulent on Philippine rice varieties						
	Batangas n = 18	Ifugao n = 15	Laguna n = 15	Nueva Ecija n = 18	Zamboanga del Sur n = 18	Others n = 13	Mean n = 97
IR36	28	60	93	94	11	77	58
IR42	61	60	93	100	11	77	66
IR50	28	60	93	100	11	77	60
IR52	28	60	93	100	11	77	60
IR54	28	53	73	100	11	69	55
IR56	0	0	7	0	0	0	1
IR58	22	60	87	100	11	77	58
IR60	17	20	27	89	11	69	38
IR62	11	7	7	39	11	38	18
UPLRi3	28	7	0	0	5	0	7
UPLRi5	22	13	7	0	0	0	6
UPLRi7	6	33	13	0	67	23	24
C22	11	47	20	0	89	23	32
Kinandang Patong	89	60	60	67	78	54	55
Denorado	33	13	0	0	0	0	9
Mal-os	89	73	67	67	78	46	71

[a]All isolates tested at least twice. Check variety CO 39 was susceptible to all isolates.

and Laguna were collected from nurseries and seed increase plots planted to many varieties. The diversity of host germplasm seemed to result in a broader spectrum of virulence. For example, only five isolates were compatible with both C22 and one or more IR varieties, and all of these originated from Batangas, Ifugao, and Laguna. Further work is necessary to establish if *P. oryzae* populations from farmers' fields sown to one or a few varieties are less diverse than populations from plots sown to many varieties.

Virulence on IR56 was rare, even in areas where virulence on IR varieties was common (Table 13). Only one isolate was virulent on IR56 and, as in the previous year's study, this isolate could attack the other tested IR varieties. It originated from line IR29725-3-1-3-2 that has the variety PTB33 in its pedigree. Unlike the other IR varieties tested, IR56, IR60, and IR62 have PTB33 in their pedigrees. IR56 may perhaps carry a Bl resistance gene from PTB33 that is not present in the other IR varieties.

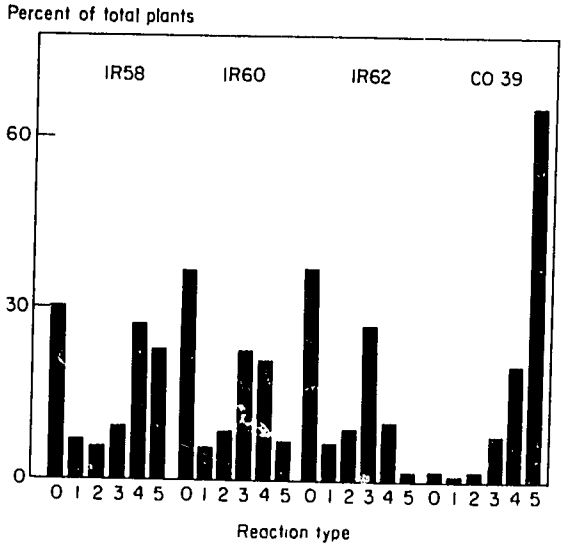
The overall frequency of virulence on IR36, IR42, and IR50 was similar (Table 13). Consequently, the more common occurrence of Bl observed on IR50 in farmers' fields is presumably due to other factors, such as the relative partial resistance of the varieties, rather than to a higher frequency of virulence in the fungus population on IR50.

IR62 was released in 1984, and IR60 and IR58 were released in 1983. Although virulent isolates were less frequent on IR62 and IR60 than on IR58, virulence on these varieties was present in the pathogen population (Table 13). Virulence on IR36, IR42, IR50, IR52, IR54, and IR58 was strongly associated: if an isolate was virulent on one of these varieties it was nearly always virulent on all of them. Isolates capable of attacking these IR varieties showed either a type 3 or type 4-5 reaction on IR60 and IR62. Type 3 reactions were more common on IR60 and IR62 than on IR58 (Fig. 7). Against many of the isolates, IR60 and IR62 apparently show incomplete resistance because they produce lesions capable of sporulation (reaction type 3), but these lesions are not typical of a fully susceptible reaction.

Agriculturally important isolates that differed from one another, such as those virulent or avirulent on the widely grown IR36, were often classified as the same race using the international, Japanese, and Korean differentials. Thus, data from these differential sets did not provide an adequate description of the pathogen population in the Philippines. For practical work, widely grown varieties and prospective varieties should be used in *P. oryzae* virulence surveys within a rice-producing region or country.

Genetic studies (*Plant Breeding and Plant Pathology*). The genetics of Bl resistance was studied in the F_1, F_2, F_3, and BC_1 generations of IR36, IR46, IR54, IR56, and IR60 and of four highly resistant varieties — Carreon, Pai-kan-tao, Pankhari 203, and Tetep. CR155-5029-216 and CO 39 were the susceptible parents. We used three Philippine isolates of the fungus belonging to the international races IB-47, IA-61, and IH-1. In all cases, resistance was shown to be inherited as one or two major genes (Table 14). Only one recessive gene was found — that in IR54 — for isolate PO6-6. All other genes were dominant.

Inoculation of different sets of F_3 lines with more than one isolate indicated that resistance to different isolates was conditioned by different genes (Table 15). In several cases, the frequency of parental types was more than expected by independent segregation, indicating that some of the resistance genes may be linked. These results indicated that several of the recent IR varieties possess major genes for resistance to different Bl races.



7. Frequency distribution of reaction types for 3 newly released Philippine rice cultivars and the susceptible check CO 39 inoculated with 97 isolates of *Pyricularia oryzae*. IRRI, 1985. Data are from about 1,600 plants/cultivar.

Table 14. Genes for resistance to Bl present in some improved IR and traditional varieties. IRRI, 1985.

Variety	Genes[a] (no.) for each isolate		
	PO6-6 (IB-47)	IK81-3 (IA-61)	43 (IH-1)
IR36[b]	–	2D	1D
IR46[b]	–	2D	2D
IR54[c]	1R	2D	–
IR56[c]	1D	2D	–
IR60[b]	–	2D	1D
Carreon	2D	2D	1D
Pai-kan-tao	1D	2D	2D
Pankhari 203[c]	1D	2D	–
Tetep	1D	2D	2D

[a]D = dominant gene, R = recessive gene. [b]Susceptible to isolate PO6-6. [c]Not tested against isolate 43.

Table 15. Reaction of F_3 lines from crosses between resistant and susceptible parents to combinations of *Pyriculuria oryza* isolates, IRRI, 1985.

Cultivar	Lines[a] (no.) observed				Expected ratio	Probability
	R/R	R/S	S/R	S/S		
			PO6-6 and IK81-3			
IR54	148	7	57	2	45: 3:15:1	0.25-0.50
IR56	159	7	39	9	45: 3:15:1	<0.01
Carreon	185	14	13	2	255:15:15:1	0.50-0.75
Pai-kan-tao	163	4	38	9	45: 3:15:1	<0.01
Tetep	158	7	41	8	45: 3:15:1	0.01-0.05
			IK81-3 and 43			
IR36	162	35	6	11	45:15: 3:1	<0.01
IR46	193	5	4	12	225:15:15:1	<0.01
IR60	149	45	16	4	45:15: 3:1	0.10-0.25
Pai-kan-tao	194	7	4	9	225:15:15:1	<0.01
			PO6-6 and 43			
Pai-kan-tao	155	12	43	4	45: 3:15:1	0.50-0.75

[a]R/R = resistant to both isolates, R/S = R to first isolate and susceptible to second, S/R = S to first isolate and R to second, S/S = S to both isolates.

Development of isogenic lines (*Plant Breeding and Plant Pathology*). The major difficulty in the genetic analysis of resistance to Bl is the large number of genes present in individual varieties, making tests for allelism and linkage very difficult because of the small number of susceptible recombinants expected in crosses. To overcome this difficulty, individual resistance genes are being transferred to a susceptible parent by backcrossing. The cultivar CO 39 is highly susceptible to all isolates tested so far at IRRI, and its very early duration (95 d) makes it an excellent recurrent parent. Five backcrosses have been completed using the resistant donors Tetep, Pai-kan-tao, LAC23, and 5173 (a breeding line from Colombia) against five Philippine Bl isolates. Homozygous lines isolated from these backcrosses should allow more detailed genetic analysis of resistance to Bl.

SHEATH BLIGHT

Plant Pathology Department

Screening nursery. A mass screening upland nursery for sheath blight (ShB) was initiated. Its field layout is similar to that of the Bl nursery except for the three-row planting and a wind barrier of a moderately resistant variety. Plants are inoculated twice, at 45 and 60 DAS, with rice grain-hull medium. Damage severity is computed using the ShB scoring system developed in 1984.

Initially, 150 entries were evaluated. Many of the materials from the germplasm bank were moderately resistant or resistant, while some of the GEU lines were highly susceptible. Grouping of materials based on maturity and plant height would be helpful for determining proper inoculation and evaluation time. Maintenance of proper humidity and temperature after inoculation is important for inducing good disease conditions.

Varietal resistance. Varietal resistance to ShB observed in the field is not well characterized. Also, its long-term effect on the rice-ShB system in continuous cropping is not known. A series of studies was thus initiated.

Evaluation at adult stage. To compare two types of inoculation — the injection or syringe method and the wrapping method — selected rice varieties or lines were planted in clay pots (12 cm in diameter) at 4 hills/pot under lowland conditions. Upland conditions were then established 1 wk before inoculation. Planting was staggered to synchronize flowering.

All plants were inoculated at booting. In the injection method, 0.25 ml of mycelial suspension from a 3-day-old culture of *Rhizoctonia solani* was injected into the interstice between the third leaf (from the flag leaf) and culm. For the wrapping method, a 14-day-old culture of the same fungus in rice grain-hull medium was fastened around the basal portion of a hill at booting by means of a 10-cm-high plastic strip.

In both methods, a humidifier was turned on at night for 1 wk to provide favorable conditions for ShB development and to minimize variation. Incubation was thereafter continued for another 7 d without humidifier.

Severity was recorded 14 d after inoculation (DAI) from a severity scale based on percentage of leaf sheath area affected for the wrapping method, and on lesion type (Annual report for 1984). The disease was generally higher in plants inoculated by the wrapping method than in injected plants or plants inoculated in the field (Table 16).

The reactions of some varieties to the two methods of inoculation tended to coincide, i.e., Kataktara DA2, IR20, and IR26. While disease levels with both methods and in field conditions differed, the range of their severities roughly coincided. Although varietal reactions were clearly differentiated in both methods, variation was higher in injected plants than in plants inoculated by the wrapping method.

Assessment of resistance at tissue level. Although several mechanisms account for ShB resistance under field conditions, it is not yet known whether they operate in the sheath tissue, leaf tissue, or both.

To assess resistance at the tissue level, electrolytic leakage was measured using a conductivity meter. Flag leaves and uppermost sheaths of different varieties were taken from plants grown in the greenhouse and inoculated with *R. solani* by dipping one side of the sheath or leaf tissues into a mycelial suspension in a vial. All the vials were kept at 26 °C for 48 h. Later, infected tissues were cut into 0.5-cm pieces and shaken in glass double distilled water before the electrolytic leakage from the infected tissues was measured. Uninoculated leaf or sheath tissues were included as controls. After 3 h, the percentage increase of electrolytic leakage over control was computed and analyzed.

A wide varietal variation in the degree of both leaf and leaf sheath tissue leakage was observed (Fig. 8). Leakage increase was higher per unit length of tissue (4 cm) in infected leaf tissue than in sheath tissue, even in several known resistant cultivars such as IR8, Tetep, and Ta-poo-cho-z. Although correlation between the increase of leakage from leaf tissue and that from sheath tissue tended to be negative, it was not statistically significant.

Electrolytic leakage from infected sheath tissue (but not leaf tissue) was well correlated with damage severity observed in the field (Fig. 9), strongly indicating that ShB resistance operates mainly in sheath tissue rather than in leaf tissue. Hence, increasing resistance at the sheath level would decrease ShB damage more efficiently.

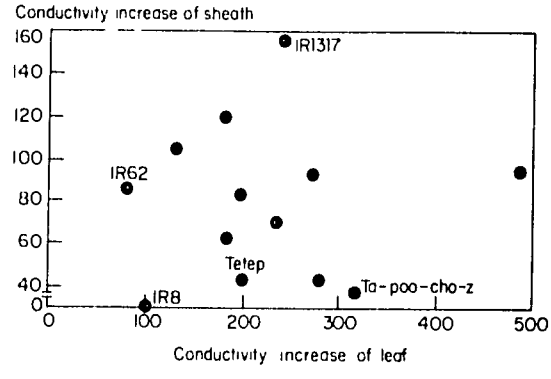
Evaluation at seedling stage. Several methods of inoculation were tested to evaluate resistance at the seedling stage: topdress inoculation at 25 DAS, injection at 35 DAS (Annual report for 1984), and dipping at 35 DAS.

Twenty-day-old rice seedlings of selected cultivars were topdressed with a 14-day-old culture of *R. solani* in rice grain-hull medium. Severity was determined based on a scale devised for adult

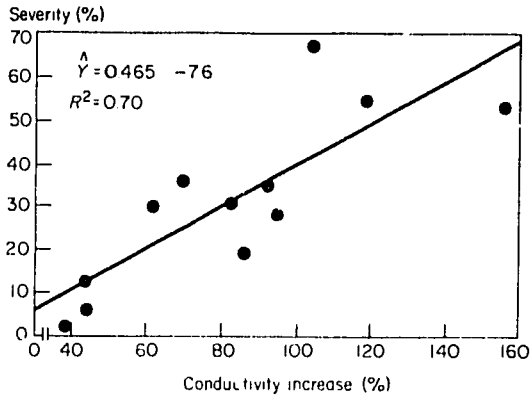
Table 16. ShB severity in adult plants of selected rice varieties or lines inoculated with *Rhizoctonia solani* by the wrapping and injection methods. IRRI, 1985.

Variety or line	Severity[a]		
	Wrapping	Injection	Field (1984 DS)
Tetep	0.00	1.25	5.67
Ta-poo-cho-z	4.17	19.96	0.00
Kataktara DA2	6.67	7.88	16.38
IR26	10.92	7.38	0.25
IR20	11.50	12.35	1.38
Nampungbyeo	27.92	14.67	12.00
IR62	33.81	6.29	6.00
IR36	94.50	22.10	40.13
IR58	100.00	45.31	71.63

[a]0 = highly resistant, 100 = highly susceptible. Av of 3 replications. Standard error of the difference: wrapping = 12.9, injection = 6.11.



8. Relation between increase of electrolytic leakage from rice leaf tissue and sheath tissue. IRRI, 1985.



9. Relation between increase of electrolytic leakage from ShB-infected rice sheath tissue and severity observed in the field. IRRI, 1985.

plants (Annual report for 1984) and converted for the seedling stage.

For the injection and dipping methods, 35-day-old seedlings of selected cultivars were inoculated with a mycelial suspension of *R. solani* (Annual report for 1984). Another set of the same seedlings was dipped in mycelial suspension (95% of top portion submerged) prepared from 2-day-old cultures of *R. solani* in potato dextrose agar medium with 0.8% agar.

Both medium and mycelial suspension were enriched with urea at 1.3 g/liter. Leaf blades were removed prior to inoculation. Severity was determined based on lesion type (Annual report for 1984).

Severity in dipped plants was significantly higher than in injected plants (Table 17). Although the three methods showed a tendency to differentiate varietal reactions, ranking was not always consistent. However, ranking of varietal reactions in the topdressing method was almost comparable to field reaction.

Severity under selected environmental factors. The stability of resistance of selected rice varieties was studied under changes in environment favorable to ShB development, namely N level and humidity. IR64, Nampungbyeo, IR62, and the susceptible IR58 were artificially inoculated with *R. solani* at booting. Differences among moderate or moderately resistant varieties were observed at all levels of N and at high humidity lasting under 2 wk (Table 18).

Varietal resistance and inoculum dynamics. The effect of varietal resistance on the disease and inoculum dynamics of ShB was studied in continuous cropping of four rice cultivars with known levels of resistance.

The percentage of *R. solani* recovered from crop debris, starting with land preparation of the first crop until 15 d after flowering of the second crop,

Table 17. ShB severity on rice seedlings inoculated with *R. solani* by different methods of inoculation in the greenhouse. IRRI, 1985.

Variety	Severity[a]			
	Topdress	Injection	Dipping	Field (1984 DS)
RP4-14	17.25	4.82	16.10	10.46
Ratna	23.75	3.78	13.00	13.00
Nampungbyeo	26.37	6.89	8.11	12.00
IR56	39.25	5.82	17.83	61.25

[a]0 = highly resistant, 100 = highly susceptible.

Table 18. ShB severity due to varietal reaction at different regimes of N and humidity under greenhouse conditions. IRRI, 1985.

Regime	Severity[a]				
	IR64	Nampungbyeo	IR62	IR58	Average[b]
N level (g/pot)					
0	50.20 b	46.00 b	53.20 b	100 a	62.35 a
1.0	62.80 b	47.80 b	63.40 b	100 a	68.50 a
1.7	62.80 b	51.80 b	69.40 b	100 a	71.00 a
Humidity duration[c] (wk)					
0	1.60 b	16.00 b	23.40 ab	40.40 a	20.35 a
1	52.40 a	43.35 a	50.20 a	48.20 a	48.54 b
2	64.60 a	67.40 a	74.20 a	67.60 a	68.45 c

[a]Av of 5 replications. 0 = highly resistant, 100 = highly susceptible. Separation of varietal means in a row by DMRT at the 5% level. [b]Separation of treatment means in the column by DMRT at the 5% level. [c]Relative humidity was 78% at 0 wk, 97.9% at 1 and 2 wk.

was generally higher with susceptible varieties IR36 and IR58 than with resistant varieties IR62 and IR64 (Table 19).

NEMATODE DISEASES OF RICE

Plant Pathology Department

Upland rice. The upland rice areas of the IRRI farm were surveyed for nematode damage. Results of nematode extractions, particularly from roots, and direct observations of stained plant tissues showed extremely high root populations of the migratory, endoparasitic, lesion nematode *Pratylenchus zeae*. The nematodes were causing obvious damage to the root systems, stunted growth, poor panicle formation, and empty seeds. *P. zeae* occurred at all but one of the upland sites sampled, and populations exceeded 1,000 nematodes/g root in some cases (Table 20). Unquestionably, the nematodes were causing yield loss in the upland areas. Very few *Helicotylenchus crenacauda* and no *Hirschmanniella oryzae* or *H. mucronata* were found.

Lowland rice. An earlier survey of lowland rice demonstrated the presence of damaging levels of *Hirschmanniella* spp. in field plots sampled at IRRI. Samples taken in 1985 showed *Hirschmanniella* spp. in all lowland ricefields, with numbers exceeding 2,000 nematodes/5 g roots. Yield losses in many of the lowland fields were estimated to be 5-10%, and possibly higher in some fields (Table 21). No *P. zeae* or *H. crenacauda* were found.

Table 19. Recovery of *R. solani* from crop debris of susceptible and moderately resistant varieties in 2 successive cropping seasons.[a] IRRI, 1985.

Time of sampling	% recovery of *R. solani*/200 g soil			
	Susceptible		Moderately resistant	
	V1	V2	V1	V2
Land preparation of first crop	6.7	11.0	12	13
Harvest of first crop	12.0	15.5	7	15
30 DAS of second crop	40.0	16.0[b]	0	3
15 DAF of second crop	43.0	4.0[b]	0	0

[a]Av of 4 replications. Susceptible cropping sequences: V1 = IR58 - IR58, V2 = IR36 - IR36. Moderately resistant cropping sequences: V1 = Ta-poo-cho-z - IR64, V2 = IR18350-175-2-3 - IR62. [b]50% colonization by *Trichoderma* spp.

Table 20. Plant parasitic nematodes in upland rice roots (also sorghum). IRRI farm, 1985.

Field site	Cultivar or breeding line	*Pratylenchus zeae* (no./5 g roots)
827	(mixed)	0
UQ4	(mixed)	135
UQ4	IR45	20
UQ4	C22	40
UQ4	Saucong	225
UD4	UPLRi5	540[a]
UW3	(mixed)	4175
UP3	IR45	2860
UI2	C22	70
UO2	IR43	1460
UZ3	(mixed)	6840
UZ3 5031	IR18838-7-6-5-2-2	559
UZ3 4351	IR7807-9-1-2-12-7-2-4	2280
UZ3 4521	IR10011-16-3-3-2	330
UZ3 4871	IR10120-7-2-1-8-18	1710
UZ3 4934	IR12601-6-3-3-4-4	2275
UZ3 4211	IR5929-12-3-6	3450
UZ3 4451	IR8990-3-8-1-20-2-3	4290
UZ3 5051	IR18841-37-2	1040
UZ3 4681	IR10070-4-1-1-2	1524
UZ3 4101	IR2992-2-1	1515
UZ3 4661	IR10068-11-1-2-25-2-2	2244
UZ2 6754	IR30707-B-1-B-5-1-19	4688[b]
UZ2 6872	IR30714-B-1-B-3-5-19	5500[c]
UZ4 325	IR30686-B-2-B-6-4	1665
UZ4 374	IR43	832
UZ4 331	UPLRi-5	1575
UZ4 389	IR12979-24-3-4	1050
UZ4 354	IR27095-20-12	3975
UZ4 357	Kinandang Patong	1770

[a]Plus 30 *Helicotylenchus crenacauda*. [b]Plus 16 *H. crenacauda*. [c]Plus 20 *H. crenacauda*.

Table 21. Plant parasitic nematodes in lowland rice roots (also sorghum). IRRI farm, 1985.

Field site	Cultivar or breeding line	*Hirschmanniella oryzae* and *H. mucronata* (no./5 g roots)
UL7	(mixed)	70
329	IR58	80
UC4	(mixed)	860
UB3	IR58	130
218	(mixed)	10
418	IR58	460
629	IR58	525
H3	IR64	345
S1	IR58	2224
B3	IR25588-7-3-1	680
Farmer's field opposite IR600	?	820

TUNGRO

Plant Pathology Department

IR varieties and lines in Mindanao. In northern and southern Cotabato, Mindanao, tungro (RTV) incidence was high in 1985 WS. Leaf samples were randomly collected from plants in experimental fields and tested for the presence of rice tungro bacilliform (RTBV), rice tungro spherical (RTSV), grassy stunt (GSV), and ragged stunt (RSV) viruses by enzyme-linked immunosorbent assay (ELISA). Most IR varieties showed high RTV infection, and many leaf samples collected from the IR varieties contained both RTBV and RTSV (Table 22, 23). In northern Cotabato, RTV incidence was low on IR28222-9-2-2-2-2, IR28224-3-2-3-2, IR28228-12-3-1-1-2, IR28228-119-2-3-1-1, IR29725-109-1-2-1, IR32307-107-3-2-2, IR32453-20-3-2-2, IR33043-46-1-3, and MR10993-308; IR36 and IR42 showed fairly high RSV infection.

Reaction of selected varieties to tungro-associated viruses. The 1964-82 mass screening for RTV resistance data showed that 350 varieties were resistant (0-30% infection). The rices were retested with the mass screening method, and those that showed an average infection of 35% or less after 6 trials were selected. Table 24 shows 20 selected varieties used in the study.

Six-day-old seedlings were exposed individually to 5 green leafhoppers (GLH) *Nephotettix virescens* that had fed for 2-3 d on RTBV + RTSV- or RTSV-infected TN1 plants for 1 d. One month later, leaf samples were collected and tested by ELISA for their reaction to RTV-associated viruses.

When dually infected plants were used as virus sources, most varieties showed low RTBV + RTSV infection but high RTBV infection. Balimau putih is susceptible to RTBV + RTSV, but no typical RTV symptoms were observed. Basmati 376 had the lowest RTBV infection (25%) and was

Table 22. Virus incidence on IR varieties at Midsayap Experimental Station, North Cotabato, Philippines, determined by ELISA, Sep 1985.

Variety	RTV infection (visual %)	Plants tested (no.)	Plants (no.) infected with				
			RTBV + RTSV	RTBV	RTSV	GSV	RSV
IR36	90	20	15	0	5	2	11
	80	20	4	0	15	0	0
IR42	90	20	15	0	3	0	7
IR50	90	20	0	11	0	0	0
	80	20	12	1	5	0	0
IR54	95	20	17	0	3	0	0
	70	20	11	0	0	0	1
IR62	10	20	2	0	8	0	0
IR64	85	20	17	0	3	0	0
	95	20	20	0	0	0	1

Table 23. Virus incidence on IR varieties in Marbel, South Cotabato, Philippines, determined by ELISA, Oct 1985.

Location	Variety	RTV incidence (visual %)	Plants tested (no.)	Plants (no.) infected with				
				RTBV + RTSV	RTBV	RTSV	GSV	RSV
Barrio 6	IR62	0	20	0	0	11	0	0
	IR64	0	40	1	0	1	0	0
	IR64	30	41	16	2	19	0	3
Barrio 3	IR64	20	20	5	8	1	0	0
	IR64	1	20	0	0	8	0	0
Magsaysay	IR64	20	83	30	1	40	1	2
	IR64	25	40	19	1	18	0	0
Namnama	IR64	40	82	36	1	37	2	0
	IR64	5	40	3	0	33	0	0

Table 24. Reaction of selected RTV-resistant varieties to RTV-associated viruses as determined by ELISA. IRRI, 1985.

Acc. no.	Designation	Reaction to		RTBV + RTSV as source[c]				RTSV as source[c]	
				Plants infected (%)			Total tested (no.)	Plants infected (%)	Total tested (no.)
		GLH[a]	RTV[b]	RTBV + RTSV	RTBV	RTSV			
177	Adday Sel.	9	32	0	60	5	18	20	15
3707	Andifrom n. pokhara	1	30	10	80	0	20	37	19
4021	Binicol	1	35	0	53	0	19	53	19
5346	Seratus hari T 36	9	31	26	74	0	19	53	15
7366	PI 184675-2	5	22	40	60	0	20	15	20
11062	G-378	9	21	21	79	0	14	39	18
12203	ARC 6064	3	32	6	94	0	18	35	20
16602	Tjempo kijik	7	33	22	33	11	18	83	18
16680	Utri merah	7	17	0	55	5	18	38	16
17204	Balimau putih	5	13	83	5	12	18	79	19
19680	ARC10963	9	22	0	95	0	20	45	20
20533	ARC7140	9	33	6	88	6	18	28	18
22176	ARC12596	5	27	0	80	0	20	0	18
22331	ARC12778	9	28	0	95	0	20	13	15
26295	Bale betor	1	17	6	72	0	18	41	17
26311	Bhoro nepa	1	20	7	80	0	15	60	20
26322	Chingair	1						50	10
26615	Gachia	5	30	20	75	0	20	16	19
27827	Basmati 375A	3	35	0	72	0	18	10	20
27828	Basmati 376	5	35	0	25	0	20	0	20

[a]GLH = green leafhopper. Data from IRRI Entomology Department (1 = resistant, 3 = moderately resistant, 5 = moderately susceptible, 7 = susceptible, 9 = highly susceptible). [b]Av percentage infection for 6 confirmation trials by mass screening method. [c]One-wk-old seedlings were inoculated in test tubes by 5 viruliferous *N. virescens* after 2-3 d acquisition access period on RTBV + RTSV- or RTSV-infected TN1 plants.

moderately susceptible to the vector. When RTSV-infected plants were used as virus sources, infection percentages ranged from 0 to 83. Varieties that showed <30% RTSV infection were Adday sel., PI 184675-2, ARC7140, ARC12596, ARC12778, Gachia, Basmati 375A, and Basmati 376.

Reaction of elite lines. Four elite IR lines and TN1 were exposed to GLH that had fed on plants infected with RTBV and RTSV, at 1 or 5 seedling in test tubes. Inoculated seedlings were tested for the presence of RTBV and RTSV by the latex test. IR lines became infected with mostly RTBV alone, while many TN1 seedlings were infected with both RTBV and RTSV (Table 25).

Reaction to RTV and GLH. Reactions of seven rice varieties to RTV infection and its vector GLH were studied as a part of the 1985 RTV Collaborative Project. Forty 7- to 9-day-old seedlings of each variety were individually exposed for 24 h to 1 or 5 GLH that had fed on TN1 plants infected with

Table 25. Reaction of 4 IR lines to RTV infection when exposed to 1 or 5 viruliferous GLH/seedling. IRRI, 1985.

Line, variety	Insects/ seedling	Seedlings tested (no.)	Seedlings (no.) infected with		
			RTBV + RTSV	RTBV	RTSV
IR18348-36-3-3 (IR64)	1	36	0	2	0
	5	39	1	19	0
IR31868-64-2-3-3-3	1	37	1	4	0
	5	36	0	13	0
IR32429-47-3-2-2	1	39	1	5	0
	5	38	1	19	0
IR28150-84-3-3-2	1	34	0	6	0
	5	36	0	22	0
TN1	1	38	10	10	0
	5	30	19	9	1

RTBV and RTSV for 4 d. Inoculated seedlings were tested for the presence of RTBV and RTSV by latex agglutination 1 mo later. GLH used in 1 GLH/seedling treatments were transferred to fresh seedlings in test tubes to determine their lifespan on the test varieties.

Despite GLH number for inoculation, ARC11554, Gam Pai 30-12-15, and TKM6 were infected with RTBV alone. Utri Rajapan was infected mostly with RTBV alone. GLH lifespan was shorter on ASD7, ARC11554, and Gam Pai 30-12-15 than on the susceptible check TN1 (Table 26).

Field reaction of IR varieties with TKM6 gene. IR20, IR26, IR30, and IR40 have a common RTV resistance gene derived from TKM6. Initial tests on their reaction to RTV in the greenhouse showed their resistance to RTSV infection. A study to determine the reaction of the four varieties in the field was conducted at IRRI in 1985 WS.

Three-week-old test seedlings were transplanted at 2-3 seedlings/hill and subjected to natural infection. After 30 and 60 d, plants were scored based on symptoms. The presence of RTV-associated viruses was also detected by the latex agglutination test on 80 leaf samples taken at random from each plot.

Low RTV infection was observed at 30 d after transplanting (DT). RTSV infection was predominant initially on TN1 and IR36. RTV infection increased at 60 DT on both TN1 and IR36 but remained at a very low level on resistant IR50 and IR58. IR20, IR26, IR30, and IR40 remained free from RTSV infection (Table 27) despite the prevalence of RTSV in the field as indicated on TN1 and IR36.

Reaction of green leafhopper-resistant varieties to tungro-associated viruses. Varieties with GLH-resistant genes were tested for their reaction to RTV-associated viruses. Six-day-old individual seedlings of test varieties were inoculated in test tubes for 1 d by 5 GLH that had fed on RTBV and RTSV source plants. RTV-associated viruses were detected by the latex test 1 mo after inoculation.

Variations in reaction to RTV viruses between varieties with the same GLH resistance gene were observed. Jingasail plants were infected with RTBV + RTSV, and Pankhari 203 with RTBV only, although both have the *Glh-1* gene. IR36 and TAPL 796 have *Glh-6*; IR36 reacted to RTBV + RTSV, while TAPL 796 reacted to RTBV alone (Table 28). Pankhari 203, Palasithari 601, and ASD8 showed low levels of infection. The results proved further that resistance to RTV is not always correlated with resistance to the vector.

RAGGED STUNT

Plant Pathology Department

Plant height reduction and virus accumulation in ragged stunt virus-infected tolerant varieties. Sitopas and Lemo were susceptible to RSV infection in test tube inoculation, but they were tolerant and produced more grains than TN1 when infected (Table 29).

Table 26. Reactions of 7 rice varieties to RTV-associated viruses and GLH. RTV Collaborative Project, IRRI, 1986.

Variety	Average life span (d)	1 GLH/seedling					5 GLH/seedling				
		Plants with symptoms (%)	Plants (no.) infected with				Plants with symptoms (%)	Plants (no.) infected with			
			RTBV + RTSV	RTBV	RTSV	None		RTBV + RTSV	RTBV	RTSV	None
ASD7	3.78	25.0	5	10	3	17	51.4	15	9	1	10
ARC11554	4.10	0	0	4	0	33	11.1	0	8	0	28
Gam Pai 30-12-15	4.40	25.0	0	4	0	24	25.0	0	8	0	24
Kataribhog	8.00	38.6	3	26	1	4	36.4	9	9	0	15
TKM6	6.60	31.4	0	11	0	24	20.0	0	9	0	26
TN1	9.30	64.9	18	9	3	7	94.3	31	3	1	0
Utri Rajapan	7.08	8.1	1	5	0	31	13.2	2	12	0	24

Table 27. Reaction of IR varieties (with TKM6 RTV resistance gene) to RTV-associated viruses under field conditions. IRRI, 1985 WS.

Variety	30 d after transplanting					60 d after transplanting				
	Infection[a] (%)	Plants[b] (%) infected with				Infection[a] (%)	Plants[b] (%) infected with			
		RTBV + RTSV	RTBV	RTSV	No infection		RTBV + RTSV	RTBV	RTSV	No infection
IR20	0.3	0	1.3	0	98.7	1.2	0	2.5	0	97.5
IR26	0.5	0	3.8	0	96.2	0.7	0	3.8	0	96.2
IR30	0.3	0	0	0	100.0	0.7	0	3.8	0	96.2
IR36 (moderately resistant check)	1.6	1.3	0	8.8	89.9	12.2	6.3	0	37.5	56.2
IR40	0.1	1.3	0	0	98.7	0.3	1.3	0	0	98.7
IR50 (resistant check)	0.1	1.3	1.3	0	97.4	0.1	1.3	1.3	0	97.4
IR58 (resistant check)	0.1	0	0	0	100.0	0.2	0	0	2.5	97.5
TN1 (susceptible check)	13.2	16.3	1.3	25.0	57.4	98.4	52.5	2.5	37.5	7.5

[a]Scored based on symptoms, taking all plants/plot. [b]From 80 plants randomly selected and examined by latex test.

Table 28. Reaction of GLH-resistant varieties to RTV-associated viruses. IRRI, 1985.

Variety	Resistance gene	Reaction to RTV[a]	Plants tested (no.)	Plants[b] (%) with			
				RTBV + RTSV	RTBV	RTSV	No infection
Pankhari 203	*Glh-1*	R	65	0.0	27.7	0.0	72.3
Jingasail	*Glh-1*	I	67	41.8	17.9	6.0	34.3
Palasithari 601	*Glh-2*	S	34	0.0	23.5	0.0	76.5
IR8	*Glh-3*	S	72	8.3	30.6	13.9	47.2
Ptb 8	*glh-4*	–[c]	54	13.0	37.0	0.0	50.0
IR42	*glh-4*	S	51	43.1	19.6	13.8	23.5
ASD8	*Glh-5*	I	42	2.4	26.2	0.0	71.4
TAPL 796	*Glh-6*	R	60	0.0	50.0	6.7	43.3
IR36	*Glh-6*	S	49	46.9	24.5	0.0	28.6
Moddai Karuppan	*Glh-7*	I	71	46.5	11.3	4.2	38.0
TN1 (susceptible check)	None	S	63	87.3	7.9	4.8	0.0

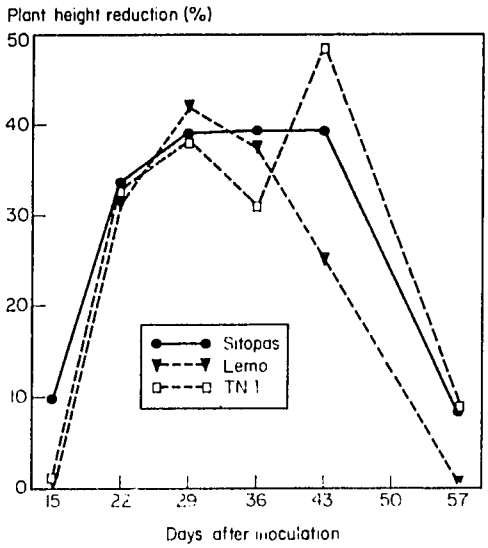
[a]Greenhouse mass screening data, IRRI Plant Pathology Department: 0-30% infection = resistant (R), 31-60% = intermediate (I), 61-100% = susceptible (S). [b]Plants were inoculated by GLH carrying RTBV and RTSV at 5/seedling and tested by latex for the presence of viruses 30 d after inoculation. [c]Not tested.

Table 29. Reactions of 3 rice cultivars to RSV infection. IRRI, 1985.

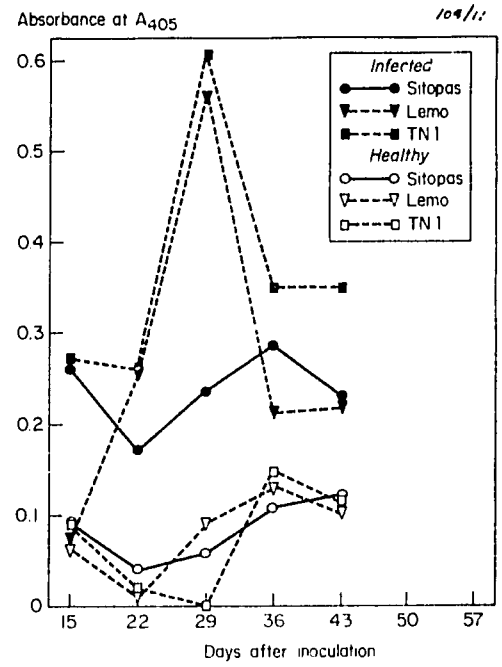
Variety	RSV infection[a] (%)	Plant ht reduction[b] (%)	Yield reduction[c] (%)
Sitopas	76.9	24.43	39.75
Lemo	50.0	58.66	56.63
TN1	76.0	55.73	84.47

[a]Inoculated in test tubes at 5 BPH/seedling. [b]Compared with the control at 30 d after inoculation. [c]Total weight reduction of filled grain in infected plants (inoculated 7 d after soaking) compared with the control.

Seven-day-old seedlings of Sitopas, Lemo, and TN1 were exposed to RSV-viruliferous brown planthopper at 5/seedling for 24 h. Both inoculated and uninoculated seedlings were transplanted in pots. At 14, 22, 29, 36, and 43 DAI, plant height was measured, and whole plants except roots were weighed and then homogenized with buffer. Homogenate at 1/2 dilution (volume/weight) was tested by ELISA. The relative amount of RSV accumulated in the plants was indicated as absorbance at 405 nm. Uninoculated seedlings of each cultivar served as controls.



10. Reduction of plant height on Sitopas, Lemo, and TN1 infected with RSV at various times after inoculation. IRRI, 1985.



11. Relative amount of RSV accumulated in plants of Sitopas, Lemo, and TN1, determined by ELISA at various times after inoculation. IRRI, 1985.

In all cultivars tested, plant height reduction was low at 15 DAI, increased to a high level at 22-43 DAI, and then declined at 57 DAI (Fig. 10). In moderately tolerant Lemo and less tolerant TN1, accumulated RSV was at a low level at 15 and 22 DAI, increased to the highest level at 29 DAI, and then declined; in tolerant Sitopas, accumulated RSV was at a low level regardless of growth stage (Fig. 11). This indicates some correlations between tolerance for RSV and amount of accumulated RSV in plants.

Genetic evaluation and utilization (GEU) program

Insect resistance

Entomology, Plant Pathology, and Plant Breeding Departments

SOURCES OF RESISTANCE 56
Evaluation of germplasm and breeding lines 56
Resistance of GEU elite lines 56
Mass rearing of pink stem borers 56
Screening methods for sources of resistance 56
Influence of susceptible plants on screening 57
NATURE OF RESISTANCE 57
Fertilizer-resistance interaction 57
Mindanao brown planthopper 58
Resistance to green leafhopper and tungro 58
Virulence of field-collected green leafhopper 58
Resistance to striped stem borer 58
BIOCHEMICAL BASES OF RESISTANCE 59
Resistance to thrips 59
Effect of plant extracts on leaffolder 59
Low temperature and yellow stem borer 59
INSECT-DISEASE INTERACTION 60
Brown planthopper and sheath blight interaction 60
BIOTYPES AND GENETIC CHARACTERISTICS 60
Mating signals of BPH 60
Morphometric variations in brown planthopper 61
Meiotic chromosomes in primary spermatocytes of brown planthopper 61
Multiple allelism in brown planthopper body coloration 63
Cytogenetics of planthoppers 64
Morphometric variations in green leafhopper 65
Comparative cytology of green leafhopper 65

55

SOURCES OF RESISTANCE

Entomology and Plant Breeding Departments

Evaluation of germplasm and breeding lines. Most IRRI screening work against insect pests involves evaluation of breeding lines for resistance to the brown planthopper (BPH) *Nilaparvata lugens* and the green leafhopper (GLH) *Nephotettix virescens* (Table 1). Of the lines tested for BPH and GLH, more than 50% were rated resistant or moderately resistant. Additional germplasm accessions were identified as resistant to specific insects. Screening for resistance to the yellow stem borer (YSB) *Scirpophaga incertulas* was continuous because of the successful rearing of this insect in the greenhouse. A method is being developed for rearing and screening rices for resistance to the shoot fly *Atherigona oryzae*.

Resistance of GEU elite lines. Seventy-one elite lines and IR varieties were evaluated for resistance to seven insect pests (Table 2). About 60% exhibited multiple resistance to YSB, GLH, BPH, and whitebacked planthopper (WBPH) *Sogatella furcifera*. None was found resistant to the leaffolder, caseworm, or whorl maggot.

Mass rearing of pink stem borers. Two methods were compared for rearing the pink stem borer *Sesamia inferens*. In the first, 50-day-old stems of susceptible Rexoro plants were placed in vials with water for oviposition and subsequent insect development. In the other, a southwestern corn borer (SWCB) diet (Bio-Mix #9763) was used.

Larval development was more rapid on the SWCB diet. The larvae completed development in 22 d on the diet vs 29 d on rice plants (Table 3). The incubation period and the pupal duration were identical with the two dietary sources. Weights of last-instar larvae and pupae were higher on the SWCB diet, indicating that it was better than rice stems (Table 4).

The SWCB diet was then used for detailed life history studies of two other stem borer species, the striped stem borer *Chilo suppressalis* and the dark-headed stem borer *Chilotraea polychrysa*.

Screening methods for sources of resistance. Two screening methods were used for evaluating resistance to GLH in IR8, IR22, IR24, IR28, IR29, IR34, IR36, IR42, IR44, IR45, IR50, IR58, IR64, and TN1; to BPH in IR62, Triveni, Utri Rajapan, Intan, Peta, and TN1; and to WBPH in Jhona 349, Jhona 393, Lakkar, Chempan, Cheriya Chittari, Jhinuwa, N22, Podiwi A8, IR48, IR52, IR60, IR62, IR2035-117-3, and TN1. In the free-choice method, the materials were sown in 5-cm rows and the seedlings enclosed within a large mylar cage. In the no-choice method, each row of seedlings was excluded from the others by intervening mylar partitions.

When 7 d old, the seedlings were thinned to 15/row and infested with third instars of 4 GLH, 8 BPH, and 8 WBPH nymphs/seedling. No major differences were recorded in seedling damage caused by the insects regardless of screening method.

Table 1. Screening of germplasm and breeding lines for resistance to insect pests. IRRI, 1985.

Insect	Germplasm collections			Lines		
	Tested (no.)	Resistant (no.)	Resistant (%)	Tested (no.)	Resistant (no.)	Resistant (%)
Brown planthopper *Nilaparvata lugens*						
Biotype 1	19	2	10.5	63,182	40,467	64.1
Biotype 2	46	7	15.2	44,193	21,137	47.8
Biotype 3	60	1	1.7	40,769	25,566	62.7
Whitebacked planthopper *Sogatella furcifera*	1,465	10	0.7	2,829	139	4.9
Green leafhopper *Nephotettix virescens*	1,478	17	1.1	91,801	48,776	53.1
Yellow stem borer *Scirpophaga incertulas*	1,857	93	5.0	2,021	482	23.9
Leaffolder *Cnaphalocrocis medinalis*	826	88[a]	10.7	5,230	432	8.3
Leaffolder *Marasmia patnalis*	227[b]	67	29.5	0	0	–
Whorl maggot *Hydrellia philippina*	3,215	0	–	0	0	–
Caseworm *Nymphula depunctalis*	3,053	0	–	0	0	–

[a]For retesting. [b]Wild rices.

Table 2. Reaction of a few of the 71 GEU elite lines and IR varieties tested for resistance to insect pests.[a] IRRI, 1985.

Entry	BPH biotype			GLH	WBPH	YSB
	1	2	3			
IR8	S	S	S	S	S	MR
IR58	R	MR	MR	R	S	R
IR64	R	R	R	R	MR	R
IR92002-5-2-2-2	R	R	R	MR	S	MR
IR9758-K2	R	R	R	R	S	R
IR13155-60-3-1-3	MR	S	MR	MR	S	MR
IR21820-154-3-2-2-3	R	R	R	MR	MR	R
IR25587-133-3-2-2-2	R	R	R	R	MR	R
IR28228-119-2-3-1-1	R	R	R	R	MR	R
IR29658-43-3-2-1	R	R	R	R	MR	R
IR29558-69-2-1	R	R	R	R	MR	R
IR29723-88-2-3-3	R	R	R	R	MR	MR
IR31802-48-2-2-2	R	R	R	R	MR	R
IR33043-46-1-3	R	R	R	R	MR	R
IR35546-52-3-3-2	R	R	R	R	MR	R
IR37721-5-2-1-3	R	R	R	R	MR	R
IR39423-124-3-3-1	R	R	R	R	MR	R

[a] R = resistant, MR = moderately resistant, S = susceptible.

Table 3. Duration of egg, larval, and pupal stages and longevity of adult pink stem borer reared on rice stems or southwestern corn borer diet. IRRI, 1985.

Stage	Duration (d ± SD)	
	Rice stem	Artificial diet
Egg	7.6 ± 1.0	6.5 ± 1.1
Larva	28.9 ± 3.8	22.1 ± 5.9
Pupa	8.4 ± 1.1	10.5 ± 1.1
Adult	4.9 ± 0.9	3.3 ± 0.5

Table 4. Weight of last-instar larvae and pupae of pink stem borer reared on rice stems or southwestern corn borer diet. IRRI, 1985.

Stage	Weight (mg ± SD)	
	Rice stem	Artificial diet
Larva	170 ± 46	217 ± 47
Pupa		
Female	165 ± 22	210 ± 39
Male	123 ± 21	148 ± 48

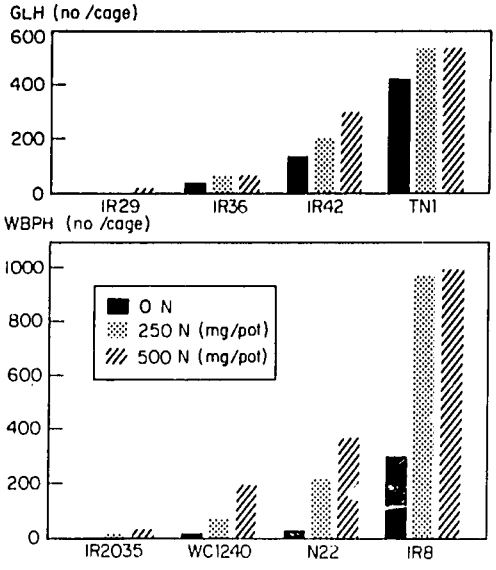
In the free-choice method, the insects initially moved to the susceptible varieties, then moved to the resistant plants a few days after initial infestation and several days before recording of damage ratings. But in the no-choice method, escape was unlikely from the start of the experiment. In both methods, however, moderately resistant varieties were likely to be rated susceptible if damage scoring was delayed.

Influence of susceptible plants on screening. In the free-choice seedbox technique, the test entries generally include an unknown proportion of resistant, moderately resistant, and susceptible materials. Regardless of the ratio of susceptible plants in a seedbox of infested seedlings, damage to the moderately resistant varieties did not vary. However, infestation duration was prolonged for the susceptible check to attain an 8-9 damage rating when the ratio of moderately resistant and susceptible plants was 1:9.

NATURE OF RESISTANCE

Entomology Department

Fertilizer-resistance interaction. We applied two levels of N to potted test plants on which first instars of GLH and WBPH were reared to the adult stage. Three pairs of adults/pot were caged, and insect progenies were counted at 22 d after caging. In general, the insect population increased with increasing fertilizer (Fig. 1). However, the



1. Population growth of GLH and WBPH on rice plants treated with different rates of N. IRRI, 1985.

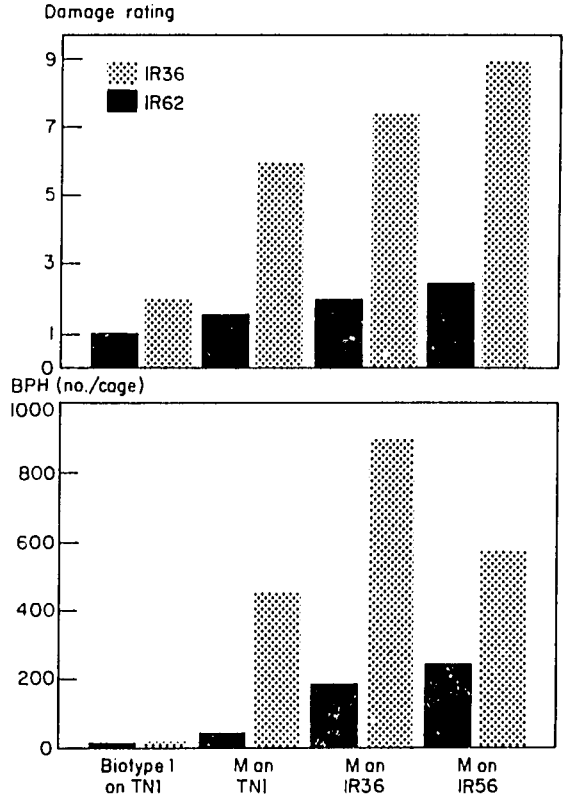
moderately resistant and resistant plants maintained their levels of resistance compared with susceptible TN1 plants.

Mindanao brown planthopper. The BPH from Mindanao, Philippines, that reportedly damaged IR36 has been reared at IRRI since 1983 on TN1 (no BPH resistance gene), IR36 (*bph-2* gene), and IR56 (*Bph-3*) for 25 generations. The insects maintained their virulence on IR36, but the TN1 colony caused less damage and the IR56 colony caused more damage to IR36 than the IR36 colony (Fig. 2). The three BPH colonies produced relatively high BPH populations on IR36; the IR36 colony was the most fecund. No colony damaged IR62 (*Bph-3* gene) or produced normal BPH population levels on it.

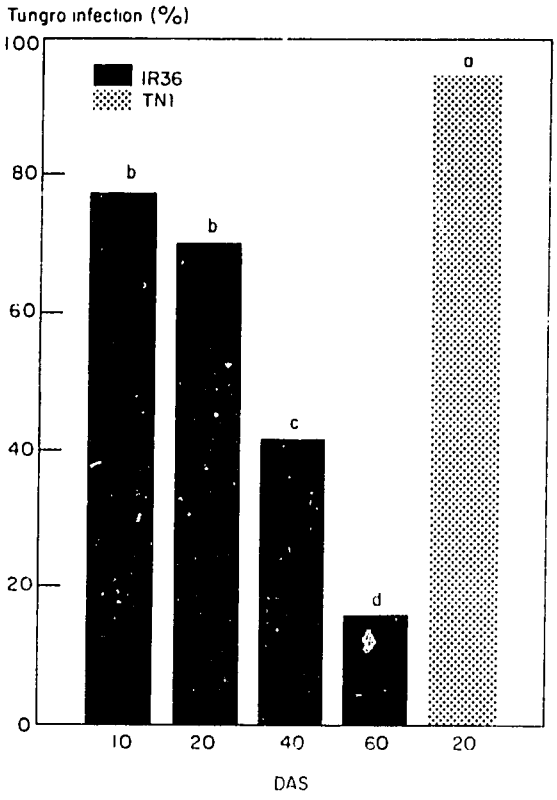
Resistance to green leafhopper and tungro. GLH developmental period was longer and population growth lower on IR36 than on TN1 plants. When a 500-ppm extract of IR36 plants was sprayed on TN1 plants, GLH adults were repelled. Plant growth stage affected resistance: younger IR36 plants were preferred over older plants. Likewise, higher adult recovery and shorter developmental period were registered on younger plants. When 10-, 20-, 40-, and 60-day-old IR36 plants were infested with viruliferous adults, tungro infection was higher on younger plants (Fig. 3). The insect's preference, coupled with the tungro susceptibility of younger IR36 plants, would cause greater yield loss than when infection occurs at later plant growth stages.

Virulence of field-collected green leafhopper. GLH samples collected from 15 locations on Luzon, Philippines, were compared with the greenhouse colony maintained on TN1. Six field-collected colonies were more virulent as evidenced by their significantly higher population increase on IR36 and IR42 than that of the greenhouse colony on TN1. If IR36 and IR42 are planted exclusively in locations that abound in virulent GLH populations, a higher incidence of tungro may be expected.

Resistance to striped stem borer. Grain yield loss was determined at the vegetative and reproductive stages in six commercial IR varieties with varying levels of vegetative stage resistance to striped stem borer *Chilo suppressalis* and at different rates of infestation. IR29 and IR46 (susceptible), IR52 and



2. Population growth of BPH from Mindanao (M) reared on TN1, IR36, and IR56, and its damage on IR36 and IR62. IRRI, 1985.



3. Tungro infection on IR36 and TN1 plants at different days after sowing (DAS). IRRI, 1985. Values with the same letter are not significantly different at the 5% level.

IR54 (moderately resistant), and IR36 and IR40 (resistant) were infested at rates of 0, 5, 10, and 20 first-instar larvae/plant. Resistant varieties had the least deadhearts and whiteheads. At 5 larvae/plant during the vegetative stage, grain yield was reduced 69% in IR29 and 8% in IR36 (Table 5). At 5 larvae/plant during the reproductive stage, grain yield reduction was 40% for IR29 and 11% for IR36 (Table 6). At the vegetative growth stage, percentage of unfilled grains was highest in the susceptible varieties. Considering a 10% yield loss, an action threshold of 1 egg mass/m^2 for susceptible and 2 egg masses/m^2 for resistant varieties is suggested.

BIOCHEMICAL BASES OF RESISTANCE

Entomology Department

Resistance to thrips. Susceptible Nira plants were sprayed with 1,000-ppm extracts of different varieties. When offered to adult thrips *Stenchaetothrips biformis*, the plants treated with the extract of *Oryza officinalis* (Acc. no. 101155) or Dahanala 2220 (Acc. no. 50730) were least preferred. Population growth was low on Dahanala and Kinanda (Acc. no. 3882).

Effect of plant extracts on leaffolder. Leaves of susceptible TN1 plants treated with 1,000-ppm extract of *O. brachyantha* (Acc. no. 101231), Darukasail (Acc. no. 45493), Kamalbhog, or TKM6 were least preferred for feeding by *Cnaphalocrocis medinalis* larvae. The larvae excreted very little feces when fed for 24 h with TN1 leaves treated with IR50 extract (Table 7). Hatchability was reduced when eggs were dipped in a 1,000-ppm TKM6 extract.

Low temperature and yellow stem borer. Newly laid eggs of YSB were stored at 17 and 20 °C in an incubator. After 10 d, the eggs were hatched at room temperature (27 °C). Susceptible IR62 plants at booting were infested with newly emerged larvae

Table 5. Grain yield of rice varieties with varying levels of resistance when infested with different populations of striped stem borer larvae at 30 d after transplanting.[a] IRRI screenhouse, 1984.

Larvae (no.)/plant	Grain yield[b] (g/8 plants ± SD) in					
	IR29	IR46	IR52	IR54	IR36	IR40
0	46.6±3.7 a (c)	45.1±2.1 a (c)	45.4±1.0 a (c)	42.7±2.4 a (c)	70.0± 1.7 a (a)	54.7±3.4 a (b)
5	14.4±3.7 b (d)	16.4±2.2 b (cd)	20.6±5.5 b (c)	23.0±4.0 b (c)	64.5± 6.9 b (a)	44.9±2.8 b (b)
10	7.1±1.6 c (d)	12.2±1.9 c (cd)	15.5±4.0 c (c)	18.1±1.3 c (c)	53.0±10.4 c (a)	39.0±4.4 c (b)
20	4.7±1.6 c (d)	5.8±2.4 c (d)	14.9±3.1 c (c)	15.6±1.7 c (c)	46.8± 9.0 d (a)	37.2±3.1 c (b)

[a]In a column and in a row (within parentheses), means followed by a common letter are not significantly different at the 5% level. [b]% yield reduction = $100 - \left(\frac{\text{yield with infestation}}{\text{yield without infestation}} \times 100\right)$.

Table 6. Grain yield of rice varieties with varying levels of resistance when infested with various populations of striped stem borer larvae 2 wk before flowering.[a] IRRI screenhouse, 1984.

Larvae (no.)/plant	Grain yield[b] (g/8 plants ± SD) in					
	IR29	IR46	IR52	IR54	IR36	IR40
0	74.2±11.0 a (ab)	86.9± 8.1 a (a)	45.3±19.4 a (c)	57.6±20.3 a (bc)	70.6±37.2 a (ab)	66.4± 9.1 a (abc)
5	44.3±13.5 b (a)	41.1±30.9 b (a)	40.3±18.6 a (a)	48.4± 1.9 a (a)	62.8±11.6 a (a)	53.8±12.5 a (a)
10	44.0±11.9 b (ab)	30.3±10.7 b (b)	35.8± 9.5 a (ab)	40.8± 3.6 a (ab)	58.0±16.4 a (ab)	55.1± 3.3 a (a)
20	37.9±16.6 b (ab)	22.6± 9.6 b (b)	33.4± 5.6 a (ab)	38.3± 7.5 a (ab)	53.5± 4.7 a (a)	52.1±10.4 a (a)

[a]In a column and in a row (within parentheses), means followed by a common letter are not significantly different at the 5% level. [b]% yield reduction = $100 - \left(\frac{\text{yield with infestation}}{\text{yield without infestation}} \times 100\right)$.

and insect survival determined 20 d later. The incubation period of eggs stored at 17 and 20 °C was prolonged to 16 d compared with the 8-d incubation period at room temperature. Survival of larvae emerging from cold-stored eggs was reduced to 50-55% in contrast to 90-94% of larvae emerging from eggs stored at room temperature. Hatchability of eggs was 98% regardless of temperature.

INSECT-DISEASE INTERACTION

Entomology and Plant Pathology Departments

Brown planthopper and sheath blight interaction. IR22, IR36, ASD7, and Utri Rajapan were tested to determine whether BPH infestation and damage would enhance sheath blight (ShB) infection. The following insect-pathogen treatments were compared: 1) BPH males + ShB, 2) BPH females + ShB, and 3) ShB alone. The disease increased over time. ASD7 and Utri Rajapan were more resistant than IR22 and IR36 to ShB. BPH infestation had no effect on ShB severity.

Table 7. Quantity of food ingested by first-instar larvae and hatchability of eggs of leaffolder on TN1 leaves treated with extracts of wild rices or rice varieties. IRRI, 1985.

Wild rice or rice variety	Accession no.	Dry weight of feces[a] (mg)	Unhatched eggs[b] (%)
Oryza brachyantha	101231	0.038 abc	24 b
O. brachyantha	101232	0.078 c	18 b
O. brachyantha	101233	0.066 abc	35 b
O. brachyantha	101234	0.058 abc	26 b
Dularsukasail	45493	0.076 c	20 b
Kamalbhog	49020	0.072 bc	30 b
IR50	53433	0.018 a	23 b
TKM6	237	0.036 abc	57 a
TN1 (susceptible check)	105	0.026 ab	26 b

[a]Ten first-instar larvae were fed for 24 h with TN1 leaves treated with the extracts; dried feces were weighed after 24 h. [b]Eggs laid on TN1 leaves were dipped in a 1,000-ppm steam distillate extract.

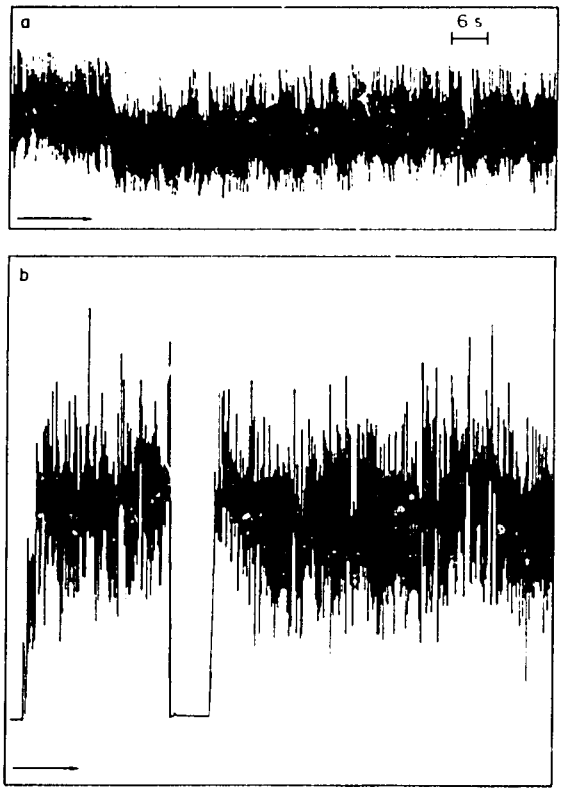
BIOTYPES AND GENETIC CHARACTERISTICS

Entomology Department

Mating signals of BPH. Previous studies showed certain genetic incompatibilities between sympatric BPH biotype 1, biotype 2, and biotype 3 infesting rice and a biotype infesting the weed grass *Leersia hexandra* (Swartz). We investigated whether premating isolating mechanisms existed among these biotypes. The courtship and mating behavior in both sexes was observed. The mating signals emitted were amplified, tape recorded, and later fed to a chart recorder.

The female call in the grass-infesting biotype was characterized by slow drumming in contrast to a fast drumming, approximating a trill, in rice-infesting biotypes (Fig. 4); the number of calls/min or pulse repetition frequency was more in biotype 3 than in the other biotypes (Table 8). The grass- and the rice-infesting biotypes differed in the average duration of the female call.

The quality of the male call also differed between the rice- and the grass-infesting biotypes. The croaking male call in the grass-infesting biotype was more hoarse and longer than that in the rice-infesting biotypes; however, the pulse repetition frequency was similar.



4. The female call of the grass-infesting biotype (a) and the rice-infesting biotype 2 (b) of *N. lugens* monitored with an amplifier and recorded on a chart recorder. IRRI, 1985.

Hybridization between the grass- and the rice-infesting biotypes was monitored using an amplifier during a 30-min observation period. Successful mating occurred in all the cases between males and females of the grass-infesting biotypes; however, only 30% successful mating occurred between females of grass-infesting biotypes and males of biotype 1. No mating occurred between females of the grass-infesting biotype and males of biotype 2 or biotype 3.

In heterogametic crosses, the females responded to the males as readily as in homogametic crosses. However, the males made little attempt to locate the drumming females. In cases where heterogametic mating occurred, it took longer for the male to mount the female than when the cross was homogametic.

Morphometric variations in brown planthopper. Morphometric parameters of rostrum, legs, and antennae in brachypterous and macropterous

Table 8. Mating signals in both sexes of *N. lugens* biotypes infesting rice and a weed grass.[a] IRRI, 1985.

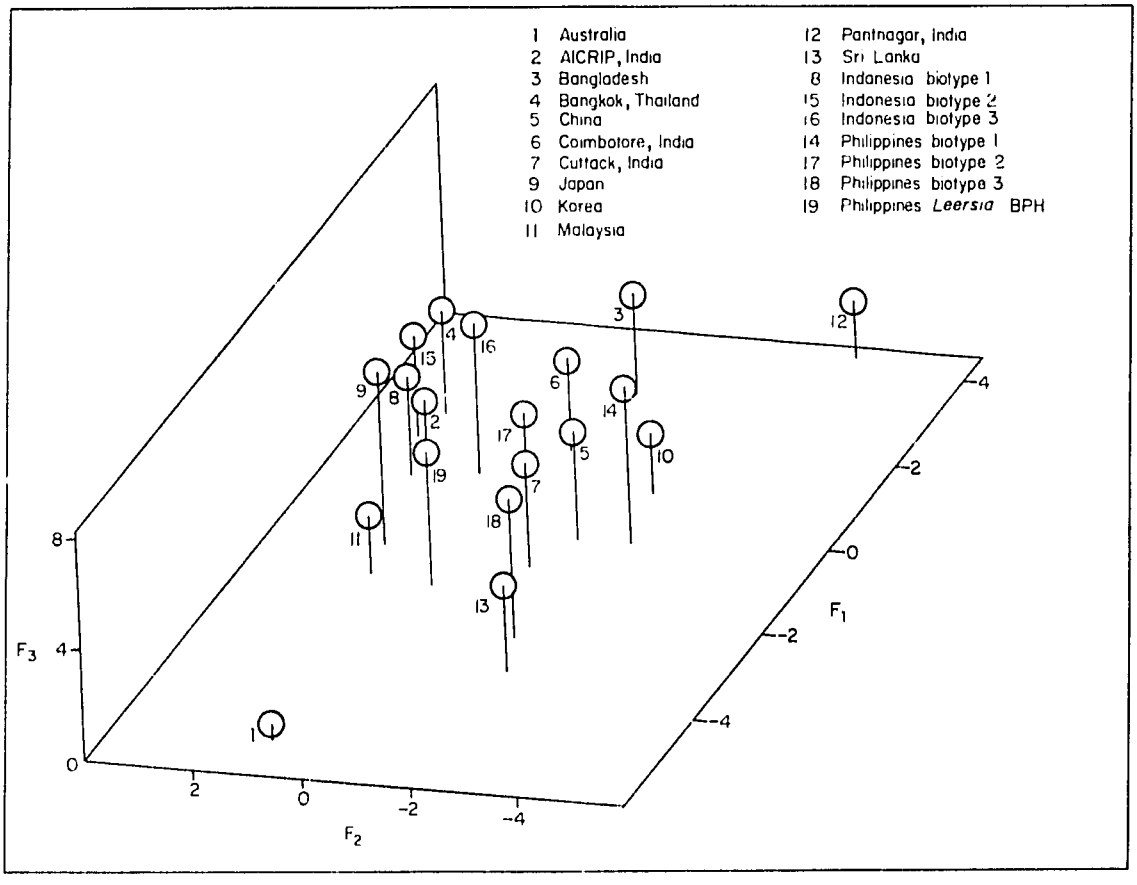
Item	Rice-infesting biotype 1	Rice-infesting biotype 2	Rice-infesting biotype 3	Grass-infesting biotype
		Female		
Calls (no.)/min	3.7 b	2.8 b	5.3 a	2.1 bc
Duration(s) of call	12.9 b	17.6 b	10.3 b	34.8 a
		Male		
Calls (no.)/min	11.6 a	12.3 a	11.1 a	12.0 a
Duration(s) of call	2.1 a	2.0 a	2.0 a	1.6 b

[a]Av of 10 replications; each replication used a new male and a new female. In a row, means followed by a common letter are not significantly different at the 5% level.

males and females were used for differentiating 19 sympatric and allopatric BPH populations from Australia and South, Southeast, and East Asia. Various populations were compared with the sympatric rice-infesting BPH biotype 1, biotype 2, and biotype 3 that have been identified in the Philippines. Morphometric data were subjected to multiple discriminant analysis, the Mahalanobis generalized distance test, and cluster analysis; distinct segregation of the populations was obtained in most cases. Figure 5 shows the 3-dimensional spatial relationships of 19 populations of macropterous BPH females. The allopatric populations showed a higher magnitude of segregation than the sympatric populations.

Using the generalized distance values (D^2) each population could be segregated as a distinct biotype, except the Bangkok population from the Indonesian biotype 2, and the Indonesian biotype 1 from the Indonesian biotype 2.

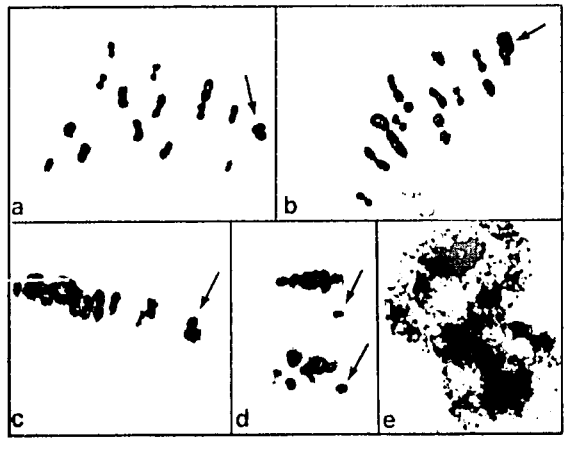
Meiotic chromosomes in primary spermatocytes of brown planthopper. Genetic plasticity and high reproductive rate in BPH have contributed significantly to its notoriety as a problem pest of the rice crop. BPH populations were collected at IRRI and mass-reared on TN1. Cellular and karyological features in primary spermatocytes of 5th-instar nymphs or newly emerged brachypterous males were analyzed. The meiotic division was reductional at the spermatocyte I stage and equational at the spermatocyte II stage, or simultaneously reductional and equational in all spermatocytes. The karyotype of the male BPH was



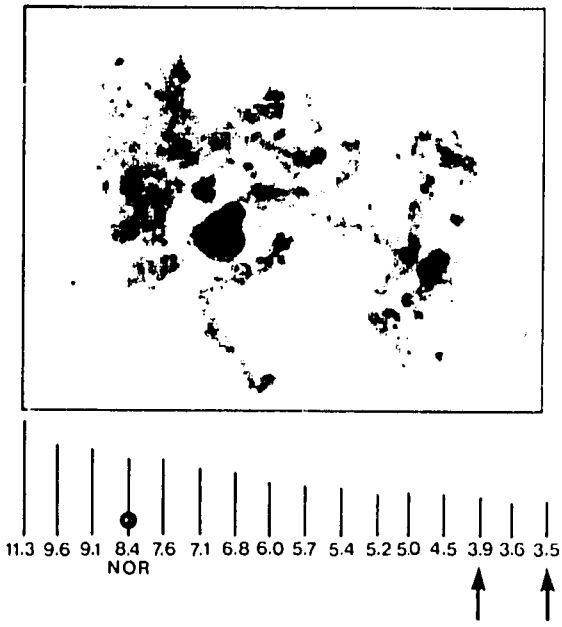
5. Three-dimensional spatial relationships of 19 BPH populations of macropterous females based on discriminant function analysis. IRRI, 1985.

2n=30 (14IIA + XY), yielding 2 types of spermatozoa: 14IA + X and 14IA + Y (Fig. 6). Homologous chromosomes possessed diffused centromeres. Pachytene autosomes had relative mean lengths of 3.6-11.3; the X chromosome measured 3.9 and the Y chromosome 3.5 (Fig. 7). The total chromosomal volume was 0.153 μ^3 (0.140 μ^3 autosomal and 0.013 μ^3 sex chromosomal). The meiotic index was 0.65. The sperm head was 12.9 μ long.

At metaphase I, the heterochromatic XY chromosomes isolated themselves from the autosomal grouping. Later during anaphase I and telophase I, they aligned themselves with autosomes in respective polar ends. Chromosomal aberrations included aneuploidy and agmatoploidy. Centric fusions reduced chromosome



6. Primary spermatocytes of BPH showing meiotic chromosomes at a) diakinesis, b) premetaphase I, c) metaphase I, d) anaphase I, and e) telophase I. Sex chromosomes are indicated by arrows. 1,000X. IRRI, 1985.



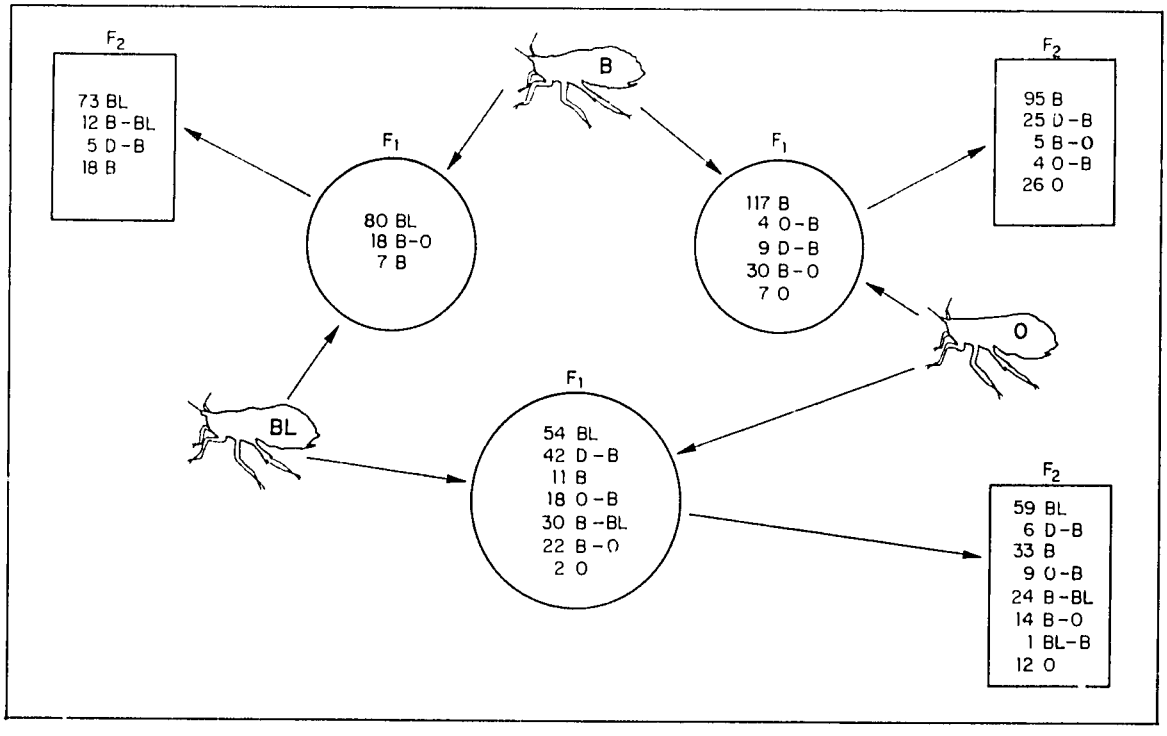
7. Idiogram of pachytene chromosomes of BPH. Sex chromosomes are indicated by arrows. NOR = nucleolar organizing region. 1,500X. IRRI, 1985.

numbers and occurred more frequently than fragmentations, which increased chromosome number.

Multiple allelism in brown planthopper body coloration. BPH adults have a characteristic brown (B) coloration. Occasionally, orange (O) and black (BL) color variants appear in low numbers in stock cultures maintained on rice plants. Cross breeding of purified color morphs and inbreeding of their progenies have enabled the expression of intermediate color morphs that are dark brown (D-B), brownish orange (B-O), orange-brown (O-B), blackish brown (BL-B), and brownish black (B-BL). The mode of inheritance of BPH body coloration and the influence of environment were investigated.

The parental insects came from pure breeding lines and were homozygous for body coloration. Figure 8 summarizes the results of the hybridization experiments. The inheritance of color morphism had the following trends:

- The gene for color morphism in BPH exists in three allelic forms, although any one diploid



8. Hybridization scheme between brown (B), orange (O), and black (BL) BPH color morphs. Progenies comprising additional color morphs — dark brown (D-B), brownish orange (B-O), orange brown (O-B), blackish brown (BL-B), and brownish black (B-BL) — are depicted within circles (F_1) and boxes (F_2). IRRI, 1985.

male or female can carry no more than two alleles. Thus, body coloration exhibits multiple allelism. The three alleles can be designated b^+ (brown or wild type allele), b^o (orange allele), and b^b (black allele). Considering the results of backcrosses, BPH has six possible genotypes: three homozygotes — b^+b^+ (brown), b^ob^o (orange), and b^bb^b (black) — and three heterozygotes — b^+b^o (brownish orange), b^bb^+ (blackish brown), and b^bb^o (dark brown). The heterozygotes exhibited some other allelic interactions leading to further variations in the expression of body coloration such as b^ob^+ (orange-brown) and b^+b^b (brownish black); no allelic interaction occurred between b^b and b^o.

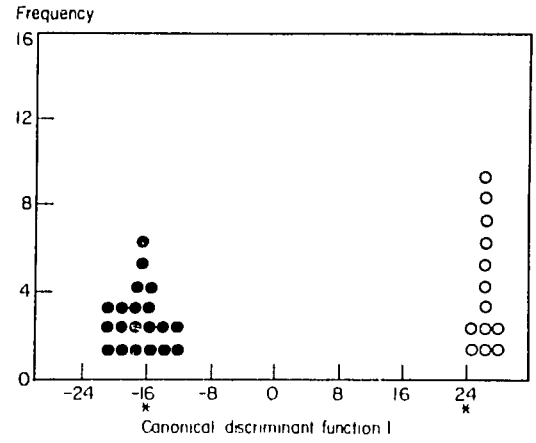
- The six possible genotypes produced as many as eight different phenotypes, indicating that in this species the relation between phenotype and genotype is not fixed. The observed phenotypes may result from an interaction among different genes or between genes and the environment. All possible color morphs were obtained in reciprocal crosses of black and orange BPH.
- Crosses between B and O as well as between B and BL produced F_2 frequency ratios that fit with monogenic inheritance or segregation of a pair of alleles at a single locus. B coloration exhibited a certain degree of dominance over O, and BL over B. However, no specific pattern of inheritance could be depicted between BL and O, although there was partial dominance of BL over O.
- The unexpected occurrence of intermediates between the extreme parents in the F_1 and F_2 of all the crosses manifested certain variabilities that could be attributed to:
  a. residual heredity of filial regression due to 1) incompleteness of dominance, 2) effects of environment, or 3) epistasis; or
  b. modifier genes that change the phenotypic effects of major genes in quantitative fashion through dilution or enhancement.

Cytogenetics of planthoppers. Wild populations of rice-infesting BPH and WBPH were collected from IRRI, while *Nilaparvata bakeri* and grass-infesting BPH were collected from the grass *L. hexandra* growing in irrigation canals. The planthoppers were mass-reared on their respective hosts. Newly emerged brachypterous males and females were used for cytogenetic investigations. The following are salient cellular and karyological features:

- Gametic meioses of grass-infesting *N. bakeri* and BPH followed the standard prereductional sequence, whereas the rice-infesting BPH and WBPH manifested more labile meioses, being sometimes prereductional, or reductional and equational simultaneously.
- The male karyotypic formulae were BPH: 2n=30 (14HA + XY); *N. bakeri*: 2n=29 (14HA + XO); and WBPH: 2n=29 (14HA + XO).
- The four delphacid populations possessed chromosomes with diffused centromeres.
- In terms of meiotic index, the planthoppers ranked as follows: BPH (rice) > WBPH > BPH (grass) > *N. bakeri*. The sperm head in rice planthoppers was longer than that in grass-infesting planthoppers. The rice-infesting BPH had the longest sperm head, whereas the grass-infesting BPH possessed the shortest.
- Pachytene chromosomes revealed that rice- and grass-infesting BPH had 16 linkage groups, whereas *N. bakeri* and WBPH had 15 each. The total chromatin length was greater in rice planthoppers than in grass-infesting planthoppers. In terms of chromatin length, the planthoppers ranked as follows: BPH (rice) > WBPH > *N. bakeri* > BPH (grass).
- The nucleolus of rice-infesting BPH was larger and sometimes biforked compared with the smaller ovoid nucleoli of grass-infesting BPH, WBPH, and *N. bakeri*. The nucleolar organizers of the planthoppers varied in relative mean lengths: rice-infesting BPH (8.4) > WBPH (6.3) > grass-infesting BPH (6.2) > *N. bakeri* (6.0).
- At pachytene, the X-body of WBPH condensed precociously into an ovoid body measuring about 1 μ long and 0.5 μ wide, with a relative mean length of 2. The X chromosomes of other planthoppers were still in their relaxed configuration and had the following relative mean lengths: *N. bakeri* (5.2), rice-infesting BPH (3.9), and grass-infesting BPH (3.2).

- The grass-infesting planthoppers had higher chromosomal (autosome + sex chromosome) volume than the rice-infesting planthoppers. By chromosomal volume (μ^3), they ranked as follows: *N. bakeri* (0.295) > grass-infesting BPH (0.283) > rice-infesting BPH (0.153) > WBPH (0.083).
- In planthoppers, the heterochromatic sex chromosomes were differentiated by their isolating behavior. The X-bodies in *N. bakeri* and WBPH invariably lagged behind and congressed later, whereas the XY chromosomes in BPH segregated normally during anaphase.
- During diakinesis, the chromosomes in rice-infesting BPH intensively coiled and shortened more than in grass-infesting BPH.
- In terms of spontaneous chromosomal variabilities (aneuploidy and agmatoploidy), the planthoppers ranked as follows: BPH (rice) > WBPH > *N. bakeri* > BPH (grass). Fusion and fission of chromosomes are probable modes of speciation in planthoppers.

Morphometric variations in green leafhopper. We compared morphometric variations between *N. virescens* populations indigenous to the Philippines and to Bangladesh. The abdominal, genital, rostral, antennal, and tarsal characters were quantified in adult males and females. Multiple discriminant analysis differentiated the two populations. All characters were combined in a single run for each sex in the populations. The individual groupings of characters were also run for discriminant analysis. Wilk's lambda was used for stepwise selection of independent variables to be entered into the final analysis. When all the characters in males or females were analyzed, a significantly high degree of discrimination was obtained between the two populations. The group centroids of the two populations were distinctly separated (Fig. 9).



9. Discriminant scores of *N. virescens* biotypes from the Philippines (●) and Bangladesh (o) based on rostral, leg, antennal, and genital characters of males without spot on corium. Group centroids are represented by asterisks. IRRI, 1985.

Comparative cytology of green leafhopper. Cellular and karyological features of testicular meiocytes in GLH indigenous to the Philippines were compared with those from Bangladesh. In both populations, the first meiotic division was reductional, followed by equational division. The male genome in both populations was 2n=15, comprising 7 homomorphic bivalent autosomes and a univalent X-body. All chromosomes had diffused kinetochores. The single heterochromatic sex chromosome could be identified during different meiotic stages by its isolation from the autosomal grouping. The two GLH populations differed:

- The Philippine population had a higher (0.80) meiotic index than the Bangladesh population (0.54). Spermatozoa in both populations had almost equal head length.
- The pachytene chromosomes had eight linkage groups with equal total chromatin length in both populations. However, the chromosome with the nucleolar-organizing region was relatively longer (0.153) in the Philippine population than in the Bangladesh population (0.146). The reverse was true of their sex chromosomes: the relative length of the sex chromosome in the Philippine population was 0.083; that in the Bangladesh population was 0.088. The individual autosomes also varied in length in the two populations.
- At the diakinesis and premetaphase stages, the length and volume of bivalents in the Philippine population were greater than those in the Bangladesh population.
- Spontaneous chromosomal abnormalities, particularly hypoploidy, were 71% in the

Philippine population and 85% in the Bangladesh population. Other aberrations included increased chromosomal complements or endonuclear polyploidy.

These cytological differences suggest that a certain degree of isolation has occurred between the two geographically separated GLH populations, which may even qualify as subspecies.

Genetic evaluation and utilization (GEU) program

Drought tolerance

Agronomy Department, International Rice Germplasm Center, Upland Rice Breeding Program, and International Rice Testing Program

VARIETAL SCREENING **68**
Field drought screening, 1985 dry season **68**
Field screening for drought resistance **68**
Screening upland rice at reproductive stage **70**
1985 upland observational nurseries **71**
SOIL-PLANT WATER RELATIONSHIPS **71**
Drought tolerance under limited rooting depth **71**
Micronutrient uptake by lowland rice under drought stress **71**
Varietal differences in root characteristics **73**
Infrared screening of lowland rice for drought tolerance **76**
Management for drought tolerance **77**
Effect on water use coefficient **78**
Root, shoot, and leaf water status **78**
Grain yield **78**

VARIETAL SCREENING

Agronomy Department, International Rice Testing Program, and Upland Rice Breeding Program

Field drought screening, 1985 dry season (*Agronomy*). Screening rices for drought tolerance at the vegetative growth stage is geared toward selecting varieties for rain-dependent drought-prone culture and identifying possible sources of germplasm for drought tolerance.

The 8,561 varieties and lines tested came from the germplasm bank (GB) and the Genetic Evaluation and Utilization (GEU) and International Rice Testing (IRTP) programs. Each entry was scored for drought reaction at 2, 5, and 10 bars soil moisture tension (SMT) at 20-cm depth and for recovery from 10 bars SMT by the Standard evaluation system (SES) for rice.

Among the 64 outstanding selections were 9 upland and deep water GB accessions, 20 IRTP 1984 nursery entries, and 35 GEU materials (Table 1); 31 were IRRI-bred lines, and the others originated from 9 areas: 14 from Thailand; 5 from Ivory Coast; 3 each from India and Indonesia; 2 each from Bangladesh, Korea, and Philippines; and 1 each from Sierra Leone and Taiwan, China.

All the outstanding entries showed no or slight leaf tip drying at 2 and 5 bars SMT (Table 1). At 10 bars SMT, 26 entries exhibited drying of up to 25% of the length of the leaves, while 38 had up to 25% of leaves fully dried. All 64 selections recovered fully when 10 bars SMT was relieved by sprinkler irrigation.

Drought-tolerant check Salumpikit had 50% of the leaves fully desiccated at 10 bars SMT, but it completely recovered when water was applied (Table 2). Drought-susceptible IRAT9 dried completely, and less than one-third of the plants produced new shoots when re-irrigated.

Indian variety ARC10372, which had been tested for drought tolerance for 7 yr, and IRRI-bred line IR9782-111-2-1-2, tested for 6 yr, showed consistently outstanding drought tolerance.

Field screening for drought resistance (*Upland Rice Breeding*). A total of 4,077 GB accessions,

Table 1. Outstanding selections for drought tolerance in field screening during the vegetative growth stage, IRRI, 1985 DS.

Selection	Source	Origin	Drought score[a]	
			2 bars SMT	5 bars SMT
Group I – drought score of 3 at 10 bars SMT and recovery score of 1[b]				
BKN6986-1	IRDWON 84-024	Indonesia	0	0
Buluhan Yakei 289	GB Acc. no. 64206	Sierra Leone	0	1
Chaw Ma Gawk	GB Acc. no. 64235	Thailand	0	1
Daeng Chai Ta La	GB Acc. no. 64240	Thailand	1	1
IRAT134	IURYN-E 84-006	Ivory Coast	0	0
IRAT140	IURON 84-019	Ivory Coast	0	1
IRAT142	IURYN-E 84-008	Ivory Coast	0	1
IRAT144	URYT 84W-032	Ivory Coast	0	0
Jao Loi	GB Acc. no. 64345	Thailand	0	1
Jeh Ruang Dan	GB Acc. no. 64351	Thailand	1	1
Kanahi	GB Acc. no. 640[illegible]3	Indonesia	1	1
Khiaw Nak	GB Acc. no. 6443[illegible]	Thailand	1	1
Pawn	GB Acc. no. 64580	Thailand	0	1
Tuggal Raya	GB Acc. no. 64069	Indonesia	0	1
IR9782-111-2-1-2	IRON 84-185	IRRI	0	1
IR19058-107-1	IRRSWON 84-026	IRRI	0	0
IR42221-2-1-3	Aug '84 PN-R73074	IRRI	0	0
IR42221-2-2-3	Aug '84 PN-R73077	IRRI	1	1
IR42221-45-3-2	Aug '84 PN-R73108	IRRI	0	0
IR42221-51-2-3	Aug '84 PN-R73118	IRRI	0	1
IR43522-78-2	Jun '84 PN-R61967	IRRI	0	1
IR43522-85-2	Jun '84 PN-R61976	IRRI	0	1
IR43522-91-3	Jun '84 PN-R61990	IRRI	0	0
IR43522-94-3	Jun '84 PN-R61996	IRRI	0	0
IR43522-98-2	Jun '84 PN-R62002	IRRI	0	0
IR43522-105-2	Jun '84 PN-R62017	IRRI	1	1

Continued on opposite page

Table 1 continued

Selection	Source	Origin	Drought score[a]	
			2 bars SMT	5 bars SMT
Group II – drought score of 4 at 10 bars SMT and recovery score of 1[b]				
ARC10372	IURON 84-109	India	0	1
BKN6988-52-1-3-0	IRDWON 84-025	Thailand	0	1
BKNFR76042-18-1-1	IFRON 84-004	Thailand	1	1
BKNFR80023-2-501-1-1-1-1	Dec '84 PN-836058	Thailand	0	1
BKNFR80023-2-501-1-1-1-2	Dec '84 PN-836059	Thailand	1	1
BKNFR80023-2-501-1-1-2-1-3	Jun '84 PN-D59654	Thailand	1	1
BKNFR80023-3-505-1-3-5-2	Dec '84 PN-836066	Thailand	1	1
BKNFR80023-3-505-1-3-5-3	Dec '84 PN-836067	Thailand	0	1
BR306-B-3-2	IFRON 84-005	Bangladesh	1	1
Chenab 64-117	HB84W-0339	India	0	1
C1158-7	IURON 84-078	Philippines	0	1
IRAT116	URYT 84W-028	Ivory Coast	0	0
Jalamagna	IFRON 84-013	India	0	1
Milyang 54	IRON 84-074	Korea	0	1
Sail Kotha	IFRON 84-015	Bangladesh	1	1
Salumpikit	HB 84W-0316	Philippines	0	1
SPR7295-53-2-1-2	IFRON 84-023	Thailand	0	1
Suweon 294	IRON 84-074	Korea	1	1
Taichung Sen Yu 321	IRON 84-391	Taiwan, China	0	1
IR5853-198-1-2-1F-P1	IRRSWON 84-185	IRRI	1	1
IR9761-19-1	IURYN-E 84-009	IRRI	0	1
IR11141-6-1-4	IRDWON 84-046	IRRI	1	1
IR23235-6-1-4	URYT 84W-076	IRRI	0	1
IR30716-8-8-8-5-4	UPN 84W-37904	IRRI	0	1
IR31432-4-1-3	RYT 84W-1513	IRRI	1	1
IR31432-8-6	OYT 84W-8817	IRRI	0	1
IR32333-42-1-3-3	RYT 85D-1659	IRRI	1	1
IR33434-35-1-3-1-2-1	Dec '84 PN-836176	IRRI	0	1
IR37003-15-3-2-2-2	Jun '84 PN-R64648	IRRI	0	1
IR38691-27-6-1-1	Jun '84 PN-D58155	IRRI	1	1
IR38691-27-6-1-3	Jun '84 PN-D58157	IRRI	0	1
IR43486-27-3	Jun '84 PN-R59941	IRRI	0	0
IR43487-11-2	Jun '84 PN-R59984	IRRI	0	0
IR43522-69-3	Jun '84 PN-R61949	IRRI	1	1
IR43522-68-1	Jun '84 PN-R62136	IRRI	0	1
IR43552-105-1	Jun '84 PN-R62525	IRRI	1	1
IR43559-103-3	Jun '84 PN-R62846	IRRI	0	1
IR43559-134-3	Jun '84 PN-R62893	IRRI	0	1

[a]SES 0-9 scale: 0 = no visible effects of soil moisture stress, 9 = all plants apparently dead. [b]SES 1-9 scale: 1 = 90-100% plants fully recovered, 9 = 0-19% plants fully recovered.

Table 2. Drought and recovery scores of tolerant and susceptible checks in field screening during the vegetative growth stage. IRRI, 1985 DS.

Variety	Drought score[a]			Recovery score[b]
	2 bars SMT	5 bars SMT	10 bars SMT	
Salumpikit (tolerant)	1	2	5	1
IR442-2-58 (tolerant)	1	3	6	3
IR20 (susceptible)	4	6	9	5
IRAT9 (susceptible)	4	6	9	7

[a]SES 0-9 scale: 0 = no visible effects of soil moisture stress, 9 = all plants apparently dead. [b]SES 1-9 scale: 1 = 90-100% plants fully recovered, 9 = 0-19% plants fully recovered.

breeding lines from the upland and lowland nurseries, and the African species *O. glaberrima* were screened for field resistance to drought under simulated upland culture (Table 3).

The 419 entries from the GB had been selected for multiple resistance to various biotic or edaphic stresses; about 29% of them showed a high level of drought resistance (drought score of 1-4) at the vegetative stage, and about 18% were resistant at the reproductive stage.

Among upland breeding lines, about 73% showed drought resistance at the vegetative stage

Table 3. Field screening for drought resistance under upland conditions. IRRI, 1985 DS.

Nursery	Total no. tested	Plants (no.) showing a given drought score[a]								
		1	2	3	4	5	6	7	8	9
					Vegetative stage					
Germplasm bank accessions	419		1	32	90	171	102	23		
Breeding lines from upland nurseries	974	80	101	309	217	176	59	32		
Breeding lines from shallow-rainfed and medium-deep water nurseries	1209		4	144	242	383	265	171		
Breeding lines from deep water nurseries	1007	5	10	71	132	345	285	157		2
GEU elite lines	53				5	20	23	5		
Lines tested for abscisic acid (ABA) content	86		10	32	29	14	1			
O. glaberrima strains	329	46	61	154	49	16	1	2		
					Reproductive stage					
Germplasm bank accessions	234	8		32	1	40	1	72		80
Breeding lines from upland nurseries	810	11		104		126		187		382
Breeding lines from shallow-rainfed and medium-deep water nurseries	397			3		20		99		275
Breeding lines from deep water nurseries	212							12		200
GEU elite lines	31					6		5		20
Lines tested for ABA content	75			1		5		5		64
O. glaberrima strains	501	23		73		181		101		123

[a]Drought resistance scores: 1 = resistant, 9 = susceptible.

and about 14% at the reproductive stage. The 115 lines showing a drought score of 1-3 at the reproductive stage had been selected in earlier seasons for deep and thick roots in the F_5 generation. The deep-and-thick root component of the avoidance mechanism was verified during the drought that prevailed in the wet season (WS). Most of the lines also showed good recovery, which led to good grain filling.

From the shallow-rainfed and medium-deep water nurseries, 32% showed drought resistance at the vegetative stage; of those, only 3 lines were resistant at the reproductive stage: IR37135-14-1-3-1, IR40860-31-6-3, and IR43553-20.

Twenty-two percent of the breeding lines from the deep water nurseries showed high levels of drought resistance at the vegetative stage. No lines were identified as resistant at the reproductive stage.

Lines analyzed for abscisic acid content by the Plant Breeding Institute in England were found to range from resistant to intermediate in drought score at the vegetative stage but were mostly susceptible at the reproductive stage. Six lines that had drought scores of 3-5 were progeny of the cross IR20/63-83. 63-83 is a drought-resistant traditional upland variety from Africa. As in our past field screening, progenies with upland parentage usually showed high levels of drought resistance.

Most (94%) African cultivars (*O. glaberrima*) showed high levels of drought resistance at the vegetative stage. Most of the entries flowered early in dry season (DS) at about 50-60 d after seeding (DAS). About 19% showed drought resistance at the reproductive stage. Drought escape through early maturity seems to be the main contributory factor to drought resistance in this group.

Screening upland rice at reproductive stage (*Agronomy*). The 1985 DS screening of upland rice sought to identify varieties and lines with superior drought tolerance at the reproductive stage. It included 390 genotypes, most of which had been selected in 1984 for further testing.

Different maturity classes were seeded on different dates in an attempt to synchronize flowering. Water was applied by a whole-plot sprinkler

system; the irrigation amount was gradually increased from seeding to full canopy. Thereafter, irrigation was applied at a rate equivalent to 1.2 × pan evaporation except during a stress period from 26 Apr to 17 May, when no irrigation was applied. The stress period was originally scheduled for 14 d, but was extended to 21 d because of rain. Because in previous years, visually estimated spikelet fertility correlated well with actual fertility and with grain yield, spikelet fertility was estimated visually for each plot as the only measure of drought tolerance.

Despite staggered seeding, flowering dates of different genotypes spanned the entire stress period. Although there was no significant relationship between days to flowering after stress onset and spikelet fertility (Table 4), only genotypes that flowered from 10 to 21 d after beginning the stress (90 varieties and lines) were compared. Genotypes that flowered during the first 9 d of the stress period were excluded to ensure that spikelet fertility indicated drought tolerance, not drought escape.

1985 upland observational nurseries (*International Rice Testing Program*). Results from the 1984 IRTP upland observational nurseries indicated the genotypes listed below to be promising for drought tolerance or recovery.

Drought tolerance

ARC10372	IRAT146	TOx1785
IRAT104	IR1973 -5-2-3-2-1	
IRAT131	IR25890 -82-5-3	

Drought recovery

IRAT131	IR9729-67-3	NDR111
IRAT134	IR13240-10-1	NDR119
IRAT141	IR25924-51-2-3	PLA1100
IR50	IR28128-45-2	
IR146	IR28143-51-3-3-1	

More detailed results appear in the IRTP part of the Cooperative Programs section.

SOIL-PLANT WATER RELATIONSHIPS

Agronomy Department and International Rice Germplasm Center

Drought tolerance under limited rooting depth (*Agronomy*). A total of 105 GEU elite and selected lines were screened in the greenhouse for drought tolerance at limited rooting depth (45 cm) and for the ability to recover from drought stress.

Table 4. Spikelet fertility of top 15 genotypes that flowered from 10 to 21 d after onset of drought stress treatment. IRRI, 1985 DS.

Variety or line	Spikelet fertility (%)	Flowering (d after stress onset)
Sein Ta Lay	43	13
IR9560-2-6-3-1	37	15
IR7807-9-1-2-8	37	15
IR12721-24-3-1	30	18
B2992B-TB-73-4-2-3-3-3-2	30	17
B3622E-TB-5-4-4	30	14
B2433B-KN-10-1-1-1	30	12
IRAT140	30	10
IR7835-28-2-3 (B)	27	14
IR7812-16-1-4-9	27	14
IR10110-4-1	27	12
IR3880-10	27	11
B3623G-TB-41	23	18
IR7790-18-1-2-5	23	16
SYE3226-43-5	23	16

The rices, including the drought-tolerant check Leb Mue Nahng, were seeded in dry soil in steel drums and watered regularly up to 30 DAS. Then water was withheld and the soil allowed to dry by evapotranspiration. When Leb Mue Nahng was apparently dead, plants were scored for drought tolerance and then rewatered.

Table 5 shows some of the entries that performed better than Leb Mue Nahng. In DS, IR25588-7-3-1 and IR29658-43-3-2-1 recovered well, as did RD19 and IR21015-196-3-1-3 in WS. Although IR30812-B-3-B-1-1 and IR29723-143-3-2-1 appeared dead, they were able to recover. Leb Mue Nahng did not recover.

The promising entries may be used for breeding rices for rainfed lowland and upland culture where rooting depths are restricted.

Micronutrient uptake by lowland rice under drought stress (*Agronomy*). A field study in 1984 DS determined the effects of drought on growth and nutrient accumulation and distribution among plant parts of rice at different growth stages. Drought effects on macronutrient uptake and distribution were reported last year; effects on micronutrient uptake are reported here.

IR54 was grown in a lowland field with the water level maintained at 3-4 cm except during treatment,

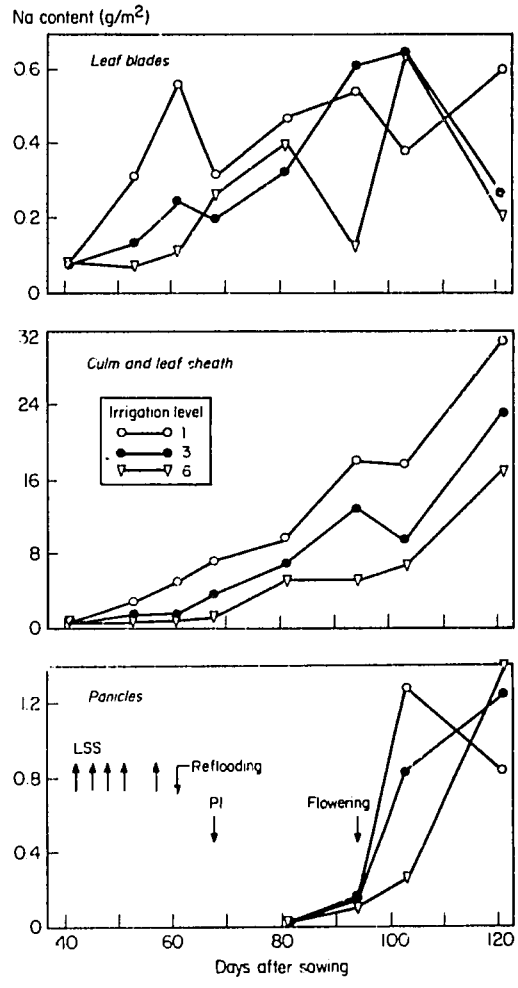
Table 5. Drought tolerance ratings of promising entries during the vegetative phase and recovery of entries after relief from stress. IRRI greenhouse, 1985.

Variety or line	Drought tolerance rating[a]	Tillers (%) that recovered 7 d after stress was relieved
	Dry season	
IR25588-7-3-1	6	86
IR29658-43-3-2-1	7	75
IR28150-84-3-3-2	7	44
RD19	6	39
IR12665-7-1-3-6	7	31
UPLRi-7	7	30
IR30812-B-3-B-1-1	9	26
IR29723-143-3-2-1	9	26
B2997C-Tb-8-1	7	10
Leb Mue Nahng	9	0
	Wet season	
RD19	6	63
IR21015-196-3-1-3	7	62
IR9669 Sel.	7	44
IR30686-B-2-B-6-3	7	38
IR30707-B-1-B-5-1	7	23
B44b-50-2-2-2-5-1	7	18
IR9782-111-2-1-2	7	18
B2997C-Tb-8-1	7	16
IR28228-119-2-3-1-1	7	15
Leb Mue Nahng	9	0

[a]By the SES 0-9 scale: 0 = no visible effects, 9 = all plants apparently dead.

when the crop was subjected to 6 irrigation levels using a line source sprinkler (LSS). The treatment period was 42-61 DAS. Position 1 was continuously flooded, while positions 2-6 were drained prior to and reflooded after treatment. Results from LSS levels 1, 3, and 6 were used to summarize the treatments. Total irrigation applied to the three levels during the treatment period was 89, 54, and 0 mm, respectively. About 10 mm of rain fell and 90 mm of pan evaporation occurred during treatment.

Micronutrient content of the crop components throughout the experiment (Figs. 1-7) reflects the effects of drought on both dry matter assimilation and micronutrient concentration in crop tissues (Table 6). Although micronutrient concentration in crop tissues was more strongly affected during the treatment period, treatment effects on micronutrient content were observed until harvest, largely through treatment period effects on crop growth.



1. Na content of various parts of IR54 at 3 irrigation levels. IRRI, 1985. LSS = line source sprinkler, PI = panicle initiation.

Of all micronutrients studied, Mn concentration responded most strongly to the irrigation treatments after stress had been relieved. Since tissue Mn concentrations were inversely related to water availability, there was no treatment effect on the Mn content of panicles.

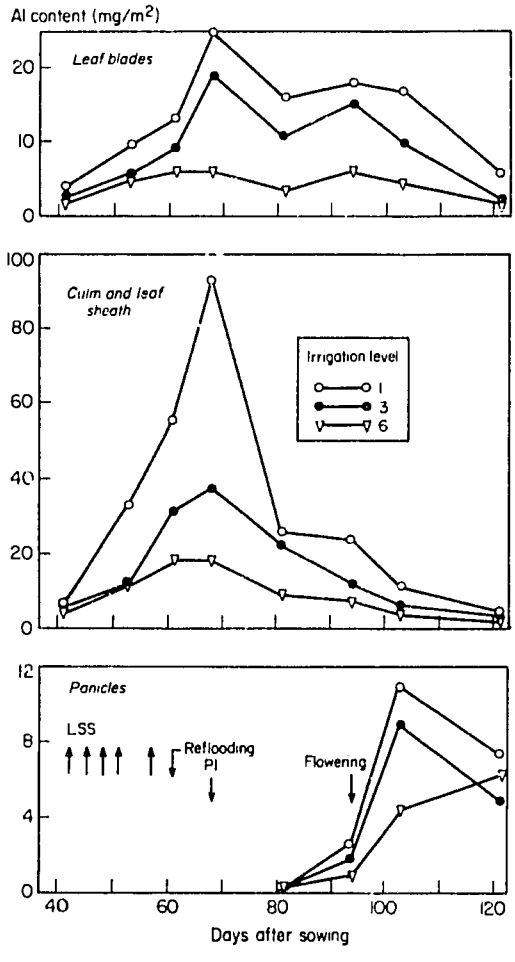
The only anion among the micronutrients studied was B, which showed the anomalous response of decreased concentration in culms and leaf sheaths but increased concentration in leaf blades under water deficit.

Although water deficit affected micronutrient concentrations and contents, under no irrigation treatment were either deficiency or toxicity symptoms observed.

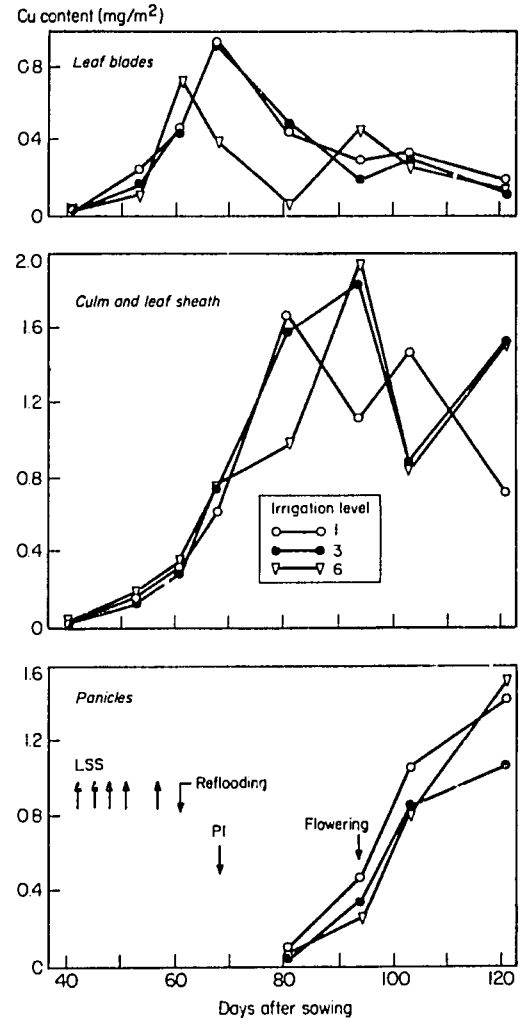
Varietal differences in root characteristics (*Agronomy, IRGC*). Based on the Poiseuille-Hagen equation for resistance to water flow in capillaries, the number and diameter of xylem vessels may limit water uptake by rice roots. The greater the number and diameter of xylem vessels in roots, the lower the axial resistance to water flow, because axial resistance is inversely proportional to total cross-sectional area for water flow. This relationship is important if plants are to extract available water at greater soil depths during drought.

To determine genotypic variability, a greenhouse experiment was conducted to examine the number and diameter of metaxylem vessels in the roots of well-watered (control) and drought stressed rice plants, and the distribution of vertical primary roots (root axes) at different soil depths. Four upland (63-83, IAC25, Azucena, MI-48) and 2 lowland (IR36, IR20) cultivars were grown in root boxes (20 × 20 × 90 cm) under aerobic conditions. N, P, and K were applied at 60-30-30 kg/ha. Control and stress treatments received identical amounts of water until 37 DAS, after which water was withheld from the stress treatment for 16-22 d. Destructive plant sampling was done on 3 separate days for the 3 replications.

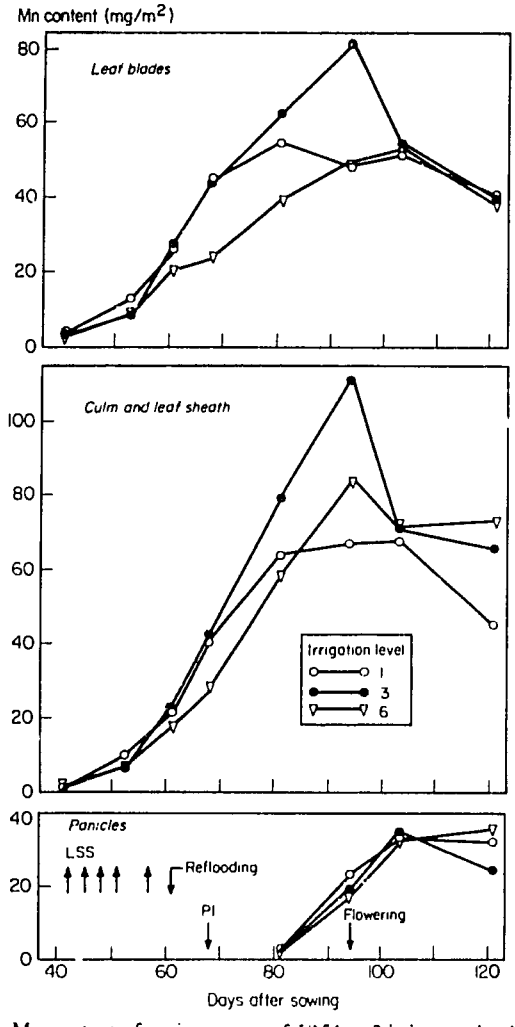
Upland cultivars had more and larger metaxylem vessels than lowland cultivars (Table 7). The total cross-sectional area of the metaxylem vessels



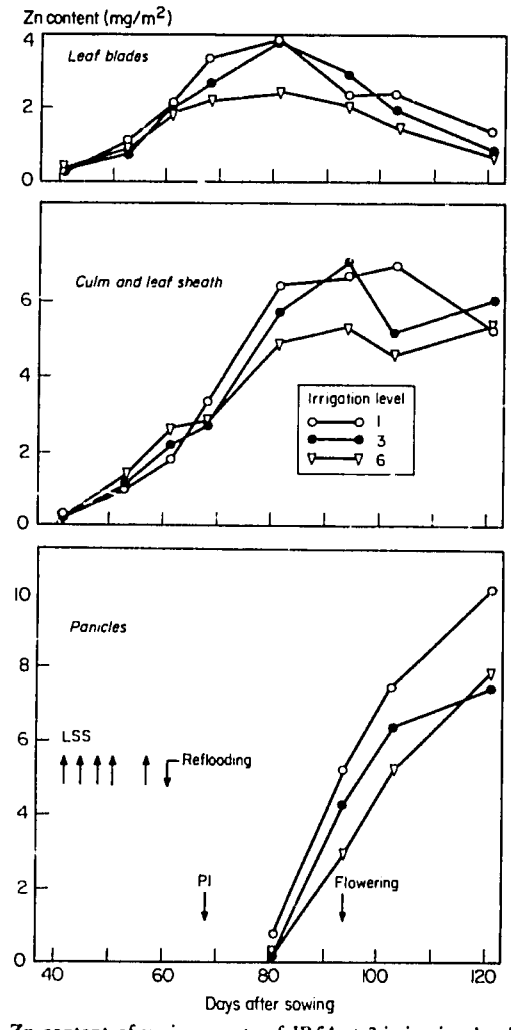
2. Al content of various parts of IR54 at 3 irrigation levels. IRRI, 1985.



3. Cu content of various parts of IR54 at 3 irrigation levels. IRRI, 1985.



4. Mn content of various parts of IR54 at 3 irrigation levels. IRRI, 1985.

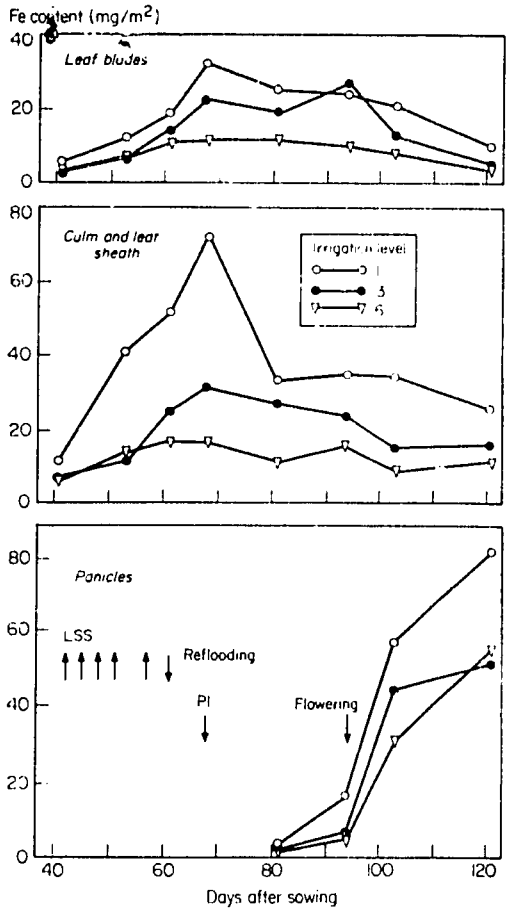


5. Zn content of various parts of IR54 at 3 irrigation levels. IRRI, 1985.

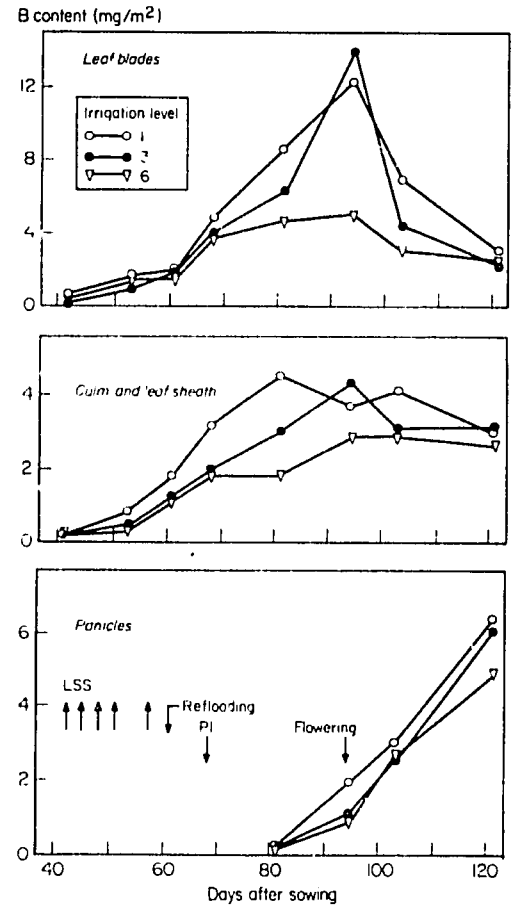
Table 6. Direction of relationship between water availability during stress and nutrient concentration in rice tissues. IRRI, 1985.

Nutrient	Relationship[a]				
	During stress		After stress		
	Blade	Culm + sheath	Blade	Culm + sheath	Panicle
Na	+	+	0	+	0
Al	+	+	+ (weak)	0	+ (weak)
Fe	0	+	0	0	0
Cu	0	– (weak)	0	0	0
B	–	+	0	0	0
Zn	– (weak)	–	0	0	0
Mn	– (weak)	– (weak)	–	–	–

[a]+, –, 0, respectively indicate positive, negative, or no relationship.



6. Fe content of various parts of IR54 at 3 irrigation levels. IRRI, 1985.



7. B content of various parts of IR54 at 3 irrigation levels. IRRI, 1985.

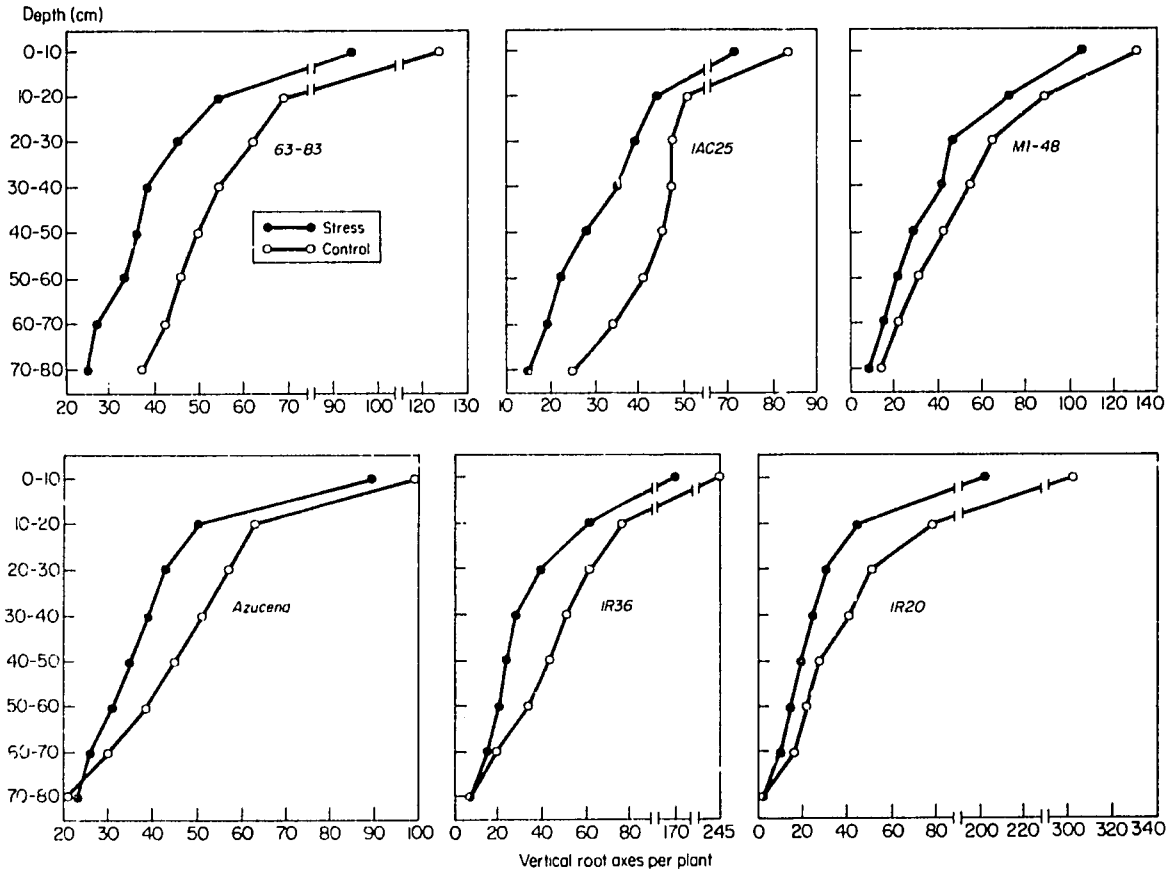
of lowland cultivars in the upper 10 cm of soil was smaller than that of the upland cultivars. These root characters were not significantly affected by drought stress. Greater numbers of vertical root axes were observed in lowland cultivars in the upper 20 cm of the soil profile, but below 40 cm, upland cultivars had more root axes (Fig. 8). Drought stress significantly reduced the number of vertical root axes at all depths except in IR20, IR36, and Azucena below 70 cm depth.

Varieties differed in number and diameter of root metaxylem vessels and number of vertical root axes. By manipulating or selecting for greater number of deep roots with large xylem vessels, a variety may be developed that is better adapted to areas where water is available at greater soil depths. Further study is in progress to determine

Table 7. Number, radius, and total cross-sectional area of metaxylem vessels of the primary roots of rice in the upper 10 cm of soil.[a] IRRI, 1985.

Variety	Av no. of metaxylem vessels per root	Mean radius (μm) of metaxylem vessels	Total cross-sectional area (mm^2) of metaxylem vessels/plant
63-83	6.8	31.0	2.20
IAC25	7.2	32.0	1.77
Azucena	6.2	30.5	1.69
Mi-48	6.7	28.0	1.94
IR36	4.7	21.1	1.41
IR20	4.3	20.5	1.21
LSD (0.05)	0.5	1.7	0.44
CV (%)	0.3	3.6	21.3

[a]Each value is the mean of 6 replications. Control and stress treatments were not significantly different; hence, they were combined.



8. Distribution of vertical root axes of 6 rice cultivars at different soil depths. IRRI greenhouse, 1985 WS.

the effects of these root characters on water uptake and plant water status.

In related continuing studies of root characters, it was shown that Marichbati — an aus variety — and three hill rices — Jhum Kamarang, Jhum Sonalichikon, and Mijingem — which all have high levels of drought resistance, have high xylem vessel number and xylem vessel area. These characters may increase the conductance of water and nutrients from the soil to the above-ground parts.

Infrared screening of lowland rice for drought tolerance (*Agronomy*). Over the past few years, IRRI has evaluated the usefulness of remotely sensed canopy temperature (*Tc*) measured with a hand-held infrared thermometer (IRT), crop water stress index (CWSI) computed from wet and dry bulb temperatures, net radiation, and canopy-air temperature differential (*Tc-Ta*). The ability of these IRT-based measurements to screen for drought tolerance was compared with visual scoring using 100 entries from GEU elite breeding lines, and best genotypes from 1983 trials and IRRI breeding programs.

The genotypes were seeded on 20 Jan 1984 and transplanted on 10 Feb to 1- × 1.2-m plots in a lowland clay soil (Andaqueptic Haplaquoll). Plots were kept flooded for the first 56 d after transplanting and then drained. *Tc*, *Tc-Ta*, CWSI, and visual drought scores were taken on 16 Apr 1984 — 27 d after drainage — between 0900 and 1500 h.

Genotype was a significant source of variation for all screening methods (Table 8). Visual drought scores ranged from 2 to 8, indicating that all genotypes were under at least a mild stress. For all genotypes, *Tc-Ta* was positive, further indication that they were under stress.

Among the 16 most drought-resistant genotypes for each screening method, 9 were common to all methods (Table 9). Although all screening techniques were significantly correlated with one

Table 8. Analysis of variance for IRT-based and visual drought tolerance screening methods.[a] 1984 DS.

Screening method[b]	Observed F		Grand mean	SD	CV (%)	Number of DMRT groupings
	Blocks	Genotypes				
IRT-based						
Tc (°C)	46.25**	2.47**	35.50	0.86	3	15
Tc-Ta (°C)	40.58**	2.40**	2.48	0.84	44	18
CWSI	58.31**	2.34**	0.74	0.10	17	15
Visual						
Scorer A	1.84[ns]	5.26**	5.19	1.02	17	13
Scorer B	16.42**	4.08**	4.49	0.80	17	11

[a]Av of 4 replications. [b]IRT = infrared thermoter, Tc = canopy temperature, Tc-Ta = canopy-to-air temperature differential, CWSI = crop water stress index.

Table 9. Correlation coefficients for 4 screening methods. 1984.

Screening method[a]	*Tc* (°C)	*Tc-Ta* (°C)	CWSI	Scorer A	Scorer B
Tc (°C)	1.0000				
Tc-Ta (°C)	0.9978**	1.0000			
CWSI	0.9980**	0.9993**	1.0000		
Scorer A	0.5925**	0.5961**	0.5992**	1.0000	
Scorer B	0.6300**	0.6315**	0.6323**	0.9000**	1.000

[a]Acronyms are explained in the footnote to Table 8.

another (Table 10), the IRT-based measurements gave more Duncan's multiple range test groupings than did visual scoring (Table 8).

The results suggest that IRT techniques provide greater resolution among genotypes than visual scoring, especially when screening under mild water deficit. Of all methods evaluated, CWSI has the interpretive advantage of being most closely linked to water use. On the practical side, visual scoring is simpler and more rapid than IRT-based scores, but IRT-based scores, particularly CWSI, offer much greater ability to interpret drought resistance and to evaluate the physiological effects of drought stress.

Management for drought tolerance (*Agronomy*). Three rice varieties (IRAT104, IRAT9, and IR20) and two levels of organic metabolism modifiers were used in a greenhouse experiment on plant-water relations and rice response to drought under two moisture regimes. Soil moisture treatments were 1) continuously flooded and 2) automatically irrigated to maintain SMT from 0.075 to 0.100 MPa. A foliar spray of 0 (C0 [control]) and 60 ppm (C60) solution of equimolar salicylic-sulfosalicylic acid (SSAc) was applied weekly from 28 DAS until flowering. Although the mode of action of SSAc has not been elucidated, it apparently acts as a protein stabilizer to help maintain membrane stability during stress.

Table 10. Promising genotypes[a] and their drought tolerance scores. IRRI, 1984 DS.

Genotype[a]	Visual score[b]	*Tc*[c] (°C)	*Tc–Ta*[d] (°C)	CWSI[e]
IR13365-253-3	3.25	34.9	1.8	0.67
IR24761-35-3	3.50	34.0	0.9	0.57
IR48	3.50	34.0	0.9	0.56
IR29723-143-3-2-1	3.50	34.3	1.2	0.60
IR8192-200-3-3-1-1	3.75	34.4	1.4	0.61
IR12979-24-1	4.00	34.6	1.6	0.65
IR28150-84-3-3-2	4.00	34.8	1.8	0.66
IR19661-131-1-3-1-3	4.00	34.0	1.0	0.58
IR13540-56-3-2-1	4.25	34.7	1.6	0.65

[a]The 9 were among the 16 most drought tolerant genotypes for all screening methods used. [b]Based on SES scale 1-9: 1 = no visible effects, 9 = all plants apparently dead. [c]The cooler the canopy, the greater the drought tolerance; thus, *Tc* is inversely related to drought tolerance. [d]The smaller the *Tc–Ta*, the greater the drought tolerance. [e]Crop water stress index based on a 0.00 to 1.00 scale: 0.00 = most drought tolerant, 1.00 = least drought tolerant.

Table 11. Effects of SSAc and soil moisture regime on water consumptive use coefficient, Kc, at the reproductive stage. IRRI greenhouse, 1985 WS.

Variety	Water consumptive use coefficient (Kc)[a]					
	Continuously flooded			Water stressed[c]		
	C0	C60	Δ%[b]	C0	C60	Δ%[b]
IRAT104	0.90	0.80	−11	0.40	0.44	+10
IRAT9	0.80	0.77	− 4	0.47	0.54	+15
IR20	0.97	0.86	−11	0.47	0.48	+ 2
$\bar{X}$[d]	0.89 a	0.81 a		0.45 b	0.49 b	

[a]Kc = evapotranspiration divided by potential evapotranspiration. [b]Δ% = 100 (C60−C0) divided by C0. [c]0.075-0.10 MPa matric suction. [d]In the row, means followed by the same letter are not significantly different by DMRT at the 5% level.

Table 12. Effects of SSAc and soil moisture regime on root dry weight at harvest. IRRI greenhouse, 1985 WS.

Variety	Root dry weight (g/pot)					
	Continuously flooded			Water stressed[a]		
	C0	C60	Δ%[b]	C0	C60	Δ%[b]
IRAT104	37	31	−16	23	29	+26*
IRAT9	18	21	+17	16	24	+57*
IR20	28	26	− 8	20	21	+ 7
$\bar{X}$[c]	28 a	26 a		19.4 b	25 a	

[a]0.075-0.10 MPa matric suction. [b]Δ% = 100 (C60−C0) divided by C0. [c]In the row, means followed by the same letter are not significantly different by DMRT at the 5% level.

Effect on water use coefficient. The ratio of actual to potential evapotranspiration is the water use coefficient (Kc). In all varieties, SSAc slightly decreased Kc in continuously flooded soil but produced contrary effects under the drought stress treatment. Differences between C0 and C60 in both moisture regimes, however, were not significant (Table 11).

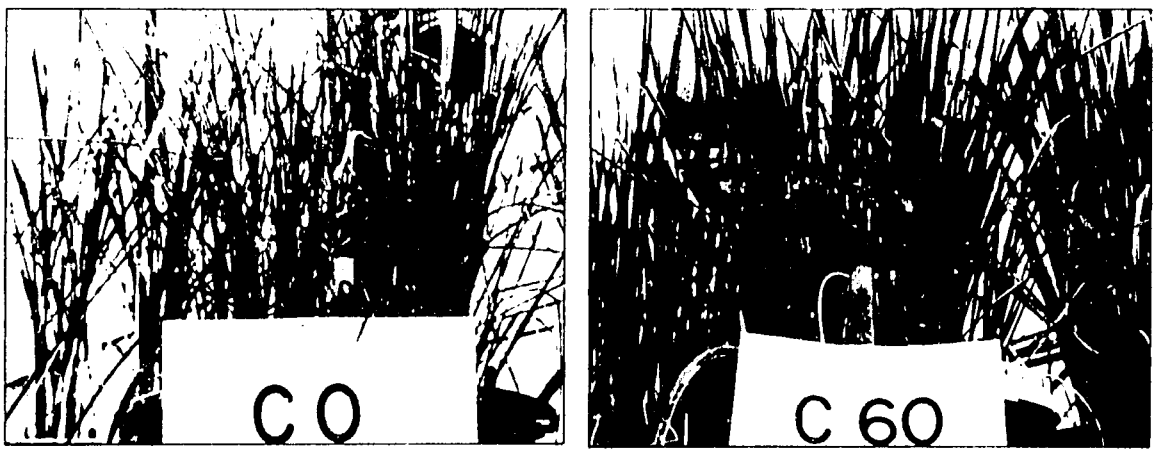
Root, shoot, and leaf water status. SSAc had more effect on root than shoot weight. The effect of C0 and C60 differed among varieties and soil moisture regimes (Table 12). The root ratio (stress to no stress) was only 0.70 in C0, compared with 0.97 in C60.

C60 plants maintained higher leaf water potential at low soil matric potential and high evaporative demand than C0 plants. C60 plants therefore suffered relatively less stress (Fig. 9). Leaf water retention was also positively affected by C60, although the varieties did not respond equally (Fig. 10). Moreover, C60 plants had lower leaf diffusive resistance at low leaf water potential than did C0 plants (Fig 11). Despite its effects on plant water status, SSAc seemed not to affect shoot dry weight (Table 13).

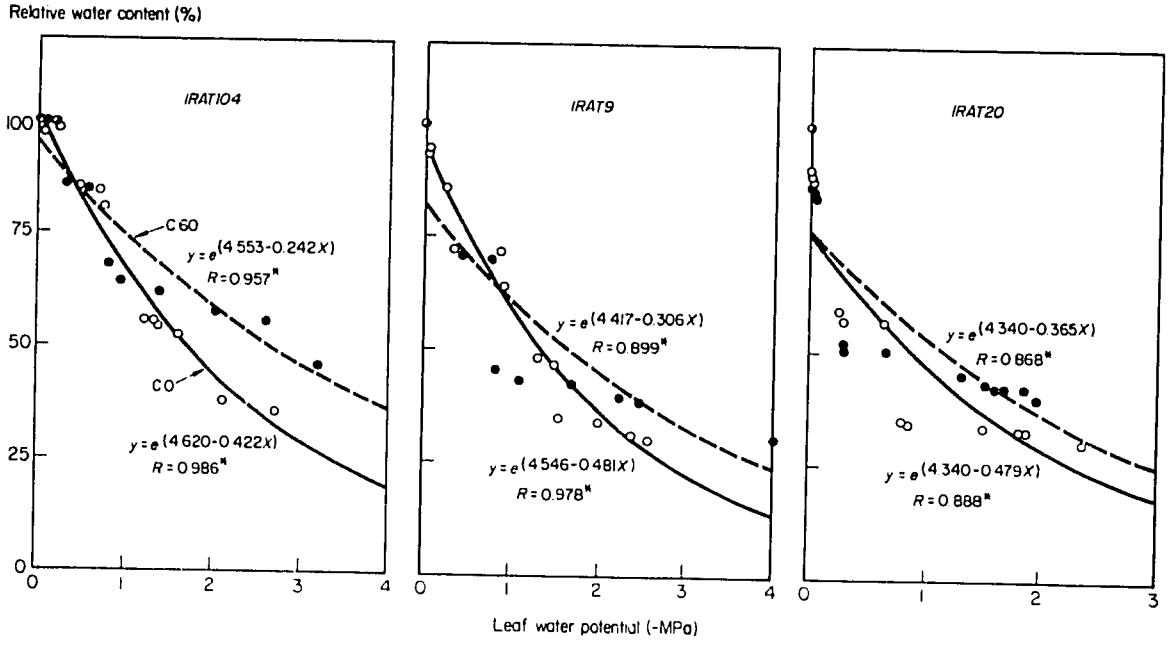
Grain yield. The effect of SSAc on grain yield followed the trend described for root weight and plant water status but was opposed to leaf diffusive resistance as in the following model:

$$Y = 67.90 + 1.13X_1 - 35.89X_2$$

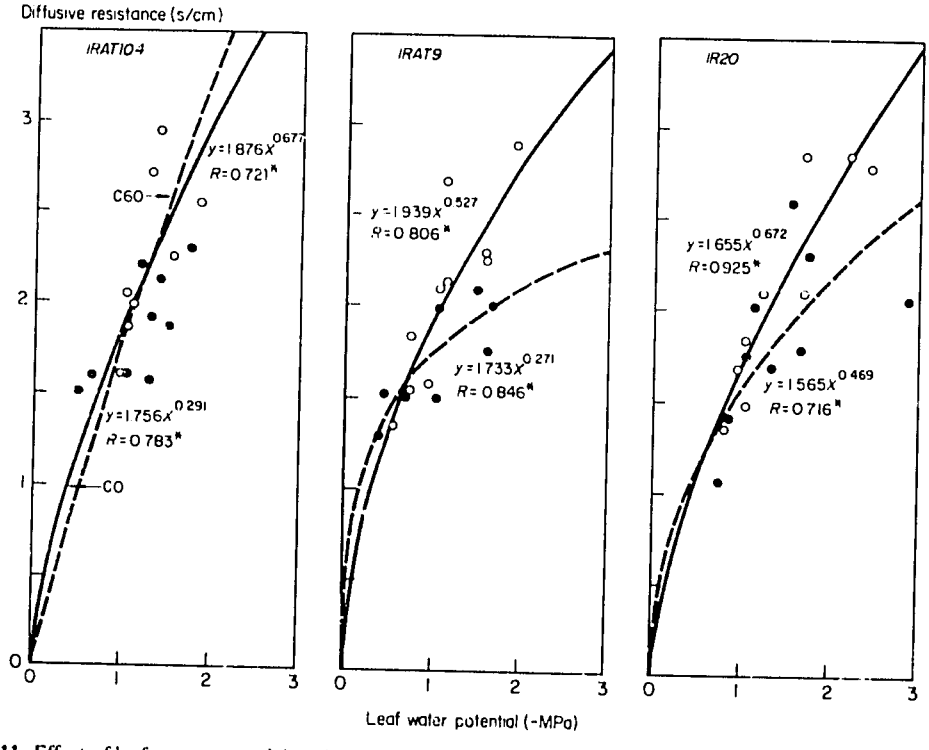
$$(R_{Y.12} = 0.520,\ N = 36)$$



9. Effect of organic metabolism modifier on the frequency and intensity of wilting (C0 = 0, C60 = 60 ppm of equimolar salicylic-sulfosalicylic acid mixture). IRRI greenhouse, 1985 WS.



10. Leaf water characteristics curve of 3 rice varieties at 2 organic modifier levels (C0 = 0, C60 = 60 ppm of equimolar salicylic-sulfosalicylic acid mixture). IRRI greenhouse, 1985 WS.



11. Effect of leaf water potential on leaf diffusive resistance of 3 rice varieties at 2 organic modifier levels (C0 = 0, C60 = 60 ppm of equimolar salicylic-sulfosalicylic acid mixture). IRRI greenhouse. 1985 WS.

Table 13. Effects of SSAc and soil moisture regime on shoot dry weight at harvest. IRRI greenhouse, 1985 WS.

Variety	Shoot dry weight (g/pot)					
	Continuously flooded			Water stressed[a]		
	C0	C60	Δ%[b]	C0	C60	Δ%[b]
IRAT104	100	91	- 9	41	48	+16
IRAT9	75	83	+10	57	53	- 7
IR20	92	84	- 9	53	56	+ 5
$\bar{X}$[c]	89 a	86 a		50 b	52 b	

[a]0.075-0.10 MPa matric suction. [b]Δ% = 100 (C60–C0) divided by C0. [c]In the row, means followed by the same letter are not significantly different by DMRT at the 5% level.

Table 14. Effect of SSAc and soil moisture regime on grain yield. IRRI, 1985 WS.

Variety	Grain yield (g/pot)					
	Continuously flooded			Water stressed[a]		
	C0	C60	Δ%[b]	C0	C60	Δ%[b]
IRAT104	47	46	-2	1	4	+206*
IRAT9	55	54	-2	5	11	+ 98*
IR20	48	50	+4	4	7	+ 46
$\bar{X}$[c]	50 a	50 a		4 c	7 b	

[a]0.075-0.10 MPa matric suction. [b]Δ% = 100 (C60–C0) divided by C0. [c]In the row, means followed by the same letter are not significantly different by DMRT at the 5% level.

where Y = grain yield (g/pot), X_1 = root dry weight (g/pot), and X_2 = leaf diffusive resistance (s/cm).

Grain production under drought stress was 40% of that under continuous flooding, irrespective of variety or SSAc treatment. Nevertheless, SSAc supported yield recovery varying from 46% in IR20 to 206% in IRAT104 (Table 14).

Although SSAc application did not significantly affect water use efficiency in the tested varieties, it lowered the threshold water consumption for grain production.

Genetic evaluation and utilization (GEU)

Adverse soils tolerance

Plant Physiology, Plant Breeding, and Soil Chemistry/ Physics Departments

SCREENING FOR SALINITY TOLERANCE **82**
Rice cultivars **82**
Variants from tissue culture **82**
EFFECT OF NUTRIENT CONCENTRATION AND pH ON SALT TOLERANCE **83**
GENETICS OF SALT TOLERANCE **85**
PHYSIOLOGICAL STUDIES OF BORON TOXICITY **85**
Effect of boron on growth and yield **85**
Effect of nitrogen on boron concentration **86**
RESPONSE TO ALUMINUM **87**
Graded nutrient levels **87**
Seedling age **88**
SCREENING FOR ALUMINUM TOXICITY TOLERANCE **88**
Traditional varieties from northeast India **88**
Deep water rices from Vietnam **88**
Absolute root length as a criterion **89**
INHERITANCE OF PHOSPHORUS UTILIZATION EFFICIENCY **89**
SCREENING FOR ADVERSE SOIL TOLERANCE **90**

SCREENING FOR SALINITY TOLERANCE

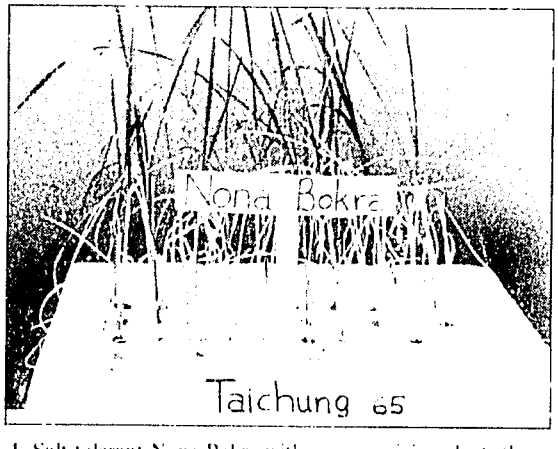
Plant Physiology Department

Rice cultivars. The screening technique for selection of salt-tolerant varieties and variants regenerated by tissue culture (Annual report for 1981) was modified in 1983 by using, instead of the Koito KG growth cabinet, the phytotron glasshouse maintained at 29/21 °C (day/night), 0900-1700 day hours, 1700-0900 night hours, about 70% relative humidity (RH), and natural light intensity.

One-week-old (3-leaf stage) seedlings were transplanted to a styrofoam board with 60 holes; 30 seedlings of the same variety were transplanted to 30 holes and designated as one replication. The plants were grown in standard culture solution and left overnight. The next day, they were transferred to standard culture solution plus 0.5% NaCl. Electrical conductivity of the solution was about 10.5 dS/m. Susceptible variety Taichung 65 and salt-tolerant Nona Bokra were included in every set (Fig. 1).

After 3 d of salinization, plants began to die. A plant was judged dead when more than 90% of the leaf area of the youngest leaf blade had become necrotic and dry. The dead plants were counted when only 3 of 30 plants survived in the Taichung 65 check. A scoring system based on percent seedling survival was devised: more than 60% survival was rated resistant, 31-60% moderately resistant, and 0-30% susceptible.

In 1983, 70 cultivars were tested for salinity tolerance. Rated resistant were Nona Bokra, IR4595-4-1-13, KR1-24, and BR 4-10 (Table 1). In 1985, 23 entries from the International Rice Salinity Tolerance Yield Nursery were screened for salinity tolerance, and IR4595-4-1-13 was again rated as resistant.



1. Salt-tolerant Nona Bokra with more surviving plants than salt-susceptible Taichung 65. IRRI, 1984.

Table 1. Screening for salinity tolerance. IRRI, 1983.

Variety or line	Survival (%) after salinization	Score	Tolerance rating[a]
Nona Bokra	92	1	R
IR4595-4-1-13	78	2	R
KR1-24	72	2	R
BR4-10	63	3	R
ADT4	57	4	MR
Kalarata	57	4	MR
Khao Gao Diao	51	4	MR
MK47-22	51	4	MR
ADT28	43	5	MR
IR3858-6	41	5	MR
Khao Tah Haeng 17	43	5	MR
SP3-9	49	5	MR
Bir Ta Pan	32	6	MR
Daeng Noi	40	6	MR
Khao Tah Haeng	38	6	MR
Moroberekan	37	6	MR
SR26 B	36	6	MR

[a]R = resistant, MR = moderately resistant.

Variants from tissue culture. Tissue culture is a technique that can generate a wide range of salt tolerance. In 1981, plants were regenerated from Taichung 65, Fujisaka 5, Reiho, and Nona Bokra through somatic cell culture. Of 526 R_1 lines of japonica variants tested, 725 R_2 seedlings were selected and treated as individual lines. Screening of R_3 plants produced 17 variants that were moderately tolerant of salinity. Further selection of the R_4 showed 13 of 120 variants moderately tolerant. In the R_5, 6 of 33 variants showed moderate tolerance. Although the percentage of variants with moderate tolerance for salinity increased with advancing generation, the variants still segregated in the R_5.

In the 1984 wet season (WS), an observational nursery was set up at IRRI. Seeds from 1,720 regenerated plants of Nona Bokra were planted at 100 seedlings/line and grown to maturity. Two hundred eighty-two variants were found semidwarf to intermediate in plant height, with erect leaves and compact tillering. The variants were planted in the 1985 dry season at IRRI; three R_3 lines were observed to be homozygous for compact

2. Nona Bokra variant NB III 10-5-2-2 L with erect leaves and compact tillers in contrast with the open type exhibited by the parent. IRRI, 1984, December seeding.

tillers and erect leaves in contrast to the open type characteristic of the parent Nona Bokra (Fig. 2). When the three lines were tested using the method previously described, they were found susceptible (Table 2). It appears that, although the plant type of Nona Bokra was improved by tissue culture, its tolerance for salinity was altered, giving rise to susceptible plants in the R_4. Further improvement must be done on the generation of variants at the cellular level to produce plants with stable and heritable tolerance for salinity.

EFFECT OF NUTRIENT CONCENTRATION AND pH ON SALT TOLERANCE

Plant Physiology Department

Pregerminated seeds of 18 rice varieties were grown in full and 20% nutrient concentrations at 2 pH levels — pH 5 and pH 9. The composition of culture solution was prepared following Yoshida's recommendation, except that Fe-EDTA was substituted for $FeCl_3 \cdot 6H_2O$. The solutions were salinized from just after germination using 2 EC levels — 5 and 10 dS/m. The plants were kept in the phytotron glasshouse at 29/21 °C and 70% RH, and harvested at 3 wk after seeding (WAS).

At various levels of EC, pH, and nutrients, the response of varieties to salt changed significantly, as shown by relative growth (total dry weight in salinized solution relative to that of the control) (Table 3, 4). Pokkali was found to be the most tolerant: its growth was least affected by changes in EC, pH, and nutrient concentration.

When the wide adaptability to salt at EC 5 and 10 dS/m was evaluated, Pokkali ranked first, followed by Taichung 65, KRI-24, and Nona Bokra (Table 5). At 5 dS/m, Salumpikit showed the highest tolerance in full nutrient at pH 5; M242 and ADT28 showed higher tolerance at pH 5 both in full and in 20% nutrient. At 10 dS/m, M242 and ADT28 showed higher tolerance only in full nutrient solution at pH 5, while most IRRI varieties showed comparatively higher tolerance only in 20% nutrient. Some varieties tolerant at 10 dS/m such as Nona Bokra and KRI-24 showed lower tolerance at 5 dS/m. Taichung 65 had been classified as susceptible by the previous method, but it showed remarkable tolerance when evaluated by relative growth. Nona Bokra exhibited marked root growth reduction in 20% nutrient concentration at pH 5 and pH 9 (Table 6). The order of varietal tolerance for salt was greatly affected by pH and nutrient concentration. The mechanism for salt tolerance might differ among varieties.

Table 2. Plant height, maturity, and salinity tolerance of Nona Bokra R_3 variants compared with the parent, IRRI, 1984, December seeding.

Parent or variant	Height (cm)	Days to maturity	Salinity tolerance[a]
Nona Bokra	114	109	R
NB III 10-5-2-2L	123	135	S
NB III 19-12-1-2H	113	135	S
NB IV 10-3-1B	108	135	S

[a]R = resistant, S = susceptible.

Table 3. Relative growth of varieties at EC 5 dS/m at 2 pH and 2 nutrient levels. IRRI, 1985.

Rank[a]	Relative growth							
	pH 5				pH 9			
	Full nutrient		20% nutrient		Full nutrient		20% nutrient	
1	Salumpikit	1.12	Pokkali	1.00	KR1-24	0.83	Taichung 65	1.09
2	IR4595-4-1-13	1.07	ADT28	0.98	Taichung 65	0.77	IR4595-4-1-13	1.02
3	ADT28	0.96	BR4-10	0.84	Pokkali	0.75	Pokkali	0.92
4	Pokkali	0.95	Taichung 65	0.81	Getu	0.67	KR1-24	0.88
5	M242	0.95	M242	0.76	BR4-10	0.65	BR4-10	0.82
6	Getu	0.94	KR1-24	0.71	IR4595-4-1-13	0.60	M242	0.79
7	Nona Bokra	0.83	IR36	0.71	Salumpikit	0.57	Getu	0.74
8	BR4-10	0.76	Getu	0.69	M242	0.54	Nona Bokra	0.72
9	Bluebonnet 50	0.71	Nona Bokra	0.68	Nona Bokra	0.52	ADT28	0.70
10	Taichung 65	0.68	Bluebonnet 50	0.64	IR8	0.49	IR8	0.52
11	KR1-24	0.67	IR56	0.58	ADT28	0.46	Dawk Mali	0.43
12	IR8	0.66	IR4595-4-1-13	0.55	IR56	0.44	IR56	0.37
13	IR56	0.56	Dawk Mali	0.39	Bluebonnet 50	0.38	Bluebonnet 50	0.36
14	IR50	0.54	IR58	0.33	IR36	0.38	IR36	0.34
15	Dawk Mali	0.53	IR54	0.26	IR5	0.38	Salumpikit	0.34
16	IR5	0.52	IR50	0.24	IR54	0.37	IR50	0.24
17	IR54	0.47	IR5	0.20	IR50	0.36	IR54	0.23
18	IR36	0.46	Salumpikit	0.18	Dawk Mali	0.35	IR5	0.21
Av of 18 varieties		0.74		0.59		0.53		0.60

[a]According to tolerance for salt.

Table 4. Relative growth of varieties at EC 10 dS/m at 2 pH and 2 nutrient levels. IRRI, 1985.

Rank[a]	Relative growth							
	pH 5				pH 9			
	Full nutrient		20% nutrient		Full nutrient		20% nutrient	
1	Pokkali	0.69	Taichung 65	0.23	Pokkali	0.59	Taichung 65	0.10
2	M242	0.55	Pokkali	0.15	KR1-24	0.52	Pokkali	0.08
3	Taichung 65	0.39	Nona Bokra	0.14	Taichung 65	0.51	Nona Bokra	0.07
4	KR1-24	0.39	KR1-24	0.12	Nona Bokra	0.38	KR1-24	0.07
5	ADT28	0.35	IR4595-4-1-13	0.10	IR4595-4-1-13	0.30	IR54	0.07
6	Nona Bokra	0.34	IR54	0.09	BR4-10	0.24	IR8	0.07
7	Getu	0.31	BR4-10	0.08	Getu	0.18	BR4-10	0.06
8	IR4595-4-1-13	0.24	IR56	0.08	IR56	0.18	IR50	0.06
9	BR4-10	0.21	IR8	0.07	M242	0.16	IR5	0.06
10	IR36	0.21	IR50	0.07	Dawk Mali	0.15	Bluebonnet 50	0.06
11	IR8	0.19	Bluebonnet 50	0.06	IR54	0.14	Salumpikit	0.06
12	IR5	0.15	IR5	0.06	Bluebonnet 50	0.14	IR4595-4-1-13	0.05
13	Dawk Mali	0.12	IR36	0.06	IR8	0.13	Getu	0.05
14	IR54	0.11	Getu	0.06	IR5	0.12	ADT28	0.04
15	IR56	0.11	ADT28	0.06	ADT28	0.11	M242	0.04
16	Salumpikit	0.10	M242	0.05	IR50	0.10	IR36	0.04
17	Bluebonnet 50	0.09	Dawk Mali	0.05	Salumpikit	0.09	IR56	0.04
18	IR50	0.05	Salumpikit	0.04	IR36	0.08	Dawk Mali	0.04
Av of 18 varieties		0.26		0.09		0.23		0.06

[a]According to tolerance for salt.

Table 5. Ranking and adaptability of varieties by tolerance for salinity at EC 5 and 10 dS/m at 2 pH and 2 nutrient levels. IRRI, 1985.

Variety	Rank								Adaptability[a]		
	5 dS/m				10 dS/m						
	pH 5		pH 9		pH 5		pH 9		5 dS/m	10 dS/m	Both levels
	Full	20%	Full	20%	Full	20%	Full	20%			
Pokkali	4	1	3	3	1	2	1	2	11	6	17
Taichung 54	10	4	2	1	3	1	3	1	17	8	25
KR1-24	11	6	1	4	3	4	2	3	22	12	34
Nona Bokra	7	9	9	8	6	3	4	3	33	16	49
BR4-10	8	3	5	5	9	7	6	7	21	29	50
IR4595-4-1-13	2	12	6	2	8	5	5	12	22	30	52
Getu	6	8	4	7	7	11	7	12	25	37	62
M242	4	5	8	6	2	16	9	14	23	41	64
ADT28	3	2	11	9	5	11	15	14	25	45	70
IR8	12	14	10	10	11	9	13	3	46	36	82
Bluebonnet 50	9	10	13	13	17	11	11	7	45	46	91
IR56	13	11	12	12	14	7	7	14	48	42	90
Salumpikit	1	18	7	14	16	18	17	7	40	58	98
IR54	17	15	16	17	14	6	11	3	65	34	99
IR36	18	6	13	14	9	11	18	14	51	52	103
IR5	16	17	13	18	12	11	14	7	64	44	108
Dawk Mali	15	13	18	11	13	16	10	14	57	53	110
IR50	14	16	17	16	18	9	16	7	63	50	113

[a]Summation of ranking. Lower values indicate wider adaptability.

GENETICS OF SALT TOLERANCE

Plant Breeding Department

Salt tolerance studies were conducted under controlled conditions using solution and pot culture techniques. Varieties Nona Bokra and Pokkali (tolerant), Damodar and Jhona 349 (moderately tolerant), and IR28 and IR5657-33-2 (sensitive) were selected for genetic analysis of traits under salinization (EC 12 dS/m) at the seedling and reproductive stages.

Both additive and dominance effects were important in the inheritance of all the traits studied.

Table 6. Root growth of Nona Bokra at EC 5 dS/m in 20% nutrient concentration.[a] IRRI, 1985.

Variety	pH 5		pH 9	
	Root	Total	Root	Total
Nona Bokra	0.29 (43)	0.68	0.36 (50)	0.72
Av of 18 varieties	0.42 (71)	0.59	0.41 (68)	0.60

[a]Figures in parentheses indicate percentage of total.

Shoot length, Na and Ca content in the shoots, and dry weight of shoots and roots showed significant additive effects with a high degree of heritability. Genes controlling Na and Ca levels in shoots were found to be partially dominant. At least three groups of genes were found to be involved in the inheritance of Na and Ca levels at the seedling stage.

Highly significant additive effects were also observed for plant height and yield per plant, with high heritability. Selection on the basis of shoot length, Na level in the shoots, dry weight of shoots and roots, plant height, and yield per plant, which show predominance of additive effects and high heritability, could lead to the development of salt-tolerant cultivars.

PHYSIOLOGICAL STUDIES OF BORON TOXICITY

Plant Physiology Department

Effect of boron on growth and yield. Growth and yield of IR36, IR58, and IR21820-154-3-2-2 in 0.2 (standard), 1.0, 2.0, 3.0, 4.0, and 5.0 ppm B were studied in the phytotron at 29/21 °C.

B toxicity symptoms were observed at 1.0-5.0 ppm in culture solution. Symptoms were most pronounced at 6 wk after transplanting (WT). B concentration in the plant organs increased with increasing level of B in the medium (Table 7, 8). B content in the plant organs followed the order shoot > panicle > root.

At 6 WT, B content in the shoot followed the order IR58 > IR36 > IR21820. However, B contents in the roots were comparable.

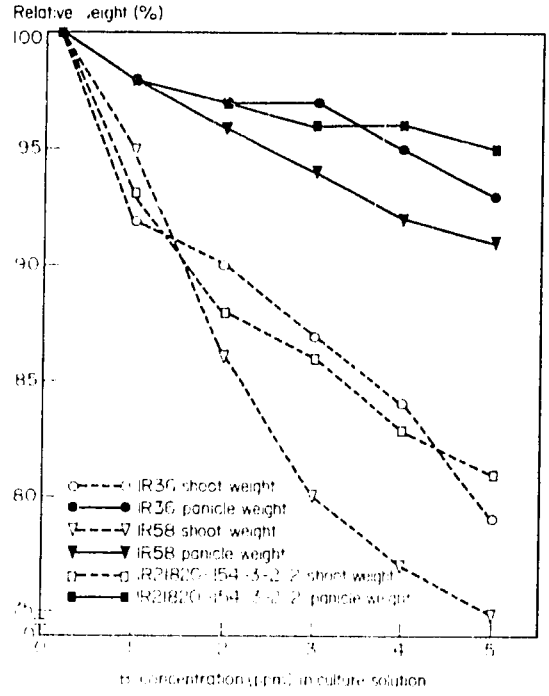
Increasing B concentration to 5 ppm decreased growth by 20-30% (Fig. 3) and yield by 4-10%. Straw weight at harvest tended to be similar to that of the panicle.

Table 7. Boron concentration at 6 wk after transplanting in plant parts of 3 water culture-grown rice varieties with 6 B treatments. IRRI, 1985.

Variety	Boron content (ppm)					
	0.2 (standard)	1.0	2.0	3.0	4.0	5.0
			Roots			
IR36	3.0	6.2	12.0	18.8	20.6	30.4
IR58	3.4	7.4	11.8	16.6	26.6	29.9
IR21820	2.4	9.8	12.6	15.2	20.4	33.0
			Shoots			
IR36	12.2	29.6	49.2	68.2	79.0	88.0
IR58	12.8	26.0	45.0	62.6	84.6	92.2
IR21820	13.0	30.2	54.6	65.6	75.2	82.2

Table 8. Boron concentration at maturity of plant parts of 3 water culture-grown rice varieties with 6 B treatments. IRRI, 1985.

Variety	Boron content (ppm)					
	0.2 (standard)	1.0	2.0	3.0	4.0	5.0
			Roots			
IR36	7.7	8.6	11.2	9.6	9.0	10.0
IR58	7.1	7.9	8.2	9.0	9.2	10.8
IR21820	6.8	8.5	13.4	13.1	17.7	19.4
			Straw (leaves + culm)			
IR36	16.8	24.7	30.8	42.8	54.2	60.3
IR58	19.1	21.7	33.7	45.0	53.2	68.5
IR21820	18.7	21.6	32.4	37.2	45.0	49.6
			Panicles			
IR36	7.2	9.1	14.6	18.8	22.4	29.7
IR58	6.6	10.4	15.8	22.9	29.1	40.4
IR21820	6.6	8.6	12.0	17.1	19.2	24.2



3. Effect of B on shoot dry weight and panicle weight of 3 varieties. IRRI, 1985. Dry weight at 0.2 ppm B = 100% for each variety.

Effect of nitrogen on boron concentration. To determine the effect of N on B toxicity in the rice plant at different growth stages, susceptible variety IR8 was grown in the phytotron in culture solution containing 2 levels of N — 10 and 100 ppm — in 3 replications. In each replication, three pots were sampled at every growth stage. B was added at 0.2 and 5.0 ppm in the form of boric acid. The culture solution was renewed weekly and adjusted to pH 5.0 every other day.

As early as 7 d after transplanting, B toxicity symptoms were observed at both levels of N at 5.0 ppm B. Symptoms were more pronounced at 6-7 WT.

With increasing N in the growth medium, the concentration of B in the shoots increased at all growth stages (Table 9). However, B concentration in the shoots at 5 ppm levels decreased at booting compared to that at 5 WT.

Total plant dry weight decreased at 5.0 ppm B at both N levels for all growth stages (Table 10). The decrease was higher at the higher N level, especially at booting.

Table 9. Boron concentration in plant parts of IR8 grown in culture solution with 2 N and B treatments at 3 growth stages. IRRI phytotron, 1985.

Treatment (ppm)		B content (ppm)						
		5 WT[a]		Booting		Maturity		
N	B	Shoots	Roots	Shoots	Roots	Straw	Panicle	Roots
10	0.2	22.13	4.22	23.89	5.96	67.20	5.60	8.8
10	5.0	143.20	8.76	112.58	1[illegible].80	304.26	28.93	12.93
100	0.2	41.33	4.67	46.53	6.89	73.60	6.80	5.47
100	5.0	170.67	8.93	141.38	12.06	322.26	30.0	12.0

[a]Weeks after transplanting.

Table 10. Plant dry weight of IR8 at 2 levels of N and B at 3 growth stages. IRRI phytotron, 1985.

Treatment (ppm)		Plant dry weight (g/pot)					
		5 WT[a]		Booting		Maturity	
N	B	Shoots	Roots	Shoots	Roots	Shoots	Roots
10	0.2	6.5	3.2	43.3	17.9	48.5	12.1
10	5.0	5.7	2.8	37.2	11.3	46.2	11.1
100	0.2	15.7	3.0	130.8	17.9	233.3	19.9
100	5.0	12.8	2.1	87.5	12.9	192.7	18.9

[a]Weeks after transplanting.

Little difference in grain weight was observed at low N. At 5.0 ppm B at the higher N level, grain weight was reduced by 12% (Table 11). The decrease was due to decreased number of spikelets per panicle.

RESPONSE TO ALUMINUM

Plant Physiology Department

Graded nutrient levels. Al toxicity is affected not only by the absolute concentration of Al but also by nutritional condition. Varietal and differential response to Al may also vary, depending on the balance between Al and nutrient concentrations.

The response of rice varieties in graded Al and nutrient concentrations was examined. Treatment was applied at 0-2 WAS.

The average response of nine varieties to Al was in the order: root length > root weight > shoot weight > shoot length (Table 12). This response was further enhanced by diluting the nutrient solution from full strength to 10%. Among the four growth indices, maximum root length was the best measure of Al toxicity. In practice, relative root length (RRL), which is the ratio of maximum root length in Al to that in Al-free medium, is used as the index of Al tolerance.

Varietal response occurred in 4 nutrient and Al combinations (10% nutrient and 8 ppm Al, 20% and 8, 20% and 30, and full and 30), but it was best expressed in 10% nutrient and 8 ppm Al (Fig. 4). This response was also observed in root weight, shoot length, and shoot weight. The combination of 8 ppm Al and 10% nutrient solution appears to be suitable for screening, not only because it produces a distinct varietal response but also because it closely simulates prevailing acid soil conditions.

Table 11. Grain weight and yield components of IR8 at 2 levels of N and B. IRRI, 1985.

Treatment (ppm)		Panicles/pot (no.)	Spikelets/panicle (no.)	Filled grain (%)	1,000-grain weight (g)	Grain weight (g/pot)
N	B					
10	0.2	17	62	84	23.5	23.1
10	5.0	15	60	90	25.0	24.3
100	0.2	47	60	94	26.5	80.7
100	5.0	47	52	89	27.8	71.0

Table 12. Relative response of 9 rice varieties to graded Al and nutrient solutions.[a] IRRI, 1985.

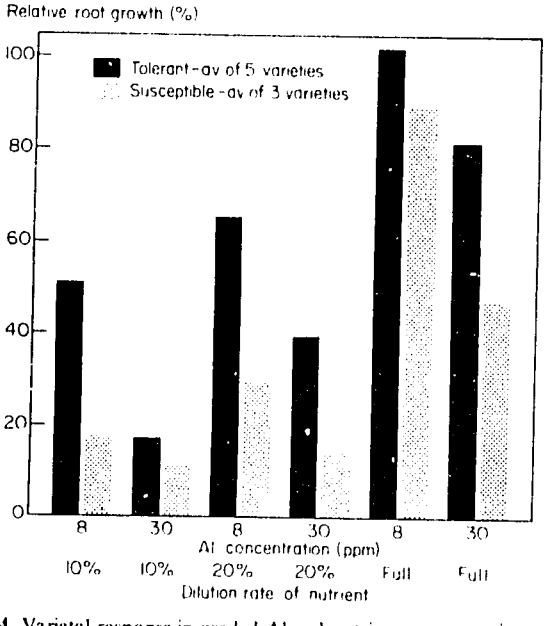
Nutrient solution	Al (ppm)	Response (%)			
		Root length	Shoot length	Root weight	Shoot weight
Full	0	100	100	100	100
	8	97	101	95	102
	30	70	95	79	98
20%	0	79	71	79	64
	8	51	73	63	64
	30	29	58	42	49
10%	0	79	57	68	49
	8	38	55	53	49
	30	13	40	26	36

[a]Av response of 9 rice varieties with full strength nutrient solution and Al-free treatment as reference.

RRL was significantly correlated with root length in Al-free medium in three Al and nutrient combinations (Table 13). The association between Al tolerance and deep roots depends on the balance between Al and nutrient levels.

Seedling age. Nine Al-tolerant and susceptible rice cultivars were grown in graded Al and nutrient concentrations at 0-2 WAS and at 2-4 WAS.

RRL of 4-wk-old seedlings was always greater than that of 2-wk-old seedlings (Fig. 5). The



4. Varietal response in graded Al and nutrient concentrations. IRRI, 1985.

Table 13. Regression coefficients between relative root length and root length in Al-free medium. IRRI, 1985.

Nutrient level	Coefficient
8 ppm Al	
10%	0.7405*
20%	0.7111*
Full	0.1300ns
30 ppm Al	
10%	-0.0275ns
20%	0.6696*
Full	-0.2817ns

difference between 2-wk-old and 4-wk-old seedlings increased by increasing Al from 8 to 30 ppm and by diluting the nutrient concentration from full strength to 10%. Varietal response in 2-wk-old seedlings held through the 4-wk-old seedlings but to a lesser degree. Because of distinct varietal response and greater sensitivity to high Al and low nutrient concentrations, the 2-wk-old rice seedling is at a suitable growth stage for screening for Al toxicity tolerance.

SCREENING FOR ALUMINUM TOXICITY TOLERANCE

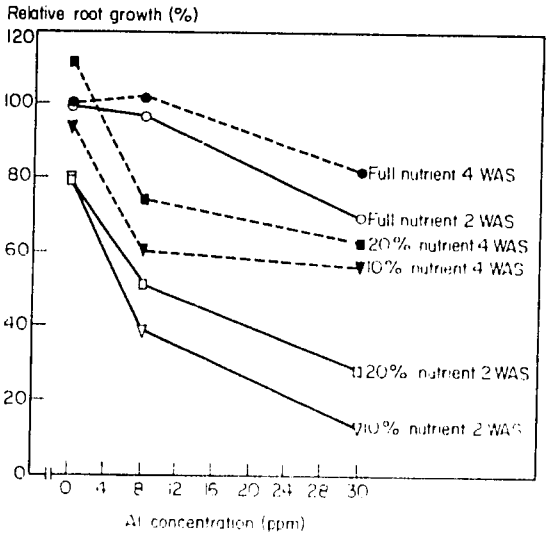
Plant Physiology and Plant Breeding Departments

Traditional varieties from northeast India. The northeastern hill region of India is predominantly red lateritic acid soil. Besides P deficiency, Al toxicity is prevalent.

Eighty varieties from the region were screened for Al toxicity using the RRL technique. Tolerance is based on the ratio of the maximum root length at 30 ppm to that at 0 ppm Al. RRL ranged from 0.29 to 0.95. The most tolerant varieties were Azucena, Ate local, Thlanchuah, Chao, and Nikhunkati.

Deep water rices from Vietnam. About 1.2 million ha in the Cuu Long Delta are planted to local deep water rices. Almost all of these soils are acid sulfate. Al toxicity may be a problem where rice is broadcast on the unflooded land at the start of WS.

Fifty-two deep water rices from Vietnam, four from Thailand, and breeding lines from IRRI were screened for Al toxicity tolerance. RRL of all the varieties tested was lower than that of IAC3, the tolerant check.



5. Effect of Al and nutrient concentrations on rice growth at 2 and 4 wk after sowing (WAS) (av of 9 varieties). IRRI, 1985.

The best varieties were Leb Mue Nahng 111, a Thai floating rice adapted to potentially acid sulfate soil; Tau Nut, a Vietnamese transplanted deep water rice for acid sulfate areas; Ba Sao, a Vietnamese broadcast floating rice for acid sulfate areas; Khao Daeng, a Thai rice for potentially acid sulfate areas; Nang Phuoc, a Vietnamese rice tolerant of acid sulfate soil; Xa Guay, a Vietnamese rice for tidally flooded areas; and Nang Dum To, a Vietnamese floating rice.

Absolute root length as a criterion. In screening for Al toxicity tolerance, RRL is a valuable criterion. For F_2 screening, however, this measurement cannot be made. Therefore, the correlation between RRL and root length at 30 ppm Al for 107 varieties was evaluated. The correlation was highly significant (r = 0.798), meaning that populations having one Al toxicity-tolerant parent could be screened in the F_2 at 30 ppm Al using absolute root length as the criterion.

INHERITANCE OF PHOSPHORUS UTILIZATION EFFICIENCY

Plant Breeding Department

Seven rices representing varying responses to P stress were crossed in all possible combinations, excluding reciprocals. Stress was induced using greenhouse and field methods.

P utilization efficiency was expressed in three ways:

- shoot dry weight,
- P content per seedling, and
- P efficiency ratio (dry weight produced per unit of P accumulated).

The first measurement is equal to the product of the second and third measurements.

Table 14 lists for each situation and measurement technique the two parents with the highest P utilization efficiency. If one considers shoot dry

Table 14. Best parents for P efficiency using various treatments and measurements to induce P-related growth differences. IRRI, 1985.

Treatment	Best parents for		
	Shoot dry weight	P content	P efficiency ratio
		Greenhouse	
Nutrient solution, 0.5 mg/liter	IR13149-3-2-2 IET1444	IR13149-3-2-2 IR14632-2-3	IR13149-3-2-2 IET1444
Nutrient solution, 10 mg/liter	IET1444 IR13149-3-2-2	IR13149-3-2-2 IR14632-2-3	IET1444 IR36
		Field, acid soil	
3.2 ppm + 0 kg P/ha	IR13149-32-2 IR36	IR14632-2-3 IR13149-3-2-2	IR9884-54-3 IR13149-3-2-2
3.2 ppm + 110 kg P/ha	IR9884-54-3 IR14632-2-3	IR14632-2-3 IET1444	Mahsuri IR13149-3-2-2
		Greenhouse	
Na + soil (pH 8.5)	IET1444 IR13149-3-2-2	IET1444 IR13149-3-2-2	IR14632-2-3 IR9884-54-3

weight as a measure of broad sense P utilization efficiency, then P content represents the component that enables the plant to absorb P from a deficient soil; and the P efficiency ratio represents the ability of a plant to get more dry matter for less P absorbed.

IR13149-3-2-2 was the most consistently outstanding entry across situations and measurements, whereas IR14632-2-3 had high P content in its offspring but generally failed to impress in terms of shoot dry weight. IR20 was the only parent that did not show outstanding progeny performance in any situation.

Table 15. Screening tests for adverse soils tolerance, IRRI, 1985.

	Latries (no.)	
	Tested	Tolerant
Salinity	5,176	1,130
Alkalinity	1,691	217
Peat soil conditions	198	25
Fe toxicity	307	63
P deficiency	800	120
Zn deficiency	2,612	192
Al or Mn toxicity	232	49
B toxicity	114	24
Total 1985	11,130	1,820
Total 1969-85	155,776	26,026

SCREENING FOR ADVERSE SOIL TOLERANCE

Soil Chemistry/ Physics Department

Selecting and testing rice for adaptability to adverse soil conditions continued. Of 11,130 rices selected and tested for adaptability to adverse soil conditions, 1,820 were rated tolerant (Table 15). Yield trials and location testing confirmed the exceptional tolerance of IR9764-45-2 for almost all soil toxicities and nutrient deficiencies in lowland soils; the tolerance of IR54 and IR62 for acid sulfate soil conditions, P deficiency, and Zn deficiency; the tolerance of UPLRi-7 for the growth limiting factors of upland soils regardless of pH. The main emphases of research were on Al and Mn toxicities in upland soils and acid sulfate soil conditions, and on Fe toxicity in rainfed environments.

Screening and performance trials in acid upland soils (pH 3.9-4.8) at 4 locations in Laguna, Albay, and Iloilo, Philippines, revealed that 49 selections had similar or better performance than the resistant check IR43. In Albay, IR45, IR56, and UPLRi-7 each yielded more than 3 t/ha. Mass selection in the greenhouse and farmers' fields was intensified, and trials on acid sulfate and Fe toxic soils verified screening results.

A study of the chemical kinetics of two saline soils and the mineral content, nutrient uptake, and nutrient ratio of two rices showed that in saline soils growth and yield of rice are limited by nutritional imbalances involving K, Na, Ca, and Mg. The tolerant variety appeared to have an inherent capacity to accumulate selectively the essential ions K and Ca in its shoots and maintain this balance, while the less tolerant variety appeared to be less capable of this mechanism. Besides salinity and nutrient imbalances, other nutritional problems that can render saline soils more injurious are B toxicity, Fe deficiency, and H_2S toxicity.

Genetic evaluation and utilization (GEU) program

Deep water and flood tolerance

Plant Physiology, Agronomy, and Plant Breeding Departments, and International Rice Testing Program

FACTORS AFFECTING ELONGATION OF DEEP WATER RICE UNDER SUBMERGENCE 92
- Light 92
- Water turbidity 92
- Water temperature 93
- Flooding 94
- Plant parts 94

SCREENING FOR SUBMERGENCE TOLERANCE 94
SCREENING FOR ELONGATION ABILITY 94
YIELD POTENTIAL OF DEEP WATER RICES 94
DEEP WATER OBSERVATIONAL NURSERIES 94
SCREENING DEEP WATER RICE FOR FERTILIZER RESPONSE 94
MEASURING INTERNODE ELONGATION 96
SUBMERGENCE TOLERANCE SCORING METHODS 97

91

FACTORS AFFECTING ELONGATION OF DEEP WATER RICE UNDER SUBMERGENCE

Plant Physiology Department

In deep water rice areas, cultivars must have the ability to grow above the water surface. Traditional cultivars with elongation ability are used.

Plant elongation is generally the combined effect of internode, leaf sheath, and leaf blade elongation. Several factors affect the elongation of plants under submergence (Fig. 1).

Thirty-day-old seedlings of Habiganj Aman VIII (HBJ), a traditional deep water rice cultivar that elongates primarily by internodes, were used in studying the effects of light, presubmergence carbohydrate content, O_2 concentration in water, water temperature, water turbidity, and flooding depth on elongation.

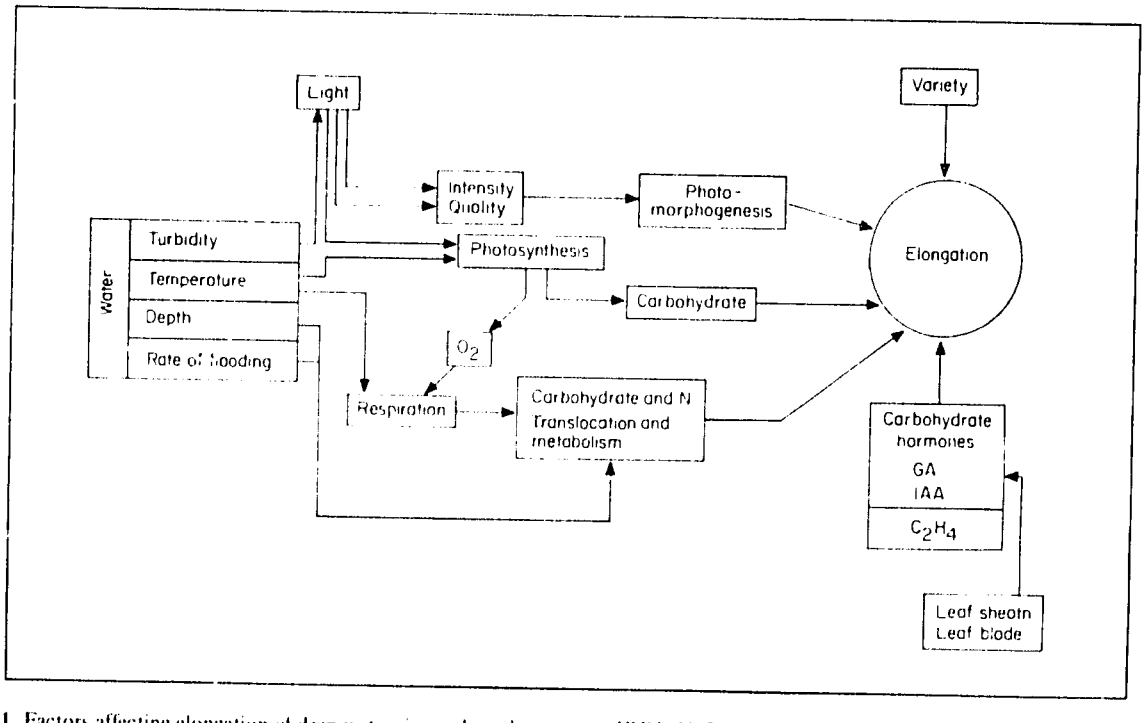
Light. Internode elongation increased with decrease in light intensity under water (Fig. 2). In contrast, the dry matter content of the elongating plant parts increased with increase in light intensity. The differences in elongation response at different light intensities are not the consequence of current photosynthetic activity but are a photomorphogenetic phenomenon.

Compared with white light as it affects internode elongation, green, yellow, and red light were stimulatory, while blue and far-red light were inhibitory under submerged conditions (Fig. 3). Internode elongation may not express its full potential in highly transparent water because of the dominance of blue light.

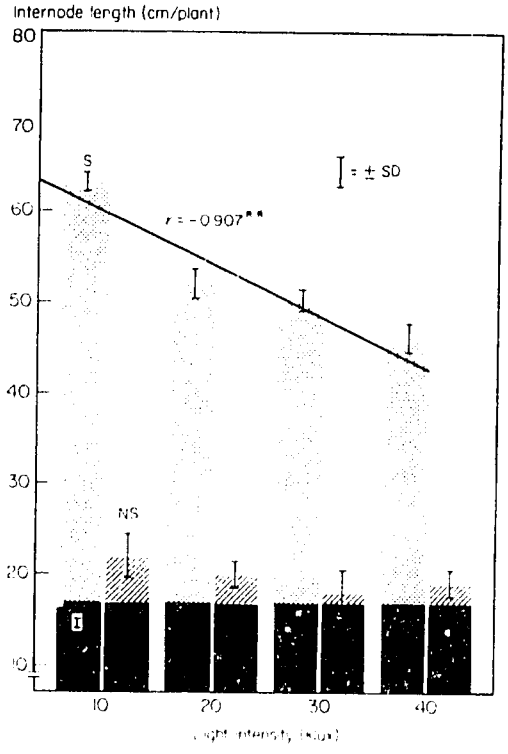
Presubmergence carbohydrate reserves were found sufficient to support the elongation of internodes (Fig. 4). Internode elongation depends on current photosynthate when presubmergence carbohydrate content is highly depleted.

The amount of O_2 produced during current photosynthesis was found sufficient to support internode elongation.

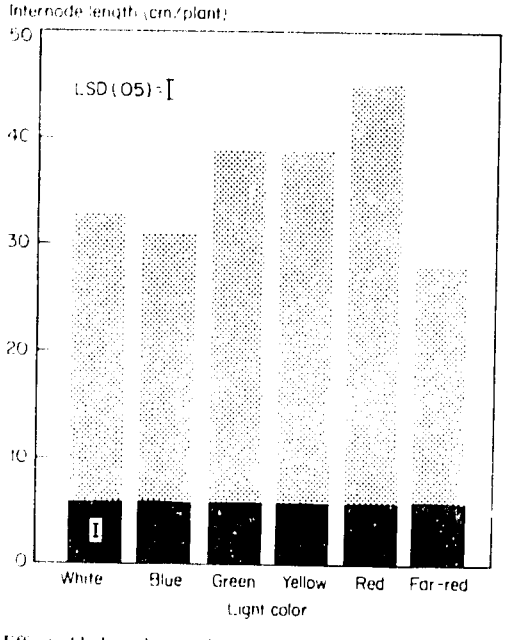
Water turbidity. Water turbidity reduces photosynthesis under water by reducing light intensity and not by hindering gas exchange in the leaves. The dry weight of internodes of 4-wk-old seedlings decreased with increase in turbidity, but elongation was not inhibited by any level of turbidity tested. However, internode elongation of 3-wk-old seed-



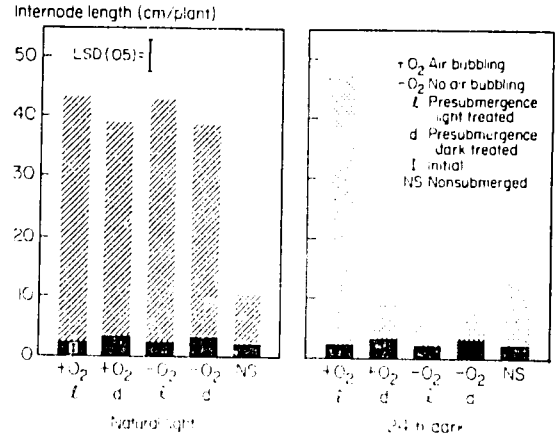
1. Factors affecting elongation of deep water rice under submergence. IRRI, 1985.



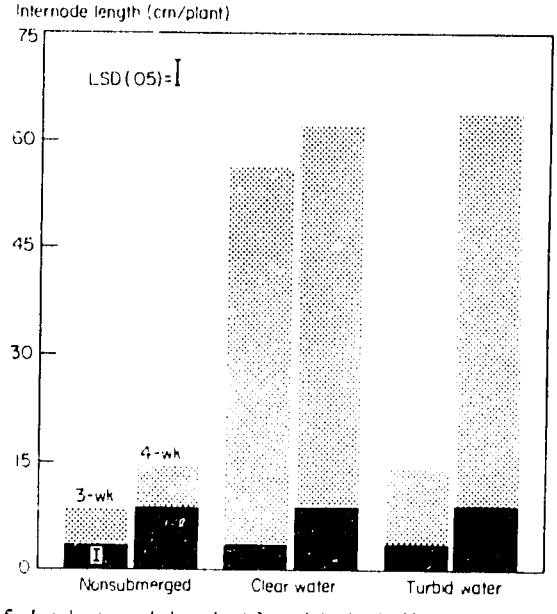
2. Relation between light intensity and total length of internodes of Habiganj Aman VIII under submerged (S) and nonsubmerged (NS) conditions. IRRI, 1985. I = initial length.



3. Effect of light color on elongation of internodes of Habiganj Aman VIII. IRRI, 1985. I = initial length.



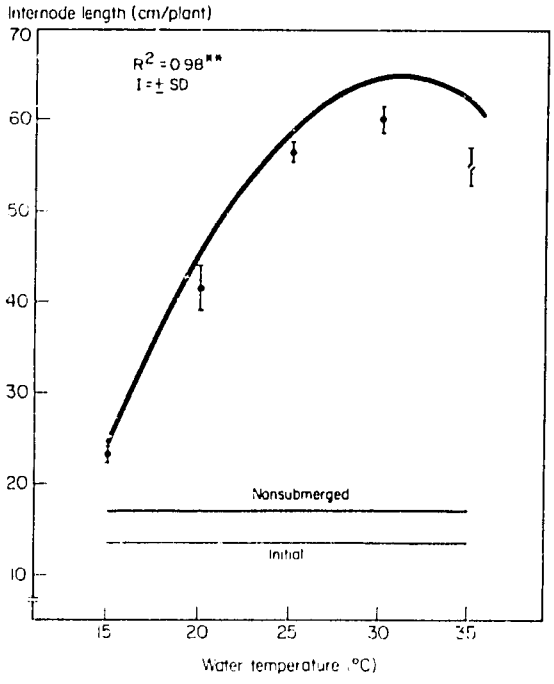
4. Cumulative length of elongated internodes of Habiganj Aman VIII in different submergence treatments under natural light and 24 h dark. IRRI, 1985.



5. Total internode length of 3- and 4-wk-old Habiganj Aman VIII seedlings under clear and turbid water submergence and under nonsubmerged conditions. IRRI, 1985. I = initial.

lings was severely inhibited by highly turbid water (Fig. 5). Three-week-old seedlings had much lower presubmergence carbohydrate content than 4-wk-old seedlings.

Water temperature. Both elongation and growth of the elongating plant parts increased with increase in water temperature from 15 to 30°C and then dropped at 35°C (Fig. 6).



6. Relation between water temperature and total length of internodes of Habiganj Aman VIII under submergence. IRRI, 1985.

Flooding. Elongation of internodes was found to be positively correlated with depth of submergence as well as with rate of increase of water depth.

Plant parts. A synchronous relationship existed between elongation of the developing n^{th} leaf and the $(n-1)^{th}$ internode. Removal of the nth leaf inhibited elongation of the $(n-1)^{th}$ internode by 50%.

Clipping of the mature $(n-2)^{th}$ leaf sheath inhibited the elongation of the $(n-1)^{th}$ internode by 80%. The $(n-2)^{th}$ leaf is the "active center" leaf that controls the elongation of the $(n-1)^{th}$ internode.

SCREENING FOR SUBMERGENCE TOLERANCE

Plant Physiology Department

More than 26,290 entries – 23,930 from the pedigree nursery for rainfed lowland and deep water – were screened for submergence tolerance. Suitable tolerant entries were transplanted in the field for further evaluation by plant breeders.

SCREENING FOR ELONGATION ABILITY

Plant Physiology Department

A total of 323 entries were tested for elongation ability in a deep water tank. The entries came from the 1985 International Tide-Prone Rice Observational Nursery, 1985 International Floating Rice Observational Nursery (IFRON), 1985 International Rice Deep Water Observational Nursery, hybridization blocks, and GEU elite lines. Habiganj Aman II and Sarsari from IFRON received an SES score of 1, while Baishbish, Sail Kotha, SPR7411-7-2-1, BKN6986-1, Jalamagma, TCA178, Chenab 64-117, FRRS43-3, IR20897-B-6, IR20910-B-67, IR20913-B-26-1-2-2-3, IR23325-R-R-B-1-3-1, SR4095-19-2-3-5-4, and Nam Sa Gui 19 had a score of 3.

YIELD POTENTIAL OF DEEP WATER RICES

Agronomy Department

Twenty-eight promising rices were tested at IRRI in controlled water up to a maximum depth of 100 cm. In both dry and wet (WS) seasons, flash flooding as early as 3 d after transplanting and rodent problems before harvest prevented collection of yield data. The gradually increasing water drastically reduced tillers and panicle production more severely during WS (Table 1).

DEEP WATER OBSERVATIONAL NURSERIES

International Rice Testing Program

In the 1984 International Rice Testing Program (IRTP) deep water observational nurseries, the following were promising: BKNFR76035-108-1, IR31338-30-2-1, NC493, BKNFR76035-112-1, HTA7403-110-1-5, IR13259-185-2E-P4-3, BKNFR76035-108-2, BKN6988-52-1-3-0, DWCT156-1-2-0, IR29159-16-2-1-3, and RD19.

More detailed results appear in the annual IRTP nursery reports.

SCREENING DEEP WATER RICE FOR FERTILIZER RESPONSE

Agronomy Department

Statistical analyses of sampling methods have shown that for broadcast deep water rice, repli-

Table 1. Some agronomic characteristics of deep water (maximum 100 cm) rice tested at IRRI, 1985 DS and WS.

Deep water rice	Tillers/m²	Panicles/m²
1985 DS		
IR13149-3-2-2-P1	144	90
IR13260-100-1E-P3	147	85
IR21037-2-1-2E-P3-6	269	130
IR21038-77-P2-5-2-3-1-1-1-1	268	159
IR21071-53-2-2-1E-P1	241	191
IR21071-53-2-2-2E-P2	228	159
IR21071-53-2-3-1E-P4-5	294	272
IR26662-196-2-1-1-3-3-2	156	94
IR28333-10-1-1	247	129
IR28932-9-3-3-2	213	102
IR28932-9-3-3	194	93
IR33188-8-2-1-3-2-1-2	250	131
IR33188-8-2-1-3-2-1-3	203	119
IR33188-8-2-1-3-6-1-3	213	103
IR38685-7-2-3-3	253	209
IR38730-88-3-1-1	272	100
1985 WS		
IR38784-137-5-3-4	184	106
IR38787-26 2-2-1	193	88
IR38787-26-2-2-3	156	99
IR38787-26-6-1-3	163	103
IR38787-26-6-6-1	131	75
IR21038-77-P2-5-2-3-1-1	116	66
PR11141-6-1-4	181	103
IR30730-88-3-3-1	103	47
IR3878-26-6-6-3	175	81
IR38784-137-2-6-6	178	106
BKNFR76026-3-2-2-2	116	75
RD19	156	78

cated samples of a minimum of 5 × 5 m are usually necessary for adequate determination of yield, and even larger plots are often needed to measure fertilizer response. Thus, it is difficult and expensive to test the response of many new lines from a plant breeding program.

In cooperation with Thai scientists, an attempt was made to develop a small-plot technique to evaluate the fertilizer response of promising deep water lines. A split-plot experiment with fertilizer treatments as main plots and deep water rice as subplots was conducted on an acid sulfate soil (treatment details in Table 2). Fertilizer was basally incorporated for first or single applications, or broadcast before the onset of the flood for a second application. Seeds of each entry were sown in 3-row plots, with 25 cm between rows and measured amounts of seed in each row. To standardize interplot competition and reduce edge effects, plots were separated by two rows of the tall photoperiod-sensitive rice RD27, these interplot rows being cut off at the end of October, about the time of maximum water depth (130 cm). This gave good separation of the plots and allowed an accurate harvest.

To test edge effects, the center row yield was determined separately from the yield of the two outer rows. No significant difference was found

Table 2. Grain yields for entries from 3-row plots of a fertilizer response trial. Prachinburi, Thailand, 1985 WS.[a]

Entry	Yield (g/m²) with fertilizer (kg NPK/ha)						Regression on treatment mean		
	Check	0-37-0	37-0-0	0-37-0 fb 37-0-0	37-0-0 fb 37-0-0	37-37-0 fb 37-0-0	Slope (b)	Y-intercept (a) (g/m²)	Correlation coefficient
SPRLR77279-43-1-1	106 c	106 c	205 b	219 b	304 a	325 a	1.988	−98.29	0.972
SPR'76 com 3-5-2	106 c	148 c	161 c	226 b	280 ab	305 a	1.646	−51.63	0.956
SPR'76 com 3-239-1	118 b	115 b	127 b	165 a	214 a	260 a	1.178	−16.72	0.910
RD19	143 b	127 c	149 bc	168 bc	203 ab	247 a	0.877	36.50	0.898
HTAFR79256-1	81 c	145 bc	151 b	183 ab	155 ab	235 a	0.937	12.60	0.851
HTAFR79256-2	69 d	86 cd	117 bcd	160 ab	153 bc	221 a	1.173	−48.08	0.967
BKNFR76042-18-1-1	89 c	87 c	132 bc	183 ab	188 ab	217 a	1.192	−35.96	0.995
BKNFR76045-35-1-2-1	134 bc	107 c	129 bc	182 ab	213 a	217 a	0.934	18.45	0.915
HTAFR79256-4	90 b	103 b	181 a	181 a	182 a	206 a	0.996	2.25	0.947
SPR7233-32-1-6-1	52 d	60 cd	158 ab	122 bc	161 a	205 a	1.216	−62.80	0.919
BKNFR76010-108-2	98 a	87 a	115 a	209 a	127 a	201 a	0.937	− 6.23	0.815
HTAFR79256-3	99 bc	61 c	108 bc	156 ab	206 a	187 a	1.112	−36.79	0.909
HTAFR77059-6-2-0	71 c	105 bc	207 a	183 ab	213 a	177 ab	1.015	1.44	0.802
HTAFR77058-45-3	136 a	147 a	136 a	198 a	154 a	161 a	0.277	112.29	0.548
HTAFR77085-1-1-1	88 b	88 b	135 ab	171 a	138 ab	110 ab	0.413	54.66	0.607
SPR7411-7-2-3-2	111 a	114 a	174 a	163 a	111 a	110 a	0.058	121.52	0.089
Mean	100	105	149	179	188	212			

[a]Means in a row followed by a common letter are not significantly different at the 5% level by DMRT.

except for the treatment 37-0-0 followed by (fb) 37-0-0, where the center row averaged 8% more yield than the 2 outer rows, and for one individual entry, where the center row had 18% higher yield. No other entries showed more than a 7% difference.

Yields of individual entries in Table 2 were regressed against treatment mean yields to give an estimate of the response to fertilizer from the slope of the regression. Treatment 37-37-0 fb 37-0-0 was consistently the best. SPRLR77279-43-1-1 gave the highest yield in this treatment and the highest response to fertilizer. SPR'76 com 3-5-2 consistently performed well in yield trials. RD19 gave a lower maximum yield but better yield in the check plot.

MEASURING INTERNODE ELONGATION

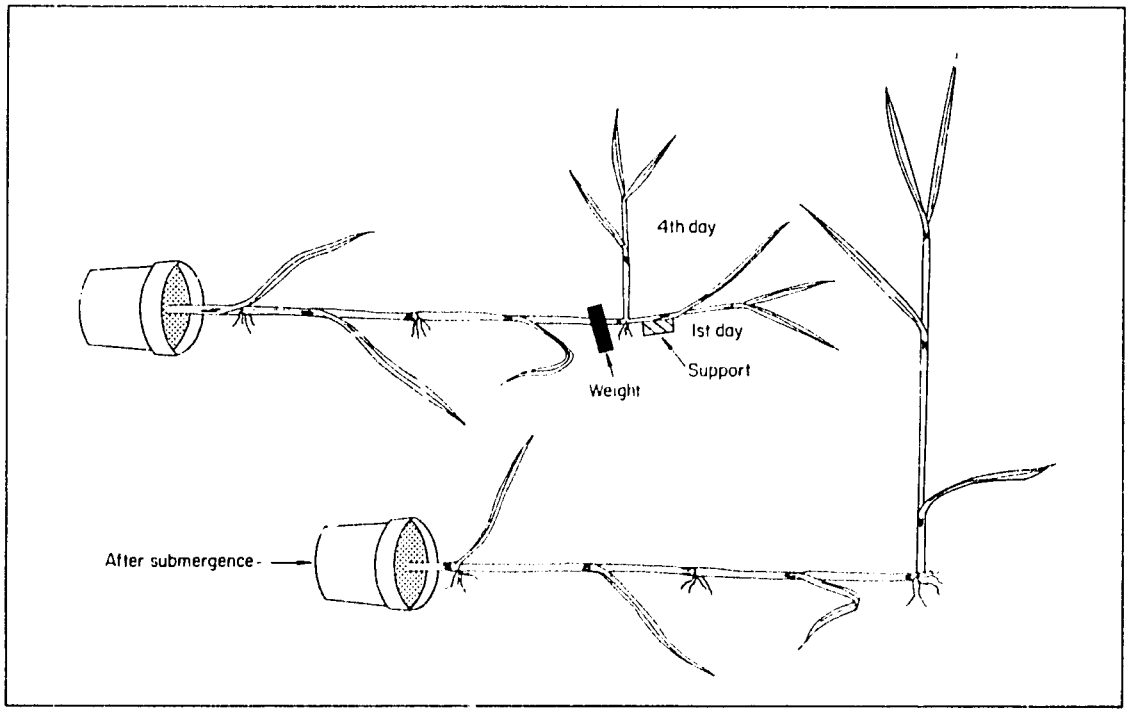
Plant Breeding Department

There are two difficulties in measuring elongation ability of elongating deep water rice (including floating rice): 1) While the desirable stage of measuring elongation ability would be the one corresponding to farming practice, some 70 d after (broadcast) seeding (DAS), that would take fairly deep tanks. For savings in time and water, tests are therefore carried out mostly at 30 DAS and in water of no more than 150 cm. 2) In genetics work, it is essential to do progeny tests on families from all measured plants, including those found unable to elongate. The latter category, however, is destroyed in all tests currently in use.

We tried a different approach to elongation testing by forcing plants to be tested in a horizontal position, except the upper plant parts. This method requires less deep flooding to induce elongation, can test nondestructively, and can score (in cm internode length) on a continuous scale between "no elongation" and "very good elongation."

Six varieties were selected: TCA4, TCA177 (floating), Janki (deep water, submergence tolerant), IR11141-6-1-4 (modern variety [MV], deep water, with elongation ability), IR42 (MV), and Lal Dhan (tall traditional).

Five 8-wk-old plants of each variety were grown in 5- × 5-cm plastic pots. Only the main tillers were maintained. Plants were placed horizontally in



7. Test for kneeing ability. IRRI, 1985.

trays; a weight was applied at the uppermost node, and a support ventrally under this node (Fig. 7) to stimulate vertical growth of the upper portion of the plant. Four days after this treatment, TCA4, TCA177, Janki, and IR11141-6-1-4 showed excellent kneeing, while IR42 and Lal Dhan were not able to knee, possibly because there were no sufficiently developed internodes.

Kneeing took place only at the nodes, and varieties elongating by leaf blade or sheath would not be able to knee. Subsequently, plants were submerged for 6 d, initially keeping the leaves partly above the water. While IR42 and Lal Dhan had no internode elongation, all other varieties developed two internodes while partially submerged, with the first internode being the smaller one. TCA4 had the longest average total internode elongation, followed by TCA177 (Table 3).

SUBMERGENCE TOLERANCE SCORING METHODS

Plant Breeding Department

Seven techniques for measuring submergence tolerance in rice were compared for precision and relevance.

Precision was compared among the different experiments using the F-value of the respective analyses of variance.

Relevance was assessed using the linear correlation coefficients of submergence tolerance measurements obtained, with submergence tolerance ranking scores obtained on the same lines in many previous experiments.

Table 3. Internode elongation in the apical parts of plants where the lower portion was placed horizontally. IRRI, 1985.

Variety	Av length (mm) of internodes/plant	
	Before submergence (initial)	After submergence (increase)
TCA4	39.8	34.6
TCA177	32.6	32.6
Janki	15.3	12.4
IR11141-6-1-4	5.6	10.4
Lal Dhan	0	0
IR42	0	0

Table 4. Comparison of methods for submergence tolerance testing using various water depths and durations of submergence. IRRI, 1985.

Treatment			Relevance	F-value	Parameter for measurement
Depth (cm)	Days	DAS			
30	5	10	0.62	4.22	% survival
30	9	10	0.73	5.89	% survival
50	8	30	0.77	9.98	Submergence tolerance score
30	7	10	0.77	61.24	% survival
30	5-9	10	0.83	19.77	Days to 50% mortality
30	7	10	0.84	4.78	% survival
50	8	30	0.84	5.31	% survival
50	8	20	0.86	19.27	% survival
50	8	10	0.87	28.93	Submergence tolerance score
50	8	20	0.89	10.48	Submergence tolerance score
30	6	10	0.90	0.86	% survival
50	8	10	0.91	15.66	% survival
30	7	10	0.91	37.40	Submergence tolerance score
30	6	10	0.93	21.67	Submergence tolerance score

Table 4 compares several tests using submergence at various water depths, duration of submergence, and DAS. Submergence tolerance was assessed both as survival percentage and using a standard submergence tolerance score based on the appearance of seedlings after submergence.

The relevance of all submergence tests was high. Tests combining high precision and relevance were that using 10-day-old seedlings and that using scores.

Table 5 assesses various tests designed to simulate submergence treatment by applying dark treatment instead. The bases were survival (if mortality was sufficiently high), dark tolerance score, a visual assessment of yellowing, percent increase in seedling height during dark treatment, and decrease in leaf color.

The relevance (correlation with previous results) of the tests was much lower than that in Table 4 using actual submergence. The best precision was generally obtained in tests using 50-day-old seedlings.

Table 5. Comparison of methods for submergence tolerance testing using dark treatment. IRRI, 1985.

Treatment			Relevance	F-value	Parameter for measurement
Temperature (°C)	Days	DAS			
35	10	35	0.32	9.05	% survival
25	10	50	0.37	17.38	% increase in seedling height
30	10	35	0.38	2.09	% survival
30	10	50	0.39	2.75	% survival
35	10	35	0.48	13.11	Dark tolerance score
35	10	50	0.53	10.75	% survival
25	10	35	0.54	12.34	% increase in seedling height
30	10	50	0.57	15.48	Dark tolerance score
25	10	35	0.58	11.38	% decrease in leaf color
25	10	50	0.59	10.88	% decrease in leaf color
30	10	35	0.60	6.22	Dark tolerance score
35	10	50	0.72	14.57	Dark tolerance score

Given the low individual relevance, dark treatment may not be useful for actual screening. However, all correlation coefficients indicating relevance were consistently of the same sign, and given the high F-values obtained in some of these experiments, the dark treatment may be used to study components of or factors contributing to submergence tolerance in different rice varieties.

Genetic evaluation and utilization (GEU) program

Adverse temperature tolerance

Plant Breeding and Plant Physiology Departments and International Rice Testing Program

COMBINING ABILITY FOR COLD TOLERANCE **100**
SELECTION CRITERIA FOR TRAITS ASSOCIATED WITH LOW TEMPERATURE TOLERANCE **100**
RAPID GENERATION ADVANCE MATERIALS FOR COLD TOLERANCE **101**
INTERNATIONAL RICE COLD TOLERANCE SCREENING NURSERY **101**
COOPERATIVE COUNTRY PROJECTS **101**
Korea **101**
Vietnam **101**

91

COMBINING ABILITY FOR COLD TOLERANCE

Plant Breeding Department

We tried to use line × tester analysis to predict the prepotency of parents and to evaluate the type of gene action involved in cold tolerance.

Seventeen cold-tolerant varieties (eight japonicas, six indicas, two indica/japonica hybrids, and one japonica/indica) originating from India, China, Japan, Korea, Indonesia, and USSR were used as female parents crossed in a line × tester fashion to six high yielding or blast-resistant indica male parents from elite IRRI lines. All parents and the 102 F_1 hybrids were evaluated for low temperature tolerance at the early seedling, seedling, booting and flowering stages under controlled conditions.

The indica parents had higher mean emergence coefficients (speed of emergence divided by vigor of emergence), flowering duration, number of spikelets, and depression in fertile spikelets. Compared with this, the japonica parents were high in seedling height, cold tolerance indices (based on leaf discoloration and survival percentage), and fertility percentage.

The japonica/indica hybrids showed high cold tolerance at the vegetative stage but low cold stability at the reproductive stage, as opposed to the indica/indica hybrids, which had high mean fertility percentage.

The correlations of measures of cold hardiness and emergence ability at low temperature suggested that these responses are controlled differently and only in part by the same genetic mechanism. Highly significant associations of seedling height with tolerance indices at the early seedling and seedling stages suggested similarity in the inheritance of these traits. Seedling height at the early stage and tolerance indices at any stage appeared to be highly effective indicators of cold hardiness at the vegetative stage. Elite indicas or indica/indica hybrids appeared to be less cold hardy at the seedling stage.

Seedling height, cold tolerance indices, number of fertile spikelets at booting, and fertility percentage seemed to be predominantly under additive gene action. A preponderance of nonadditive gene action was revealed in the inheritance of emergence coefficient, flowering duration, and number of fertile spikelets.

The cultivar Barkat was the best general combiner for cold tolerance at the vegetative stage, followed by Stejaree 45, K332, SR3044-78-3, and SR5204-91-4-1 — all japonicas. For cold stability at the reproductive stage, K39-96, China 988, Shoa-Nan-Tsan, Leng Kwang, and Suweon 287 were good combiners.

SELECTION CRITERIA FOR TRAITS ASSOCIATED WITH LOW TEMPERATURE TOLERANCE

Plant Physiology Department

Four-year data on agronomic characters measured in the Korea-IRRI collaboration on rice cold tolerance were evaluated to identify which rice plant traits are important in predicting low temperature tolerance and to establish the relative weight of each.

The cold tolerance nursery consisted of entries planted in single rows of 13 m. Cold water at 17°C flowed in at one end of the row and out at the other, subjecting each entry to a water temperature gradient from 17 °C to normal temperature. A resistant check and a susceptible check were planted every 20 entries. Analysis of the resistant and susceptible checks showed that the use of data from outlet minus inlet (i.e., the degree of reduction of traits as a result of the low water temperature treatment) is not a reliable criterion for identifying low temperature tolerant entries in this nursery because of the very high coefficient of variation (>50%). Analysis of the resistant check using data from the inlet showed an acceptable coefficient of variation (Table 1).

Table 1. Coefficients of variation of the checks for traits measured at the inlet of the cold tolerance screening nursery, 1980-83.

Trait	Coefficient of variation (%)			
	1980	1981	1982	1983
Number of days to heading	5	1	14	3
Fertility percentage	15	11	22	7
Spikelets/panicle	13	15	21	17
Culm length	18	7	15	10
Panicle number	34	14	24	19
Panicle exsertion	29	22	19	21
Phenotypic acceptability	12	0	57	37
Discoloration at seedling stage	44	0	13	46

The highest coefficient of variation observed for any given trait and season was no greater than 34% except for discoloration (46%) and phenotypic acceptability (57%). Later analysis established that discoloration has no significant effect on total fertile spikelets (used as a measure of low temperature tolerance). The high coefficient of variability for phenotypic acceptability can be explained by the subjective nature of the observation.

A temperature gradient is not necessary in screening for cold tolerance based on filled spikelets. A water temperature of 17 °C maintained throughout the field is sufficient. This would require a smaller field. Separate plots with normal irrigation water can be used to monitor in detail the performance of elite entries.

A multiple regression equation was fitted, with total filled spikelets as the dependent variable and all other traits as independent variables, to establish the significant effects of each trait. The standardized regression coefficient showed the following order of significant effects on total filled spikelets: fertility > panicle number > spikelets per panicle > days to heading = culm length > phenotypic acceptability. It was found that discoloration and panicle exsertion have no significant effect on total filled spikelets. (It is also possible that the effects of these two traits are nonlinear.) Fertility percentage is the most important trait in selecting for low temperature tolerance. Panicle number and spikelets per panicle also have significant direct effects (as measured by path coefficient), but both have large indirect effects via fertility.

RAPID GENERATION ADVANCE MATERIALS FOR COLD TOLERANCE

Plant Physiology Department

One hundred twenty-nine rapid generation advance (RGA) materials were planted in five-row plots to screen for resistance to field pests and diseases and to rejuvenate and increase the seed supply. Bulk populations were harvested for further screening for low temperature tolerance at the seedling stage.

Thirteen F_2 crosses made from Bhutan varieties and 31 advanced RGA crosses earlier evaluated in the field were screened for low temperature tolerance at the seedling stage. One bulk and 51 individual plant selections were made.

INTERNATIONAL RICE COLD TOLERANCE SCREENING NURSERY

International Rice Testing Program

Results from the 1984 IRTP cold tolerance nurseries indicated the following as promising: K39-96-1-1-1-2, Ching-shi 15 (Acc. no. 36852), Tatsumi mochi, CI 5309 (Acc. no. 00955), China 1039, Chechon-chun-shun 1 (Acc. no. 04532), and IR24132-R-R-19-3-B. Ching-shi 15 and Chechon-chun-shun 1 came from the screening of Chinese entries in the germplasm bank, while IR24132-R-R-19-3-B was generated in the RGA program at IRRI.

COOPERATIVE COUNTRY PROJECTS

Plant Physiology and Plant Breeding Departments

More detailed information on the following projects may be found in the section Cooperative Programs.

Korea (*Plant Physiology and Plant Breeding*). In the eighth year of collaborative work with the Rural Development Administration of the Republic of Korea, the main objective was cold tolerance screening of breeding materials.

Vietnam (*Plant Physiology*). Rice varieties from Vietnam were screened at IRRI for cold tolerance at different growth stages by a Vietnamese scientist. Bong Sen was the most promising, having excellent tolerance at panicle initiation and anthesis.

Genetic evaluation and utilization (GEU) program

Innovative breeding methods

Plant Breeding and Plant Physiology Departments, Tissue Culture Facility, and International Rice Germplasm Center

HYBRID RICE **104**
- Growth and yield of F_1 hybrids at two N levels **104**
- Combining ability and heterosis **104**
- Relation between yield heterosis in F_1 hybrids and genetic divergence among parents determined through isozymes **105**
- Physiological analysis of heterosis **105**
  - Embryo size **106**
  - Initial growth rate **106**
- Cytoplasmic male sterility and fertility restoration **107**
- Identification and purification of restorers **108**
- Genetics of fertility restoration **109**
- Agronomic evaluation of maintainer and restorer lines **109**

WIDE HYBRIDIZATION **110**

BIOCHEMICAL MARKERS **112**
- Identification of genes coding for isozymes **112**
- Mapping of genes coding for isozymes **113**
- Classification based on isozymes **114**

TISSUE CULTURE **114**
- Anther culture **114**
  - Pathways of androgenic initiation in Taipei 309 **114**
  - Heat treatment and callus formation **115**
  - Irradiation of Basmati 370 seeds **116**
  - Production of salt-tolerant lines from F_1 hybrids **116**
  - Recovery of Al-tolerant variants through anther culture **116**
- Somatic cell culture **116**
  - Salinity tolerance studies **116**
  - Somatic embryogenesis **116**

DIRECT SELECTION FOR YIELD IN EARLY GENERATIONS **117**

COOPERATIVE COUNTRY PROJECTS **118**
- Korea **118**
  - Nitrogen response of heterotic F_1 rice hybrids **118**
  - Anther culture **118**
- India, Indonesia, Philippines, and Korea **118**
- Mexico **118**
- Peru **118**
- Philippines and Korea **118**
- WARDA **118**

Plant Physiology and Plant Breeding Departments

Growth and yield of F_1 hybrids at two N levels (*Plant Physiology and Plant Breeding*). Two F_1 rice hybrids (IR747A/IR50 and MR365A/IR36) and their parents along with check variety IR58 were evaluated in the field to investigate the physiological basis of heterosis for growth and yield under 2 N levels (40 and 150 kg/ha) during dry season (DS).

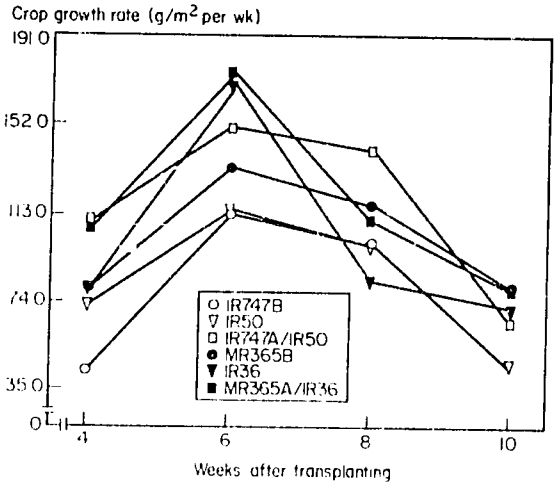
The F_1 hybrids expressed a numerical yield advantage over their parents and the check variety at both levels of fertilization, but highly positive heterosis for grain yield was attained at the lower N level. The total dry weight of the hybrids was higher than that of the parents or the check (Table 1). Higher dry weight in the hybrids was due to higher crop growth rate, especially at the initial growth stage (Fig. 1).

In the heterotic cross, the degree of heterosis in number of spikelets was the highest, followed by 1,000-grain weight.

Combining ability and heterosis (*Plant Breeding*). To select prospective male and female parents of F_1 rice hybrids, the combining ability of 7 maintainer and 11 restorer lines was studied using line × tester analysis. On the basis of grain yield, dry matter (DM), harvest index (HI), plant height, and days to flowering (DTF), three maintainer lines IR19746-27-3-3-1-3, IR19657-87-3-3, and IR21845-90-3 and one restorer IR21576-4-3-3 were identified as good general combiners. Maintainer lines IR19657-87-3-3 and IR21845-90-3 were converted into cytoplasmic male sterile (CMS) lines by backcrossing and are being used to develop new F_1 combinations. The third maintainer line is still in the backcross nursery for conversion into a stable CMS line. The restorer line is also being purified for use in hybrid development.

Table 1. Yield and total dry weight at harvest of F_1 hybrids, their parents, and check variety IR58 at 2 N levels. IRRI, 1985 DS.

Variety or hybrid	40 kg N/ha		150 kg N/ha	
	Yield (t/ha)	Total dry wt (t/ha)	Yield (t/ha)	Total dry wt (t/ha)
IR747B	3.34	7.36	4.77	9.29
IR50	3.36	8.29	4.74	10.73
IR747A/IR50	4.59	8.97	4.92	14.26
MR365B	3.14	6.76	4.66	11.91
IR36	4.49	9.37	5.00	10.73
MR365A/IR36	4.93	9.88	5.07	13.49
IR58 (check)	3.45	8.19	4.89	11.99



1. Crop growth rate in F_1 hybrids and their parents at 40 kg N/ha. IRRI, 1985 DS.

We observed a high correlation between per se performance and general combining ability (GCA) effects of the parental lines for DTF ($r = 0.91$**) and plant height ($r = 0.86$**). For yield ($r = 0.04$), DM ($r = 0.41$), and HI ($r = 0.45$), the correlation coefficients were low and nonsignificant. Hence, per se performance for the latter traits cannot help to predict GCA for those traits.

Significant specific combining ability (SCA) effects were observed in many combinations for all five traits. The combination IR19746-27-3-3-1-3/IR2797-105-2-2-3 was the best because of its high yield, medium growth duration, semidwarf plant height, and reasonable DM production and HI value. Several other good cross combinations were identified.

The study of the relation between GCA and SCA effects showed that almost all kinds of SCA effects could be obtained from any type of parental combinations (Table 2). But the majority of the high SCA combinations involved at least one parent possessing high GCA effect; the other parent could have high, medium, or low GCA effects. Therefore, at least one parent should have high GCA.

Table 2. Number and frequency of cross combinations generated from parents with different types of GCA effects and their corresponding SCA effects[a] for yield, dry matter (DM), harvest index (HI), days to flowering (DTF), and plant height. IRRI, 1985.

GCA of parents	SCA effects	Cross combinations generated									
		Yield		DM		HI		DTF		Plant ht	
		no.	Frequency (%)	no.	Frequency (%)	no.	Frequency (%)	no.	Frequency (%)	no.	Frequency (%)
+/+	+	6	54.5	4	44.4	1	33.3	13	54.2	5	50.0
	0	2	18.2	4	44.4	2	66.7	1	4.2	2	20.0
	−	3	27.3	1	11.1			10	41.6	3	30.0
Total		11		9		3		24		10	
+/− or −/+	+	8	36.4	4	30.8	1	20.0	5	15.6	10	40.0
	0			5	38.4	2	40.0	1	3.7	2	8.0
	−	14	63.6	4	30.8	2	40.0	26	81.2	13	52.0
Total		22		13		5		32		25	
+/0 or 0/+	+	5	26.3	5	25.0	6	28.6	3	75.0	8	61.5
	0	3	15.8	9	45.0	8	38.1			2	15.4
	−	11	57.9	6	30.0	7	33.3	1	25.0	3	23.1
Total		19		20		21		4		13	
−/0 or 0/−	+	5	41.7	5	29.4	4	25.0			2	20.0
	0	4	33.3	7	41.2	5	31.3				
	−	3	25.0	5	29.4	7	43.7	3	100	8	80.0
Total		12		17		16		3		10	
0/0	+			3	27.3	9	32.1				
	0	2	50.0	3	27.3	9	32.1				
	−	2	50.0	5	45.4	10	35.8			2	100
Total		4		11		28				2	
−/−	+	1	14.2	2	33.3	2	100	8	66.7	10	66.7
	0	1	14.2	3	50.0			3	25.0	2	13.3
	−	5	71.4	1	16.7			1	8.3	3	20.0
Total		7		6		2		12		15	

[a] +, 0, or − = positive significant, nonsignificant, or negative significant general (GCA) or specific combining ability (SCA).

Heterosis studies conducted on 75 F_1 hybrids developed from 18 parental lines used for combining ability analysis indicated F_1 superiority over parental lines and the best check variety for all traits (Table 3). The combination IR19746-27-3-3-1-3/IR2797-105-2-2-3 showed significant increase in yield with a standard heterosis value of 33.6%. Nine other hybrids also showed positive standard heterosis values for yield from 14 to 21%, but the values were statistically nonsignificant. Nine hybrids showed yield significantly lower than the check by −59 to −39%. With appropriate choice of parental lines, it should be possible to develop F_1 rice hybrids possessing significant yield superiority over the best purelines in the tropics.

Relation between yield heterosis in F_1 hybrids and genetic divergence among parents determined through isozymes (*Plant Breeding*). Electrophoretic variation was surveyed for 6 enzymes in the 7 maintainers and 11 restorer lines and 75 of their 77 F_1 hybrids. Variation was observed at two loci for esterase and at one locus each for leucine amino-peptidase, shikimate dehydrogenase, phosphogluconate dehydrogenase, and phosphoglucose isomerase.

Heterozygosity at any individual locus was not more frequent among the heterotic hybrids than among the nonheterotic hybrids (Table 4). When isozyme data were pooled to compute interparental distances, the heterotic crosses did not appear to involve parents more distant from each other than the nonheterotic crosses. Thus, the isozymes investigated are of no use in predicting heterosis in the material studied.

Physiological analysis of heterosis (*Plant Physiology and Plant Breeding*). Hybrid rices have higher initial growth rates than their parents, because of either higher initial embryo weight or

Table 3. Summary of heterosis, heterobeltiosis, and standard heterosis ranges for yield, dry matter, harvest index, plant height, and days to flowering. IRRI, 1985.

Trait	Range[a]	Heterosis		Heterobeltiosis		Standard heterosis	
		%	Hybrids (no.)	%	Hybrids (no.)	%	Hybrids (no.)
Yield	A	-45 to 157	31	-59 to 98		-59 to 34	
	B	28 to 157	1	39 to 98	13	34	1
	C	-45		-59 to -31	5	-59 to 30	9
Dry matter	A	-24 to 65		-42 to 60		-40 to 58	4
	B	29 to 65	14	23 to 60	6	36 to 58	4
	C	<-24	0	-42 to 25	7	-40 to 32	4
Harvest index	A	-35 to 98		-35 to 1		-36 to 15	
	B	25 to 98	13	25 to 31	2	>20	0
	C	-35 to -23	2	-35 to 29	2	-36 to 25	8
Days to flowering	A	-16 to 14		-12 to 29		-27 to 19	
	B	3 to 13	3	3 to 29	40	4 to 19	10
	C	-16 to - 3	44	-12 to - 3	13	-26 to 53	
Plant height	A	- 9 to 24		7 to 55		-21 to 27	
	B	7 to 24	41	10 to 55	63	8 to 27	20
	C	- 7 to 8	2			-20 to - 8	21

[a]A = overall range, B = positive significant range, C = negative significant range.

Table 4. Comparison of heterotic and nonheterotic crosses for isozyme characteristics.

Type of cross	Number	Frequency (%) of F_1 progenies heterozygous at given locus						Av interparental distances	
		Est-Ca	*Est-E*	*Lap-F*	*Sdh-A*	*Pgi-B*	*Pgd-A*	D_1[a]	D_2[b]
Heterotic	31	16.1	45.2	45.2	29.0	51.3	29.0	2.26	3.94
Nonheterotic	44	4.5	61.4	61.4	25.0	63.6	59.1	2.75	4.66

[a]Av number of gene differences between the parents. [b]Av number of isozymes produced in the hybrids in addition to the parental ones.

higher relative growth rate. Experiments were conducted to determine the causes for such higher initial growth rate in hybrid rice.

Embryo size. The embryos of all F_1 hybrids tested were bigger than those of the midparents, and the embryos of 9 of 15 F_1 hybrids were significantly bigger than those of the better parents (Table 5). The heterosis for embryo weight in the F_2s of two crosses, IR747 IR50 (heterosis 1.01) and MR365A IR36 (heterosis 0.98), was significantly reduced from the heterosis values obtained in the corresponding F_1s (1.16 and 1.26, respectively).

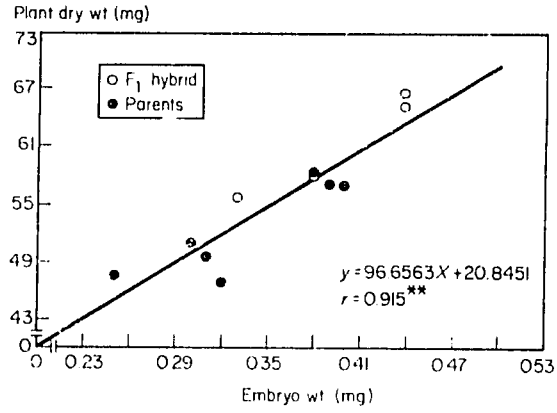
Initial growth rate. There was a highly positive correlation between embryo size and plant dry weight 16 d after germination when 4 F_1 hybrids and their parents were grown in full strength nutrient solution (Fig. 2). There was no correlation between endosperm weight and plant dry weight 16 d after germination. However, little variation was found in the relative growth rates of hybrids and of their parents.

The higher initial growth of F_1 hybrid rices is thus due to bigger embryos and not to higher growth rate.

In a related study of germination properties of F_1 seeds of a different set of 10 hybrid rices and their parents, chemists found that heterosis for degermed brown rice weight correlated positively better than heterosis for germ weight with heterosis for shoot weight after growing 10 d in water or 9 d in nutrient solution. The best performer was the F_1 combination 97A IR13420-6-3-3-1, with heterosis values of 50% for caryopsis weight, 49% for shoot weight in water, and 50% for shoot weight in nutrient solution.

Table 5. Weight of embryos of F_1 hybrids and their parents. IRRI, 1985.

Parents and F_1 hybrids	Weight (mg)	
	Embryo	Parents' mean values
IR46830B	0.40 a	
IR9761-19-1	0.30 b	0.35
IR46830A/IR9761	0.38 a	
IR21845-90-3B	0.25 b	
IR54	0.32 a	0.285
IR21845A/IR54	0.33 a	
97B	0.38 b	
Milyang 54	0.39 b	0.385
97A/Milyang 54	0.44 a	
IR46830B	0.40 b	
IR50	0.31 c	0.355
IR46830A/IR50	0.44 a	
IR46830B	0.37 b	
Milyang 54	0.38 b	0.375
IR46830A/Milyang 54	0.45 a	
V20B	0.37 b	
Milyang 54	0.38 b	0.375
V20A/Milyang 54	0.44 a	
V20B	0.37 b	
Iri 347	0.35 b	0.36
V20A/Iri 347	0.40 a	
IR46830B	0.37 ab	
Iri 347	0.35 b	0.36
IR46830A/Iri 347	0.38 a	
IR46828B	0.28 b	
IR54	0.32 a	0.30
IR46828A/IR54	0.32 a	
IR46828B	0.28 b	
IR13524-21-2-3-3-2	0.30 b	0.29
IR46828A/IR13524-21-2-3-3-2	0.34 a	
IR46830B	0.37 a	
Milyang 46	0.38 a	0.375
IR46830A/Milyang 46	0.38 a	
IR46830B	0.37 a	
Suweon 294	0.31 b	0.34
IR46830A/Suweon 294	0.36 a	
V20B	0.37 b	
IR9761-19-1	0.31 c	0.34
V20A/IR9761-19-1 or Wei You 64	0.45 a	
IR747B	0.38 b	
IR50	0.33 c	0.355
IR747A/IR50	0.41 a	
MR365B	0.35 c	
IR36	0.28 b	0.315
MR365A/IR36	0.39 a	



2. Relation between embryo size and plant dry weight of F_1 hybrids and parents 16 d after germination. IRRI, 1985.

Cytoplasmic male sterility and fertility restoration (*Plant Breeding*). The seven CMS lines developed and designated at IRRI during 1983 were evaluated at IRRI and in India, Indonesia, and Korea. The seven are better adapted to the tropics than the Chinese CMS lines V20A, Zhen Shan 97A, and V41A. IR46828A, IR46830A, and IR48483A showed wider adaptability than the others. Observations made on a large number of testeross F_1s made with these CMS lines, however, indicated that they are poor general combiners.

During 1985 seven additional CMS lines were developed and designated at IRRI (Table 6). Three of them are in the genetic background of varieties or elite lines developed in Korea and India, and the maintainers of the remaining lines were bred at IRRI. Combining ability studies on two of the lines, IR54752A and IR54754A, indicated that they are good general combiners.

The line IR54755A has been derived from a cytoplasmic source ARC13829 (Acc. 42469). Its maintainer is also the maintainer for wild aborted (WA) cytosterile lines, viz., V20A and IR46828A. Studies are in progress to determine if the cytoplasmic factor inducing male sterility in CMS lines derived from WA and ARC13829 cytoplasm are the same.

We identified additional effective maintainer lines for WA CMS lines. For CMS lines possessing the cytosterility system different from WA, we also identified some maintainers (Table 7). Suweon 326 was the first semidwarf maintainer of the cytosterile line P203A developed at IRRI from

Table 6. CMS lines designated at IRRI during 1985.

Line	Parentage		Origin of maintainer line
	Female	Male parent (maintainer)	
IR54752A	97A/8*IR21845-90-3	IR21845-90-3	IRRI
IR54753A	97A/8*IR19657-34-2-2-3-3	IR19657-34-2-2-3-3	IRRI
IR54754A	V20A/8*IR19657-87-3-3	IR19657-87-3-3	IRRI
IR54755A	ARC13829-16/6*IR10179-2-3-1	IR10179-2-3-1	IRRI
IR54756A	97A/8*Iri 356	Iri 356	Korea
IR54757A	97A/7*Suweon 310	Suweon 310	Korea
IR54758A	V20A/4*PAU269-1-8-4-1-1-1	PAU269-1-8-4-1-1-1	Punjab, India

Table 7. Maintainers and restorers for 4 cytosterile systems identified among Korean and IRRI rices. IRRI, 1985 WS.

Line	Varietal type[a]	F_1 spikelet fertility[b] in testcrosses with CMS lines				
		P203A (S_1) TN1	Wu 10A (S_1) BT	YAZA (S_3) Gam	MS577A (S_4)	Reimei A (*O. rufipogon*)
Suweon 287	i X j	PF	–	–	S	S
Suweon 288	i X j	PS	–	–	S	S
Suweon 325	i X j	PS	–	F	–	S
Suweon 326	i X j	S	–	–	–	–
Milyang 68	i X j	PF	–	F	S	S
Suweon 222	j	PS	–	S	S	S
Suweon 303	j	–	–	S	S	S
Suweon 304	j	PF	S	S	–	S
Milyang 75	j	PS	S	S	–	S
Cheolweon 21	j	–	–	S	S	S
Cheolweon 29	j	–	–	S	S	S
Jibu 2	j	PF	S	S	–	S
Jinheung	j	–	S	S	S	S
Pungok	j	–	–	S	S	S
IR46828B	i	PS	PF	PF	PS	S
IR46831B	i X j	PS	–	PF	PS	S

[a]j = japonica, i = indica, i X j = indica/japonica derivative. [b]

Code	Spikelet fertility (%)	Remark
F =	89-100	Restorer
PF =	30- 80	Partial restorer
PS =	1- 30	Partial maintainer
S =	0	Maintainer

Taichung Native 1 cytoplasm. P203A is a tall, photoperiod-sensitive CMS line; hence, it could not be used in developing F_1 hybrids possessing improved plant type. Several lines showed the ability to maintain the sterility of more than one cytosterile line, e.g., Suweon 304, Suweon 303, Cheolweon 21, Cheolweon 29, Jibu 2, and Jinheung. An effective restorer line for cytosteriles P203A, Wu 10A, MS577A, and Reimei A is still to be identified.

Identification and purification of restorers (*Plant Breeding*). We continued to identify additional restorer lines for new WA cytosterile lines developed at IRRI. About 200 restorers were identified during the year. Most of the elite lines identified as restorers over the years are not genetically pure for restoration ability. Their use as such in the development of the experimental hybrids results in some F_1 plants with partial spikelet fertility, which reduces the yield potential of the hybrids.

We initiated a restorer purification program by testcrossing and retestcrossing single plants of the elite lines identified as restorers with the selected

CMS lines. The testcross and retestcross progenies were grown along with the single plant progenies of the elite lines. Their spikelet fertility was observed, and the testcross and retestcross F_1 progenies showing normal seed set were marked. The seeds were collected from the corresponding single plant progenies of the testcross F_1s marked for complete fertility restoration. These were purified restorers and were designated with the suffix "R." During the year, 40 restorer lines (Table 8) were purified. These are being used in developing new experimental F_1 hybrids.

Table 8. Purified restorers, IRRI, 1985.

Restorers[a]	Tester CMS line
IR15795-23-2-3-3-3-2R	IR46826A
IR36R	IR46828A
IR54R	IR46828A, IR46830A, and IR54752A
IR2797-125-3-2-2R	IR46828A
IR19392-98-1-2-2R	IR46828A
BR201-193-1R	IR46829A
AD9246R	IR46829A
IR21916-128-2-2-2-3R	IR46829A
IR25924-92-1-3R	IR46829A
IR27280-39-2-2-3-2R	IR46829A
IR28413-66-3-3-3-2R	IR46829A
IR28237-31-3-2-1R	IR46829A
IR31802-56-4-3-3R	IR46829A
IR32841-46-1-1R	IR46829A
IR50R	IR46830A
IR9761-19-1R	IR46830A
IR13292-5-3R	IR46830A
Milyang 46R	IR46830A
Milyang 54R	IR46830A
IR46R	IR54753A
IR27315-145-1-3-2R	IR54753A
ARC11353R	IR54753A
IR13419-113-1R	IR54752A
IR13429-150-3-2-1-2R	IR54752A
IR15324-12-3-3-2R	IR54752A
IR19661-63-1-2-3-1-3R	IR54752A
IR20959-11-3-2R	IR54752A
IR25537-67-2-2-1-2R	IR54752A
IR25683-8-2-3R	IR54752A
IR28226-24-1-2-3-2R	IR54752A
IR28228-119-2-3-1-1R	IR54752A
IR31432-6-2-1R	IR54752A
IR31432-9-5-2R	IR54752A
IR31833-38-2-2-2R	IR54752A
IR31916-9-2-2-2R	IR54752A
IR32358-90-3-3R	IR54752A
IR33043-55-1-2R	IR54752A
IR33047-69-3-3R	IR54752A
IR2797-105-2-2-3R	MR365A
IR42R	Zhen Shan 97A

[a]A purified restorer line is designated as "R."

Genetics of fertility restoration (*Plant Breeding*). Continuing genetic analysis of fertility restoration of WA (S_2) type cytosterility involved additional crosses with restorers. Previous results (Annual report for 1984) had indicated that the fertility restoration ability of IR54, IR9761-19-1, and IR42 was governed by two independent and dominant genes, and that one of the genes was stronger in action. The mode of interaction of the 2 genes varied in different crosses, indicating dominant epistasis (F_2 ratio of 12 fertile:3 partially fertile or partially sterile:1 sterile), recessive epistasis (F_2 ratio of 9:3:4), or semi-epistasis (F_2 ratio of 9:6:1). We obtained similar results in additional crosses involving restorers IR26, IR36, and IR54 (Table 9). It was noted, however, that the mode of interaction of the two genes was not always consistent; it would change in different crosses. The crosses made with IR36 restorer displayed differential segregation behavior in F_2 and the corresponding backcrosses with regard to the mode of interaction of the two genes, perhaps because of the effect of variable expression of the "weak" gene in different genetic backgrounds and its differential expressivity under different environments.

The allelic test was conducted by crossing different restorer lines and testcrossing their F_1s with a CMS line. The absence or presence of male sterile plants in the testcross F_1 progenies indicated presence or absence of identical genes, respectively, in the two restorers. Results (Table 10) showed that IR26 and IR36 possessed identical restorer genes, as did IR9761-19-1 and IR54. IR9761-19-1 and IR54 appeared to possess at least one of the two restorer genes different from those in IR26 and IR36.

Agronomic evaluation of maintainer and restorer lines (*Plant Breeding*). In a hybrid breeding program based on the CMS fertility restoration system, it is imperative to identify a large number of restorer and maintainer lines. To reduce them to a manageable number, the lines need to be critically evaluated for days to flowering and yield. During 1984, we evaluated 302 maintainer and restorer lines selected from national and international rice breeding programs and 5 check varieties and elite lines (IR58, IR36, IR62, IR54, and IR29723-143-3-2-1) representing growth duration from 100 to 140 d. The evaluation used 3-row

Table 9. Segregation pattern for pollen fertility restoration of wild aborted CMS system in some crosses, IRRI, 1985.

Cross	Generation	Total no. of plants observed	Plants (no.) with indicated pollen fertility reactions[a]						P
			FF	F	PF	PS	S	HS	
V20A//V20A/IR26	BC	82	6	12	21	13	6	24	0.75-0.50 (1:2:1)
V20A/IR26//V20B	BC	76	21	3	17	6	8	21	0.25-0.10 (1:2:1)
V20A/IR26	F_2	281	122	41	45	35	14	24	0.25-0.10 (9:6:1)
V20A//V20A/IR36	BC	45	14	8	8	2	1	12	0.975-0.950 (2:1:1)
V20A/IR36//V20B	BC	82	28	13	12	6	3	20	0.990-0.975 (2:1:1)
V20A/IR36	F_2	286	139	32	59	24	10	22	0.25-0.10 (9:6:1)
IR46828A//IR46828A/IR36	BC	68	7	8	10	10	0	33	0.75-0.50 (1:1:2)
IR46828A/IR36//IR46828B	BC	108	18	11	13	14	3	49	0.75-0.50 (1:1:2)
IR46828A/IR36	F_2	301	143	35	54	30	11	28	0.10-0.50 (9:6:1)
V20A//V20A/IR54	BC	71	28	3	14	6	1	19	0.75-0.50 (2:1:1)
V20A/IR54//V20B	BC	68	24	5	14	4	2	19	0.50-0.25 (2:1:1)
V20A/IR54	F_2	291	203	28	30	8	1	21	0.10-0.05 (12:3:1)

[a]FF (fully fertile) = 80-100% pollen fertility, F (fertile) = 60-80%, PF (partially fertile) = 30-60%, PS (partially sterile) = 10-30%, S (sterile) = 1-10%, HS (highly sterile) = 0.

Table 10. Test of allelism in some restorers, IRRI, 1985.

Testcross	Total no. of plants observed	Plants (no.) with indicated pollen fertility reaction[a]					
		FF	F	PF	PS	S	HS
V20A//IR26/IR36	68	60	8	–	–	–	–
V20A//IR26/IR9761-19-1	73	61	7	2	2	–	1
V20A//IR36/IR9761-19-1	82	68	7	2	1	–	4
V20A//IR36/IR54	94	85	4	3	0	–	2
V20A//IR9761-19-1/IR54	175	157	15	3	–	–	–

[a]FF (fully fertile) = 80-100% pollen fertility, F (fertile) = 60-80%, PF (partially fertile) = 30-60%, PS (partially sterile) = 10-30%, S (sterile) = 1-10%, HS (highly sterile) = 0.

plots of 25 plants each with 20- × 20-cm spacing and employed the augmented design proposed by Federer in 1956. On the basis of performance per se, we identified 6 maintainer and 15 restorer lines (Table 11) as promising potential parents in developing heterotic hybrids. One maintainer line, IR19657-34-2-2-3-3, was converted into a CMS line (IR54753A) to develop experimental F_1 hybrids.

WIDE HYBRIDIZATION

Plant Breeding Department

The wild species of *Oryza* are a rich source of useful traits for rice improvement. It is easier to transfer genes from the wild species with AA genome to cultivated rice; species with BB, CC, DD, and EE genomes are difficult to cross with cultivated rice. We attempted crosses between 3 breeding lines of

Table 11. Mean (adjusted) data on flowering and yield of promising maintainer and restorer lines. IRRI, 1984 WS.

Line or variety	Days to 50% flowering	Yield (g/m^2)	% increase in yield over comparable check
Maintainers			
IR15429-268-1-2-1	68	294	47
IR19819-31-2-3-1-1	71	348	74
IR19728-9-2-2-3-3	74	308	54
IR28138-43-3-1-3-2	76	371	66
IR25560-109-3-1-3-2	80	397	62
IR19657-34-2-2-2-3-3	94	580	136
Restorers			
IR9752-222-3-2	72	523	161
IR25571-5-3	72	378	89
IR25924-92-1-3	73	381	90
IR19743-25-2-2-3-.	73	355	78
IR8455-78-1-3-3	74	341	71
IR28192-40-2-1-3	77	380	70
IR9129-209-2-2-2-1	80	371	51
IR50	82	340	38
IR21916-128-2-2-2-3	87	433	76
IR64	87	379	54
IR25912-63-2-2	88	543	121
IR13146-45-2-3	88	448	82
IR28178-28-1-2	88	438	78
IR22083-75-3-3-1-3	89	427	74
ARC 13558	89	405	65
Checks			
IR58	73	200	–
IR36	79	223	–
IR62	83	246	–
IR54	87	240	–
IR29723-143-3-2-1	97	394	–
LSD (5%)	5	88	
LSD (1%)	5	123	

cultivated rice and 18 accessions of *O. officinalis*. *O. officinalis* is highly resistant to brown planthopper (BPH), whitebacked planthopper (WBPH), and green leafhopper, and has the CC genome.

The crossability between *O. sativa* and *O. officinalis* is very poor. However, we obtained 438 F_1 plants through embryo rescue. The highest number of F_1 plants was obtained in the crosses with *O. officinalis* from the Philippines, followed by those from Japan, Malaysia, and Thailand. The hybrids were intermediate between the two parents in some respects but showed a preponderance of wild species traits. They were robust, extremely vigorous, and completely male sterile.

Five F_1 plants were triploids and probably resulted from the union of unreduced gametes with haploid gametes. The rest were diploid, in which there was complete absence of chromosome pairing at diakinesis and metaphase I. Twenty-four univalents were observed in most pollen mother cells (PMCs) except in a few that had occasional pseudobivalents (Table 12).

The F_1s were backcrossed with the respective *O. sativa* parents. Seed set was extremely poor. Since the spikelets of the F_1 plants were highly shattering, we applied exogenous growth regulators (GA_3, NAA, and K in the ratio of 20:5:1) 2 times a day for 5 d. Out of 41,437 F_1 spikelets that were pollinated, 1.3% set seed. Some BC_1 seeds failed to germinate, but well-formed seeds gave 367 BC_1 plants. Out of these, 10 plants were hypotriploid and the rest triploid, indicating that the unreduced gametes on the female side were mostly functional. These triploids were of AAC constitution.

The hypotriploids were extremely weak and

Table 12. Chromosome associations at diakinesis in the interspecific hybrids between 3 breeding lines of *Oryza sativa* and *O. officinalis* accessions. IRRI, 1985.

O. sativa line used as female	Pollen mother cells studied (no.)	Bivalents (no./cell)		Univalents (no./cell)	
		Mean	Range	Mean	Range
IR1529-680-3-2	236	1.73	0-4	22.27	20-24
IR25587-109-2-3-3-3	232	0.5[illegible]	0-3	23.45	21-24
IR31917-45-3-2	50	0.46	0-3	23.52	21-24

stunted, but all triploids were vigorous. They had intermediate height, profuse tillering, long panicles, and large spikelets with long awns. However, all of them were completely male sterile.

All of the 357 allotriploid plants were backcrossed with the respective cultivated recurrent parents. Of 41,487 spikelets pollinated and treated with growth regulators, we obtained 153 imperfectly developed seeds. When germinated in vitro, the seeds produced 94 BC_2 plants. The chromosome number of these plants varied between 2n and 2n + 6 (Table 13). Twenty-five disomic plants were fully fertile and resembled the *O. sativa* parent closely. The modal chromosomal association in these plants was 12II, but 11II + 2I was observed in some cells. The plants with extra chromosomes had the full chromosome complement of *O. sativa*; the extra chromosomes came from *O. officinalis*. Thus these plants showed 12 bivalents, but the alien chromosomes were present as univalents. The plants with 26, 27, 28, 29, and 30 chromosomes were highly sterile and greatly modified. However, the plants with 25 chromosomes — monosomic alien addition lines — are of great interest.

When the morphology of the monosomic alien addition lines was compared with that of the primary trisomics of *O. sativa*, some plants showed striking resemblances to specific trisomics. Three plants each resembled triplo-4 and -9; 2 plants each resembled triplo-1, -2, -6, and -10; and 1 each resembled triplo-3, -5, -7, -8, -11, and -12. Thus, monosomic alien addition lines corresponding to each of the 12 chromosomes of *O. officinalis* were obtained. However, some 2n+1 plants cannot be matched with any of the trisomics of *O. sativa*; their extra chromosomes may be modified chromosomes.

The salient morphological features of the monosomic alien addition lines are given in Table 14. During meiosis, 12 bivalents and 1 univalent are formed in all the alien addition lines. We are now studying the transmission rates of the alien chromosomes in these lines. We are also characterizing the alien addition lines as well as disomic BC_2 progenies for various agronomic traits and for resistance to leafhoppers and planthoppers. Preliminary observations indicate that several useful traits such as earliness and resistance to BPH and WBPH have been transferred from *O. officinalis* to *O. sativa*.

Table 13. Chromosome number of BC_2 progeny in the cross of *O. sativa*/*O. officinalis*, IRRI, 1985.

Chromosome no.	Plants obtained (no.)	Percentage
24	25	26.6
25	40	42.5
26	11	11.7
27	10	10.6
28	4	4.3
29	3	3.2
30	1	1.1
Total	94	100.0

BIOCHEMICAL MARKERS

Plant Breeding Department and International Rice Germplasm Center

Identification of genes coding for isozymes. Electrophoretic variation of 10-14 enzymes from coleoptiles + plumules of 5- to 7-day-old seedlings was surveyed among 3,131 varieties of *Oryza sativa* L. and was found explainable by gene polymorphism at 21 loci (Table 15). Data on segregation of the electrophoretic markers in F_2 progenies obtained at IRRI and elsewhere confirmed the genetic hypotheses for 18 of the 21 loci. *Amp-4*, *Pgd-2*, and *Pox-5* still have to be tested.

Table 14. Vegetative and reproductive features of 12 alien addition lines of rice having 1 chromosome of *O. officinalis*. IRRI, 1985.

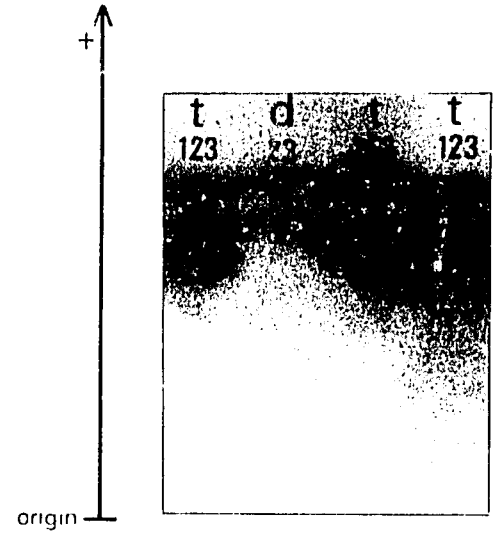
Addition line (no.)	Plant height (cm)	Leaf length (cm)	Leaf width (mm)	Ligule length (mm)	Panicle length (cm)	Spikelets/ panicle	Pollen fertility (%)	Spikelet fertility (%)
1	49	31.67	5.2	5.5	15.5	50	17.49	1.0
2	41	33.54	12.6	13.8	16.1	70	23.5	1.0
3	54	29.10	10.2	11.0	15.8	39	54.6	2.0
4	68	34.10	10.0	6.0	22.7	151	0.0	0.0
5	65	29.12	11.0	6.5	18.0	85	41.2	40.0
6	91	28.10	13.8	9.4	21.5	96	85.0	54.6
7	93	31.00	9.6	5.8	26.7	87	40.8	13.7
8	45	37.20	7.8	10.8	23.8	74	35.0	12.7
9	80	51.50	17.0	14.5	30.0	136	94.5	43.2
10	78	41.40	11.3	11.3	23.0	71	72.1	38.8
11	80	35.50	15.0	7.5	24.8	113	64.5	29.2
12	110	22.17	15.1	8.5	25.9	159	56.4	82.4
IR31917-45-3-2	88	35.58	16.2	15.4	26.86	142	95.0	89.0

Mapping of genes coding for isozymes. *Est-2* is known to be located on chromosome 3. *Amp-3* and *Pgi-2* were found tightly linked with it with respective recombination values of 0.0009 ± 0.0008 and 0.072 ± 0.013. *Est-2*, *Amp-3*, and *Pgi-2* are thus located on chromosome 3. The location of *Pgi-1*, *Sdh-1*, *Est-8*, and *Adh-1* was investigated by trisomic analysis. Trisomics with IR36 background were crossed with two indica lines (Acc. 33364 and 56036). From each F_1, 30-60 plants were analyzed to look for gene dosage effects. Variations among their zymograms explainable by gene dosage effects were found in trisomic 6/Acc. 56036 for *Sdh-1*, trisomic 7/Acc. 56036 for *Est-8*, and trisomic 11/Acc. 33364 for *Adh-1*. In addition, a plant of trisomic 6 that was heterozygous for *Sdh-1* gene could be used in a cross with Acc. 56036 to create F_1 plants carrying three alleles, which produced electrophoretic patterns with three bands (Fig. 3). Segregation of the bands was analyzed in

Table 15. Genetic interpretation of the electrophoretic variation observed for 14 enzymes in a survey of Asian cultivated rice. IRRI, 1985.

Enzyme	Polymorphic loci (no.)	Alleles (no.)
Phosphoglucose isomerase	2	4, 4
Glutamate oxaloacetate transaminase	1	2
Shikimate dehydrogenase	1	4
Alcohol dehydrogenase	1	5[a]
Isocitrate dehydrogenase	1	4[a]
Phosphogluconate dehydrogenase	2	3, 2
Malic enzyme	1	2
Leucine aminopeptidase	2	7[a], 5
Alanine aminopeptidase	1	5[a]
Arginine aminopeptidase	1	3
Esterase	4	2, 3[a], 3[a], 3[a]
Acid phosphatase	2	3, 2
Catalase	1	3
Peroxidase	1	2

[a]Including one silent allele.



3. Zymograms of shikimate dehydrogenase (SDH) in a progeny of trisomic 6/Acc. 56036. SDH is coded by gene *Sdh-A*. From left to right: trisomic plant with alleles 1, 2, and 3; disomic plant with alleles 2 and 3; trisomic plant with 2 copies of allele 2 and 1 copy of allele 3; and trisomic plant with alleles 1, 2, and 3.

Table 16. Segregation (A only: B only: A and B) in progenies of primary trisomics (A only) and disomics (B only) for 4 loci coding for isozymes. IRRI, 1985.

Primary trisomic	Progeny and disomic segregation (A only: B only: A and B)	Segregation for each locus[a]			
		Pgi-A	*Sdh-A*	*Est-Ca*	*Adh-A*
1	BC (0:1:1)	0:44:55	0:47:54	0:43:57	0:45:54
2	F_2 (1:1:2)	25:25:50	32:29:62	24:30:62	32:29:62
3	F_2 (1:1:2)	37:45:78	31:28:62	30:26:62	35:30:65
4	BC (0:1:1)	0:37:103*	0:82:96	0:67:81	0:86:102
5	F_2 (1:1:2)	25:14:46	20:18:39	29:29:64	24:22:49
6	F_2 (1:1:2)	79:57:135	78:22:103*	28:25:54	36:32:69
7	F_2 (1:1:2)	25:22:60	31:25:51	33:5:72*	31:30:64
8	F_2 (1:1:2)	29:23:68	20:21:42	26:25:54	24:20:49
9	F_2 (1:1:2)	65:55:111	28:28:64	53:132:177*	38:30:64
10	F_2 (1:1:2)	21:24:48	28:30:62	26:30:60	39:36:76
11	F_2 (1:1:2)	38:33:79	20:21:46	34:35:73	59:20:98*
12	F_2 (1:1:2)	21:32:48	29:28:48	32:29:67	35:28:56

[a]* = significantly (5%) different from disomic segregations.

backcrosses with the disomic parent for trisomics 1 and 4 and in F_2 progenies for the other trisomics (Table 16). Eleven disomic segregations and one trisomic segregation were observed for loci *Pgi-1*, *Sdh-1*, and *Adh-1*. *Est-8* segregated in a disomic manner in 10 progenies, in a trisomic manner in 1 progeny, and in an opposite distorted manner in 1 progeny not attributable to trisomy. Thus, *Pgi-1* is located on chromosome 4, *Sdh-1* on chromosome 6, *Est-8* on chromosome 7, and *Adh-1* on chromosome 11.

Classification based on isozymes. Enzymatic characters present several advantages over the usual macroscopic traits used for varietal classification:

- They are independent of the environment.
- They are free from epistatic relationships.
- They have the same genetic weight.
- They are not subject to conscious human selection.

Data obtained in 1983 and 1984 on 1,688 traditional varieties for 15 genes coding for enzymes were reanalyzed using factor analysis of correspondences. The existence of the six varietal groups previously identified was confirmed (Fig. 4). Most traditionally recognized ecotypes have a clear position in the classification (Fig. 5), and their mutual relationships can be reevaluated (Fig. 6). Major elements are

- the similarity between the temperate japonica rices, the tropical japonica rices (javanica), and most upland rices; all fall into group VI; and
- the existence of well differentiated types among the varieties usually classified as indica (groups I to V), some of which (groups IV and V) appear close to the japonica group (group VI).

Identification of such varietal groups separated by restricted recombination in natural conditions permits improved exploitation of available germplasm. Crosses within the groups will facilitate transfer of characters between the parents. Crosses between the groups may create novel variations, but genetic and physiological imbalances may be met during their exploitation.

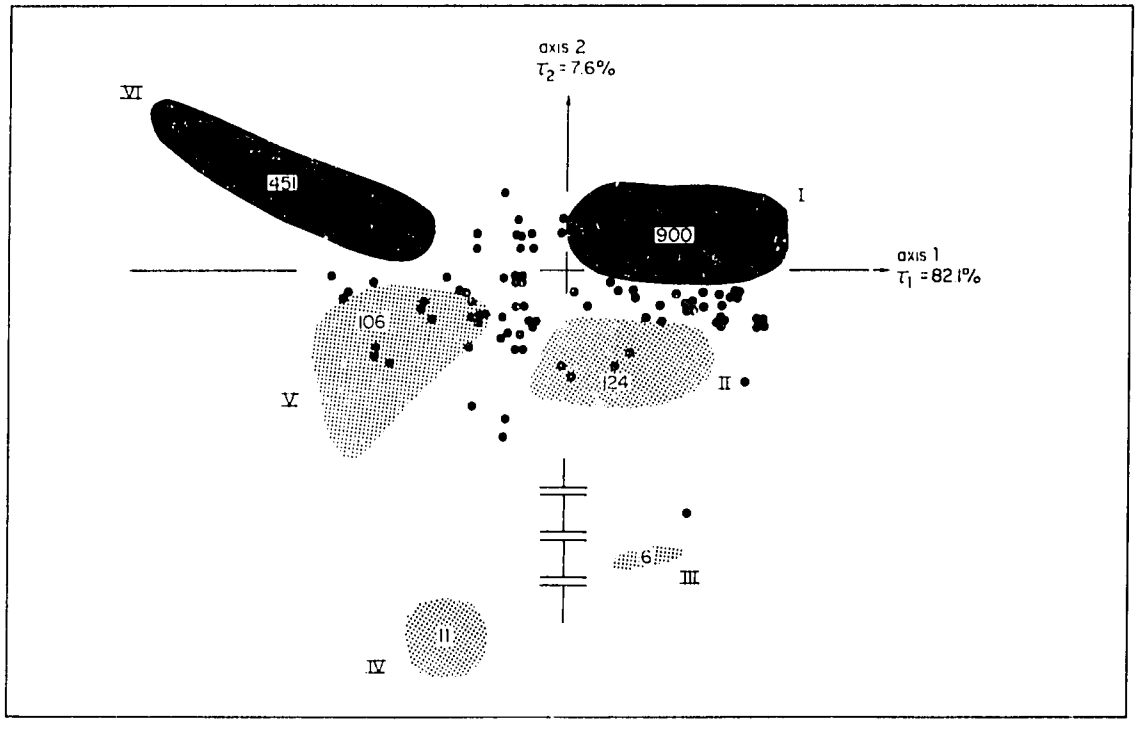
In 1985, 1,443 other varieties or lines were classified by this method.

TISSUE CULTURE

Tissue Culture Facility and Plant Physiology and Plant Breeding Departments

Anther culture (*Tissue Culture, Plant Physiology, and Plant Breeding*). Low efficiencies of callus production and green plant regeneration are constraints to the use of anther culture techniques in rice breeding. Understanding the mechanisms of switching the development of pollen grains from their usual gametophytic role toward sporophytic functions and manipulation of conditions either before or during anther culture itself are beneficial.

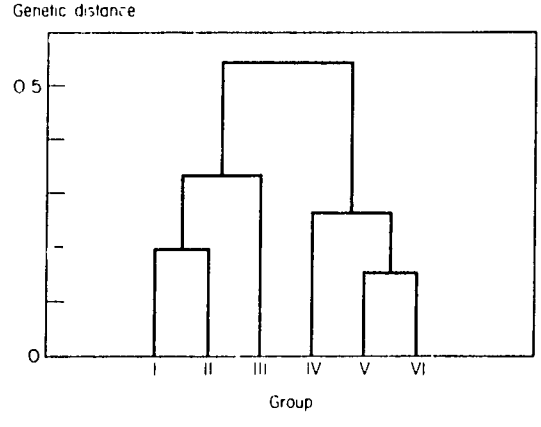
Pathways of androgenic initiation in Taipei 309 (*Tissue Culture*). Three pathways of androgenesis were identified in the development of uninucleate



4. Six varietal groups on plane (1, 2) of a factor analysis of correspondences of isozyme variation at 15 loci among 1,688 traditional varieties. IRRI, 1985. Sizes of the groups are indicated. Isolated dots represent 90 varieties with intermediate positions or unstable classification when axes 3 and 4 are considered.

	Groups based on isozymes					
	I	II	III	IV	V	VI
Main groups	Indica					Japonica • temperate • tropical (javanica)
Local ecotypes	—Hawa— —Tjeroh—					—Kong— —Bulu—
		—Bern— —Aus—				
	—Amar—		----------			
Water regimes				—Lowland—		
	----------					—Upland—

5. Correspondence between classification based on isozymes and other classifications. IRRI, 1985.



6. Dendrogram constructed from the genetic distances among 6 groups of varieties as estimated from 21 polymorphic loci coding for isozymes. IRRI, 1985.

and binucleate pollen grains. Pathway I occurred in uninucleate pollen grains where the derivative nuclei were similar. Pathways II and III occurred in binucleate pollen. In pathway II only the vegetative nucleus took part in the formation of callus; in pathway III the generative nucleus divided first, followed by the vegetative nucleus; both contributed to the development of the callus. Pathway I was observed to be the most frequent (18.1 vs 6.2% for pathway II and 1.0% for pathway III).

Heat treatment and callus formation (Tissue Culture). The increase in callus induction efficiency as a result of cold treatment has been ascribed to a number of factors such as dissolution of microtubules, alteration in the first pollen mitosis, and maintenance of a higher ratio of viable pollen

capable of pollen embryogenesis. Heat shock (35 °C for 15 min) followed by cold shock for 7 d doubled callus production in IR42. In Taipei 309 the optimum heat treatment was 35 °C for 20 min.

Irradiation of Basmati 370 seeds (Tissue Culture). Previous experiments on anther culture of Basmati 370 yielded only albino plants. Hence irradiation was applied to the seeds to serve as a stress to induce a shift in plant regeneration from albino to green. Aside from this genetic alteration, the regenerated plants may also manifest new variability such as resistance to lodging or reduced plant height. Green plants were produced from anthers originating from seeds exposed to 20 and 25 krad (Table 17). Of the 46 plants produced, 22 lines were autodiploids.

Production of salt-tolerant lines from F_1 hybrids (Tissue Culture, Plant Physiology, and Plant Breeding). Twenty-six IR crosses were passed through anther culture to immediately produce salt-tolerant homozygous diploids. Of the 19 F_1 hybrids that produced calli, 4 regenerated green plants. By year end, 425 green plants had been recovered from 23 calli.

Recovery of Al-tolerant variants through anther culture (Tissue Culture). Gametoclonal variants were recovered from Al-susceptible varieties Giza 170 and Fujisaka 5. In initial screening of 71 anther culture-derived lines of Giza 170, 53 were more tolerant than the parents, as indicated by higher values of their relative root length. Four were considered tolerant. All 29 anther culture lines of Fujisaka 5 were more tolerant than the parent, and 4 were considered tolerant. When seeds of the eight tolerant lines were subjected to second screening, two lines from Giza 170 and one from Fujisaka 5 maintained their tolerance. Anther culture could thus be a tool for producing Al-tolerant variants. In some cases, physiological adaptation of the plants to the stress occurred, causing loss of tolerance of some lines in the second screening. Genetic change that involved Al tolerance simultaneously occurred as shown by the consistent tolerance of some lines in the first and second screening.

Somatic cell culture *(Tissue Culture). Salinity tolerance studies.* The capacity to regenerate plants from cultured cells varies inversely with the time the cells are cultured in vitro. On the other hand, the chance to select mutant cell lines is in direct proportion to the duration of cell exposure to the selection agent, in this case NaCl-enriched medium (15 g/liter).

Calli of variety Reiho previously cultured on NaCl-enriched medium for 32 mo showed higher growth in the control than at different levels of NaCl (Table 18). Decreasing weight at increasing NaCl concentration indicated that the cells had undergone only physiological adaptation and not mutation. Furthermore, green plants that were regenerated from calli stressed with 15 g NaCl/liter did not survive when grown in a culture solution containing 5 g NaCl/liter. The controls survived but were all sterile, and chromosome studies later revealed that they were aneuploids. Tolerance at the cellular level does not mean subsequent tolerance at the whole plant level.

Somatic embryogenesis. Somatic embryogenesis, a one cell-one plant phenomenon, allows the production of true-to-type plants. Somatic embryos, if produced in large quantities and properly synchronized and encapsulated, could serve as synthetic seeds for the hybrid rice program. In the conventional way one seed produces one plant, but by using this technology, one hybrid seed can produce numerous asexual seeds.

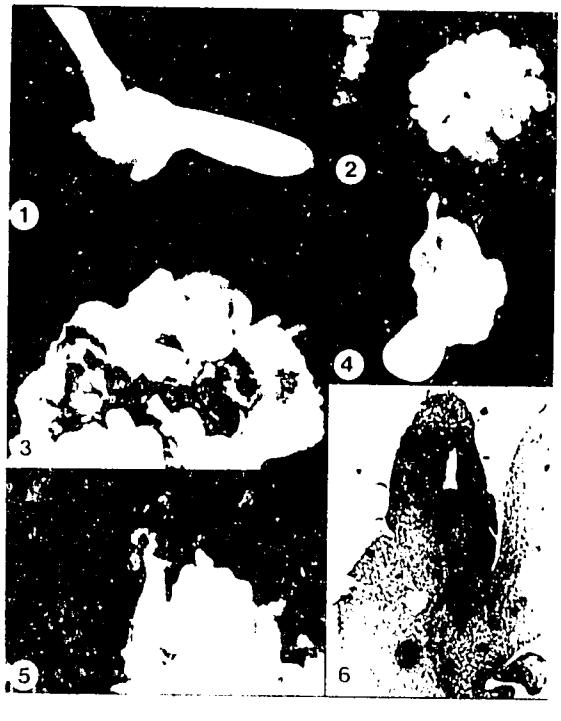
Table 17. Anther culture response of irradiated Basmati 370.

Irradiation dosage (krad)	Anthers plated (no.)	Callus production (%)	Calli producing green plants		Green plant production	
			no.	%	no.	Av
0	3,043	9.9	0	0	0	0
15	3,053	14.3	0	0	0	0
20	1,402	19.4	7	6.3	36	5.1
25	3,539	10.3	4	2.9	10	2.5
Total	11,037	–	11	–	46	
Average		12.5		2.0		

Table 18. Weight increase of NaCl-stressed calli of variety Reiho at different NaCl concentrations. IRRI, 1985.

Treatment (g NaCl/liter)	Weight		
	Initial (g)	Final (g)	Increase (%)
0	0.0498	0.6882	1282
5	0.0513	0.6446	1157
10	0.0512	0.4551	789
15	0.0497	0.2762	456
20	0.0521	0.1607	208

Somatic embryogenesis was demonstrated for the first time in rice. Somatic embryos in calli derived from scutellar tissues were observed in IR43 (Fig. 7), IR20, IR40, Tetep, and the wild rice *Oryza perennis*. Regeneration efficiency decreased with time in culture (Table 19). Individualizing the embryos 2 wk after transferring them to the regeneration medium increased the efficiency of their development into plants.



7. Stages in the development of a somatic embryo from mature seed of IR43. IRRI, 1985. 1) Callus induced after 4 wk in culture. 2) Compact and organized whitish structures resembling globular embryoids. 3) Embryos enlarging and giving rise to interfoldings that became cup-like structures. 4) Shoot coming out of scutellum. 5) Regenerated plant showing both shoot and root. 6) Bipolar axis of embryo with both shoot and root.

DIRECT SELECTION FOR YIELD IN EARLY GENERATIONS

Plant Breeding Department

In the conventional breeding method at IRRI, pedigree lines are bulked and evaluated for yield, usually in the F_5 or F_6. In earlier generations, selection for yield is done indirectly through visual observation of plant type and screening for disease or insect resistance and other stress tolerance. Since the variability for the segregating traits is higher in early generations (F_2-F_4), it is possible that, by using this procedure, we may be losing some higher yielding genotypes in early generations. To correct this shortcoming, we have devised a breeding approach designated as Direct Selection for Yield in Early Generations. The steps follow:

1. Selecting F_1 crosses (derived from semidwarf parents possessing multiple disease and insect resistance) showing positive standard heterosis in the F_1 nursery.
2. Evaluating F_2 populations of heterotic crosses in replicated yield trials in comparison with the best available check varieties for different maturity groups.
3. Selecting F_2 populations giving mean yields higher than or equal to that of the best check variety.
4. Growing F_3 bulk (4,000-5,000 plants) from each of the selected F_2 populations.
5. Collecting five seeds from each plant of the F_3 population to comprise the F_4 bulk.

Table 19. Regeneration efficiency in seed-derived embryogenic calli of IR43. IRRI, 1985.

Passages (no.)	Calli inoculated (no.)	Calli producing green plants (%)	Av plant production[a] (no.)
4	67	61.2	2.8
5	41	56.1	2.4
6	44	29.5	2.0
10	38	33.1	13.5[b]

[a] $\frac{\text{No. of plants produced}}{\text{No. of calli producing plants}}$.

[b]Somatic embryos individualized after 2 wk in regeneration medium.

6. Growing F_4 bulk populations along with check varieties of different growth at two fertility levels (0 N and optimum N, i.e., 90 kg/ha in wet season and 120 kg/ha in dry season).
7. Selecting F_4 single plants at three or four times, corresponding to the date of maturity of the four check varieties looking better than the plants of the corresponding check variety growing nearest to the selected plant. The yield measurements are taken on selected F_5 plants and on 20 plants of each of the check varieties of different growth duration grown at the 2 fertility levels. The F_4 plants yielding higher than the mean + confidence limit value of the check variety of a given maturity group are selected for further evaluation.
8. Growing F_5 progenies of selected F_4 plants along with check varieties for evaluation at two fertility levels (0 N and optimum).
9. Selecting F_5 lines looking better than the adjacent check variety at the two fertility levels and harvesting five plants of each selected progeny and check variety for yield measurements.
10. Selecting F_5 lines of different growth durations based on their yield superiority over the check variety of the corresponding growth duration at both fertility levels.
11. Evaluating selected F_5 bulk in the F_6 along with the check varieties developed through conventionally used breeding methods in small-scale yield trials with two replications and simultaneously screening lines for resistance to and tolerance for major biological and physicochemical stresses.
12. Evaluating selected F_6 lines found superior in yielding ability and possessing the required level of resistance to and tolerance for major biological and physicochemical stresses in the regular replicated yield trial.

During 1985, we reached step 11 of the breeding procedure involving 10 crosses. We had 56 additional crosses in steps 1 to 11.

COOPERATIVE COUNTRY PROJECTS

Plant Breeding and Plant Physiology Departments and Tissue Culture Facility

More detailed information on the following projects may be found in the section Cooperative Programs.

Korea (*Plant Breeding, Plant Physiology, and Tissue Culture*). *Nitrogen response of heterotic F_1 rice hybrids* (*Plant Breeding*). Three experimental rice hybrids and 2 nonhybrid varieties were evaluated at 2 locations in Korea at 5 N levels from 0 to 300 kg/ha. The heterotic hybrid V20A/Milyang 46 used applied N more efficiently than the nonhybrid checks.

Anther culture (*Tissue Culture and Plant Physiology*). The use of anther culture techniques for producing homozygous lines from F_1 hybrids was continued.

India, Indonesia, Philippines, and Korea (*Plant Breeding*). Experimental rice hybrids developed at IRRI were evaluated in replicated yield trials at IRRI and in the collaborating countries. Some showed superiority over commercial varieties at some locations but had either inadequate disease or insect resistance or poor grain quality.

Mexico (*Tissue Culture*). We established informal collaboration with the national rice program of Mexico.

Peru (*Tissue Culture*). The use of anther culture techniques for producing homozygous lines from F_1 hybrids adapted to Peruvian conditions was initiated.

Philippines and Korea (*Plant Breeding*). Seed yields in hybrid seed production ranged from 7 to 493 kg/ha at IRRI and from 70 to 1,470 kg/ha in Korea. The causes of low yield were identified.

WARDA (*Tissue Culture*). Tissue culture-derived lines were tested in collaboration with the West Africa Rice Development Association (WARDA).

Genetic evaluation and utilization (GEU) program

Computerized data management

Statistics and Plant Breeding Departments, International Rice Germplasm Center, and International Rice Testing Program

GERMPLASM BANK **120**
EVALUATION OF BREEDING LINES **120**
INTERNATIONAL RICE TESTING PROGRAM **120**
GEU DATA BASE MANAGEMENT SYSTEM **121**

119

GERMPLASM BANK

Statistics Department and International Rice Germplasm Center

At year end, the germplasm computer data bank contained 2,411,334 records representing existing information on the 45 basic morphoagronomic characters and 35 GEU traits of 64,744 accessions. A large variation exists among accessions in both the basic morphoagronomic characters (Table 1) and GEU traits (Table 1, 2).

In 1985, 1,254 newly registered accessions of *O. sativa* and basic morphoagronomic data on 6,423 accessions were added to the file. A total of 2,802 accessions in the file were also recharacterized.

Seventy sets of computer-generated data sheets were provided for GEU scientists to screen accessions in the germplasm bank for various GEU traits. Data on 16 GEU traits representing 18,335 records were updated to the file in 1985.

The interactive version of the Germplasm Bank Information Retrieval System (GBIRET) was revised to make it more "user-friendly" and to facilitate queries based on prescribed accession numbers in addition to the standard queries on joint specification of characters. The response time of the interactive GBIRET was greatly improved with the upgrading of IRRI's IBM 4331 system to IBM 4361 in mid-1985. More than 70 GBIRET runs were made in response to requests from GEU scientists in 1985.

A microcomputer-based system was initiated to computerize the germplasm bank-related operations of IRGC (i.e., recording of incoming seeds, planting and characterization, and assignment of accession numbers). This is expected to hasten the process of adding new accessions to the central germplasm computer data bank and updating data on their characterization.

Table 1. Accessions in the germplasm computer data bank described according to 13 basic morphoagronomic characters and 2 grain quality characters, 31 Dec 1985.

Character	Accessions (no.)	Mean	Range
Seedling height (cm)	49,960	36.6	8-79
leaf length (cm)	49,847	57.4	10-100
Leaf width (cm)	49,855	1.4	0.4-3.1
Ligule length (mm)	49,809	18.8	3-53
Heading (d)	18,719	101.0	54-180
Culm length (cm)	49,816	117.8	19-213
Culm number	49,821	15.8	2-52
Culm diameter (mm)	49,760	4.7	2-13
Panicle length (cm)	48,818	25.4	10-41
100-grain weight (g)	49,257	2.5	0.8-5.4
Grain length (mm)	48,908	8.7	3.0-13.7
Grain width (mm)	48,908	3.1	1.8-4.8
Maturity (d)	49,810	128.2	82-212
Brown rice protein (%)			
DS crop	17,587	9.4	4.3-18.2
WS crop	13,631	9.4	4.5-17.8
Amylose content (%)	17,669	20.0	0-33

EVALUATION OF BREEDING LINES

Plant Breeding and Statistics Departments

Activities focused primarily on the following routine processing and maintenance of the system, with emphasis placed on providing prompt and relevant information to efficiently service the operation of the nurseries:

- generation of fieldbooks and data sheets for use by GEU scientists in data recording,
- update of nursery data files, and
- information retrieval.

INTERNATIONAL RICE TESTING PROGRAM

International Rice Testing Program and Statistics Department

With the addition of the following 8 nurseries and screening sets, the system now handles 26 nurseries:

- International Tide-Prone Rice Observational Nursery (ITPRON)
- International Floating Rice Observational Nursery (IFRON)
- International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON)
- International Rice Bacterial Blight Nursery (IRBBN)
- International Rice Whitebacked Planthopper Nursery (IRWBPHN)
- International Rice Deep Water Observational Nursery (IRDWON)
- Acid Upland Soils Screening Set
- Acid Lowland Soils Screening Set

Activities in 1985 for these nurseries included the generation of the 1984 preliminary and final reports and of the fieldbooks for 1985 nurseries and the master fieldbook. Computerization of the seed increase records was initiated.

Table 2. Accessions in the germplasm computer data bank described according to 27 GEU traits, 31 Dec 1985.

Character	Accessions (no.)	Frequency of scores[a] (%)									
		0	1	2	3	4	5	6	7	8	9
Bacterial leaf blight	43,249	0	8	–	4	–	3	–	83	–	2
Blast	29,061	1	14	2	8	15	14	15	11	13	7
Sheath blight	23,088	<1	<1	–	9	–	88	–	3	–	<1
Brown planthopper											
Biotype 1	21,838	0	1	–	1	–	3	–	8	–	87
Biotype 2	4,489	0	1	–	2	–	2	–	5	–	90
Biotype 3	6,219	0	1	–	1	–	2	–	4	–	92
Green leafhopper	46,726	<1	1	–	2	–	10	–	13	–	74
Rice whorl maggot	22,949	0	<1	–	3	–	7	–	18	–	72
Whitebacked planthopper	48,554	<1	<1	–	2	–	10	–	28	–	60
Rice leaffolder	8,115	0	<1	–	10	–	12	–	20	–	58
Zigzag leafhopper	2,756	–	<1	–	<1	–	4	–	31	–	65
Gelatinization temperature	14,854	–	3	–	13	–	42	–	25	–	17
Drought											
Seedling vigor	20,040	–	30	1	21	3	27	2	11	<1	5
Rate of recovery											
After 1st stress	13,016	–	61	2	18	<1	14	<1	4	<1	1
After 2d stress	7,574	–	51	2	23	3	6.	2	13	<1	<1
Field resistance											
Early vegetative	18,213	–	1	3	14	23	32	21	6	<1	<1
Late vegetative	14,670	–	<1	2	5	14	39	30	9	1	<1
Reproductive	7,712	–	<1	1	3	6	12	5	24	9	40
Field tolerance (3-4 bars)	2,920	0	2	2	20	8	43	4	20	1	<1
Field tolerance (3-10 bars)	2,400	0	0	0	1	1	18	12	56	7	5
Rate of recovery after exposure to 9-10 bars	2,401	0	3	1	24	5	42	3	18	1	4
Alkalinity	2,693	–	3	–	36	–	50	–	9	–	2
Salinity	8,095	–	<1	<1	11	12	19	20	16	12	10
Zn deficiency	964	–	0	<1	5	2	17	9	39	6	22
Elongation	1,192	–	6	–	15	–	25	–	51	–	3
Flood tolerance	7,221	–	2	–	<1	–	1	–	2	–	95
Cold tolerance	4,013	–	2	–	8	–	30	–	33	–	27

[a] – = score not used.

At year end, the IRTP master entry file had 10,342 entries, 8,420 of which had been tested in one or more IRTP nurseries.

GEU DATA BASE MANAGEMENT SYSTEM

Statistics Department

In addition to the constantly expanding size and number of computer files involved in the GEU data management system, the demand from the users on the system rapidly increased in both volume and diversity.

As a means to improve the on-line data retrieval capabilities and reduce the cumbersome programming efforts involved with the conventional system, the integrated data base approach in the management of data was adopted. This was made possible with the upgrading of the Institute's system.

A project was initiated in early 1985 to determine the most appropriate commercially available mainframe data base software for the GEU system. The study involves two phases: 1) a comprehensive review of the existing GEU data management system to determine the specific facilities required from a data base software; and 2) evaluation and test of several potentially suitable data base software products to select one that will best suit the needs of GEU.

Phase 1 of the project was completed at the start of the last quarter of 1985. Phase 2 is expected to be completed in early 1986, to be followed by the implementation of the new GEU data base management system.

Genetic evaluation and utilization (GEU) program

Seed technology

International Rice Testing Program

EFFECT OF DEHYDRATION OF GERMINATING RICE SEEDS ON THEIR SUBSEQUENT GERMINATION AND VIGOR **124**

EFFECT OF DEHYDRATION OF GERMINATING RICE SEEDS ON THEIR SUBSEQUENT GERMINATION AND VIGOR

Seeds of rice varieties CR-222-MW10, TNAU9039-14, IR31785-58-1-2-3-3, and RP1140-28-3-3-6 were germinated under aerobic and anaerobic conditions at 25 °C. The germinating seed lots were removed at 12-h intervals from 0 h to 96 h and dried back to their original moisture content of 11.5%.

During imbibition, seed moisture content increased from 11.5% to 34.0% under aerobic conditions and to 37.1% under anaerobic conditions.

In all varieties, germination percentage following imbibition and drying under aerobic conditions was similar to that of the control up to 48 h after imbibition. Afterwards, it declined significantly and progressively until 96 h. Under anaerobic imbibition, the regermination percentage was similar to that of the control at all duration levels of imbibition except in RP1140-28-3-3-6, where regermination significantly declined beyond 48 h (Table 1).

Shoot length of seedlings in seeds pregerminated for 60 h or longer under aerobic conditions showed a declining trend in all varieties except in RP1140-28-3-3-6, which showed an increasing trend. Under anaerobic conditions, shoot length differences due to pregermination treatments were not significant in any of the varieties.

Root length and dry weight of seedlings decreased significantly in all varieties under both aerobic and anaerobic conditions.

Regermination rate of seeds increased with duration of pregermination under both aerobic and anaerobic conditions. However, under anaerobic condition, the rate declined sharply beyond 48 h.

Germination after accelerated ageing was maximum at 12 h under both aerobic and anaerobic conditions, beyond which germination declined.

Rate of O_2 uptake of the seeds exhibited a steady increase as the duration of pregermination advanced under both aerobic and anaerobic conditions.

Rice seeds pregerminated for 48 h can withstand drying for additional storage without any deleterious effect on subsequent germination and vigor, although varietal differences exist.

Table 1. Seed germination and vigor in rice variety RP1140-28-3-3-6 as influenced by dehydration after germinating under aerobic (A) and anaerobic (AA) conditions. IRRI, 1985.

Duration (h) of germination before dehydration	Seed germination (%)		Shoot length of seedlings (mm)		Root length of seedlings (mm)		Dry weight (mg/10 seedlings)		Rate of germination (%)		Germination (%) after accelerated ageing		Rate of O_2 uptake (nmol O_2/h per seed)	
	A	AA	A	AA	A	AA	A	AA	A	AA	A	AA	A	AA
0	92	92	72.7	72.7	241.3	241.3	78.8	78.8	20.5	20.5	40	40	17.1	17.1
12	88	99	75.7	76.6	219.0	264.8	79.5	81.8	45.0	86.8	55	62	18.5	19.1
24	90	96	72.4	76.1	238.5	255.4	79.0	76.8	74.4	93.6	52	55	20.0	20.0
36	91	91	76.5	77.5	204.4	232.4	80.0	76.8	90.2	89.0	42	50	22.8	21.4
48	93	91	74.2	76.4	176.4	224.7	72.0	77.8	93.8	83.6	37	43	21.4	24.2
60	79	78	86.3	76.6	145.5	208.9	60.5	70.0	97.0	66.6	15	39	25.7	25.7
72	80	80	88.7	79.6	155.7	221.0	64.5	70.8	100.0	53.2	10	33	27.1	26.3
84	26	66	86.5	74.2	99.2	189.8	38.3	66.8	100.0	22.1	0	29	26.7	27.0
96	29	67	80.0	76.9	102.0	203.4	44.5	70.5	100.0	17.5	0	27	27.9	27.4
LSD at 5%	8.5	8.7	8.8	ns	33.2	19.1	7.4	7.9	4.3	4.7	5.2	4.9	1.2	1.4

Genetic evaluation and utilization (GEU) program

Integrated GEU program

Plant Breeding, Plant Physiology, Agronomy, and Multiple Cropping Departments and International Rice Germplasm Center

IRRIGATED RICE **126**
- IRRI lines named varieties **126**
- Elite breeding lines **126**

COLD-TOLERANT RICE **127**

RAINFED LOWLAND RICE **127**
- Breeding program **127**
- Submergence-tolerant breeding lines **127**
- Medium-deep rainfed lowland **129**
- Thai-IRRI Collaborative Breeding Project **129**
- Integrated performance trials for shallow, rainfed lowland, drought-prone environments **129**

UPLAND RICE **130**
- Favorable environments **130**
  - Yield trials in acid upland soils **130**
  - Upland observational yield trial **130**
- Adverse environments **131**
  - Germplasm field screening **131**
  - Study of progenies **133**
  - Mutagenesis **133**
  - Acid upland observational trial **133**
  - Acid upland yield trial **134**

TIDAL WETLAND RICE **137**

DEEP WATER RICE **139**
- Hybridization **139**
- Collaborative screening in Thailand **139**
- Selection for elongation in farmers' fields **139**
- Selection of deep water rices at IRRI **139**

125

We made 2,816 crosses in 1985, grew F_2 populations from 1,908 crosses, evaluated 155,724 pedigree nursery rows, tested 924 breeding lines in the replicated yield trials, and sent 129,673 seed packets of IRRI breeding lines abroad. Of the total, 48,050 seed packets filled 385 seed requests, and 81,623 packets went through International Rice Testing Program (IRTP) nurseries.

IRRIGATED RICE

Plant Breeding Department

Of the 668 crosses made for irrigated rice in 1985, 395 were single crosses and 273 were multiple crosses. F_2 populations from 384 cross combinations were grown, and 69,308 pedigree nursery rows were evaluated. A total of 800 breeding lines were evaluated in replicated yield trials (RYT).

Thirty-four elite breeding lines were evaluated in the lowland rice performance trials conducted at 12 locations by the Rice Varietal Improvement Group of the Philippine Seed Board, and more than 200 elite breeding lines were evaluated internationally in IRTP nurseries. Many promising lines introduced on the basis of seed requests were also evaluated by national rice improvement programs.

IRRI lines named varieties. After worldwide evaluations, 7 national programs released as varieties 10 breeding lines from the irrigated breeding program, bringing to 147 the number of IRRI lines named as varieties.

- IR1561-228-3-3 — an early maturing, high yielding line with excellent grain quality — was recommended in the Ivory Coast as IR1561. It had previously been released in Vietnam, China, Egypt, Mauritania, and Kenya.
- IR2058-78-1-2-3 was released as IR46 in the Ivory Coast. This line had been released as IR46 in the Philippines, Cameroon, Brazil, and Indonesia.
- IR2061-214-3-8-2 — an early maturing line with long, slender, translucent grains — was released as Amol 2 in Iran. This line had been released as IR28 in the Philippines and had also been recommended in Burma, Bangladesh, China, India, Indonesia, Cameroon, and Gambia.
- IR4422-98-3-6-1 was released as IR4422 in Liberia. It has high and stable yield potential and long, slender, translucent grains.
- IR5657-33-2-2-3 was recommended as Citanduy in Indonesia. This is a high yielding line with salinity tolerance and intermediate amylose content (AC).
- IR7167-33-2-3 — an early maturing, high yielding line — was released in Cameroon as IR7167.
- IR13525-43-2-3-1-3-2, which had been released as IR62 in the Philippines in 1984, was released as IR62 in Andhra Pradesh, India. It is resistant to the local BPH biotype and is highly suited for growing during rabi.
- IR15529-253-2-2 was released as Bahbalon in Indonesia. This is a high yielding line with long, slender, translucent grains.
- IR18348-36-3-3 was released as IR64 by the Philippine Seed Board in May 1985. This early maturing variety outyielded IR36 by 21% in Philippine Seed Board trials conducted at 12 locations throughout the country. It is resistant to brown planthopper (BPH) biotypes 1 and 3, green leafhopper (GLH), bacterial blight (BB), and grassy stunt (GSV) and moderately resistant to blast (Bl), BPH biotype 2, tungro (RTV), and stem borer (SB). It has intermediate AC and intermediate gelatinization temperature (GT), making its grain quality much better than that of other IR varieties.
- The glutinous variety IR21015-196-3-1-3 was released as IR65 by the Philippine Seed Board. It is resistant to BPH biotypes 1 and 2, GLH, BB, and GSV and moderately resistant to Bl and SB.

Elite breeding lines. Multidisciplinary evaluations at IRRI and in IRTP nurseries identified several promising breeding lines suitable for irrigated rice culture.

- IR28150-84-3-3-2 is a high yielding line with intermediate AC that matures in 130 d. It is resistant to the three BPH biotypes and to other major insects and diseases. It has long, slender, translucent grains with high milling recovery.
- IR29723-143-3-2-1 has consistently outyielded other elite lines of the medium maturity group.

It matures in 135 d and has long, slender, translucent grains with high AC and low GT. It is resistant to the three BPH biotypes and to GLH, and moderately resistant to Bl, RTV, and SB.

- IR28224-3-2-3-2 is an excellent breeding line that matures in 130 d and is resistant to all major diseases and insects. It has long, slender, translucent grains with high AC and low GT.
- IR31802-48-2-2-2 is an early maturing selection with a growth duration of 107 d. It has intermediate AC and intermediate GT, and is resistant to all major diseases and insects.
- IR31868-64-2-3-3-3 is an early maturing line with a growth duration of 110 d. It has long, slender, translucent grains with intermediate AC and intermediate GT. It is resistant to all major diseases and insects.
- IR32307-107-3-2-2 is an early maturing line resistant to all major diseases and insects. It has long, slender, translucent grains with high AC and intermediate GT.
- IR32429-47-3-2-2 matures in 105 d. It is resistant to all major diseases and insects and has intermediate AC and intermediate GT.
- IR32429-122-3-1-2 matures in 110 d and is resistant to major diseases and insects. It has intermediate AC and intermediate GT.
- The early maturing line IR35293-125-3-2-3 outyielded all other entries in our RYT during the last two seasons. It matures in 110 d and has long, slender, translucent grains with intermediate AC and intermediate GT. It is resistant to all major diseases and insects.

COLD-TOLERANT RICE

Plant Breeding Department

Field evaluation and selection for cold tolerance were done at Banaue (high altitude area) in collaboration with the Philippine Bureau of Plant Industry. In dry season (DS), a pedigree nursery with 1,806 lines from 66 crosses was established; 103 lines were selected based on plant type, early maturity, good panicle exsertion, seed set, and resistance to pests and diseases. In wet season (WS), selected lines were evaluated further along with 1,603 new lines from 54 crosses. Aside from low temperature, prolonged cloudy weather and heavy rainfall caused high spikelet sterility. Lines that showed good fertility (84) were selected.

Of the 8 promising lines tested in RYT conducted during both DS and WS under fertilized (60-40-40 kg NPK/ha) and unfertilized conditions, IR8866-30-3-1-4-2 and IR9202-5-2-2-2 were superior to the local check Pinidua and to Barkat, a well known cold-tolerant variety.

RAINFED LOWLAND RICE

Plant Breeding, Plant Physiology, and Agronomy Departments

Breeding program (*Plant Breeding*). In the rainfed lowland breeding program, F_1 populations from 139 single crosses and 247 multiple crosses were grown. Breeding nurseries were divided into those for drought-prone and those for medium-deep conditions. In the drought-prone nurseries, 154 F_2 populations and 20,525 pedigree rows were evaluated. In the medium-deep nurseries, 103 F_2 populations and 13,174 pedigree lines were evaluated. Observational trials with 895 breeding lines were evaluated at IRRI, and observational trials for drought-prone (241 entries) and medium-deep (186 entries) conditions were grown at IRRI and in appropriate farmers' fields in the Philippines. Some of the more promising entries, rated for phenotypic acceptability and submergence tolerance, are shown in Table 1.

In addition to nominations of promising advanced lines to IRTP trials, breeding lines and F_2 populations were sent upon request to interested scientists in Bangladesh, Burma, Haiti, India (Bihar, Kerala, Maharashtra, Orissa, Tamil Nadu, and West Bengal), Kampuchea, Laos, Malaysia, Nepal, Rwanda, Senegal, Thailand, and Vietnam.

Submergence-tolerant breeding lines (*Plant Breeding and Plant Physiology*). Combining submergence tolerance with improved plant type and other important traits has been a major goal of the breeding program. Traditional varieties, such as FR43B from India, and derived lines, such as BKNFR76106-16-0-1-0 from the Thai-IRRI deep water program, have served as excellent sources of the trait. Some improved rainfed lowland lines, evaluated and selected at IRRI in 1985, have

Table 1. Characteristics of rainfed lowland breeding lines that performed well in 1985 observational trials at IRRI and in Philippine farmers' fields.

Line	Parentage	Maturity (d)	Height (cm)	Grain quality					Reaction to					Comment
				Length[a]	Shape[b]	Chalkiness[c]	AC[d] (%)	GT[e]	BPH[f]			GLH[g]	BB[h]	
									1	2	3			
IR29341-20-3-1-3	IR54/IR46	130	120	3	1	1	26	I	1	3	9	3	1	Medium-deep
IR33360-5-1-3-1	IR52/IR5657-33-2//IR50	140	120	5	3	1	26	L	1	3	3	3	1	Medium-deep
IR33493-1-1-1-1	IR13429-196-1/IR13419-113-1// IR9764-45-22	145	130	5	5	5	25	I	3	3	3	3	1	Medium-deep
IR36974-13-3-3-3	BIET927/IR42	125	120	3	1	5	28	L	3	1	3	3	1	Medium-deep and drought-prone
IR37094-31-2-3-2	CR1009/IR54	140		3	5	1	21	I	3	7	9	5	1	Medium-deep
IR37096-49-1-3	CR1009/IR4568-86-1-3-2	140	140	5	5	1	27	I	3	3	1	9	1	Drought-prone
IR37096-50-1-3-3	CR1009/IR4568-86-1-3-2	145	140	5	5	5	27	I	3	1	1	7	1	Submergence tolerant, medium-deep
IR37096-52-3-1	CR1009/IR4568-86-1-3-2	145	130	5	5	5	27	I	3	3	3	7	1	Submergence tolerant, medium-deep and drought-prone
IR38699-6-1-2-1	GEB24/IR13146-179	–	110	5	5	5	26	I				5	1	Photoperiod-sensitive, drought-prone
IR43559-132-3	IR13423-10-2-3/FR43B// MTU7029/IR19728-9-3-2-3-3	130	100	5	5	5	28	L	3	5	3	7	1	Submergence tolerant

[a]3 = long (6.60 to 7.50 mm), 5 = medium (5.51 to 6.60 mm). [b]Length-width ratio: 1 = slender (over 3.0), 5 = medium (2.1 to 3.0). [c]1 = small (less than 10% of kernel area), 5 = medium (11-20%). [d]Amylose content. [e]Gelatinization temperature: I = intermediate, L = low. [f]Brown planthopper: 1 = very slight damage, 9 = all plants dead. [g]Green leafhopper: 3 = first and second leaves yellowing, 9 = all plants dead. [h]Bacterial blight: 1 = less than 1%.

Table 2. Advanced generation rainfed lowland breeding lines with consistent tolerance for submergence, selected in 1985.

Line	Parentage	Submergence score[a] in				
		F_3	F_4	F_5	F_6	F_7
IR40931-21-2-5-2-1	BKNFR76106-16-0-1-0/IR19661-131-1-2		1	1	1	1
IR42205-33-1-3-3-2	IR4215-301-2-2-6//IR19382-42-3-3-2/BKNFR76106-16-0-1-0		1	1	1	1
IR42207-65-2-3-2-1	IR14632-22-3//IR19382-42-3-3-2/BKNFR76106-16-0-1-0		1	5	1	1
IR42207-94-2-2-3-2	IR14632-22-3//IR19382-42-3-3-2/BKNFR76106-16-0-1-0		1	1	1	1
IR43559-81-1-2-2	IR13423-10-2-3/FR43B//MTU7029/IR19728-9-3-2-3-3	1	1	1	1	
IR43559-132-3-3-1	IR13423-10-2-3/FR43B//MTU7029/IR19728-9-3-2-3-3	1	1	1	1	

[a]1 = 100% plants surviving, in comparison with the tolerant check FR13A.

shown consistent submergence tolerance over several generations (Table 2).

Medium-deep rainfed lowland (*Plant Breeding*). A trial for rainfed lowland, medium-deep water conditions was conducted in collaboration with the Agricultural Research Institute and the Applied Research Division of Burma in Hmawbi. Twenty-five entries, including improved IRRI lines and traditional and improved Burmese cultivars, were evaluated at 40-60 cm water depth. The Burmese cultivars Shwe thwai tun and In ma ye baw showed excellent survival. The IRRI lines IR19382-42-3-3-3, IR26760-76-2-1-2-3, and IR26702-204-2-2-1-1-3, which have been among the highest yielders in medium-deep trials at IRRI, also showed good survival.

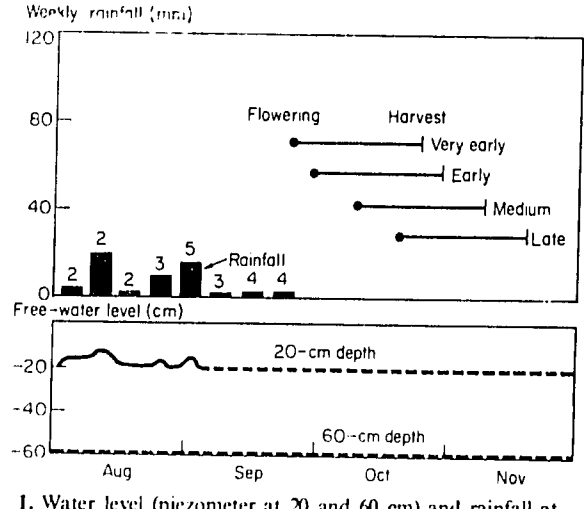
Thai-IRRI Collaborative Breeding Project (*Plant Breeding*). Collaborative breeding nurseries were grown for the third consecutive year at six research stations in northeast Thailand, under conditions ranging from very poor (drought and salinity) to very good. Plants selected at all stations totaled 3,896 from the F_2 populations and 1,012 from the pedigree nurseries. Progeny of these selections were seeded at IRRI for generation advance and selection in 1986 DS.

Integrated performance trials for shallow, rainfed lowland, drought-prone environments (*Agronomy*). Sixty genotypes were grown in shallow, rainfed lowland, drought-prone environments in 1984 WS to assess the yield performance of genotypes from 1) the International Rainfed Rice Shallow Water Yield Nursery, 2) early maturing breeding lines selected during 1983 trials, and 3) medium maturing advanced lines from IRRI's breeding program for drought-prone environments. Trials were conducted at IRRI and in farmers' fields in Ilocos Norte, Nueva Ecija, Laguna, and Cebu. A group balanced block design with four replications was used at all test sites.

Low rainfall caused severe water stress in Ilocos Norte (Fig. 1). Although genotypes of the very early, early, and medium maturity groups may have partly escaped water stress, their yields were still low (Table 3). As stress severity increased later in the season, the maturing genotypes did not even produce panicles.

Low grain yields in Nueva Ecija were attributed to RTV at the vegetative stage.

The highest yielding genotypes from all five locations included IR21567-18-3, IR19431-72-2, IR19274-26-2-3-1, IR13146-45-2, and IR13146-13-3-3 (Table 4). They are recommended for further testing and possible use as parents for rainfed lowland varieties.



1. Water level (piezometer at 20 and 60 cm) and rainfall at Dingras, Ilocos Norte, Philippines, 1984 WS. Values on the bars indicate no. of rainy days.

Table 3. Grain yield, drought tolerance rating, and day of flowering of promising genotypes in integrated performance trial for shallow, rainfed lowland, drought-prone environments. Ilocos Norte, Philippines, 1984 WS.

Genotype	Yield (t/ha)	Visual drought score[a] (1-9 scale)	Day of flowering (DAS)[b]
	Very early		
IR19735-5-2-3-2-1	0.84	3	68
	Early		
IR26894-37-2-1-3	1.04	4	76
IR58	0.90	4	75
IR19058-[illegible].07-1	0.70	4	75
IR9698-16-3-3-2	0.30	4	84
	Medium		
IR8608-82-1-3-1-3	0.52	4	86
KKN7205-39-3-SKN-1-1-1	0.25	5	90

[a]3 = tip-drying extended up to ¼ length in most leaves, 5 = one-fourth to ½ of all leaves fully dried. [b]Days after sowing.

UPLAND RICE

Plant Breeding and Multiple Cropping Departments and IRGC

Favorable environments (*IRGC*). The emphasis of our hybridization program is to upgrade the eating quality and disease resistance of the promising drought-resistant lines that have been selected from wide crosses. Two hundred seventy-five single crosses, topcrosses, double crosses, and backcrosses were made during 1985. Moreover, 170 single crosses, topcrosses, and backcrosses were produced for collaborators in Mexico, Tanzania, West Africa, Thailand, and India at their request. Some of the new collaborators were participants in the Upland Rice Training Course.

In DS, 261 F_2 and F_3 bulk populations were grown under intermittent irrigation. Diseases were very few and most of the populations were carried through WS planting. Another 210 F_5 bulk populations were sown in dry seedbeds and selected for deep and thick roots prior to transplanting. About 1,198 plants having most of the desirable traits were selected. Another 3,253 lines were grown in the pedigree nurseries. From them, 5,100 plants that showed field resistance to diseases and insect pests were grown in WS pedigree nurseries.

In WS 401 F_2, F_3, and F_4 bulk populations were grown in a farmer's field in Santo Tomas, Batangas. Only 109 populations contained plants that showed resistance to prolonged drought stress at panicle initiation and to heavy pressures of neck Bl, leaf scald (LSc), and sheath blight (ShB), which showed up at heading. Another 20 F_5 bulk populations — selected for deep and thick roots prior to transplanting — were grown; 171 plants having the desired agronomic characteristics were selected.

Yield trials in acid upland soils. We continued to test promising upland lines bred under favorable conditions in a highly acid upland soil in Caliraya. The soil pH is 4.0 and soil fertility is very poor. At seeding, 20 kg of fertilizer was applied. N (20 kg/ha) was applied at 40 and 60 d after seeding. Seedling establishment was rather poor in two replications because of the high incidence of seedling blight and mole cricket infestation. The crop suffered from 2 wk of drought stress at the vegetative stage. Yields ranged from 0.2 to 1.0 t/ha (av 0.4 t/ha). IR30714-B-1-B-1-6 and IR30716-B-1-B-7-5, previously selected for deep and thick roots, yielded 1.0 t/ha each and did not show any Bl lesions at the vegetative stage. They were moderately resistant (score of 3) to brown spot and sheath rot, but intermediate to moderately susceptible (score: 5-7) to LSc at the reproductive stage. IR30715 (RP825-70-7-1/LAC 23//LAC 23) lines were also superior to others in yield performance in the acid upland yield trials of the rainfed environment group at both the Caliraya and Claveria sites.

The traditional check varieties Kinandang Patong and Dinorado yielded 0.6 and 0.5 t/ha; the improved check varieties IR43 and UPLRi-5 gave lower yields of 0.2 and 0.3 t/ha.

The diseases observed at the reproductive stage were brown spot, LSc, glume discoloration, and neck Bl. The two leaf diseases contributed significantly to the low yields in Caliraya. Mass selection was made within the populations to upgrade the two promising lines.

Upland observational yield trial. One hundred selections were grown in an unreplicated observational yield trial in a farmer's field.

The early maturing lines suffered most from a month-long drought stress and showed highly sterile panicles. The yields obtained ranged from 0.8 to 2.7 t/ha (av 1.6 t/ha). The highest yields were

Table 4. Grain yields of the top 10 genotypes from each seed source in the integrated performance trial for shallow, rainfed lowland, drought-prone environments. 1984 WS.

Genotype	Yield (t/ha)					
	Laguna	Cebu	IRRI	Ilocos Norte	Nueva Ecija	Mean
			IRTP genotypes			
IR19431-72-2[a]	2.31 ab[b]	1.89 ab	2.13 bcd	0.00 c	2.42 a	1.75
IR13146-45-2[a]	2.43 a	1.31 defgh	2.83 a	0.20 abc	1.88 abc	1.73
IR4744-295-2-3	1.93 abc	1.97 a	1.79 bcdefgh	0.00 c	1.99 ab	1.53
IR14753-86-2	1.96 abc	1.56 cde	1.74 bcdefgh	0.00 c	1.64 bc	1.38
IR46[a]	1.88 abcd	1.54 cde	1.88 bcdef	0.00 c	0.74 d	1.21
IR4819-77-3-2	1.97 abc	0.90 ijk	1.10 h	0.00 c	1.62 bc	1.12
BR11	1.91 abc	1.63 bcd	1.97 bcdef	0.00 c	–	1.10
IR9698-16-3-3-2	1.79 bcde	1.00 hij	1.51 cdefgh	0.30 ab	0.68 d	1.05
Mahsuri	1.89 abcd	0.65 klm	1.89 bcdef	0.00 c	0.57 d	1.0
IR13257-46-1E-P1	1.96 abc	1.02 hij	1.43 defgh	0.00 c	–	0.88
			Early maturing genotypes			
IR21567-18-3	2.66 a	1.80 abc	2.29 b	0.00 d	2.79 a	1.90
IR19274-26-2-3-1[a]	2.40 abcd	1.05 ghijkl	3.34 a	0.00 d	1.90 cd	1.73
IR21188-87-3-3-2-2[a]	2.37 abcd	1.58 cde	1.99 bcd	0.00 d	2.05 bc	1.60
IR29341-85-3-1-3	2.58 ab	1.34 defg	2.10 bc	0.00 d	1.82 cd	1.56
IR28941-164-1-5	2.43 abc	1.28 efghi	1.79 bcde	0.00 d	2.03 bc	1.50
IR26717-1-1-2-1-1	2.00 cde	1.92 ab	1.63 bcdef	0.00 d	1.87 cd	1.48
IR54[a]	1.90 cde	1.66 bcd	1.51 cdef	0.00 d	2.13 bc	1.44
IR26933-16-2-3[a]	2.11 bcde	1.16 fghij	1.45 cdef	0.36 c	1.73 cd	1.36
IR19058-107-1[a]	1.88 cde	0.93 jkl	1.24 ef	0.70 ab	1.65 cde	1.28
IR21033-31-P2	1.92 cde	0.98 hijkl	1.35 def	0.00 d	0.78 g	1.00
			Medium maturing genotypes			
IR13146-13-3-3[a]	2.51 a	1.59 bcdef	2.44 a	0.08 ab	1.87 abcd	1.70
KKN7205-39-3-SKN-1-1-1[a]	2.37 ab	1.83 abc	1.50 bc	0.25 a	1.57 bcde	1.50
IR22802-41-2[a]	2.03 abcd	1.64 bcdef	1.56 bc	0.00 b	2.01 abc	1.44
IR19672-140-2-3-2-2[a]	2.10 abc	1.49 cdefg	1.74 b	0.00 b	1.67 bcd	1.40
IR33353-64-1-2-1	2.21 abc	1.42 efgh	1.25 bc	0.00 b	2.05 abc	1.38
IR33383-23-3-3-3	1.96 abcd	1.63 bcdef	1.64 bc	0.00 b	1.47 cde	1.34
IR21363-13-2-2-1-1[a]	1.91 bcd	1.99 a	1.07 bc	0.00 b	1.73 bcd	1.34
IR29341-83-2	2.05 abcd	1.44 defg	1.61 bc	0.00 b	1.26 defg	1.27
IR8997-4-18-1[a]	2.06 abcd	1.34 fghi	1.30 bc	0.00 b	1.29 def	1.20
IR9852-22-3[a]	2.05 abcd	1.54 cdef	1.08 bc	0.00 b	0.62 h	1.06

[a]Performed well during 1983 WS trials. [b]Numbers within a column and within a seed source followed by the same letter are not significantly different at the 5% level by DMRT.

obtained from IR13754-5-10 (2.6 t/ha) and IR26957-86-2 (2.7 t/ha).

Major diseases observed were neck and glume Bl, ShB, LSc, and brown spot.

Adverse environments (*Plant Breeding, Multiple Cropping, and IRGC*). *Germplasm field screening* (*Plant Breeding*). Of about 5,000 upland rice entries initially screened in the field for adverse upland condition, 363 were retained for farther studies. According to electrophoretic data, about 80% of the entries fell in group 6 (japonicas), 15% in group 1 (indicas), and 5% in group 2 (aus). Thirty-two percent (117 entries) were from Latin America, mostly Brazil; 48% (174 entries) from Asia, mostly the Philippines and Indonesia; and 20% (72 entries) from Africa, mostly the Ivory Coast.

Of 189 entries from Latin America and Africa, 182 (96%) fell in group 6; the remainder were 3 improved lines from the Centro Internacional de Agricultura Tropical, Colombia; 1 improved line from the International Institute of Tropical Agriculture, Nigeria; and 3 traditional rainfed varieties from the Ivory Coast.

According to screening results, including the IRTP, from different sites in the Philippines, promising materials could be allocated to different electrophoretic groups (Table 5). In adverse to very

Table 5. Electrophoretic categories[a] of promising material from screening in different upland soil conditions. IRRI, 1985.

Favorable site		Intermediate site		Adverse site	
Variety or line	Group	Variety or line	Group	Variety or line	Group
UPLRi-5	1	Kinandang Patong	6	B2997-C-TB-60-3-3	1
UPLRi-7	1	IAC25	6	B2992-B-TB-73-4-2	1
B3016b-TB-260-3-2	1	AUS257	2	IRAT140	6
B2997c-TB-4-2-1	1	BR319-1	1	BR319-1	1
B3623g-TB-49	1	IRAT140	6	Azucena	6
B3622c-TB-5-4-4	1	ITA235	6	IAC47	6
B2992n-TB-73-4-2	1	IRAT133	6	ARC7046	6
AUS196	2	UPLRi-5	1	AUS257	2
IR3016-B-1-B-16	1	IRAT141	6	Padi Tatakin	6
IRAT104	6	IRAT165	6	Padi Senemok	6
B2997c-TB-60-3-3	1	IAC47	6	IRAT104	6
IR12979-24-1 (Brown)	1	ITA173	6	ITA182	6
IR12103-80-1-2	1	ITA130	6	Khao Kinon	6
BG35-2	1	ITA225	6	LAC23	6
C924-9	1	IR12979-24-1 (Brown)	1	Moroberekan	6
IR30716-B-3-13-3-4	1	B2997c-TB-60-3-3	1	Makouta	6
IR30716-B-1-B-1-6	1	B3619c-TB-8-1-4	1	IR10147-113-5-1-1-5	1
IR26957-45-1	1	B3623g-TB-49	1	IR30716-B-1-B-1-6	1
IR43	1	CNA108-8-42-24-2B	1	IR5931-113-1	1
IRAT 140	6	PI358-5-19M-2-1B	1	B3622c-TB-5-4-4	1

[a]Group 1 = indica, 2 = aus, 6 = japonica.

Table 6. Characterization[a] of the 3 electrophoretic rice groups for some traits under severe upland environment. IRRI, 1985.

Trait	Group 1	Group 2	Group 6
Early vegetative vigor	+	+++	++
Tillering ability	+++	+++	++
Resistance to lodging	+++	+	++
Panicle exsertion	+	++	+++
Earliness	++	+++	++
Blast tolerance	++	+	+++
Sheath diseases tolerance	+++	++	+
Drought tolerance	+	++	+++
Adaptation in very poor soils	++	+	+++
Glume discoloration tolerance	++	+	+++
Stem borer tolerance	++	+++	++
Al toxicity tolerance	++	+	+++

[a]+++ = high to very high, ++ = intermediate, + = low to very low.

adverse soil conditions, group 6 materials were most common. Group 1 was more promising under favorable conditions. This confirmed results from adverse environments in Brazil, West Africa, Thailand, and Indonesia.

Tropical japonicas showed important variability and were considered good donors for many characters needed in adverse upland environments. Table 6 summarizes the results from the 1985 screenings — a first approach to characterization under severe constraints.

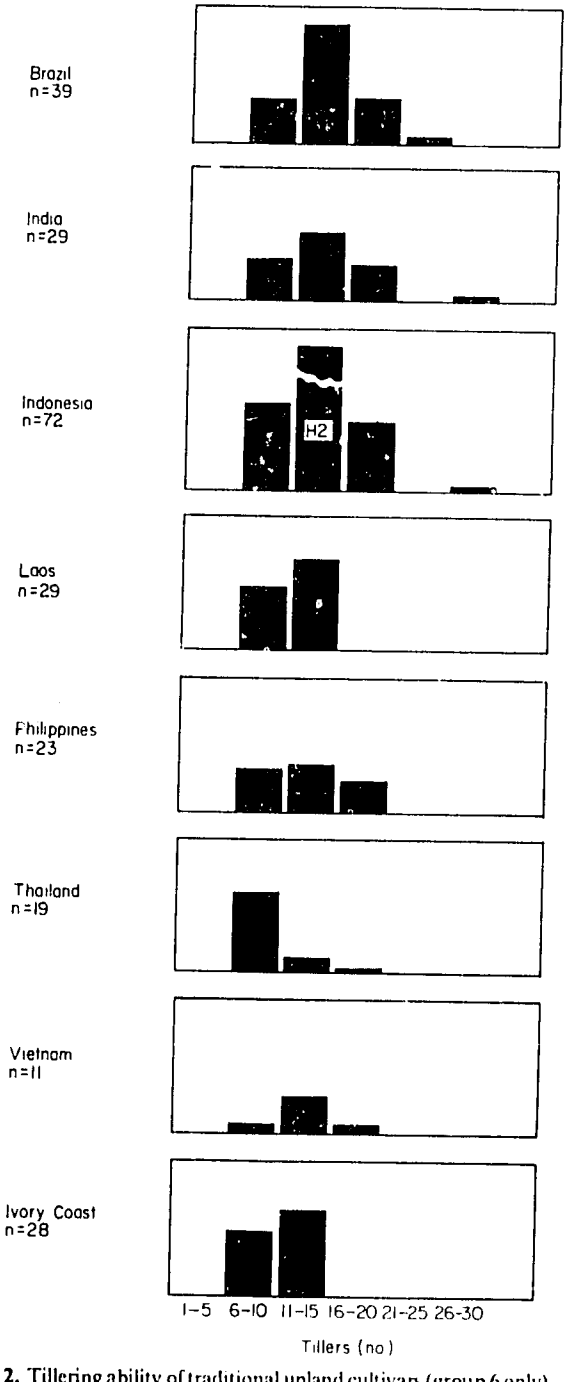
Germplasm bank data for 300 group 6 tropical upland entries from 19 countries included in the screening are compared with those for 80 temperate group 6 entries (Table 7).

Most of the tropical entries were traditional cultivars. Culm number was the most promising

Table 7. Comparison of some traits of tropical and temperate japonica entries. IRRI, 1985.

Trait	Mean		Lowest		Highest	
	Tropical	Temperate	Tropical	Temperate	Tropical	Temperate
Culm length (cm)	111	82	63	40	193	118
Culm number	13	15	4	6	30	32
Panicle length (cm)	26	22	17	12	36	31
Grain length (mm)	9.1	8.0	6.1	6.5	11.4	11.7
1,000-grain weight (g)	29	24	14	16	52	30

character. Tillering potential was therefore not a problem with group 6 varieties. They frequently showed low tillering under adverse environments, not because their tillering potential was low, but because the soil was so adverse that they could not express their potential. Figure 2 shows tillering potential for traditional cultivars from selected countries. The lowest potentials were found in Laos, Thailand, and the Ivory Coast.



2. Tillering ability of traditional upland cultivars (group 6 only) from selected countries. n = number of cultivars.

Study of progenies (Plant Breeding). F_2 and following segregating progenies were studied by the classical pedigree method because it proved to be efficient and easy. F_4 and further progenies were studied under both favorable and severe environments. Under severe constraints, group 6/group 6 crosses provided more promising progenies than other crosses, but under good conditions, group 1/group 6 crosses were more adapted.

Mutagenesis (Plant Breeding). Seven traditional upland cultivars were treated with ethyl methane sulfonate (EMS) gas during 1985. The germination percentages (modified data for comparison needs) are given in Table 8.

The responses differed according to variety and could be broadly classified into three groups: one (Kinandang Patong, Salumpikit, and Dinorado I) showing low response, a second (Cayatan and Azucena) having intermediate response, and a third (Speaker and Dinorado II) showing the highest response — response being measured in germination percentage loss after 25 h of exposure to EMS gas.

The M_1 was cultivated in 1985 WS, and about 900 plants were harvested. The M_2 was planted in December 1985, each row coming from one M_1 plant. Several M_2 rows showed high levels of chlorophyll mutants (albino plants).

Acid upland observational trial (Multiple Cropping, Plant Breeding, and IRGC). The acid

Table 8. Germination loss percentage of 7 traditional upland cultivars from the Philippines, after treatment with EMS gas. IRRI, 1985.

	Control	Germination loss (%)					
		9 h	13 h	17 h	21 h	25 h	Mean
Kinandang Patong	100	100	100	100	71	40	82
Salumpikit	100	100	100	81	81	66	86
Dinorado I	100	94	92	81	7[illegible]	60	80
Cayatan	100	87	87	67	75	51	73
Azucena	100	82	79	59	53	32	61
Speaker	100	74	67	48	29	13	46
Dinorado II	100	78	86	86	19	0	54
Mean	100	87	87	74	57	38	69

upland observational trial was developed as a mechanism to evaluate breeding material under relevant acid infertile environments as early as possible in the selection process. The trial included 165 lines grown in 2- × 2-cm plots with 1 replication/site.

Among the top 20 entries for 2 sites, IR30716-B-3-B-13-4, IR30716-B-1-B-1-2, and IR30716-B-8-B-5-6 showed yield rank stability despite environmental differences. All the other top 20 entries were affected by environmental differences: those that belonged to the top 20 entries in Cavinti, Laguna, had lower yields in Claveria, Misamis Oriental, and vice versa (Table 9). Neck Bl incidence was severe in Cavinti; however, a few of the best yielding entries had scores lower than 4.

Acid upland yield trial (Multiple Cropping, Plant Breeding, and IRGC). The evaluation of upland rice breeding materials for acid infertile upland conditions was expanded by the initiation of multilocation yield and observational trials. The materials included selected entries from the breeding program and outstanding germplasm accessions. The trials were grown at two locations in the Philippines to represent a range of acid upland conditions. The site characteristics are given in Table 10. The yield trial included 49 entries planted in a lattice design with 3 replications.

In Cavinti, the trial experienced severe drought at the vegetative stage (Fig. 3) and severe neck Bl during grain filling.

Several entries had very vigorous growth at the seedling stage but did not perform well at harvest (Table 11). IRAT104 and Kinandang Patong had poor germination but showed the best drought resistance and phenotypic acceptability at harvest. The major criteria in the determination of varietal adaptability to acid soil conditions were grain yield, phenotypic acceptability, and neck Bl susceptibility.

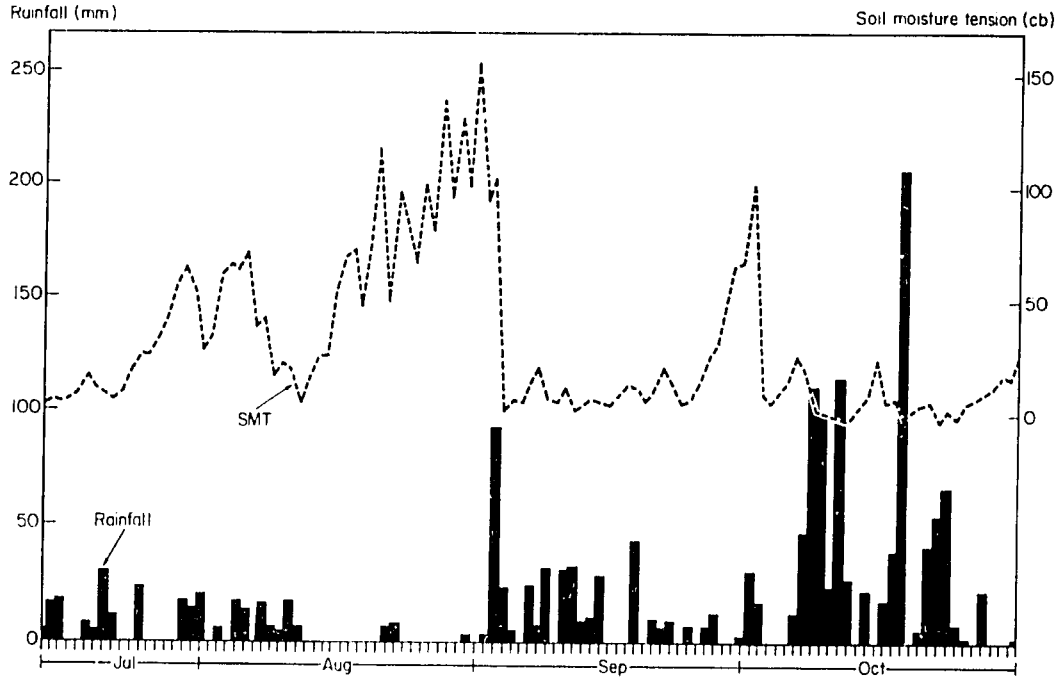
Table 9. Top 20 entries and check varieties based on overall ranking[a] in acid upland observational trial in Cavinti and Claveria, Philippines, 1985 WS.

Rank	Variety or line	Average yield (t/ha)	Cavinti				Claveria			
			Rank	Yield (t/ha)	Neck blast score	Drought tolerance	Rank	Yield (t/ha)	Flowering (DAS)[b]	Plant height (cm)
1	IR30716-B-3-B-13-4	3.9	7	2.6	4	4	6	5.3	111	108
2	IR30716-B-2-B-12-5	3.5	33	2.0	5	3	9	5.1	117	90
3	IR30716-B-1-B-1-2	3.5	15	2.3	5	3	16	4.7	95	88
4	IR11434-16-2	3.5	1	3.1	1	3	58	4.0	123	86
5	IR30716-B-12-B-1-4	3.4	26	2.1	3	3	13	4.8	104	87
6	B2997C-TB-60-3-3	3.4	28	2.0	4	3	12	4.8	104	97
7	B3016B-TB-260-3-2-1-1-3	3.4	101	0.9	7	3	1	5.9	109	109
8	Khao Kinon	3.4	8	2.5	4	3	38	4.2	104	111
9	IR10052-7-1-1	3.4	56	1.5	5	3	8	5.2	113	104
10	IR30716-B-2-B-9-1	3.4	11	2.4	5	3	31	4.3	104	94
11	IR30716-B-8-B-5-6	3.3	20	2.2	4	1	19	4.5	104	101
12	IR30716-B-2-B-8-2	3.3	14	2.4	4	3	30	4.3	95	96
13	BR319-1	3.3	16	2.3	2	3	37	4.2	111	92
14	IR23261-23-2-1-6	3.2	50	1.6	4	3	17	4.7	109	100
15	IR10110-24-1-2-1-3	3.2	31	2.0	5	3	28	4.3	109	90
16	B2997C-TB-4-2-1	3.1	129	0.6	9	2	3	5.7	104	108
17	IR30716-B-3-B-7-2	3.1	19	2.2	5	5	52	4.0	111	103
18	B3619C-TB-8-1-4	3.1	139	0.4	9	3	2	5.8	95	109
19	IR13754-6-3	3.1	41	1.8	5	3	23	4.4	119	92
20	IR30716-B-5-B-10-1	3.0	6	2.6	5	2	29	4.3	119	97
33	UPL Ri-5 (check)	2.9	143	0.3	9	4	15	4.8	113	96
43	UPL Ri-7 (check)	2.7	154	0.2	9	2	4	5.3	109	90
89	IR6023-10-1-1 (check)	2.4	88	1.1	5	5	139	3.7	123	111
116	IAC1246 (check)	2.1	108	0.9	5	3	14	4.8	111	107
123	IR12979-24-1 (check)	2.0	145	0.3	9	3	33	4.3	109	89
130	Kinandang Patong (check)	2.0	36	1.8	4	3	151	2.1	109	108

[a]Av of Cavinti and Claveria grain yield. [b]Days after sowing.

Table 10. Site characteristics of 2 acid upland ricefield locations in the Philippines. 1985.

Parameter	Mahipon, Cavinti, Laguna	Anii, Claveria, Misamis Oriental
Topography	Rolling	Undulating
Climate	Type II-1, maximum rains from July to December or January	Type II-1, maximum rains from July to December
Rainfall (mm/yr)	3,300	2,200
Dominant land use	Coconut, tomato	Upland rice, maize, tomato
Soils		
pH (1:1 H_2O)	4.0	4.5-5.8
CEC (meq/100 g)	19-24	6-12
Available P (Bray 2, ppm)	1.6-5.6	4.1-4.7
Exchangeable Al (meq/100 g)	6.8-10.7	0.5-3.0
Texture	Clay	Clay
Taxonomic classification	Palehumult	Dystropept



3. Daily distribution of rainfall and soil moisture tension (SMT) at 10-20 cm depth during growing season. Acid upland yield trial, Cavinti, Laguna, Philippines, Jul-Oct 1985.

The site is an excellent screening location for disease pressure, particularly brown spot and Bl. Although average rainfall is high, drought periods are severe due to the excessively drained soil and to long breaks in the monsoon.

In Claveria, favorable conditions prevailed during the growing season: there was no drought, and disease incidence was very low. The best yielding entries and their associated characteristics are given in Table 12. Yields were high (max 4.7 t/ha), with more than 70% of the entries yielding >3.0 t/ha.

The overall best yielding entries based on average grain yield from the Cavinti and Claveria trials are given in Table 13. Yield stability, despite environmental differences, was indicated by lines IR30716-B-1-B-1-6, IR5931-113-1, and IR10147-113-5-1-1-5, based on overall ranking in the top 5% in both Cavinti and Claveria. The other entries were affected by site differences.

Table 11. Best 15 entries and check varieties and their associated characteristics.[a] Acid upland yield trial, Mahipon, Cavinti, Laguna, Philippines, 1985.

Rank	Variety or line	Yield (t/ha)	Early vigor[b] (25 DAS)	Drought score[c] (60 DAS)	Phenotypic acceptability[d] at harvest	Neck blast[e] at harvest
1	BR319-1	2.2	3.0	4.3	2.7	1.0
2	IR10147-113-5-1-1-5	2.2	2.3	4.3	1.3	3.7
3	IR30716-B-1-B-1-6	2.1	5.0	3.0	1.3	1.0
4	IR5931-113-1	2.1	3.0	5.0	1.7	0.3
5	IR12979-24-3-4	1.9	2.3	3.0	1.7	0.7
6	AUS257	1.8	1.0	5.0	2.0	3.6
7	IR7790-1B-1-2-5	1.8	3.0	3.7	2.3	2.7
8	IR10120-3-1-1-1	1.7	3.0	3.7	2.7	2.3
9	IR10004-1-1-2	1.6	2.3	3.7	2.0	2.3
10	Madisa	1.6	3.7	4.3	2.3	5.0
11	IR5420-1-1-2-3	1.6	2.3	4.3	3.0	1.7
12	IR10068-18-2-6	1.6	3.0	5.0	3.0	1.3
13	ARC7046	1.6	1.7	4.3	2.3	5.0
14	IR13754-5-2	1.5	3.7	4.3	3.7	3.7
15	Dular	1.5	3.0	3.0	2.7	3.7
23	IRAT104 (check)	1.2	4.3	1.0	1.0	0.7
25	UPLRi5 (check)	1.0	1.7	5.0	3.3	7.0
30	IR6023-10-1-1 (check)	0.9	7.7	2.3	3.7	5.7
31	IR43 (check)	0.9	3.0	3.7	5.7	6.3
36	UPLRi7 (check)	0.6	3.0	4.3	3.0	3.0
38	Kinandang Patong	0.4	3.0	1.0	1.0	1.0
41	IAC25 (check)	0.3	2.3	1.7	6.3	5.6
	Grand mean	1.1				
	LSD (0.01)	0.7				

[a]DAS = d after sowing. [b]1 = extra vigorous, 7 = plants less vigorous than normal. [c]1 = slight tip drying, 5 = ¼ to ½ of all leaves fully dried. [d]1 = excellent, 7 = poor. [e]1 = less than 1% infected panicles, 7 = 26-50%.

Table 12. Best 15 entries and check varieties with their associated characteristics. Acid upland yield trial, Anii, Claveria, Misamis Oriental, Philippines, 1985.

Rank	Variety or line	Yield (t/ha)	Leaf blast[a]		Neck blast[b] at harvest	Brown spot[c]	Plant height (cm)	Phenotypic acceptability[d]	Flowering (DAS)[e]
			23 DE	60 DE					
1	AUS196	4.7	0.067	1.12	0.08	1.38	113	4.33	91
2	IR30716-B-1-B-6	4.5	0	0.69	0	0.24	99	1.67	95
3	IRAT104	4.4	0	0	0	0	131	1.67	109
4	IR26957-45-1	4.4	0	0	0	0	97	1	111
5	IR12979-24-1	4.4	0	0	0	0	111	3.65	111
6	IR5931-113-1	4.3	0	0	0	0	100	3	110
7	IR7790-18-1-2-5	4.3	0	0	0	0	104	1.67	95
8	Dharial	4.2	0.16	1.07	0.81	0.34	119	3	74
9	IR5420-1-1-2-3	4.2	0.003	0	0	0	88	2.33	113
10	IR10147-113-5-1-1-5	4.1	0.003	0	0	0	102	1	109
11	IR12979-24-1-8	4.1	0	0.93	0	0	111	3.67	111
12	I13761-11-3	4.1	0.003	0	0	0	109	1.67	109
13	UPL Ri7	4.0	0	0	0	0	94	2.33	104
14	IAC25	4.0	0.023	0.73	0.2	2.03	133	1.67	82
15	BG35-2	4.0	0	0	0	0	78	4.33	108
30	UPL Ri5 (check)	3.4	0	0.21	0	0.6	94	5	116
31	IR6023-10-1-1 (check)	3.4	0	0.28	0	0.59	101	3	109
35	IR43 (check)	3.2	0	0	0	0	70	7.67	117
	Grand mean	3.4							
	LSD (0.05)	1.0							
	LSD (0.01)	1.3							

[a]DE = days after emergence. 0 = no lesions, 1 = small brown specks of pinhead size. [b]0 = no incidence, 1 = less than 1% infected panicles. [c]0 = no incidence, 2 = 1-3% affected leaf area. [d]1 = excellent, 7 = poor. [e]Days after sowing.

Table 13. Overall best 15 entries and check varieties based on average grain yield from Claveria and Cavinti. Acid Upland Yield Trial, 1985 WS.

Rank	Variety or line	Overall yield (t/ha)	Cavinti				Claveria	
			Rank	Yield (t/ha)	Drought score	Neck blast	Rank	Yield (t/ha)
1	IR30716-B-1-B-1-6	3.3	3	2.1	3	1.0	2	4.5
2	IR5931-113-1	3.2	4	2.1	5	0.3	6	4.4
3	IR10147-113-5-1-1-5	3.1	2	2.2	4.3	3.7	10	4.1
4	AUS196	3.1	17	1.5	4.3	1.7	1	4.7
5	IR7790-18-1-2-5	3.1	7	1.8	3.7	2.7	7	4.3
6	BR319-1	3.0	1	2.2	4.3	1.0	19	3.8
7	IR5420-1-1-2-3	2.9	11.5	1.6	4.3	1.7	9	4.2
8	IR12979-24-3-4	2.8	5	1.9	3.0	0.7	23	3.7
9	IR12979-24-1-8	2.8	19	1.4	3.7	2.0	11	4.1
10	IR10068-18-2-6	2.7	11.5	1.6	5.0	1.3	16	3.8
11	IR10120-3-1-1-1	2.7	8	1.7	3.7	2.3	22	3.7
12	AUS257	2.6	6	1.8	5.0	3.6	28	3.4
13	IR13754-5-2	2.6	14	1.5	4.3	3.7	20	3.7
14	IR26957-45-1	2.6	33	0.8	5.0	4.3	4	4.4
15	IR13761-11-3	2.5	26	1.0	3.7	3.0	12	4.1
25	IRAT104 (check)	2.3	23	0.2	1.0	0.7	3	4.4
26	UPLRi7 (check)	2.3	36	0.6	4.3	3.0	13	4.0
29	UPLRi5 (check)	2.2	25	1.0	5.0	7.0	30	3.4
32	IAC25 (check)	2.2	41	0.3	1.7	5.6	14	4.0
33	IR6023-10-1-1 (check)	2.1	30	0.9	2.3	5.7	31	3.4
35	IR43 (check)	2.0	31	0.8	3.7	6.3	35	3.2
Grand mean				1.1				3.4
LSD (0.05)				0.5				1.0
LSD (0.01)				0.7				1.3

TIDAL WETLAND RICE

Plant Breeding Department

A breeding program to develop improved varieties adapted to tidal wetlands was initiated in 1985. There are presently about 6 million ha of these lands cultivated to rice, but if suitable high yielding varieties were developed, many million additional ha could be brought into production.

Soil salinity and submergence are the main yield-reducing factors in tidal wetlands. Most of these lands also have adverse soils: acid, acid sulfate, alkaline, or peat soils.

The breeding program uses three approaches. One is testing the adaptability to tidal wetland conditions of varieties or elite lines developed for other environments; however, major improvements are not expected through this approach. Most emphasis will therefore be on hybridization and selection, by which traditional varieties will be improved while retaining their adaptability to adverse soils and climatic stresses. Techniques such as hybrid rice, tissue culture, and wide hybridization will also be employed.

Six tidal wetland sites in the Philippines were selected for collaborative research with the Philippine Ministry of Agriculture and Food, and one acid sulfate site in Thailand was chosen for collaboration with the Rice Research Institute, Thailand. Some tidal areas with peat and alkaline soils were found, but they were not suitable for long-term breeding research.

Because tidal wetlands are usually cultivated only once a year, breeding is slow. To minimize delay, some IRRI fields that had been converted to simulate adverse soil and other stress conditions were used for shuttle breeding with outside locations. All locations and their stresses are listed in Table 14.

Most commonly grown traditional tidal wetland varieties and modern varieties that had been found to possess tolerance for certain soil and climatic stresses were assembled and multiplied. Based on their best known trait, some were selected for

Table 14. idal wetlands research sites and their main stresses, 1985.

Location	Main stress[a]	
	Soil	Climatic and others
Santo Rosario, Iloilo	Salinity (late) Acidity, acid sulfate	Tidal submergence (early) Flooding (mid)
Lanhagan, Iloilo	Salinity (throughout) Acidity	Deep water (mid)
Pili, Iloilo	Salinity (late) Acidity	Submergence (early and mid)
Santo Tomas, Pampanga	Salinity (early and late)	Submergence (early and mid) Drought (late)
Santa Monica, Bulacan	Salinity (mid and late)	Drought (late)
Castuli, Pampanga	Salinity (throughout) Organic substances toxicity	Submergence (early) Drought (late)
IRRI, Los Baños	Induced salinity (throughout)	Pests and diseases
IRRI, Los Baños	Induced alkalinity (throughout)	Pests and diseases
IRRI, Los Baños	Low fertility, no inputs	Pests and diseases
Ongkarak, Nakhon Nayok, Thailand	Acidity, acid sulfate	Submergence (mid) Deep water (mid)

[a]Period in the season at which the crop may suffer is given in parentheses.

hybridization (Table 15), and a large number of crosses were made. Tolerance for salinity and submergence was the common objective in most crosses.

About 250 bulk populations (F_2 and F_3) were evaluated at various sites. Except in IRRI fields, all were affected by tidal or flash floods two or three times during the vegetative period. Salinity increased at later stages. Plant survival ranged from 0 to 60%. Of the 247 populations established, 148 produced plants having most of the desirable traits and were selected.

A nursery consisting of well known traditional tidal wetland cultivars and some modern semidwarf varieties or elite lines was evaluated at five of the sites used for breeding work. All were affected by flooding (submergence) several times during the vegetative stage, and two were completely destroyed. At other sites, most varieties did not survive the stresses. At the site with acid sulfate soils, varieties Bayar Raden Rati, Cheriviruppu, Dudmona, Gaw Diaw Bow, Garcha, Kuatik Putih, Suakoko 8, SR26 B, IR42, IR9764-45-2-2, IR21916-128-2-2-2-3, IR31238-446-2-35, and IR31363-1-1-3-3-2 were the best performers. At the second site, where flood damage was moderate but salinity was high, only Cheriviruppu, Nona Bokra, Pokkali, AT69-4, IR4595-4-1-13, IR4630-22-2-17, IR10206-29-2-1, and IR34337-2-4-1-2-1 could withstand the stresses. Flood damage and salinity were very severe at the other site, killing all except Cheriviruppu, Pokkali, and Nona Bokra.

Tissue culture techniques were used to isolate variants with adaptability to tidal wetland conditions. The objectives were to induce salt tolerance in modern varieties and to produce variants of adaptable traditional varieties with higher yield potential. The tests were carried out with somaclonal variants from the Tissue Culture for Crops

Table 15. Varieties commonly used in hybridization for various stresses. IRRI, 1985.

Stress	Tolerant varieties	
	Traditional tall	Modern semidwarf
Salinity	Nona Bokra Pokkali Cheriviruppu	IR4595-4-1-13 IR4630-22-2-5-1-3 IR9884-54-3
Alkalinity	Damodar Pokkali	IR6 IR46
Acidity	KDML 105 Khao Daeng	IR42 IR4683-54-2-2-3
Peatiness	Lemo Pandak	IR54 IR8192-200-3-3-1-1
Submergence	FR13A FR43B	BKNFR76106-16-0-1-0 IR26702-25-1
Major pests and diseases	–	IR64 IR32429-47-3-2-2

Table 16. Parents most frequently used in crosses in the deep water rice breeding program, 1985.

Parent	Crosses (no.)	Attributes
BKNFR76026-3-2-2-2	55	Deep water rice, photoperiod-sensitive, elongating modern variety (MV), resistant to GLH, drought tolerant
FRRS 43-3	68	Floating rice with very good elongation ability and drought tolerance
IR11141-6-1-4	105	Deep water, combining MV type with excellent elongation ability, resistance to BPH biotypes 1 and 3, drought tolerance
IR11288-B-B-69-1	105	Photoperiod-sensitive deep water rice with MV type and good elongation; resistant to BPH biotypes 1, 2, and 3; and BB race 1
IR21037-2-1-2E-P2	33	Photoperiod-insensitive deep water rice with MV type, resistant to GLH and BB race 1
IR31406-333-1	79	MV type with excellent submergence tolerance, resistant to BPH biotypes 1 and 3 and BB race 1, drought and salinity tolerant
IR36 (male sterile)	34	MV type, genetic male sterile for population breeding in deep water rice
IR60	32	MV type; resistant to BPH biotypes 1, 2, and 3, GLH, and BB race 1; alkalinity tolerant; clear, slender grains

Project, Colorado State University, Colorado, USA.

R_2 variants of IR36, G159, Calrose, Mahsuri, and Pokkali were evaluated at IRRI during DS. Except for IR36 variants, almost all were seriously affected by several fungal diseases and RTV. Unaffected plants were retained; among them were two mutant-like plants of Pokkali. They were planted in WS; one was found to be an early dwarf, while the other segregated for both duration and height. Selections made from them will be tested for salinity tolerance and stability.

DEEP WATER RICE

Plant Breeding Department

Hybridization. We made 301 single and 233 multiple F_1 crosses for deep water rice improvement. The general objective was to obtain varieties and breeding materials of improved yielding ability through better plant type and resistance to pests and diseases.

Table 16 gives details on the most commonly used parents.

Collaborative screening in Thailand. Several thousand deep water pedigree lines were tested for elongation ability at the Huntra Rice Experiment Station in collaboration with the Rice Research Institute, Thailand. After selecting in the field at IRRI, we retained 1,082 lines with some degree of elongation ability: 59 excellent (elongation score of 1-2), 92 very good (3-4), 386 good (5-6), and 545 fair (7-8).

Selection for elongation in farmers' fields. F_2 populations having at least one parent from Thailand were subjected to natural flooding in Ayutthaya. Water rose to at least 1 m. The best surviving populations had both adequate elongation ability and appropriate (not too early) maturity. Populations or segregants without both attributes were destroyed by the flooding or by rats.

Selection of deep water rices at IRRI. In 1985 we bulk-harvested many hundreds of promising lines with elongation ability or submergence tolerance in combination with other favorable traits. Table 17 lists lines with elongation ability and some other attributes; Table 18 gives lines with submergence tolerance.

Table 17. Promising elongating deep water rices and their salient traits. IRRI, 1985.

Designation	Trait[a]									
	El	Sm	Ht (cm)	BB	BPH			GLH	Bl	Gra
					1	2	3			
DWCT146-2-3-0-19/B922C-MR-91-4//DWCT146-2-3-0-19/RD19										
BKNFR80081-14-1-4-2	6		125	√				√		
IR8234-OT-9-2/HTA7403-110-1										
BKNFR81023-9-2-2-3	5		142	√	√	√	√			
BKN6987-161-3//PG56/PTB18										
HTAFR77039-17-4-0-1-2-3-2-4	6		117	√		√	√	√		
HTAFR77039-17-4-0-1-2-3-2-5	6		140	√	√		√	√		
HTAFR77039-17-4-0-1-2-3-3-2	6		139	√	√	√	√	√		
*Bhadoia 648/2*IR4422-51-1-1*										
IR18968-16-0-1-1-2-1	4		165	√				√		
IR18968-16-0-1-1-3-1	4		180	√	√			√		
Beguamon 202/IR13426-19-2//IR9764-45-2-2										
IR33188-8-2-1-3-2-1-2	6		149	√		√		√		
IR33188-8-2-1-3-2-1-5	6		166	√	√	√		√		
IR33188-8-2-1-3-2-1-6	6		165	√			√	√		
IR33188-8-2-1-3-2-3-6-2	6		149	√				√		
IR33188-8-2-1-3-6-1-3	6		166	√	√			√		
Bhusuri Sali paddy/CN540//IR9764-45-2-2										
IR33226-16-1-1-3-3-2	6		138	√				√		
IR33226-16-1-3-2-3-3-3	6		125	√				√		
Beguamon 349/IR36//HBJ Aman 2/Chenab 64-117										
IR33716-1-503-1-2-2-2-2-3	5		115		√					
IR33716-1-503-1-2-3-2-3	1		134			√		√		
RD19/IR46										
IR37025-R-R-R-29-3	6		110		√					
Chenab 64-117/IR7732-B-A96-3										
IR38685-13-2-5-2-3-1	4	8	161	√				√		
IR38685-4-1-1-2-2-2	4		165	√				√	√	
IR38685-49-2-1-6-3-1	6		120	√				√	√	
IR38685-80-3-3-2-1-3	6		168	√	√	√	√	√		
Mahsuri/IR11288-B-B-288-1										
IR38730-103-3-1-1-2-1	6		150		√			√	√	√
IR38730-103-3-1-1-2-2	6		145		√			√	√	√
IR38730-93-2-1-6-3-3	6		117	√	√	√	√	√	√	
RD19/CR1030										
IR38780-29-1-1-3-1-1	5		195					√	√	
RD19/IR50										
IR38784-100-1-3-1-2-1	5		105	√	√	√	√	√		√
IR38784-100-1-3-2-2-1	5		120	√	√	√	√			√
IR38784-100-1-3-6-1-1	5		115	√	√	√	√	√		√
IR38784-100-1-3-6-3	5		92	√	√	√	√	√		√
IR38784-137-2-3-6	6		96	√	√	√		√		√
IR38784-30-1-2-1-2	6		97	√	√	√	√	√		√
IR38784-36-2-2-1-1-1	6			√	√	√	√	√		
IR38784-36-2-2-3-2	6		86	√	√	√	√	√		√
BKN6721-5-7-4/IR9264-321-3//IR11185-R-R-R-88-2										
IR39498-18-1-3-2-1	4	6	145	√	√	√		√	√	√
DWCT156-1/DWCB-B-302-3										
IR41532-29-3-1-3	6		165		√	√	√	√		√
IR41532-70-1-3-1	6		135				√		√	

Continued on opposite page

Table 17 continued

Designation	Trait[a]									
	El	Sm	Ht (cm)	BB	BPH			GLH	Bl	Gra
					1	2	3			
HTA7406-111-0-0-2//RD19/IR11288-B-B-288-1										
IR42435-118-1-1-2	4		154				√		√	
IR42435-274-1-1-2	3		99	√	√		√		√	
IR42435-289-2-3-1	5		152	√	√		√		√	√
IR42435-34-2-3-1	4		149	√	√		√		√	
IR42435-34-5-3-3	4		144						√	
IR42435-35-6-3-3	4		167	√	√		√	√	√	
IR54//RD19/CR1030										
IR42437-70-2-1-1	7		124	√				√	√	√
IR42437-74-1-3-2	7		√√√	√				√		√

[a]El = elongation; Sm = submergence tolerance, 7 or better; Ht = plant height; BB = bacterial blight, race 1; BPH = brown planthopper, biotypes 1, 2, 3; GLH = green leafhopper resistance of 3 or better; Bl = blast, resistance of 4 or better; Gra = grain length of 3 or better, grain shape 1, chalkiness 1 or 0.

Table 18. Promising submergence tolerant deep water rices and their salient traits. IRRI, 1985.

Designation	Trait[a]									
	El	Sm	Ht	BB	BPH			GLH	Bl	Gra
					1	2	3			
IR8234-OT-9-1/IET5656										
BKNFR80026-4-1-1-2-3-1		5	142		√		√	√		
BKNFR80026-4-1-3-3-21		3		√	√			√		
FRG10/IR4219-35-3-3-2//IR42										
IR28832-37-3-4-1		5	108	√	√					
FRG10/IR48//X69-2-27-2										
IR28839-R-R-13-2-1-21		1		√	√				√	
IR28839-R-R-5-1-1-2-21		1								
G. Heenati/B1050C-MR-18-1-4//IR5657-33-2										
IR31070-48-2-2-3-1-2-1		4	140	√				√		
IR31070-48-2-2-3-3-2-1		4	140	√				√		
Kurkaruppan/IR4422-98-3-6-1//IR13419-113-1										
IR31442-1-502-1-2-1-22		3	141	√	√	√	√	√		
IR31442-1-503-1-2-1-22		1	141		√	√	√	√		
Suweon 290/FR43B										
IR36449-R-R-R-116-1		1	147	√	√					
IR36449-R-R-R-118-1		1	156							
IR36449-R-R-R-14-2		5	160				√			
IR36449-R-R-R-38-1		1	170				√			
IR36449-R-R-R-41-3		1	161		√					
IR36449-R-R-R-60-1		1	165			√				
IR36449-R-R-R-62-1		1	143		√	√	√	√		
IR36449-R-R-R-75-1		1	165			√		√		
IR36449-R-R-R-84-3		1	156		√	√	√	√		
IR36449-R-R-R-86-3		1	105			√				
IR36449-R-R-R-88-2		5	102		√	√		√		
IR36449-R-R-R-95-1		1	174	√	√					
IR36449-R-R-R-97-2		5	170	√		√				

Continued on next page

Table 18 continued

Designation	Trait[a]									
	El	Sm	Ht	BB	BPH			GLH	Bl	Gra
					1	2	3			
Chenab 64-117/IR4563-52-1-3-6										
IR38682-27-6-2-3		5		√						
Chenab 64-117/IR4744-295-2-3										
IR38683-11-2-3-4-1-3		4	110					√		
IR38683-22-3-3-2-1-1		5	115		√	√	√	√		
IR38683-35-2-9-10		1	98		√					
IR38683-35-2-9-11-1-1		3	100		√					
IR38683-35-2-9-11-3-1		3	100		√			√		
IR38683-35-2-9-2-2-3		3	100		√	√	√			
IR38683-35-2-9-2-3-3		3	95		√	√	√			
IR38683-35-2-9-4-2-2		3	92		√	√	√			
Chenab 64-117/IR15314-43-2-2-3										
IR38691-27-6-1-3		6	103		√	√		√	√	
IR38691-27-6-3-1		6	98		√	√		√	√	
IR38691-27-8-1-3		6	113		√	√			√	
BKNFR76001-99-2-2/GEB24/IRD19/FR13A										
IR39534-1-2-2-1		5	86	√	√	√		√		
CR1009/IR48//CR1002/FP43B										
IR39536-1-3-2-2		1	88							
IR39536-1-3-4-1-2-3		4	90		√	√	√			
IR39536-1-3-5-1-1-1		4	89			√	√			
IR39536-1-3-5-1-2-1		4	90			√	√			
IR39536-10-5-1-1-2-3		5	101		√	√	√		√	
IR39536-10-5-1-2-1-3		4	100		√	√	√		√	
IR39536-10-5-1-3-3-3		3	103		√	√	√		√	
IR39536-10-5-3-3-1-1		2	100		√	√	√		√	
IR39536-5-2-3-2		2	117		√	√	√		√	
IR4568-86-1-3-2/FR43B//CR1009/IR42										
IR39543-17-2-3-3-3-1		6		√	√			√	√	
IR39543-9-2-2-3-1-1		5	137	√	√		√	√		
IR39543-9-2-2-3-1-2		5	130	√	√		√	√		
IR39543-9-2-3-1-1-3		4	140	√	√			√		
IR39543-9-2-3-2-3-3		2	144	√	√			√		
IR39543-9-3-3-3-3-2		5	134	√	√			√		
IR39543-9-3-3-3-3-3		6	115	√	√			√		
IR8234-OT-9-2/Nam Sagui 19										
IR41425-121-1-1-2		6		√	√	√	√	√	√	√
IR41425-143-3-3-1		5		√	√		√	√	√	√
IR41425-188-3-3-1		4		√	√		√	√	√	√
IR41425-196-1-3-3		6		√	√		√	√	√	√
IR41425-34-3-1-1		6		√	√	√	√	√	√	√
IR41425-34-3-3-1		6		√		√	√	√	√	√

[a]El = elongation; Sm = submergence tolerance, 7 or better; Ht = plant height; BB = bacterial blight, race 1; BPH = brown planthopper, biotypes 1, 2, 3; GLH = green leafhopper resistance of 3 or better; Bl = blast, resistance of 4 or better; Gra = grain length of 3 or better, grain shape 1, chalkiness 1 or 0.

Control and management of rice pests

Diseases

Plant Pathology Department

FUNGAL DISEASES **144**
Sheath blight and related diseases **144**
Sheath blight, sheath spot, and aggregate sheath spot **144**
Inoculum distribution and infection **144**
Biological control **144**
Blast epidemiology **146**
Yield reduction due to fungal pathogens **148**
Suppression of general resistance mechanism of rice by *Helminthosporium oryzae* toxin **148**
VIRAL DISEASES **148**
Tungro **148**
Epidemiology in Central Luzon **148**
Recovery of rice tungro bacilliform virus from infected IR52 plants **149**
Development of RTV infection in the field **150**
Subsequent infection of RTBV-infected IR54 by RTSV alone **151**
Host range **151**
Occurrence of RTSV on upland rice **151**
RTV vectors carrying viruses **152**
Detection of RTV-associated viruses in infected dry leaves **152**
Viral diseases and vectors in Laguna **153**
Serodiagnosis of virus diseases in remote areas **153**
GSV and RSV carriers in trapped BPH **153**
Ragged stunt **154**
Cause of abnormal plant growth **154**
Host range **154**

Sheath blight and related diseases. *Sheath blight, sheath spot, and aggregate sheath spot.* Sheath blight (ShB) caused by *Rhizoctonia solani* is prevalent wherever rice is grown, and with the intensification of rice cultivation, its incidence is gradually increasing. *R. oryzae* causes sheath spot, and *R. oryzae-sativae* causes aggregate sheath spot. The symptoms of the three diseases are similar, and careful observation is required to distinguish them (Fig. 1). The pathogens can be easily distinguished on potato dextrose agar by colony color, growth characters, patterns of sclerotia formation, and size. *R. solani* is light brown and produces compact, irregular but spherical type, large sclerotia; colonies of *R. oryzae* are light greyish and produce many small, round, loose sclerotia; colonies of *R. oryzae-sativae* are pinkish and produce salmon-colored, small, flat sclerotia (Fig. 2).

A 1985 survey revealed these diseases on most commercial rice cultivars in the Philippines in farmers' fields as well as at IRRI. ShB frequency was highest, followed by aggregate sheath spot and sheath spot (Fig. 3, 4).

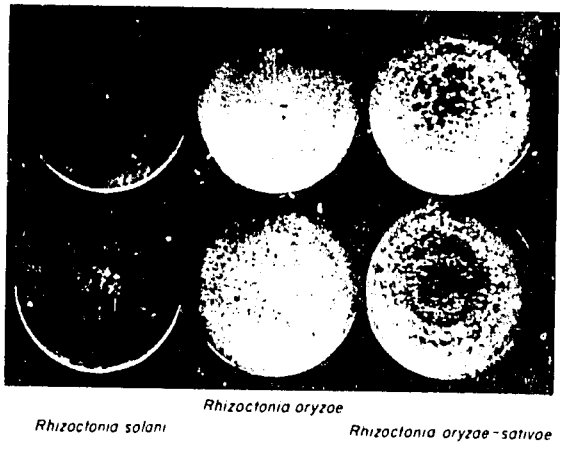
Inoculum distribution and infection. Based on the number of sclerotia extracted from soil samples using the wet-sieve method and on mycological and pathological characteristics, the pathogen frequency in lowland ricefields was 57.3% for *R. solani*, 42.3% for *R. oryzae-sativae*, and 0.4% for *R. oryzae*. It was estimated that the number of *R. solani* sclerotia in the field was 2.02-2.76 million/ha immediately after harvest and fell to 2.02-2.26 million/ha after land preparation; for *R. oryzae-sativae* sclerotia, 1.06-2.46 million/ha after harvest fell to 1.06-1.24 million/ha.

The diameter of *R. solani* sclerotia ranged from 1 to 3 mm; that of *R. oryzae-sativae* was 1 mm or less. The size of sclerotia was directly related to the infection potential; bigger sclerotia caused more disease (Table 1).

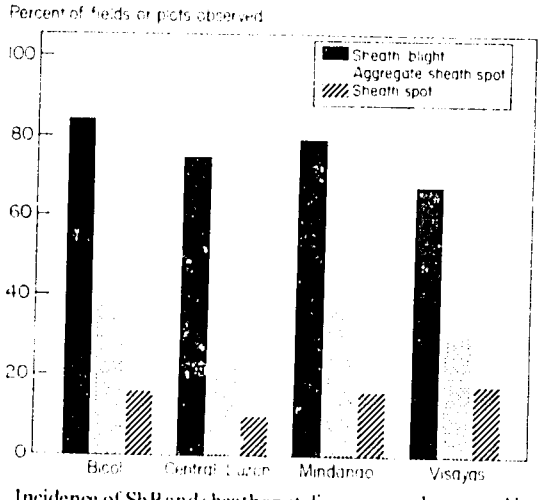
In three IRRI fields where IR36 was planted in dry season (DS), disease incidence was similar but its severity varied. The variance-to-mean ratio indicated a spatial distribution pattern (Fig. 5). A positive correlation between sclerotia numbers and disease severity was noted, but none between plant density and sclerotia on soil surface immediately after harvest. The distribution of the sclerotial pattern after land preparation showed a variance-to-mean ratio indicating a clustering or aggregate spatial pattern of inoculum distribution. Variance-to-mean ratio and the mean sclerotial number were reduced after land preparation.

Biological control. Earlier studies showed the effect of antagonistic bacteria from rice on ShB development (Annual report for 1984). Further tests on these bacteria, using both fluorescent and nonfluorescent isolates based on pigment production on King's Medium B, confirmed their ability to suppress the infectivity of *R. solani* sclerotia. When laboratory-produced sclerotia were soaked

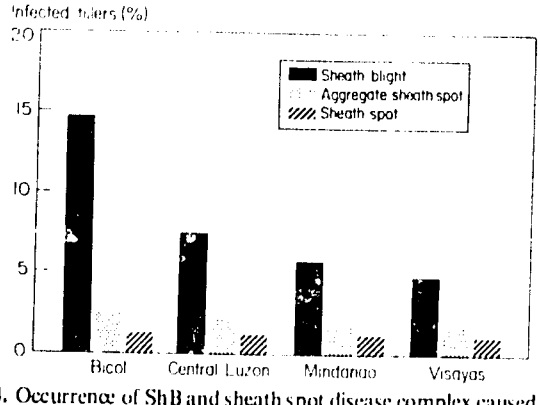
1. Symptoms of ShB caused by *Rhizoctonia solani*, sheath spot caused by *R. oryzae*, and aggregate sheath spot caused by *R. oryzae-sativae*. IRRI, 1985.



2. Colonies of the fungal pathogens causing ShB, sheath spot, and aggregate sheath spot. IRRI, 1985.



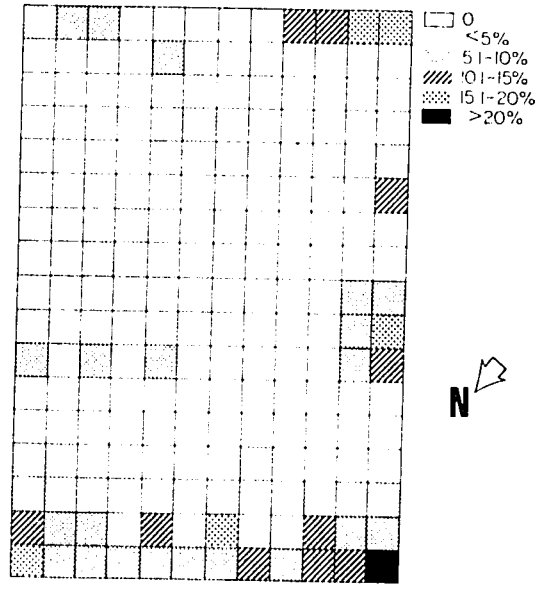
3. Incidence of ShB and sheath spot disease complex caused by *Rhizoctonia* spp. on rice. Philippines, 1985.



4. Occurrence of ShB and sheath spot disease complex caused by *Rhizoctonia* spp. on rice. Philippines, 1985.

Table 1. Distribution and size of *R. solani* sclerotia recovered from ricefield, and infectivity on detached rice leaves. IRRI, 1985.

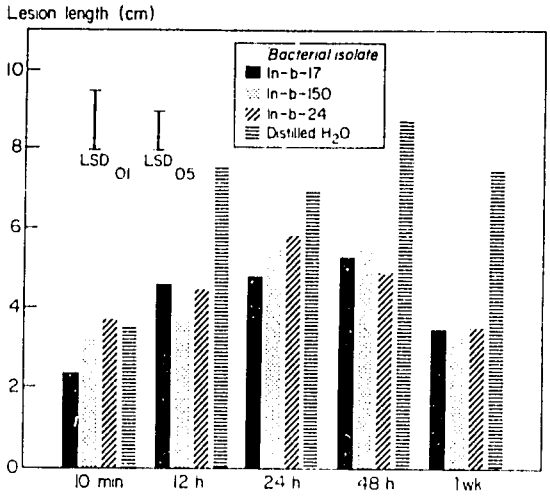
Sclerotia size (mm)	Sclerotia (no.)	Frequency (%)	Lesions (no.)	Lesion size (mm)
2 × 2	12	2.18	5.1	19 × 5.6
1.8 × 1.8	67	12.18	4.3	17 × 4.5
1.5 × 1.5	147	26.73	2.8	13 × 4.1
1 × 1	324	58.91	1.2	9 × 4.0



5. Severity and distribution of ShB on IR36 in an IRRI field. April 1985.

in bacterial suspension before being allowed to infect IR36 grown to maximum tillering, both disease incidence and lesion size were reduced (Fig. 6).

In a screenhouse experiment, treating IR36 seeds with bacteria caused the plants to grow faster, taller, and greener than those without treatment. At flowering, the apparent difference was not highly visible. Seed treatment was more effective than spraying the bacterial suspension on the plants at 45 d after transplanting (Table 2). Although tiller number at maximum tillering indicated that seed bacterization produced an effect equal to that of spraying, grain yield was higher with seed treatment. Bacterization also suppressed ShB and sheath rot.



6. Reduction of ShB lesions on IR36 infected with *R. solani* sclerotia presoaked in bacterial suspension. IRRI, 1985.

The bacteria, both fluorescent and nonfluorescent, inhibited mycelial growth of *Fusarium moniliforme*, which causes bakanae (Bak) disease. The germination of seeds collected from Bak-infected fields was improved with seed bacterization (Table 3). In the nursery seedbed, seeds treated with bacteria were observed to have fewer infected tillers.

Blast epidemiology. There are few epidemiological studies of blast (Bl) in upland rice. To understand the interactions among factors affecting Bl development, a holistic field study is simultaneously measuring host development, pathogen development, and microclimate throughout a growing season.

Table 3. Improved germination of IR42 seeds from bakanae-infected field by bacterial seed treatment with selected isolates. IRRI, 1985.

Isolate	Germination[a] (%)
In-b-148	87
In-b-157	69
In-b-17	68
In-b-150	66
In-b-591	64
In-b-157	61
In-b-149	49
Check	34

[a]Mean of 3 replications.

Several methods of measuring airborne spore densities were compared: a Burkard volumetric spore trap, glass rods, glass slides, and potted "trap" plants. Trap plants were exposed in the field overnight, then either incubated in a dew chamber for 24 h or placed directly in the greenhouse. The dew chamber treatment provided optimum conditions for infection by spores landing on the leaves, whereas the greenhouse treatment provided a measure of only the spores that infected the tissue in the field. The volumetric trap caught the most spores. Results using glass slides and trap plants incubated in a dew chamber correlated well with data from the volumetric trap (Table 4). Data from trap plants placed directly in the greenhouse did not correlate as well with the volumetric trap, but should be useful when the analysis of environ-

Table 2. Effect of antagonistic bacteria used in seed bacterization and spray inoculation at 45 d after transplanting (DT) on plant height, tiller number, and grain yield of IR36 and on sheath blight (ShB) and sheath rot (ShR) incidence in the screenhouse.[a] IRRI, 1985.

Bacterial isolate[b]	Plant height[c] (cm)		Tillers[d] (no.)		Grain yield[e] (g)		ShB incidence (%)		ShR incidence (%)	
	ST	S	ST	S	ST	S	ST	S	ST	S
NF In-b-17	52.9	49.9	10	8	107.5 a	87.0 bc	14	9	0	15
F In-b-24	55.7	51.0	9	7	105.7 ab	84.5 c	13	13	5	12
F In-b-150	52.0	54.0	8	9	108.7 a	86.5 bc	12	23	5	11
NF In-b-590	59.5	53.5	9	9	97.0 abc	93.0 ab	19	18	2	13
NF In-b-591	59.8	54.5	9	9	93.0 cd	95.0 a	32	28	19	19
Check	51.0	49.4	6	7	88.0 cd	87.0 bc	28	22	16	20

[a]ST = seed treatment, S = spraying onto plants 45 DT at about 10^9 colony-forming units/ml. [b]NF = nonfluorescent, F = fluorescent. [c]Mean of 6 tillers measured at 1 mo after transplanting. [d]Mean of 3 replications, 6 hills/replication measured at maximum tillering. [e]Grain weight taken from 6 hills.

Table 4. Correlation matrix for comparing various spore trapping methods.[a] IRRI, 1985.

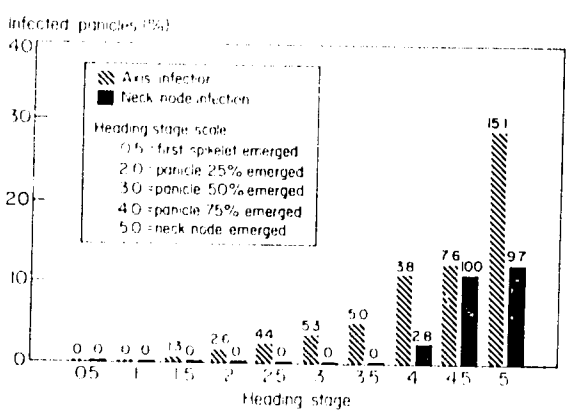
	Volumetric spore trap	Glass slides	Glass rods	Trap plant (dew chamber)
Glass slides	0.93			
Glass rods	0.63	0.82		
Trap plant (dew chamber)	0.89	0.90	0.64	
Trap plant (greenhouse)	0.38	0.42	0.24^{ns}	0.71

[a]Data from upland rice variety C22, sown in April 1985. ns = not significant, all other r values significant.

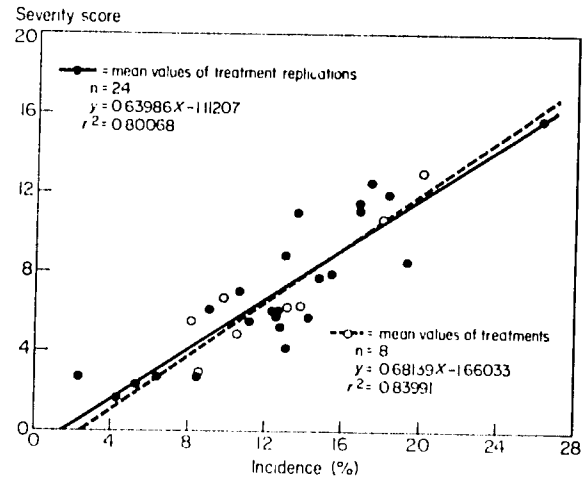
mental data is complete, because they give a measure of the infection efficiency of a particular night, not simply the total number of spores dispersed.

Because infection of the panicle by Bl results in direct yield loss, panicle and neck node infection are being studied in detail. Sampling and incubation of symptomless panicles at various stages of heading revealed that the earliest time of neck node infection is just before emergence of the neck node (Fig. 7). Some infection of the main panicle axis immediately above the node was already evident before this part emerged. Thus, with cultivar C22 used in this study, panicle infection can take place before panicle emergence.

In another experiment with 8 sowing dates, the severity of neck node and panicle infection was estimated (0 = no Bl damage, 100 = no filled grain due to Bl) and compared with the incidence of infection. Over the range of disease incidence



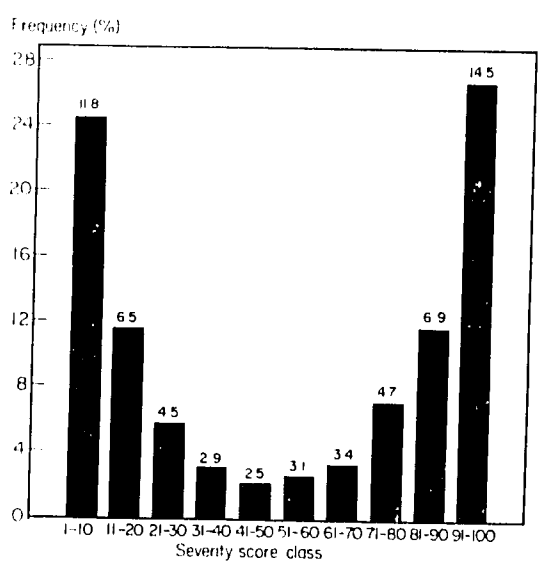
7. Percent infection of panicle axis and neck node after incubation of panicles sampled at various heading stages. IRRI, 1985. Standard deviation is given at the top of each column.



8. Relation between panicle Bl incidence and severity. IRRI, 1985.

observed (2-26%), there was a high correlation with disease severity (Fig. 8). Disease incidence is easily assessed. Thus, if the relationship between incidence and severity could be established for a greater range of disease incidence, the information would be useful for quickly estimating losses due to panicle and neck node infection.

For each trial, a frequency distribution of infection severity was constructed. The distribution in each was similar to the overall distribution, which is given in Figure 9. Panicles with intermediate



9. Frequency distribution of severity scores of Bl-infected panicles. IRRI, 1985. Standard deviation is given at the top of each column.

severity of infection were relatively rare, but those with either low severity or high severity were frequent. There may be a rapid transition of each panicle from high susceptibility to much less susceptibility to Bl damage.

Yield reduction due to fungal pathogens. In DS and wet season (WS) experiments, the systemic fungicide propiconazole was used as a foliar spray in uninoculated plots to ascertain if yield reductions due to fungal disease normally occur at IRRI. In both seasons the plots receiving fungicide had a lower incidence of sheath rot, brown spot, narrow brown leaf spot, and leaf scald; however, the severity of the diseases was generally low, even in untreated plots. ShB was much more severe, but the fungicide effectively reduced disease (Table 5). Yield differences between treated and untreated plots were evident only in the WS trial in the lines of medium (IR31868-64-2-3-3-3) and late (IR28150-84-3-3-2) maturity. No yield enhancing effect of the fungicide treatment was observed in the early maturing line (IR32429-47-3-2-2).

Suppression of general resistance mechanism of rice by *Helminthosporium oryzae* toxin. The major role of the toxin produced by *H. oryzae* appears to be the suppression of the general defense mechanism of rice plants. Rice leaves at advanced stages of infection and rice leaves treated with *H. oryzae* toxin were observed to have lower phenolic content and lower peroxidase and phenylalanine ammonia lyase activity than normal leaves (Table 6). It has been suggested that those compounds are important components of the plant's defense mechanism against pathogens. When the phenolic content of rice leaves was stimulated by giving the plants catheeol, quinic acid, phenylalanine, ethephon, and WL 28325 prior to inoculation with spores of *H. oryzae*, symptom development was appreciably delayed. When such leaves with induced higher phenolic content were treated with the toxin, the phenolic content decreased rapidly (Table 7).

VIRAL DISEASES

Tungro. *Epidemiology in Central Luzon.* Biweekly surveys of tungro (RTV) vectors and incidence of rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV) in four farmers' fields in Nueva Ecija and Tarlac, Philippines,

Table 5. Effect of fungicide on grain yield and ShB severity in 3 GEU elite lines. IRRI, 1985 DS and WS.[a]

Line	Grain yield[b] (t/ha)				Diseased leaf blade and leaf sheath area (%)			
	Dry season		Wet season		Dry season[c]		Wet season[d]	
	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated
IR32429-47-3-2-2	4.8	4.7	4.6	4.6	15.7	41.4	6.7	40.8
IR31868-64-2-3-3-3	4.9	4.7	5.5	4.8	33.9	57.1	17.0	64.7
IR28150-84-3-3-2	4.9	4.9	5.7	5.0	13.9	34.4	17.6	56.8

[a]Foliar spray at early booting and heading with propiconazole 250 EC at 250 g ai/ha. [b]LSD (0.05) = 0.5 for comparing grain yield of treated and untreated plants. [c]LSD (0.05) = 12.5 for comparing disease of treated and untreated plants. [d]LSD (0.05) = 12.0 for comparing disease of treated and untreated plants.

Table 6. Changes in phenolic content and in peroxidase and phenylalanine ammonia lyase activity in rice leaves treated with *Helminthosporium oryzae* toxin. IRRI, 1985.

Toxin treatment (μg/ml)	Phenolic content (μg/g fresh tissue)			Peroxidase (0.001 change in absorbance/min per g fresh tissue)			Phenylalanine ammonia lyase (nmol cinnamic acid produced/g fresh tissue)		
	24 h	48 h	72 h	24 h	48 h	72 h	24 h	48 h	72 h
0	1924 a	1318 a	902 a	106 a	339 a	476 a	918 a	832 a	1031 a
1	755 c	1042 c	770 b	73 b	204 b	531 a	801 b	734 b	818 b
5	865 bc	1156 b	723 b	67 b	125 c	416 b	597 c	743 b	808 b
50	974 b	1124 bc	589 c	37 c	75 d	167 c	535 c	768 b	788 b

Table 7. Changes in phenolic content of leaves of rice plants fed with different compounds and treated with *Helminthosporium oryzae* toxin.[a] IRRI, 1985.

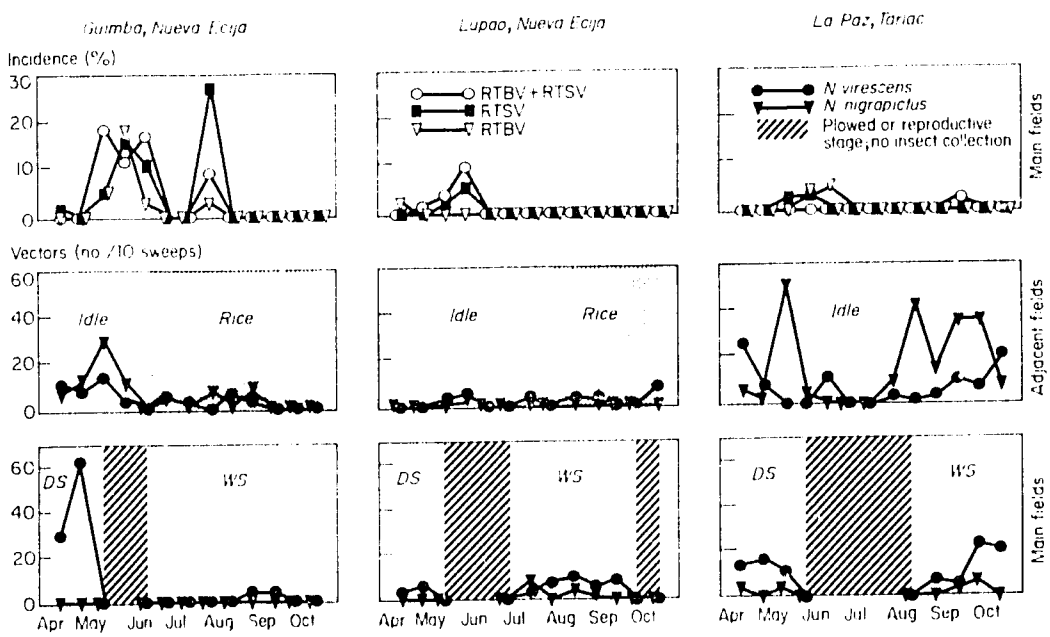
Pretreatment	Phenolic content (μg/g fresh tissue)					
	24 h		48 h		72 h	
	Toxin-treated	Untreated	Toxin-treated	Untreated	Toxin-treated	Untreated
Phenylalanine	947 ± 21	1308 ± 33	457 ± 28	878 ± 23	228 ± 18	673 ± 20
Catechol	869 ± 30	1564 ± 31	477 ± 23	1093 ± 31	343 ± 52	773 ± 25
Quinic acid	1206 ± 31	1829 ± 61	673 ± 25	1297 ± 57	377 ± 45	873 ± 32
Ethephon	437 ± 45	902 ± 28	283 ± 25	670 ± 26	250 ± 26	497 ± 15
WL 28325	397 ± 15	810 ± 30	243 ± 12	600 ± 20	240 ± 40	537 ± 41
Control	367 ± 51	843 ± 21	207 ± 31	607 ± 12	223 ± 32	513 ± 31

[a]Means of 4 replications by scanning electron microscopy.

started in April 1985 to determine the development of the disease. Vectors were collected by 10 sweeps of an insect net, and disease incidence was estimated visually and the viruses determined by the latex agglutination test on randomly sampled rice leaves.

An average of 1% RTV infection assessed visually at the Guimba, Nueva Ecija, site at the start of the study increased to 32% at the end of the 1985 DS. Comparatively higher incidences of RTBV and RTSV were obtained in plants sampled from this field (Fig. 10). RTV incidence was very low in Lupao, Nueva Ecija, and La Paz, Tarlac, and absent in Zaragosa, Nueva Ecija. Generally, *Nephotettix virescens* density was higher in fields with rice than in idle fields, where *N. nigropictus* predominated (Fig. 10). Vector density was very low at the Zaragosa site.

Recovery of rice tungro bacilliform virus from infected IR52 plants. Initial studies revealed that green leafhopper (GLH)-resistant varieties were mostly infected with RTBV alone. GLH failed to recover RTBV from plants infected with RTBV alone. On susceptible varieties, RTBV can be transmitted only by GLH carrying RTSV. This study was therefore conducted to determine the



10. Incidence of tungro-associated viruses and number of vectors in main and adjacent fields. Central Luzon, Philippines, 1985 DS and WS.

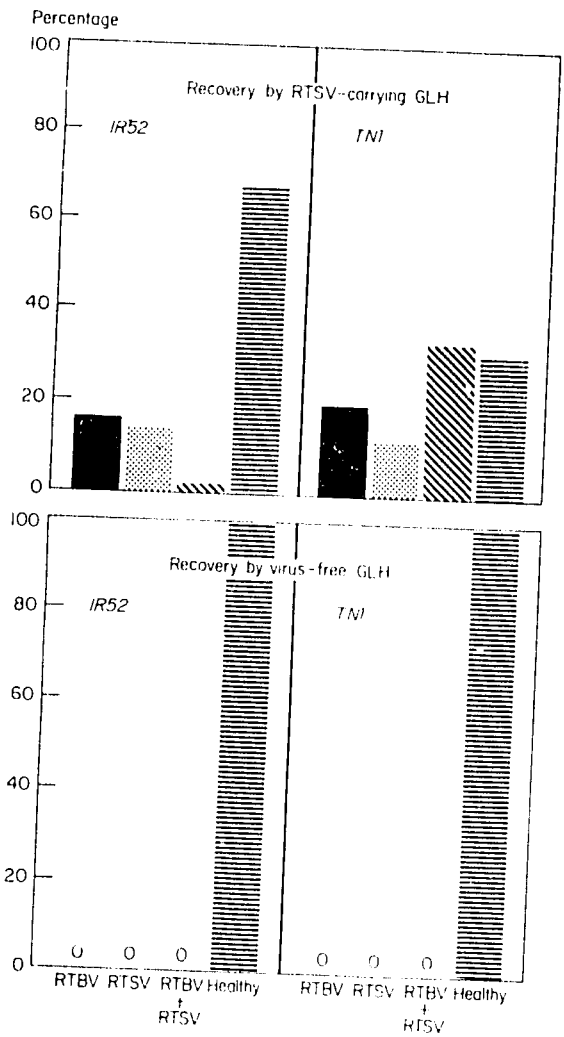
influence of RTSV on the recovery of RTBV from GLH-resistant IR52 plants infected with RTBV.

RTBV-infected seedlings at 45 d after soaking were used as the source. RTSV-carrying or virus-free GLH were given a 2-d acquisition access to the source plants. Then the GLH were given a 1-d inoculation access to 6-day-old TN1 or IR52 seedlings at the rate of 1 GLH/seedling in test tubes. All inoculated plants were tested for the presence of the RTV-associated viruses by the latex test.

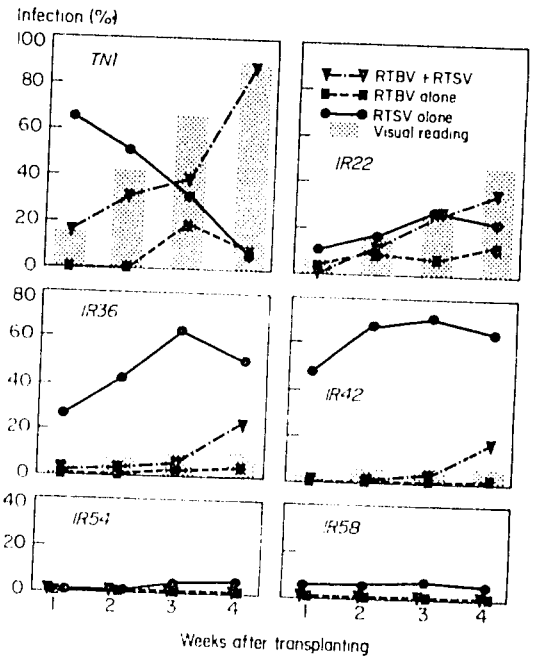
RTBV in IR52 was recovered by RTSV-carrying GLH but not by virus-free GLH (Fig. 11). The proportion of viruses recovered by GLH differed, depending on the variety used to test their infectivity. Higher recovery of both viruses was obtained in susceptible TN1 than in IR52; however, recovery of RTBV or RTSV alone was comparable in both test varieties.

Development of RTV infection in the field. Varieties with different levels of GLH resistance were exposed to natural infection at IRRI and tested weekly for the presence of RTV-associated viruses by latex agglutination.

High RTSV infection was recorded not only in GLH-susceptible TN1 and IR22 but also in moderately resistant IR36 and IR42 in the first few weeks of infection. Thereafter, the percentage of RTSV infection declined gradually but infection with RTBV + RTSV increased, indicating that RTSV source plants were predominant in the field while RTBV + RTSV source plants were scarce in the first few weeks. RTBV + RTSV infection developed quickly in susceptible TN1 but slowly in IR36 and IR42. GLH-resistant IR54 and IR58 had the lowest infection of any of the tungro viruses, while RTSV infection was relatively higher (Fig. 12).



11. Influence of RTSV on recovery of RTBV from infected IR52 plants. IRRI, 1985. Infectivity of GLH was tested on IR52 and TN1 seedlings.



12. Weekly development of RTV infection in varieties with different GLH resistance in the field based on visual reading and presence of RTV-associated viruses as detected by latex test. IRRI, 1985 WS.

An increase in infection based on visual symptoms was observed as RTBV + RTSV infection increased, especially in susceptible varieties.

Subsequent infection of RTBV-infected IR54 by RTSV alone. Greenhouse studies revealed that most GLH-resistant varieties were generally infected with RTBV and could not serve as virus sources because RTBV transmission by GLH is dependent on the presence of RTSV. A study was conducted to determine whether challenge inoculation of RTBV-infected plants with RTBV + RTSV or with RTSV alone would increase plants infected with RTBV + RTSV.

Plants initially infected with RTBV showed significantly higher infection with RTBV + RTSV when challenge-inoculated by GLH that had fed on source plants with RTSV alone than when inoculated by GLH that had fed on plants with RTBV + RTSV (Table 8). This indicates the potential threat of RTSV as a disease agent in the field, transforming RTBV-infected plants into potent sources of RTV.

Table 8. Infection of RTBV-infected IR54 exposed in field cages to GLH that fed on source plants infected with RTBV + RTSV or RTSV alone.[a] IRRI, 1985.

Plant	GLH released[b]	Plants (%) infected with	
		RTBV + RTSV	RTBV
Healthy	None	0	0
RTBV-infected	With RTSV	41	59
RTBV-infected	With RTBV + RTSV	12	88

[a]Mean of 4 replications. [b]Insecticide was applied 1 wk after GLH were released.

Host range. One-month-old potted plants of 19 weed species and 4 cereals were exposed individually to 5 GLH that had previously fed on TN1 plants infected with RTBV + RTSV or RTSV alone. One month after inoculation, leaf samples were collected and their extracts tested for the presence of RTBV and RTSV by the latex test.

Distinct clumping was observed on some leaf extracts of *Echinochloa glabrescens, E. crus-galli* ssp. *hispidula*, and *Amaranthus spinosus* when plants were exposed to GLH that had fed on plants infected with RTBV + RTSV (Table 9). When plants were exposed to GLH that had fed on RTSV-infected plants, only *A. spinosus* reacted positively to the RTSV antiserum. For virus recovery, GLH that had fed on the plants that reacted to RTBV + RTSV antiserum were given inoculation access to TN1 seedlings. None of the tested GLH transmitted either virus.

In one trial, inoculated plants were tested by enzyme-linked immunosorbent assay (ELISA) for the presence of the virus antigens. Some *E. colona* that had been exposed to GLH carrying RTBV + RTSV reacted to the RTBV antiserum. A few *E. glabrescens* that had been exposed to RTSV-infected plants also reacted to RTSV antiserum.

Weeds and cereals not infected with either RTBV or RTSV were *Eleusine indica, Dactyloctenium aegyptium, Leptochloa chinensis, Ischaemum rugosum, Fimbristylis littoralis, Eclipta prostrata, Cyperus difformis, C. iria, Paspalum paspalodes, P. scrobiculatum, Ludwigia octovalvis, Leersia hexandra, Alternanthera sessilis, Phyllanthus niruri*, maize, sorghum, wheat, and millet.

Occurrence of RTSV on upland rice. Leaf samples, 20/field, were randomly collected from

Table 9. Detection by latex test of RTBV and RTSV in some weeds that had been exposed to *N. virescens* that had fed on source plants with RTBV + RTSV or RTSV alone. IRRI, 1985.

Species	RTBV + RTSV source[a]				RTSV source[a]	
	Plants tested (no.)	Plants (no.) that reacted to			Plants tested (no.)	Plants that reacted (no.)
		RTBV + RTSV	RTBV	RTSV		
Echinochloa glabrescens	21	8	0	0	10	0
E. crus-galli ssp. *hispidula*	18	6	2	0	10	0
Amaranthus spinosus	5	3	1	0	5	2

[a]Each plant was inoculated with 5 insects.

upland rices in Zamboanga del Sur and Batangas, Philippines, and tested for the presence of RTBV, RTSV, grassy stunt (GSV), and ragged stunt (RSV) viruses by ELISA. RTSV incidence was high in both Zamboanga del Sur and Batangas (Table 10).

RTV vectors carrying viruses. *N. virescens*, *N. nigropictus*, and *Recilia dorsalis* were collected in ricefields at various locations in Laguna and Bicol (January-March) and in South Cotabato (October), Philippines. Insects were individually tested for their infectivity on TN1 seedlings, and inoculated seedlings were tested for the presence of RTBV and RTSV by ELISA or the latex test 3 wk or 1 mo after inoculation (Table 11). The three species transmitted RTBV or RTSV alone or both viruses together. Regardless of insect species, more insects transmitted RTSV alone, indicating that RTSV sources were prevalent in the Philippines.

Detection of RTV-associated viruses in infected dry leaves. The effect of storage on the antigenicity of RTV-associated viruses RTBV and RTSV was examined.

One hundred TN1 leaves infected with RTBV or RTSV alone, or both, were cut into three equal pieces, making a total of three sets. Each set of leaf samples was dried and stored at room temperature, in a refrigerator, and in a freezer. Ten leaf samples from each set were subjected to tests at 1 d, twice a month, and monthly for 6 mo after sampling. Leaf samples were wrapped with moist paper towels for 1-2 h and then separately homogenized with 75 μl of 0.02 M phosphate buffer (pH 7.4). Extracts were tested by the latex test and ELISA to study the effect of storage conditions and duration on the antigenicity of RTBV and RTSV.

In leaf samples stored at room temperature, the latex test detected virus antigens in doubly infected

Table 10. Virus disease incidence on upland rices in Zamboanga del Sur and Batangas, Philippines, determined by ELISA. IRRI, August 1985.

Location	Variety	Plants tested (no.)	Plants (no.) infected with				
			RTBV + RTSV	RTBV	RTSV	GSV	RSV
Zamboanga del Sur San Miguel	C22, UPL Ri3, Menorado, Azucena, Lubang, Menorado, Sinolognon	320	0	0	35	1	0
Visagun	C22	20	0	0	0	0	0
Midsalip	C22, Menorado, UPLRi5, UPLRi17	80	0	0	1	0	0
Mulon	Menorado	40	0	0	0	0	0
Margos	UPLRi5	40	0	0	0	0	0
Batangas Santo Tomas	IR43, UPLRi7, Kinandang Patong, Addey, NIAP415, IRAT116, ITA239, M55, and lines	360	3	6	23	2	8

Table 11. Infectivity of *N. virescens*, *N. nigropictus*, and *R. dorsalis* collected in ricefields at various locations in the Philippines, 1985.

Location	*N. virescens* (no.) that transmitted				*N. nigropictus* (no.) that transmitted				*R. dorsalis* (no.) that transmitted			
	RTBV + RTSV	RTBV	RTSV	None	RTBV + RTSV	RTBV	RTSV	None	RTBV + RTSV	RTBV	RTSV	None
Laguna[a]	8	15	20	235	2	3	7	174	2	1	8	50
Bicol[a]	2	3	8	157	0	0	10	261	2	0	0	4
South Cotabato[b]	7	1	23	43	2	2	1	58	0	0	0	37

[a]Inoculated TN1 seedlings were tested by ELISA. [b]Inoculated TN1 seedlings were tested by the latex test.

ones in 1 wk, in RTBV-infected ones in 2 mo, and in RTSV-infected ones in 1 mo. When leaf samples were stored in the refrigerator or freezer, the latex test detected RTBV and RTSV antigens even after 6 mo.

ELISA could detect RTBV and RTSV antigens from leaf samples stored for 6 mo under any conditions. With storage in the refrigerator or freezer for 6 mo, detection was 90-100% efficacious. It appears that ELISA can diagnose RTV on dried leaf samples mailed or carried from remote areas.

Viral diseases and vectors in Laguna. We continued biweekly observation of rice virus diseases, GLH density, and percentage of infective leafhoppers in 11 farmers' fields. Virus incidence was estimated by visual observation of symptoms. During the tillering and reproductive stages 20 leaf samples (1 leaf/hill) were randomly collected from each field and tested for the presence of RTBV, RTSV, GSV, and RSV by ELISA. Vector leafhoppers were collected by 10 sweeps of an insect net.

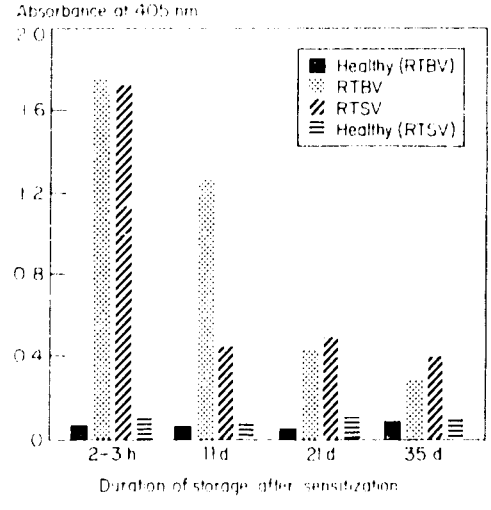
The fields visited were planted to 7 IR varieties: IR42 (26%), IR56 (22%), IR50 (17%), IR52 (13%), IR36 (9%), IR60 (9%), and IR58 (4%). An average 1% (range 0-4%) RTV infection was assessed visually at the sites. RTV incidence was high in November and low in August. GSV and RSV incidence was very low. By ELISA, percentage infection was higher than that assessed by visual observation: RTBV + RTSV 0-20%, RTBV 0-40%, RTSV 0-18%, GSV 0-12%, and RSV 0-5%. Leafhopper density was higher in April-May and lower in July-August. *N. virescens* prevailed at late tillering, while *N. nigropicta* and *R. dorsalis* were dominant in ratoon crops. The leafhoppers collected in ratoon crops transmitted more RTSV. About 15% of adult *R. dorsalis* collected transmitted orange leaf, but none of the 119 nymphs tested transmitted the disease.

Serodiagnosis of virus diseases in remote areas. ELISA is a sensitive and reliable diagnostic measure for rice viruses but is applicable only at the station where well-trained personnel and laboratory facilities are available. To overcome this problem, experiments were conducted to determine if storage of sensitized plates affects the efficiency of ELISA in detecting rice viruses. ELISA plates that had been sensitized with immunoglobulin (IgG) to RTBV or RTSV were wrapped in moist paper towels, covered with plastic bags, and stored for 10-35 d at 25 ± 2 °C.

Fresh extracts of RTV-infected or healthy TN1 leaves were added to the stored plates. Sensitized but not stored plates served as controls. The efficiency of ELISA was affected by storage (Fig. 13), since absorbance decreased significantly with length of storage. However, absorbance obtained even after 35 d of storage was significantly higher than that of healthy controls.

To further extend the application of ELISA, plates sensitized with IgG to RTBV, RTSV, GSV, or RSV were mailed to collaborators in Camarines Sur and Iloilo, Philippines. Leaf samples collected in those provinces were homogenized, and the extracts were added to the plates. After overnight incubation at room temperature, the plates were washed with water, covered with moist paper towels and plastic bags, and mailed back to IRRI for continuation of ELISA. RTBV, RTSV, GSV, and RSV could be efficiently detected, making it possible to diagnose virus diseases occurring in remote areas, especially where there are strict plant quarantines.

GSV and RSV carriers in trapped BPH. Daily trapping of brown planthopper (BPH) was continued by a light trap set on the rooftop of a three-story building at IRRI. A maximum of 100 BPH collection were individually tested by ELISA to determine GSV and RSV carriers.



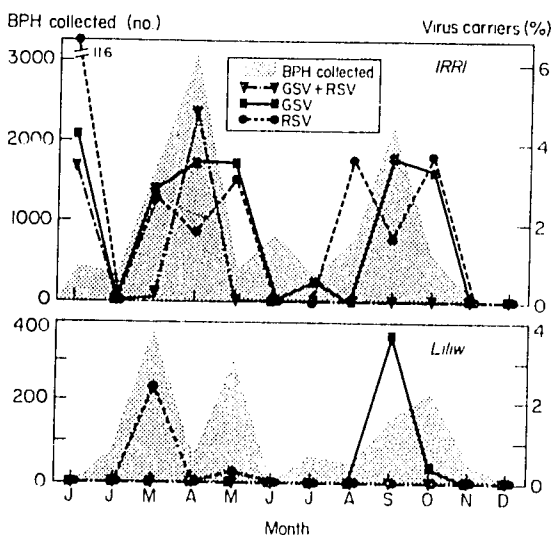
13. Effect of storage of sensitized ELISA plates at 25 °C on detection of RTBV and RTSV in leaf extracts. IRRI, 1985.

Of 10,547 BPH collected, 4,569 were tested for the presence of virus. A high number of BPH were trapped in January-October, with varying percentages of virus carriers detected except in February and June. Very low numbers of BPH carrying no virus were recorded in November and December. GSV carriers ranged from 0 to 4.1%, RSV carriers from 0 to 11.6%, and carriers of both viruses from 0 to 4.7% (Fig. 14).

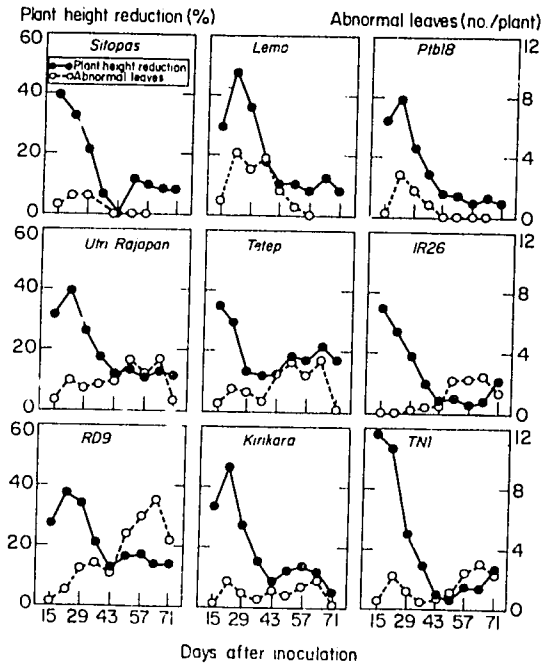
A similar light trap set at 5 m above an isolated, coconut-surrounded ricefield in Liliw, Laguna, operated 3 times a week. High trap catches were recorded in March-May and September-October (Fig. 14). Low catches coincided with the start of the cropping seasons. GSV carriers were 0.5% and RSV carriers 0.7%.

Ragged stunt. *Cause of abnormal plant growth.* Seven-day-old seedlings of selected varieties were exposed to RSV-viruliferous BPH at 5/seedling. The inoculated seedlings were transplanted singly in pots. Plant height and number of ragged or twisted leaves were recorded at 15 d after inoculation (DAI) and every 7 d thereafter.

Reduction in plant height was prominent at 2-4 wk after inoculation (WAI) and then declined regardless of variety (Fig. 15). In some varieties, height reduction increased again at the later stage of plant growth. Ragged and twisted leaves appeared at 15 DAI. Number of abnormal leaves was higher at 2-4 WAI and then decreased. In



14. Percentage of GSV and RSV carriers in BPH collected by light trap at IRRI and Liliw, Laguna, Philippines, 1985.



15. Percentage plant height reduction and number of ragged or twisted leaves on plants infected with RSV at varying days after inoculation. IRRI, 1985.

RD9, Utri Rajapan, TN1, Tetep, and IR26, the number again increased when the plants became older. Sitopas, Ptb 18, and Lemo, which show tolerance for RSV, had few or no abnormal leaves at later stages (Fig. 15).

Host range. Although weeds are not the preferred host of BPH, they are possible alternate hosts of RSV, especially if rice plants are absent. Weed species commonly found in ricefields were collected, grown, and exposed for 2 d to RSV-viruliferous BPH in the greenhouse. After 1 mo, leaf samples of inoculated weeds were tested by ELISA for the presence of RSV. *Echinochloa glabrescens, Eleusine indica, Monochoria vaginalis, Eclipta prostata*, and *Paspalum paspalodes* contained RSV antigens.

BPH nymphs that fed for 36 h on the weeds that reacted positively in ELISA were given serial daily inoculation access to TN1 seedlings. Of 3,728 TN1 seedlings inoculated, none showed typical RSV symptoms. The BPH used in the virus recovery tests were randomly selected and tested individually by ELISA for the presence of RSV. None of the 82 BPH tested reacted to the presence of RSV, indicating BPH were not able to recover the virus from the weeds.

Control and management of rice pests

Insects

Entomology Department

ECOLOGY AND BIOLOGY **156**
- Green leafhopper food web **156**
- Flea beetle pest of upland rice **156**
- *Nisia atrovenosa* not a rice pest **156**
- Host range and biology of three rice caseworms **156**
- Caseworm preference for vegetative stage **159**
- Ephydrid flies of rice in the Philippines **160**
- Yield loss to black bug *S. coarctata* **161**

INTEGRATED PEST MANAGEMENT **161**
- Action threshold development **161**
- Insect sampling **161**
- Rice whorl maggot **163**
- Green semilooper and hairy caterpillar **164**
- Caseworm **164**
- Leaffolders **164**
- Stem borers **164**
- Green leafhopper **164**
- Planthoppers **164**

BIOLOGICAL CONTROL **165**
- Insect diseases **165**
- Predators **166**
- Predators of rice caseworm larvae **167**
- Predator-pest-host plant resistance interaction **168**
- Parasites **169**
  - Rice bug parasite **169**
  - Leaffolder parasites **169**
  - Black bug parasites **169**
- Snails kill caseworm eggs **171**

CHEMICAL CONTROL **171**
- Laboratory evaluation **171**
  - Contact toxicity **172**
  - Foliar spray **172**
  - Granules **173**
  - Mite **173**
- Field evaluation **173**
  - Foliar spray **173**
  - Granules **173**
  - Seedbox treatment **173**
- Insectistatics **173**
- Susceptibility of BPH and GLH to insecticides **174**
- Tungro prevention on susceptible cultivars and lines **175**
  - Seedbox treatment **175**
  - Seedbox or wet seedbed treatment and foliar spray combination **175**
  - Dipping and foliar spray combination **175**
  - Foliar spray and broadcast granular insecticide **175**

155

Green leafhopper food web. The food web of GLH *Nephotettix virescens* (Distant), *N. malayanus* Ishihara and Kawase, and *N. nigropictus* (Stål) in the Philippines comprises 205 species: 35 parasites, 129 predators, 6 pathogens, and 63 secondary parasites and predators (28 spiders double as both predators and secondary predators) (Fig. 1). Predators outnumber parasites 3:1 and secondary natural enemies 2:1. The dominant predators are spiders (50), comprising hunters (26), orb-web makers (17), and space-web makers (7); amphibicorizid and hydrocorizid bugs (28); birds (11); and beetles (10). Ants, predatory flies, meadow grasshoppers, damselflies, dragonflies, and vertebrate predators — birds, frogs, and lizards — also prey on GLH.

Green lacewing *Chrysopa* larvae feed on newly hatched nymphs; damselfly naiads and adults prey on older nymphs. The eulophid wasp *Panstenon* and an undetermined tarsonemid mite attack the eggs.

Principal egg parasites are mymarids *Gonatocerus* spp., *Anagrus flaveolus*, *A. optabilis*, and the trichogrammatids *Oligosita aesopi* and *O. naias*. The predominant nymphal and adult parasites are dryinids *Haplogonatopus*, *Pseudogonatopus*, and *Echthrodelphax*; the big-headed flies *Pipunculus* and *Tomosvaryella*; and the strepsipteron *Halictophagus munroei*. Mermithid nematodes parasitize adults and 4th- to 5th-instar nymphs.

Flea beetle pest of upland rice. The adult of a small blue-black flea beetle made shot holes in dibbled upland rice seedlings at a slash-and-burn site in a Philippine rainforest near Siniloan, Laguna. The beetle, identified as *Chaetocnema basalis*, feeds not only on rice but also on seven weeds — *Brachiaria distachya, Chrysopogon aciculatus, Dactyloctenium aegyptium, Digitaria ciliaris, Ischaemum rugosum, Paspalum conjugatum, and Pennisetum polystachyon* — as well as on sorghum and maize. Host records were determined from adults caged on potted plants. Severely attacked seedlings withered and died after 3-5 d of feeding. Carbosulfan seed treatment protected them.

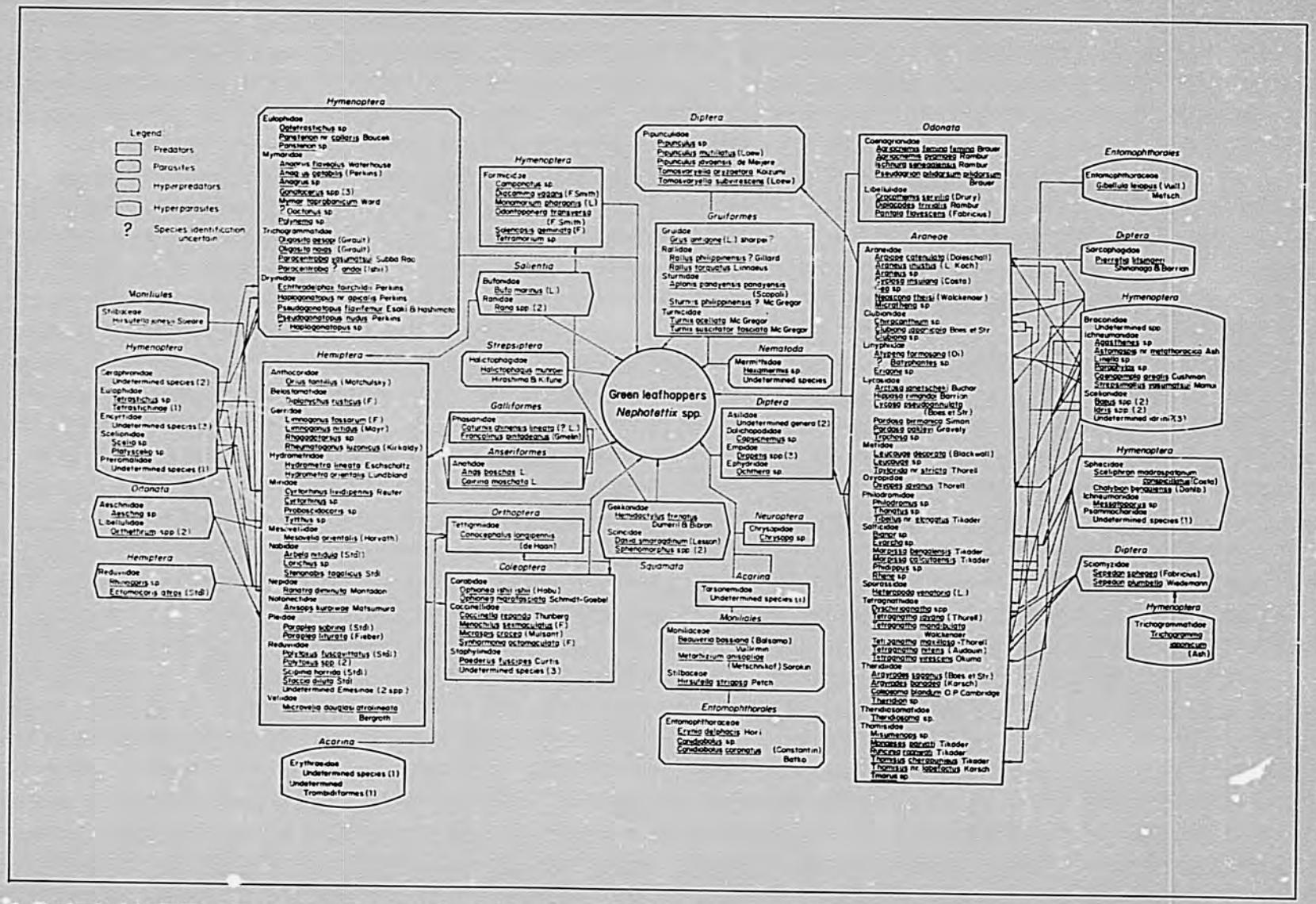
***Nisia atrovenosa* not a rice pest.** The planthopper *Nisia atrovenosa* is recorded as a rice pest in the literature and is common in South Cotabato, Philippines. It was reared there on potted *Cyperus rotundus* and *C. iria* (Table 1) enclosed in mylar cylinder cages but did not grow on over 200 rice cultivars from IRRI's germplasm collection. *C. rotundus* is a common weed on rice bunds. People walking on the bunds disturb *Nisia*, which flies to the adjacent rice plants, leading people to think it is a pest of rice.

Host range and biology of three rice caseworms. Three pyralid caseworms (CW) are commonly collected in light traps at IRRI. The rice CW *Nymphula depunctalis* (Guenée) is a pest of rice. The pest status of *Paraponyx* (= *Nymphula*)

Table 1. Development of *Nisia atrovenosa* on host plants.[a] Koronadal, South Cotabato, Philippines, 1985.

Host plant	Nymphs becoming adults (%)	Developmental period (d)	Nymphal longevity (d)
Cyperus rotundus	85	18.1	20.3 a
C. iria	40	19.1	18.7 a
C. compressus	–	–	13.7 b
C. brevifolius	–	–	12.6 b
Fimbristylis miliacea	–	–	4.5 c
Echinochloa glabrescens	–	–	5.0 c
Eleusine indica	–	–	5.3 c
Digitaria ciliaris	–	–	1 d
Brachiaria distachya	–	–	1 d
Cynodon dactylon	–	–	1 d
Leersia hexandra	–	–	1 d
Paspalum distichum	–	–	1 d
Leptochloa chinensis	–	–	1 d
Oryza sativa	–	–	4.7 c

[a]Av of 4 replications, 10 first instars/replication.



1. Food web of the GLH complex *Nephotettix virescens* (Distant), *N. malayanus* (Ishihara and Kawase), and *N. nigropictus* (Stål) in the Philippines.

fluctuosalis (Zeller) and *Paraponyx* (= *Nymphula*) *diminutalis* (Snellen) was determined by testing rice and 61 ricefield weeds as hosts. The plants were collected at IRRI and offered as food to newly hatched 1st-instar larvae. Vegetative stage plants were used, as CW occurs only during the first month after transplanting.

Free-choice tests reduced the number of potential hosts to 28 during the first round of screening. The development of each CW was further evaluated in no-choice tests from the 1st larval stage through adulthood (Table 2).

All development parameters showed rice was the most nutritious host to the rice CW, as 85% of the larvae pupated and 67% emerged as adults. The polyphagous rice CW developed on 23 plant species representing 18 genera and 2 families. Survival to adulthood was low (2-36%) on the 22 nonrice hosts. The larval growth index includes two developmental parameters: survival and days

Table 2. Plant host range determination for 3 caseworms found in ricefields.[a] IRRI, 1983.

Plant[b]	Larval growth index[c]		
	N. depunctalis	*P. fluctuosalis*	*P. diminutalis*
		Poaceae: Gramineae	
Oryza sativa	6.35 a	0	0
Leptochloa chinensis	1.92 b	1.5 c	0
Polytrias amaura	1.51 c	0	0
Echinochloa colona	1.50 c	0.6 f	0
Chrysopogon aciculatus	1.43 cd	0	0
Leersia hexandra	1.31 d	0	0
Ischaemum muticum	1.11 e	0	0
Phragmite vulgaris	1.04 ef	0	0
Digitaria ciliaris	1.01 ef	0	0
Paspalum paspalodes	0.94 fg	0.3 gh	0
E. glabrescens	0.83 gh	0	0
E. crus-galli spp. *hispidula*	0.75 hi	0	0
Paspalidium flavidum	0.74 ij	0	0
Dactyloctenium aegyptium	0.58 ijk	0	0
Cynodon dactylon	0.55 jk	0	0
Chloris barbata	0.43 klm	0	0
Eleusine indica	0.28 mn	0	0
Panicum repens	0.25 n	0	0
Paspalum conjugatum	0.20 n	0.6 f	0.1 e
		Cyperaceae	
Cyperus brevifolius	0.74 ij	2.4 b	0.2 e
C. rotundus	0.46 kl	0.7 f	0.9 d
C. difformis	0.36 lmn	0.2 h	0.8 d
Fimbristylis miliaceae	0.30 lmn	0.4 g	0.3 e
		Hydrocharitaceae	
Hydrilla verticillata	0	3.3 a	5.2 a
Blyxa echinosperma	0	0.9 e	0.8 d
Otellia alismoides	0	0.7 f	2.0 c
		Characeae	
Chara vulgaris	0	1.4 cd	2.6 b
		Commelinaceae	
Commelina diffusa	0	1.3 d	0.7 d

[a]Av of 4 replications, 25 larvae/replication. [b]The following plants were not hosts to any caseworm species: *Alternanthera sessilis, Amaranthus spinosus* (Amaranthaceae); *Pistia stratiotes* (Araceae); *Ageratum conyzoides, Eclipta prostrata, Tridax procumbens* (Asteraceae); *Azolla caroliniana, A. microphylla, A. pinnata* (Azollaceae); *Cleome rutidosperma* (Capparidaceae); *Pithopora* spp. (Cladophoraceae); *Commelina benghalensis* (Commelinaceae); *Ipomoea aquatica, I. triloba* (Convolvulaceae); *Cyperus iria* (Cyperaceae); *Euphorbia hirta, Phyllanthus niruri* (Euphorbiaceae); *Marsilia minuta* (Marsileaceae); *Mimosa pudica* (Mimosaceae); *Ludwigia octovalvis* (Onagraceae); *Aeschynomene indica, Calopogonium mucunoides, Macroptilium lathyroides* (Papilionaceae); *Ceratopteris thalictroides* (Parkeriaceae); *Peperomia pellucida* (Piperaceae); *Imperata cylindrica, Polytrias amaura, Rottboellia exaltata* (Poaceae); *Eichhornia crassipes, Monochoria vaginalis* (Pontederiaceae); *Portulaca oleraceae* (Portulaceae); *Borreria ocymoides, Hedyotis biflora* (Rubiaceae); *Lindernia anagallis* (Scrophulariaceae); *Sphenoclea zeylanica* (Sphenocleaceae). [c]Growth index = pupation (%) divided by larval development period (d).

to pupation. A high growth index occurs with high survival and short developmental period. More than 20% of adults emerged when reared on *Leptochloa chinensis, Polytrias amaura, Chrysopogon aciculatus, Leersia hexandra*, and *Ischaemum muticum*.

Neither *P. fluctuosalis* nor *P. diminutalis* survived on rice.

All three CW shared five host plants: four sedges (*Fimbristylis miliacea, Cyperus brevifolius, C. difformis, C. rotundus*) and *Paspalum conjugatum*. The three were similar in size and fertility (Table 3). *N. depunctalis* larvae are semiaquatic and climb the rice plants at night to feed.

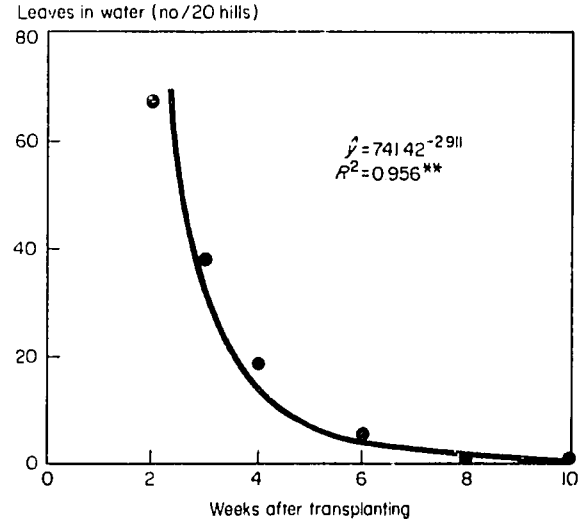
Caseworm preference for vegetative stage. An explanation was sought for why *N. depunctalis* rarely damages rice beyond the vegetative stage. CW moths oviposit on the undersides of leaves floating in water. In a no-choice test, most eggs were laid on floating leaves, few on erect leaves, and an intermediate number on leaves bent in water (Table 4). In a ricefield, only vegetative stage rice has significant numbers of leaves in contact with the water (Fig. 2). Plant age had no significant effect on oviposition if the leaves were in water.

In a test comparing seedling ages, there was no difference in the number of eggs laid on seedlings 1, 2, 3, 4, or 5 wk after seeding (WAS); nor was there a difference with leaf width (0.2-0.8 cm). Development of the CW was greatest on 2- to 6-week-old rice in terms of larval weight, larval developmental period, growth index, survival, and fertility (Table 5). There are therefore several factors that limit rice CW to vegetative rice. The most

Table 4. Ovipositional preference of *Nymphula depunctalis* on IR36 rice of different plant ages. IRRI greenhouse, 1983-84.

Plant age[a] (WT)	Oviposition site (no. eggs/10 female per 3 d)[b]		
	Excised floating leaves	Leaves bent in water	Erect leaves
2	123 b	157 a	85 a
4	378 a	189 a	157 a
6	278 ab	153 a	37 b
8	201 ab	179 a	35 b
10	109 b	90 a	31 b
Mean	218	153	69

[a]Transplanted 3 wk after germination. WT = wk after transplanting. [b]Av of 6 replications, 10 ♀ and ♂ per replication.



2. Field counts of floating leaves touching water with increasing rice crop age. IRRI rice garden, 1984.

Table 3. Life histories of *P. diminutalis* and *P. fluctuosalis* on *Hydrilla verticillata* and of *N. depunctalis* on *Oryza sativa* (IR36).[a] IRRI headhouse, 1983.

Character	*P. diminutalis*	*P. fluctuosalis*	*N. depunctalis*
Fertility[b] (no. eggs/female)	130	125	117
Egg incubation period (d)	5.5	4.5	4.5
Larval developmental period (d)			
First stadium	2.5	3.0	3.5
Second stadium	3.3	3.9	3.8
Third stadium	3.3	4.5	4.1
Fourth stadium	4.0	4.5	4.5
Fifth stadium	–[c]	5.3	5.8
Pupal period (d)	6.9	9.6	7.9
Male longevity (d)	4.2	3.1	3.0
Female longevity (d)	4.3	3.9	5.0
Sex ratio (♂:♀)	1:1.5	1:1.2	1:1
Developmental period from egg to adult[d] (d)	29.8	39.2	39.1

[a]Av of 20 replications except when otherwise indicated. [b]Av of 5 pairs. [c]No fifth stadium. [d]Female.

important is the occurrence of a suitable oviposition site only during the vegetative stage. Others are low survival and slow development of CW on older rice.

Ephydrid flies of rice in the Philippines. Rice whorl maggot (RWM) is the only ephydrid rice pest recorded in the Philippines; it damages rice leaves at the early vegetative stage.

We collected ephydrid flies by D-Vac suction machine, sweep net, and mylar plastic cone traps from 1977 to 1980 from different rice environments in the Philippines. The cone traps, placed open end down over flies on plants, caught more flies than the D-Vac suction machine or sweep nets. Plants with leaf damage were dissected for larvae and pupae, which were reared to adulthood on leaf sections kept on moist filter paper in plastic dishes.

The ephydrid fauna of Philippine ricefields includes 10 genera and 18 species. Of the species, 12 are phytophagous, 5 are scavengers, and 1 is predaceous (Table 6).

All species but *Actocetor beckeri* were recorded in lowland and irrigated areas, which suggests that ephydrid flies prefer aquatic or semiaquatic environments. The Banawe rice terraces, which have high elevation and low temperature and can

Table 5. Effect of rice plant age on growth and development of *N. depunctalis*,[a] IRRI greenhouse, 1983-84.

Plant age (WT)[b]	Larval weight (mg)	Larval developmental period (d)	Growth index[c]	Survivorship from larva to adulthood (d)	Fertility (no. eggs/female)
2	5.76 b	18 ab	4.7 ab	65 a	111 a
4	7.07 a	15 a	5.6 a	69 a	117 a
6	8.24 a	17 a	4.3 b	63 a	108 a
8	4.47 c	21 c	2.7 c	37 b	67 b
10	3.89 d	20 bc	2.1 c	36 b	74 b

[a]Av of 6 replications, 25 insects/replication. [b]Transplanted 3 wk after germination. [c]Growth index = pupation (%) divided by larval developmental period (d).

Table 6. Ephydrid flies of rice in the Philippines, 1985.

Species	Rice environment[a]			
	Upland	Rainfed lowland	Irrigated lowland	Irrigated rice terraces
Actocetor beckeri de Meijere[bc]	+	–	–	–
Brachydeutera longipes Hendel[d]	+		+	+[f]
Discomyza maculipennis (Weidemann)[ad]	–	+	–	–
Hydrellia griseola (Fallen)[bd]	–	–	+[f]	+[f]
H. philippina Ferino[b]	–	+[f]	+[f]	–
Notiphila latigenis Hendel[bd]	–	+	+[f]	+[f]
N. similis de Meijere[bd]	–	+[f]	+	–
N. spinosa Cresson[b]	–	+	+[f]	+
Ochthera spp.[e]	–	+	+	+
Paralimna lineata de Meijere[b]	+	+[f]	–	–
P. picta Kertesz[b]	–	+[f]	–	+[f]
Polytrichophora brunneifrons (de Meijere)[ad]	–	+	+	+
Psilopa flavimana Hendel[bd]	–	–	+[f]	–
P. pollinosa (Kertesz)[bd]	–	+[f]	+[f]	–
P. rufipes Hendel[b]	–	–	+[f]	+
P. sorella Becker[bd]	–	+[f]	–	–
Scatella callisicosta Bezzi[ad]	–	–	+	–
Scatella spp.[ad]	–	–	+	–
Total	3	11	13	8

[a]+ = collected, – = not collected. [b]Scavenger. [c]New Philippine record. [d]Phytophagous. [e]Predator. [f]Reared from leaf-damaged plants.

produce two rice crops a year, had almost the same species as the rainfed and irrigated lowlands.

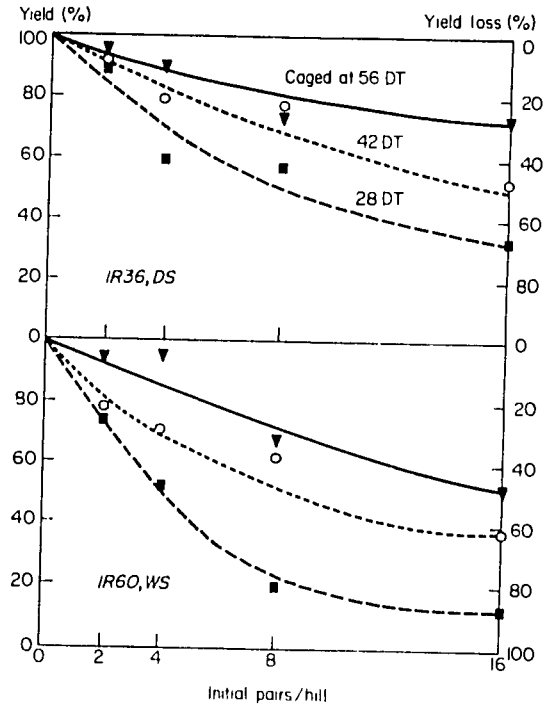
Twelve species belonging to the subfamilies *Psilopinae* and *Notiphilinae* (except *B. longipes*) emerged from the plants with RWM leaf damage and were considered phytophagous. *Hydrellia, Notiphila, Paralimna*, and *Psilopa* are phytophagous genera from the rainfed and irrigated lowlands. *Brachydeutera* was found in the terraces.

RWM was most common in irrigated lowlands, *Psilopa* spp. in rainfed lowlands, and *H. griseola* in terraces. The last-named is commonly called the rice leaf miner and occurs in temperate areas of North America, Europe, North Africa, Japan, and Korea.

N. latigenis and *N. similis* were numerous on young vegetation and usually laid eggs on stems of the perennial fern *Marsilea minuta* L. The eggs were an alternative host of *Trichogramma* spp. that parasitize stem borer eggs. *Discomyza maculipennis* is a scavenger and emerged from dead *Radix* (=*Lymnaea*) and *Pila* snails.

Ephydrid flies are generally beneficial and provide food for spiders, toads, and frogs that inhabit ricefields and marshes.

Yield loss to black bug *S. coarctata*. Black bug feeding was measured on IR36 in dry season (DS) and on IR60 in wet season (WS) by caging 0, 2, 4, 8, and 16 adult pairs/hill at 28, 42, and 56 d after transplanting (DT). Yield loss is given in Figure 3.



3. Number of *Scotinophara coarctata* pairs/hill, time of caging, and yield loss. Maasin, Brooke's Point, Palawan, Philippines, 1985.

INTEGRATED PEST MANAGEMENT

Action threshold development. Because of inconsistent yield losses and the high cost of petroleum-based synthetic insecticides relative to rice in developing countries, chemical control of rice insect pests is economical only on a need basis rather than as scheduled prophylactic application. The process of determining when insecticides are needed is complex because different decision-making modes must be developed for each insect pest group with little overlap to other pests, and the parameters in making those decisions may vary significantly with location.

Decision-making modes for each pest group involve first selecting a character as a unit of measurement to quantify pest abundance. That character should predict an imminent damaging pest population sufficiently far in advance so that a timely insecticide response can be made. Farmers and extension agents must be able to understand the unit of measurement and execute the sampling method.

Often the activities of natural enemies have a bearing on refining action thresholds, and so their numbers should be recorded. The pest population level or action threshold that triggers a decision to apply insecticide must be verified in field trials. A cost-effective insecticide must be chosen, with minimum dosage and appropriate method of application. The cost of monitoring, purchase, and application of insecticide must be covered by the value of the yield increase.

Units of measurement have been developed for the major rice insect pests by a process of trial and error (Table 7). Field trials can get results only for pests that become sufficiently abundant to test action threshold levels.

Insect sampling. Sampling of insect populations should be the basis for deciding whether insecticides are needed. We must continue to refine our sampling procedures and simplify them as much as

Table 7. Action thresholds for key rice pests in the Philippines, 1985.

Pest	Threshold	Sampling method	Use of natural enemies	Insecticide	Dosage (kg ai/ha)	Method of application
Whorl maggot *Hydrellia philippina*	0.5-2.0[a] eggs/hill	20 random hills/ricefield[b] at 5 and 8 d after transplanting	None	DS: Monocrotophos EC WS: Carbosulfan ST or D Azinphos-ethyl EC	0.4 0.5 0.5	Spray when threshold is reached[c] and 7 d later. Seedling root soak overnight[d] in 200-300 liters water.
Defoliators *Naranga aenescens* *Rivula atimeta*	2 larvae/hill	Sequential sampling of at least 4 hills/ricefield at 2-5 wk after transplanting (WT)	None	Monocrotophos EC	0.2	Spray once.
Caseworm *Nymphula depunctalis*	33% damaged leaves	20 random hills/ricefield at 2-5 WT; watch for moths	None	Carbaryl WP Malathion EC	0.2 0.2	Spray – spot treatment Spray – spot treatment
Leaffolders *Marasmia patnalis* *Cnaphalocrocis medinalis*	2 larvae/hill	20 random hills/ricefield; watch for moths 4 WT to flowering	None	Monocrotophos EC	0.4	Spray once.
Stem borers *Scirpophaga* spp.	2 egg masses/m²	100 hills/ricefield at stem elongation and panicle exsertion	Do not spray if >50% egg parasitization	Chlorpyrifos EC	0.4	Spray when larvae hatch.
Planthoppers *Sogatella furcifera* *Nilaparvata lugens*	1/tiller	Sequential sampling of at least 4 hills/ricefield at 2-10 WT	Subtract 5 planthoppers/predator	BPMC WP Buprofezin WP	0.4 0.4	Spray when older nymphs are present. Spray when older nymphs are present.
Green leafhopper *Nephotettix* spp.	5% tungro infested hills in ratoon	Look at ratoon of older crop before transplanting; confirm with iodine test	None	Carbofuran G	0.5-0.75	Incorporated in seedbed soil and at last harrowing before transplanting.

[a]0.5 in Nueva Ecija and 2.0 in Laguna and South Cotabato. [b]In DS in field itself, but in WS in earlier planted neighboring field. [c]DS. [d]WS.

possible for farmer use without losing accuracy or precision.

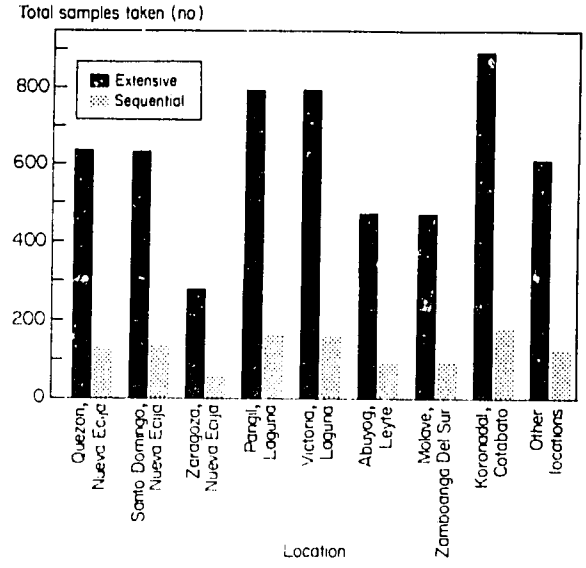
A sequential sampling plan was developed for hoppers (brown planthopper [BPH], zigzag leafhopper [ZLH], and whitebacked planthopper [WBPH]) and major predators. The plan was tested at 15 sites in the Philippines and compared with a more extensive sampling program, the surveillance and early warning system, which requires a fixed number of samples.

Results obtained from over 160 sampling occasions are in Figure 4. There was over 80% savings in time using the sequential plan, yet results agreed 100% with the more extensive sampling program.

In other experiments, several sampling methods were used to compare field population estimates of several hopper species (BPH, ZLH, GLH, and WBPH) and the predator *Cyrtorhinus lividipennis*. Samples taken by these methods, other than kerosene light traps, revealed similar trends in population buildup and decline. The kerosene light traps detected higher numbers of immigrating hoppers and *C. lividipennis* than other methods, but did not produce reliable estimates of field population density of any species. Thus, the use of kerosene light traps alone to estimate populations of hoppers and *C. lividipennis* in the field is not adequate.

Rice whorl maggot. RWM *Hydrellia philippina* has been a difficult pest on which to use action thresholds, not because it is not abundant but because insecticides should be applied no later than 10 DT for control. Damaged leaves as a unit of measurement manifest themselves only after the first week after transplanting (WT) — too late for timely insecticide response. To utilize the same character in a more timely fashion, percentage of damaged leaves was measured in neighboring, earlier planted fields. However, the correlation between older fields and the test field was low, often because populations were declining or because water status between fields differed.

RWM lays eggs singly on leaves of rice plants in standing water. The activity of natural enemies — egg parasites or predators — is insignificant. Egg density in the field during the first WT and subsequent percentage damaged leaves are highly correlated. However, this character can be effectively used only in DS, as insecticide (monocrotophos) can only be applied as a spray (0.4 kg ai/ha) once the crop is transplanted. The field is first monitored at 5 DT. If the action threshold is reached, then the field is sprayed right away, with a second application 1 wk later. If the threshold is not reached at 5 DT, then a second sampling can be done at 8 DT. If the threshold is reached, the field is sprayed at 8 and 15 DT. There is no benefit to sampling after 8 DT.



4. Comparison of numbers of samples required to make a treatment decision using sequential and more extensive sampling at several sites in the Philippines, 1985.

The action threshold varies by location. In Nueva Ecija it is 0.5 egg/hill; in Laguna and South Cotabato, it is 2 eggs/hill. In WS, neighboring fields of similar water status are sampled for egg density the day before pulling the seedlings. If the threshold is reached, the roots of seedlings are soaked overnight in insecticide in small plots lined with plastic. Carbosulfan ST or azinphos-ethyl EC are effective at 0.5 kg ai/ha in 200-300 liters water/ha. The correlation of egg density in neighboring fields with subsequent damage levels in the test field is not high, and other methods are being evaluated.

Originally, damaged leaves due to RWM and other vegetative stage pests were combined in one unit of measurement. This proved inappropriate, however, because RWM warranted a separate control technology. The other vegetative pests were controlled with less expensive insecticides and

fewer applications, and also became abundant in the third or fourth WT.

Green semilooper and hairy caterpillar. In the Philippines, two vegetative pests – the green semilooper *Naranga aenescens* and the hairy caterpillar *Rivula atimeta* – commonly occur together. The first unit of measurement for these pests was percentage of damaged leaves, but it was often unreliable if the pest population had pupated. The character now being evaluated is number of larvae per hill; thus, a larval population must be present before spraying. Only one spray application (0.2 kg ai monocrotophos EC/ha) is needed to control the caterpillars. The current action threshold is 2 larvae/hill using sequential sampling. Fields should be monitored weekly.

Caseworm. CW *Nymphula depunctalis* often becomes abundant during the vegetative stage of rice but is highly patchy in distribution. The larvae cannot be used as a character to measure because they float on the water surface and are often blown by the wind to one end of the field. Leaf damage is a reliable character, but insecticide should be sprayed only if there is standing water in the field and larvae are seen. Often, the presence of moths in the field is a forewarning of CW. Fields should be spot treated. CW is highly susceptible to insecticide. Carbaryl and malathion are effective at 0.2 kg ai/ha. The action threshold is 33% damaged leaves.

Leaffolders. LF *Marasmia patnalis* and *Cnaphalocrocis medinalis* have been monitored in terms of percentage of damaged leaves. More advanced warning signals have been studied because infestation often comes very suddenly. Recording damage in earlier planted fields gave a very low correlation compared with recording in a field itself. A threshold based on moth number was unreliable because effective egg predators often offset the expected damage. Moth number can be used to warn of a potential need for control. Once moths are seen in the field, monitoring for LF damage is increased to twice a week. Damaged leaves are opened in the field. The action threshold is based on the number of live larvae per hill. As with *Rivula* and *Naranga*, fields were often sprayed when the population was pupating. Therefore larvae are used as the unit of measurement. If the threshold is reached, larvae (2/hill) will be the target of the spray 0.4 kg ai monocrotophos EC/ha.

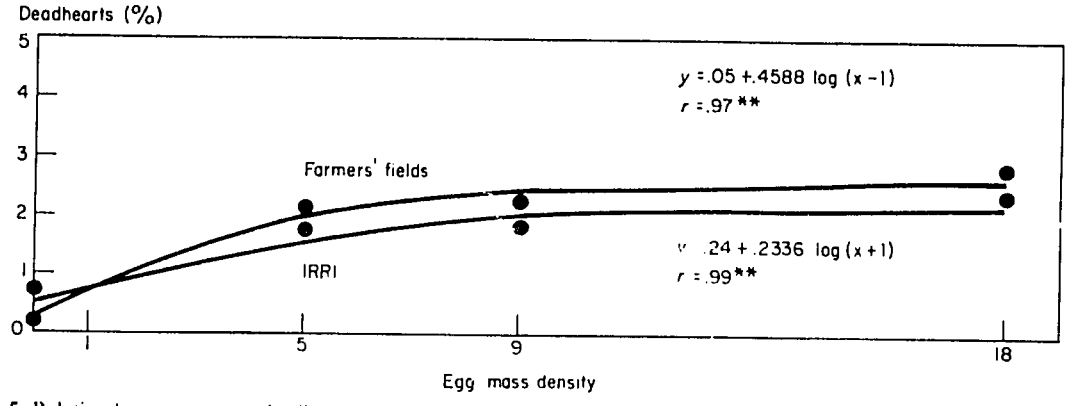
Stem borers. SB are the greatest challenge. Not only are they difficult to predict, but insecticide control technology is weak. Recording the population of moths in the field is not reliable because they tend to cling to the rice plants and go unnoticed. Use of light traps is feasible only for yellow stem borer (YSB), as other species are not particularly attracted to light. Pheromones could be valuable for predicting SB, but their use could be complicated for locations that can be damaged by up to five species.

Historically, treatment for SB has been made after assessment of the damage (deadhearts and whiteheads) they cause. This, however, may be too late. The current action threshold for YSB *Scirpophaga incertulas*, the most prevalent SB in the Philippines, is egg mass density. Large sample sizes are necessary, a minimum being 100 hills (4 m^2). Because greatest damage is expected when stems are elongating, monitoring is restricted to tiller elongation in the vegetative stage and panicle exsertion. If 2 egg masses/m^2 are recorded, then egg masses are collected from the field and held in glass jars to determine the presence of egg parasites. There is a need to spray (0.4 kg ai chlorpyrifos EC/ha) only if more larvae than parasites emerge. Spraying should be done on the day that most larvae emerge from egg masses.

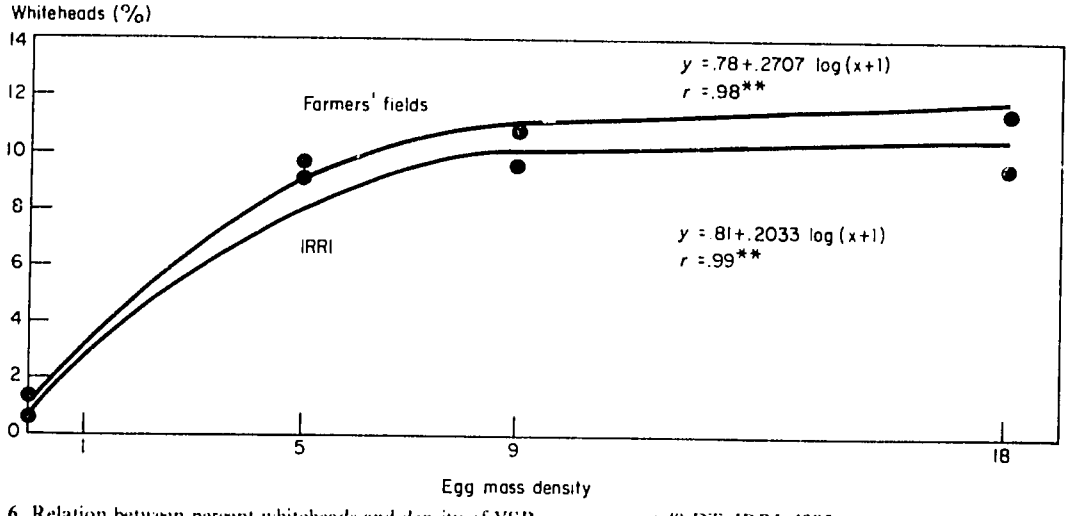
Egg mass density has shown a curvilinear relationship with deadhearts and whiteheads. Experiments in 1985 showed no increase in deadhearts or whiteheads when egg mass density was 5 or greater (Fig. 5, 6). Parasites and predators probably detected and attacked these aggregated host populations earlier than when YSB egg masses were at low density.

Green leafhopper. There is no reliable action threshold for GLH, as it causes damage by transmitting tungro (RTV). The best method for predicting RTV is to monitor the ratoons in nearby harvested fields. RTV symptoms appear most vividly in a ratoon crop, and the disease can be verified by the iodine test. Leaf sections are soaked for 10-15 min. If the veins turn black then the farmer should select the most resistant rice variety available.

Planthoppers. Sequential sampling plans have been extensively field tested for planthoppers using action thresholds to prevent hopperburn, not virus diseases. Weekly sampling has proven effective.



5. Relation between percent deadhearts and density of YSB egg masses at 40 DT. IRRI, 1985.



6. Relation between percent whiteheads and density of YSB egg masses at 40 DT. IRRI, 1985.

Planthopper number per hill is recorded, and for each predator (bug, beetle, or spider) five planthoppers are subtracted from the running total. The threshold of 1 planthopper/tiller, allowing for natural enemies, is used, but the population is sprayed (0.4 kg ai BPMC or buprofezin/ha) only when mature nymphs are present.

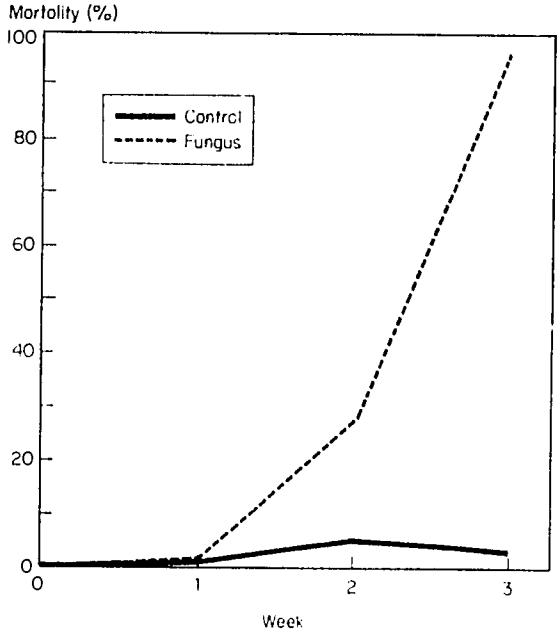
BIOLOGICAL CONTROL

Insect diseases. We developed a mass production unit for entomopathogenic fungi that produces mycelium by deep liquid fermentation. Fungi-infected insects are collected from the field and the fungi isolated on agar medium. Inoculum is prepared in liquid medium in 100-ml shaker flasks for mass production of mycelium in 10-liter fermentors. After harvesting, formulation, drying, and milling, the mycelium is stored at room temperature for viability testing. Application in the field readily yields infective conidia. With this process infective fungal materials for insect control can be produced at low cost.

Preparations of several entomopathogenic fungi were tested against BPH in the field, with levels of infection approaching 100% at 3 wk after treatment (Fig. 7). The fungi *Beauveria bassiana* and *Metarhizium anisopliae* were the most promising for further development because of their effectiveness in the field and ease of mass production.

Larvae of the rice LF *Cnaphalocrocis medinalis* were susceptible to the entomogenous fungi *B. bassiana* and *Nomuraea rileyi* in preliminary bioassay tests in the laboratory.

Several new and rare insect fungi were collected. *M. alba* and *Hirsutella strigosa* were collected from



7. Field mortality of BPH after applying mass-produced fungi. IRRI, 1985.

BPH and GLH at IRRI. A new variety of *M. flavoviride* was discovered and represents a new pathogen of BPH.

Viruses were collected from several insect pests in Laguna, Batangas, and Palawan (Philippines), including four types of nuclear polyhedrosis virus and two types of granulosis virus. Nuclear polyhedrosis virus was present in *Mythimna separata, Spodoptera litura, Herpetogramma* spp., and *Chrysodeixis* spp. Granulosis virus, collected from the brown semilooper *Mocis frugalis*, had not been reported before.

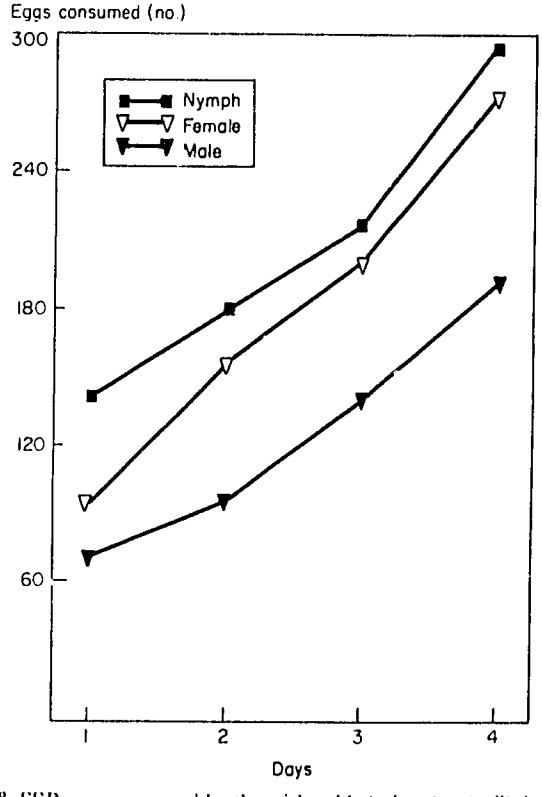
Predators. Predation by the cricket *Metioche vittaticollis* was quantitatively determined in the laboratory by placing eggs of armyworm (AW), RWM, LF, rice bug (RB), striped stem borer (SSB), and YSB on rice plants, caging the plants, and introducing the predator. Number of eggs consumed by *M. vittaticollis* was recorded every 24 h for 4-5 d.

Late stage nymphs and adult females of the cricket were more efficient than males when eggs of SSB were provided as hosts (Fig. 8). After 4 d, individual cricket nymphs had consumed about 300 SSB eggs. It is likely that this predator plays a major role in regulating the SSB population in areas where cricket populations are high. Numbers of eggs of AW, RWM, LF, and RB consumed by *M. vittaticollis* are shown in Figure 9.

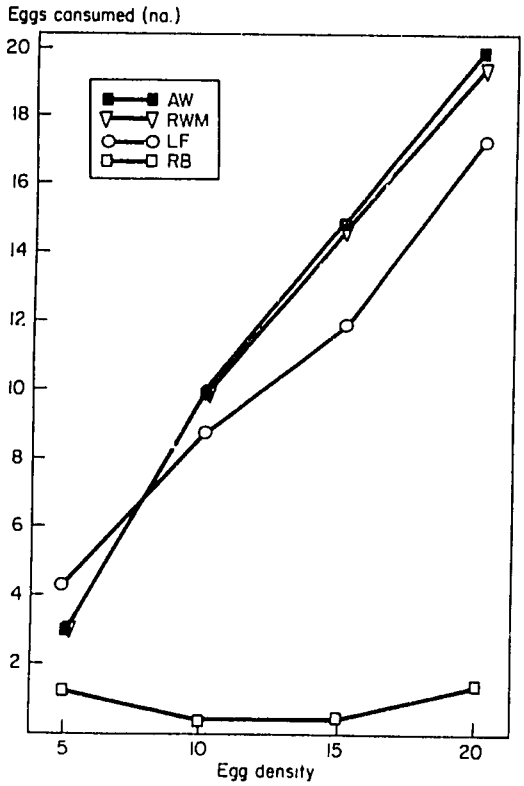
The number of BPH nymphs attacked and eaten by the cricket is shown in Figure 10, and the GLH nymphs consumed in Figure 11. In general, the rate of consumption by *M. vittaticollis* declined as nymphs of the hopper pests increased in size. More GLH than BPH were consumed.

LF eggs were exposed to indigenous populations of predators by allowing adult LF to oviposit on plants, then placing egg-laden plants among direct seeded and transplanted rice. Eggs in 5 replications remaining after 48-h periods were recorded. Over 95% of the eggs were removed by predators in direct seeded rice, and about 80% in transplanted rice. Clearly, predators can make a significant impact on natural populations of LF.

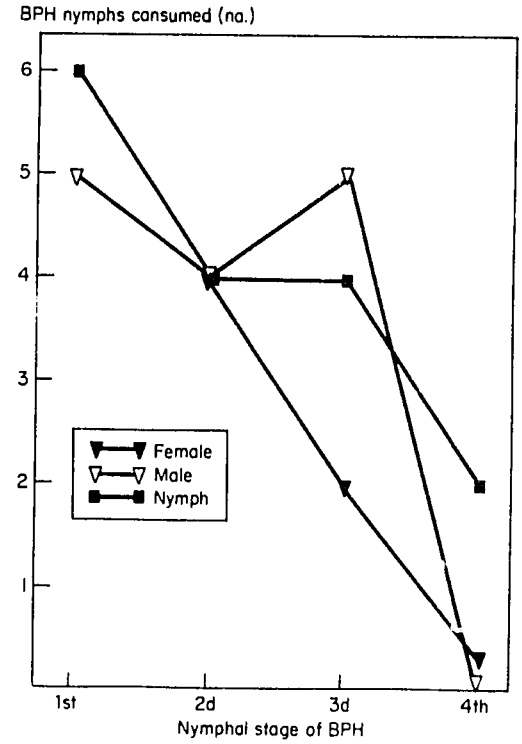
Predation on BPH by the wolf spider *Lycosa pseudoannulata* was observed in greenhouse experiments. Spiders significantly reduced BPH populations by about the same amount on potted IR26 (Fig. 12) and Triveni (Fig. 13) plants receiving



8. SSB eggs consumed by the cricket *Metioche vittaticollis* in small cages in the laboratory. IRRI, 1985.



9. Number of armyworm (AW), whorl maggot (RWM), leaf-folder (LF), and rice bug (RB) eggs consumed by the cricket *Metioche vittaticollis*. IRRI, 1985.

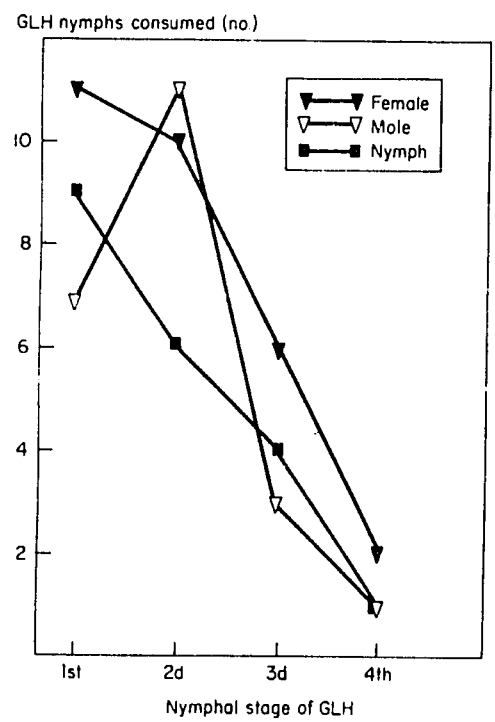


10. First- through fourth-stage BPH nymphs consumed by adults and late nymphs of *M. vittaticollis*. IRRI, 1985.

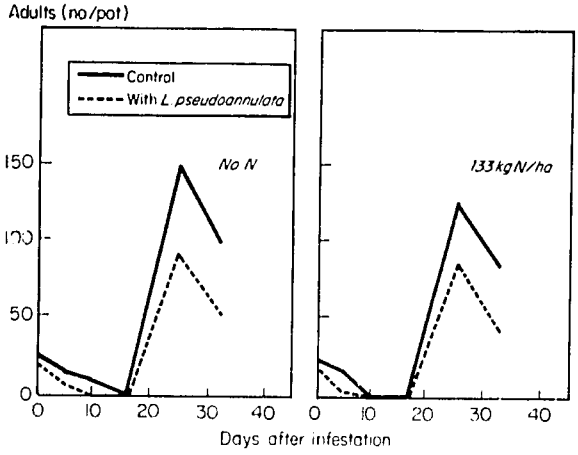
no N and those receiving 133 kg N/ha. Applying N at 133 kg/ha did not significantly increase BPH populations.

The impact of the predator *Cyrtorhinus lividipennis* on populations of BPH in small mylar cages in the greenhouse is shown in Figure 14. In general, *C. lividipennis* kept BPH populations in check better than did *L. pseudoannulata*. *C. lividipennis* feeds primarily on eggs and young nymphs of BPH, while the spider prefers larger nymphs and adults. The combined action of the two predator species is important in maintaining BPH populations below damaging levels.

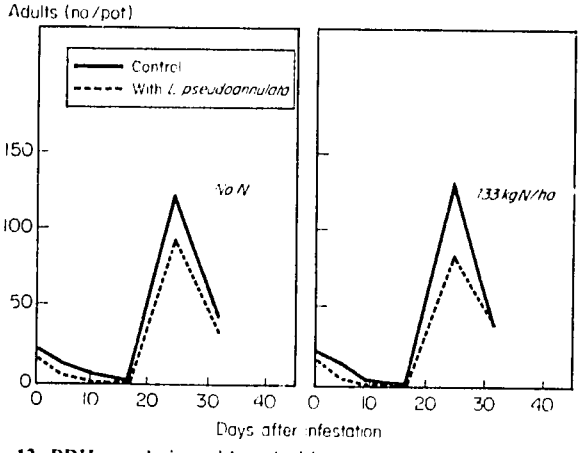
Predators of rice caseworm larvae. The leaf tube constructed by the CW *Nymphula depunctalis* protects the larvae from natural enemies. Larval parasitization is always below 5%. The role of aquatic predators was assessed in greenhouse trials. CW larvae caged in potted plants immersed in water were offered as prey to a range of aquatic insects collected from reservoirs, canals, and rice-fields. Two predatory groups were revealed. The



11. First- through fourth-stage GLH nymphs consumed by adults and late nymphs of *M. vittaticollis*. IRRI, 1985.



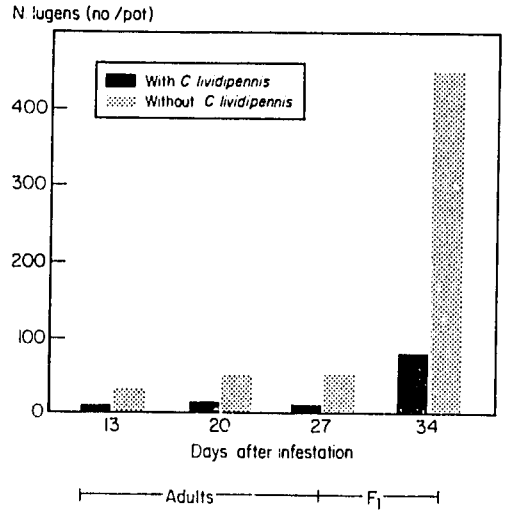
12. BPH numbers with and without *Lycosa pseudoannulata* on IR26 grown without N and with 133 kg N/ha. IRRI, 1985.



13. BPH population with and without *Lycosa pseudoannulata* on Triveni grown without N and with 133 kg N/ha. IRRI, 1985.

larvae of the hydrophilid *Sternolophus rufipes* (Fabricius) stalked CW larvae underwater and seized them as they stretched out of their protective cases while swimming; sometimes the predator entered the case to locate the CW. The larva of the dytiscid *Cybister tripunctatus orientalis* Gschwendtner held onto a submerged object waiting for the prey to swim overhead. When the predator noticed a potential prey, it rose quickly to the surface and seized the outstretched CW larva. Younger dytiscids entered the case, while older ones seized the case with their powerful sickle-shaped mandibles, forcing the larva out.

When a single dytiscid or hydrophilid larva was offered CW larvae of various ages in no-choice



14. BPH numbers with and without *Cyrtorhinus lividipennis*. IRRI greenhouse, 1985.

tests, older prey were preferred (Table 8). The hydrophilid larva consumed up to 6.7 5th-instar CW larvae daily, but only 2-3 1st- or 2d-instar larvae. The dytiscid was more voracious and preyed on more than 11 5th-instar CW larvae/d. The dytiscid, no matter how old, preferred older prey.

Aquatic predators may explain why CW is more prevalent in rainfed than in irrigated lowlands. Rice irrigated from permanent bodies of water — rivers, reservoirs, or canals — already contains dytiscids and hydrophilids. In rainfed fields, colonization by these predators occurs only after CW attacks the young crop.

Predator-pest-host plant resistance interaction. Studies were conducted to determine predation efficacy of the mirid predator *C. lividipennis* when its prey GLH *Nephotettix virescens* was reared on resistant and susceptible cultivars. Predation by *C. lividipennis* on eggs and nymphs of GLH was determined in the greenhouse using mylar cages over Pankhari 203 (resistant) and TN1 (susceptible) cultivars at 25 d after seeding.

To determine predation on GLH eggs, gravid females were introduced into cages and allowed to oviposit for 24 h. Then *C. lividipennis* adults were introduced into the cages. After 1 wk, all predators and GLH were removed from the cages, and as GLH nymphs emerged, they were counted and removed until hatching ceased. Then the plants

Table 8. Prey capacity of aquatic beetle larvae for rice caseworm larvae in no-choice tests. IRRI greenhouse, 1984.

Caseworm larval instar	Caseworm larvae consumed (no./d)		
	Hydrophilid[a] Instar IV	Dysticid[b]	
		Instar II	Instar IV
I	2.2 c	4.8 b	4.0 b
II	2.8 bc	4.8 b	4.0 b
III	4.5 ab	8.4 ab	9.0 ab
IV	5.2 ab	10.0 ab	10.8 a
V	6.7 a	11.6 a	11.4 a

[a]Av of 5 replications. Single predator larva was offered 15 prey. [b]Av of 6 replications. Single predator larva was offered 25 prey.

were dissected to determine number of eggs preyed upon.

When the GLH colony grown on TN1 plants was used in tests with Pankhari 203 cultivar, percentage of predation on GLH eggs was about the same (12-16%) as with other GLH colony-cultivar combinations except when the TN1 colony was kept on TN1 plants; then predation declined to 5% (Table 9). Total eggs laid by the TN1 colony on Pankhari 203 plants were significantly fewer than when this colony was allowed to oviposit on susceptible plants. Results from tests using resistant plants and colonies from the susceptible and resistant cultivars revealed that resistance complemented predation on GLH eggs.

Nymphal mortality was highest when GLH reared on TN1 were placed on Pankhari 203, regardless of whether the predator was present (Table 9). Predation reduced the GLH eggs and nymphs, especially when the pest was well established on a cultivar suitable for its growth and development.

Parasites. *Rice bug parasite.* Several hundred eggs of the rice bug *Leptocorisa oratorius* were placed in IRRI fields and in farmers' fields during the 1985 DS to determine the natural incidence of parasites. Parasitism ranged from 6 to 40% overall but reached peaks of over 60% in some areas. The major parasite was *Gryon nixoni*. Parasitism levels were higher in continuously cropped fields than in those cropped biannually. Egg parasites are likely the major biological control agents for this insect pest, which appears to be increasing in importance in rice in the Philippines. Indiscriminate use of chemical pesticides may reduce this parasite's populations to ineffective levels.

Leaffolder parasites. Larvae of rice leaffolders *Cnaphalocrocis medinalis* and *Marasmia patnalis* were collected twice a month from IRRI and farmers' fields. An average of 100 larvae were collected each sampling date at each site. They were reared individually, and parasites that emerged were counted and identified.

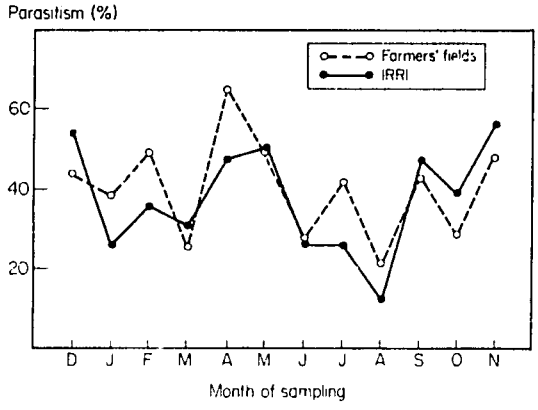
Fourteen species of parasites were collected; over 75% were in the genera *Cardiochiles, Cotesia, Copidosomopsis, Goniozus*, and *Macrocentrus*. The seasonal parasitization of LF larvae is shown in Figure 15. In April, parasitism reached 60% in farmers' fields. Over 40% of the larvae were parasitized in farmers' fields and at IRRI during November. The combined impact of egg and larval parasites and predators is a major factor regulating LF populations.

Black bug parasites. Several biological investigations were undertaken to identify species of parasites that may be useful in a biological control program against the black bug *Scotinophara coarctata*.

Table 9. Predation by *Cyrtorhinus lividipennis* on GLH eggs[a] and nymphs[b] on resistant and susceptible cultivars. IRRI, 1985.

Treatment	Total eggs laid[c]	Egg mortality		Nymphal mortality			
				With predator		Without predator	
		no.	%	no.	%	no.	%
Pankhari 203 colony on Pankhari 203 plants	314	47	16	13	44	3	9
TN1 colony on Pankhari 203 plants	46	8	15	29	96	27	90
Pankhari 203 colony on TN1 plants	420	48	12	11	38	3	11
TN1 colony on TN1 plants	510	29	5	10	32	2	7

[a]Av of 7 replications. [b]Av of 10 replications. [c]Total eggs laid by *N. virescens*; av of 7 replications with 10 females/replication.



15. Leaffolder larval parasites from IRRI and farmers' fields. 1985.

Parasitism by *Telenomus triptus* reached 80% even though the female was guarding the egg mass (Table 10). However, *T. cyrus* parasitized only 10% of the eggs and *Psix lacunatus* was unable to parasitize the eggs at all in the laboratory when the female was present. Furthermore, *T. cyrus* successfully parasitized black bug eggs of *S. latiuscula* even after they were 2 d old, but parasitism of *P. lacunatus* declined to ineffective levels after the eggs had aged 1 d (Fig. 16).

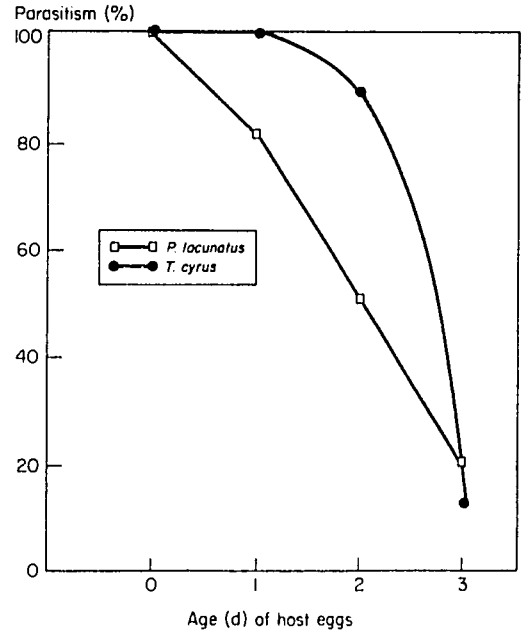
On *S. latiuscula* hosts, cumulative number of offspring produced by *P. lacunatus* and *T. cyrus* was about the same. However, *P. lacunatus* produced more offspring when the female was younger than 8 d, while *T. cyrus* females laid more eggs after this time (Fig. 17).

To determine the competitive ability of different species of black bug parasites, black bug eggs at different densities were attached to paper strips and the strips inserted into tubes containing two females from different species: 1) *T. cyrus* and *T. triptus*, 2) *T. triptus* and *T. basalis*, 3) *T. triptus* and

Table 10. Parasitization of black bug *Scotinophara coarctata* eggs in the laboratory with and without the female bug guarding the egg mass. Palawan, Philippines, 1985.

Parasitoid species	Egg parasitization[a] (%)	
	With female bug	Without female bug
Telenomus triptus	80	86
T. cyrus	10	59
Psix lacunatus	0	69

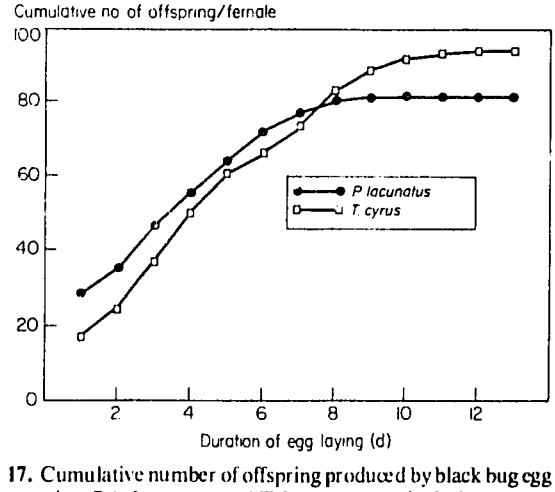
[a]Av of 19 replications.



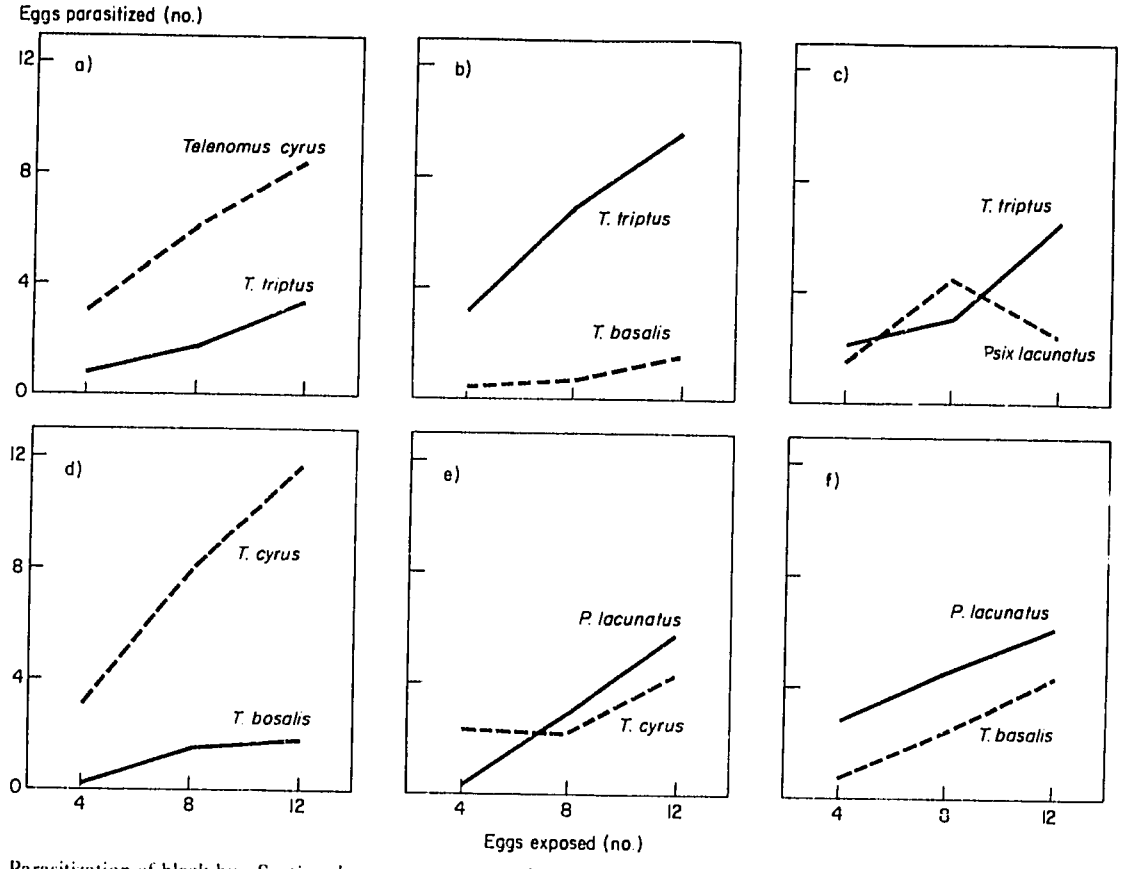
16. Effect of host age on parasitization of the eggs of the black bug *Scotinophara latiuscula* by *Telenomus cyrus* and *Psix lacunatus* in the laboratory. IRRI, 1985.

P. lacunatus, 4) *T. cyrus* and *T. basalis*, 5) *P. lacunatus* and *T. cyrus*, and 6) *P. lacunatus* and *T. basalis*.

T. cyrus was a better parasite than *T. triptus* (Fig. 18a) or *T. basalis* (Fig. 18d). *P. lacunatus* parasitized about the same number of eggs as *T. cyrus*. *T. triptus* outperformed *T. basalis* (Fig. 18b) but not *P. lacunatus* at higher egg densities.



17. Cumulative number of offspring produced by black bug egg parasites *Psix lacunatus* and *Telenomus cyrus* in the laboratory using *Scotinophara latiuscula* eggs as hosts. IRRI, 1985.



18. Parasitization of black bug *Scotinophara coarctata* eggs when 2 species of egg parasites were confined together in tubes in the laboratory. IRRI, 1985.

Snails kill caseworm eggs. Attempts to artificially infest rice plots on the IRRI farm with CW eggs laid on floating cut leaves failed. Numerous snails were observed in the field plots, predominantly *Radix quadrasi* (Fig. 19). After 3 d, 67% of 375 CW eggs laid on rice leaves were missing at a density of 50 snails/3 rice hills. To determine whether the eggs were dislodged or killed, CW eggs were removed from rice leaves and placed at the bottom of basins in 6 cm of water. Over 25% of the submerged eggs developed into larvae that made cases from rice leaves, while none developed cases in containers with snails. We concluded that the CW eggs were killed by the snails. As snails showed no preference for leaves with CW eggs, we concluded that egg mortality was due to inadvertent disturbance and not to predation. Snails graze on algae growing on submerged rice foliage and run across CW eggs laid on the undersides of floating leaves, killing them.

19. *Radix quadrasi*, which disturbs rice caseworm eggs while feeding on algae on submerged rice foliage. IRRI, 1985.

CHEMICAL CONTROL

Laboratory evaluation. Coded and commercial insecticides were evaluated in the laboratory against AW, BPH, GLH, LF, RB, CW, SSB, WBPH, and the mite *Tetranychus truncatus*.

Contact toxicity. Insecticide effectiveness as contact spray was evaluated using Potter's spray tower. Of 19 common insecticides, 3 (carbofuran, BPMC, and diazinon) were effective on BPH, 7 (carbofuran, monocrotophos, carbosulfan, triazophos, fenitrothion, azinphos ethyl, and chlorpyrifos + BPMC) on WBPH, but none on GLH.

Four synthetic pyrethroids and a mixture of a pyrethroid and an insectistatic were evaluated for use against RB using Potter's spray tower. All showed 100% mortality to adult females (Table 11).

Foliar spray. TN1 plants were sprayed with insecticide and infested with untreated insects in cages 1 d after spraying. Four of 19 insecticides were effective on BPH, 6 on GLH, and 8 on WBPH (Table 12). The residual effect was less than 7 d except for carbofuran and carbosulfan on BPH, and carbofuran, triazophos, carbosulfan, and azinphos ethyl on GLH and WBPH.

Four insecticides and three mixtures were evaluated against female RB. Three were effective (Table 13), but their residual effect was only up to 3 d. Carbofuran, a standard check, was effective up to 12 d after treatment (DAT).

Sixteen common insecticides were tested, and 13 were found effective on 3d-instar CW larvae (Table 14).

Seven insecticides (furathiocarb, profenofos Q, isazophos, monocrotophos, thiodicarb, formetanate, and bendiocarb), 4 mixtures (cypermethrin + profenofos 4 + 40, cypermethrin + diazinon 5 + 55, cypermethrin + buprofezin 5 + 10, and chlorpyrifos + BPMC 21 + 10.5 EC), and 2 coded chemicals (MK-936 and DCH) were tested against LF larvae; none caused more than 80% mortality.

Seven insecticides and two mixtures were evaluated against SSB 1st-instar larvae. Stems were infested in the laboratory and sprayed 2 d later. All nine sprays showed 100% mortality at 48 h after treatment. Residual effect was tested by subsequently infesting the same stems and recording mortality at 48 HAI. Two mixtures, carbofuran, furathiocarb, and isazophos were effective up to 12 DAT (Table 15).

Table 11. Laboratory evaluation of 4 synthetic pyrethroids and a mixture for contact toxicity against female RB. IRRI insectary, 1985.

Insecticide[a]	Mortality[b] at	
	24 HT	48 HT
Cycloprothorin (NK8116) 10EC	o	o
S1844 2.5 EC	o	o
Fenpropathrin 5EC	o	o
Cypermethrin + buprofezin 5 + 10EC	o	o
Cypermethrin + buprofezin 5 + 10WP	o	o
Carbofuran (standard) 12F	o	o
DCH 20EC	•	o

[a]Applied at 0.017% ai except carbofuran at 0.25% ai. EC = emulsifiable concentrate, WP = wettable powder, F = flowable. [b]Av of 4 replications. • = ≥80% mortality, o = 100% mortality. HT = h after treatment.

Table 12. Laboratory evaluation of insecticides as foliar spray against adult female BPH, GLH, and WBPH. IRRI insectary, 1985.

Insecticide[a]	Mortality[b]								
	BPH			GLH			WBPH		
	3	7	12	3	7	12	3	7	12
Carbofuran 12F	o	•		o	•		o	o	
Endosulfan 35EC	•								
Triazophos 40EC	•			•	•		•	•	•
Carbosulfan 25EC	•	•		o	•		o	•	
Azinphos ethyl 40EC				•	o	•	•	•	
Fenitrothion 30EC							•		
Monocrotophos 30EC				o			o		
Carbophenothion 48EC							•		
Cypermethrin 5EC				o			•		

[a]Applied at 0.75 kg ai/ha except for deltamethrin and cypermethrin, applied at 0.05 kg ai/ha. Spray volume was 500 liters/ha (3.125 ml/potted plant). SP = soluble powder. [b]Recorded 48 h after infestation (HAI) at 3, 7, and 12 d after insecticide treatment (DAT). Av of 4 replications. • = ≥80% mortality, o = 100% mortality. MIPC 50WP, chlorpyrifos + BPMC 21 + 10.5EC, BPMC 50EC, diazinon 20EC, MTMC 30EC, phosphamidon 50EC, acephate 40EC, MTMC 50WP, and acephate 75SP produced <80% mortality.

Table 13. Laboratory evaluation of insecticides as foliar spray against adult female RB. IRRI insectary, 1985.

Insecticide[a]	Mortality[b]		
	3	7	12
Phenthoate + BPMC 25 + 10EC	o		
Carbofuran 12F	•	o	o
Furathiocarb 40EC	•		

[a]Applied at 0.75 kg ai/ha. Spray volume was 500 liters/ha. [b]Recorded at 48 HAI at 3, 7, and 12 DAT. Av of 4 replications. • = ≥80% mortality, o = 100% mortality. Diazinon + cypermethrin 55 + 5EC, profenofos + cypermethrin 40 + 4EC, isazophos 50EC, and WL 108477 25WP produced <80% mortality.

Table 14. Laboratory evaluation of insecticides as foliar spray against CW. IRRI insectary, 1985.

Insecticide[a]	Larval mortality[b]
Acephate 40EC	o
Azinphos ethyl 40EC	o
Cypermethrin 5EC	o
Diazinon 20EC	o
Chlorpyrifos + BPMC 21 + 10.5EC	o
Monocrotophos 30EC	o
Triazophos 40EC	o
Carbaryl 85SP	•
Endosulfan 35EC	•
Phosphamidon 50EC	•
MIPC 50WP	•
Carbosulfan 25EC	•
Carbofuran 12F	•

[a]Applied at 0.75 kg ai/ha except for cypermethrin at 0.05 kg ai/ha. Spray volume was 500 liters/ha. [b]TN1 plants at 20 DT were infested with third-instar larvae and sprayed at [illegible] HAI. Mortality was recorded at 48 HT. Av of 4 replications. • = ≥80% mortality, o = 100% mortality. MTMC 30 EC, BPMC 50EC, and carbophenothion 48EC produced <80% mortality.

Table 15. Laboratory evaluation of 7 insecticides and 2 mixtures as foliar spray against 1st-instar SSB larvae. IRRI insectary, 1985.

Insecticide[a]	Mortality[b]		
	4	7	12
Cypermethrin + profenofos 4 + 40EC	o	o	•
Cypermethrin + diazinon 5 + 55EC	o	o	•
Carbofuran 12F	o	•	•
Furathiocarb 40EC	o	•	•
Isazophos 50EC	o	•	•
Monocrotophos 30EC	o	•	
Profenofos Q 50EC	o		
Thiodicarb 34F	o		
Formetanate 50WP	•		

[a]Applied at 0.75 kg ai/ha except for carbofuran, applied at 0.25 kg ai/ha. Spray volume was 500 liters/ha. [b]Recorded at 48 HAI at 4, 7, and 12 DAT. Av of 4 replications. • = ≥80% mortality, o = 100% mortality.

Granules. Three commercial (cartap, furadan, and trimethacarb) and 4 coded chemicals (BAS 263-30-I, BAS 263-36-I, SC 0135, and UBI B 2917) were evaluated; none caused more than 80% mortality of BPH and GLH adults.

Mite. Eleven of 13 chemicals evaluated as spray for mites caused more than 80% mortality (Table 16). All, however, caused less than 47% mortality when applied by root-soaking.

Field evaluation. *Foliar spray.* Isazophos, furathiocarb, benfuracarb, and carbofuran were effective against BPH and GLH in the field in DS. They had no residual effect at 13 DAT.

Table 16. Laboratory evaluation of chemicals as foliar spray against *Tetranychus truncatus* mite. IRRI insectary, 1985.

Insecticide[a]	Mortality[b]
Phenisobromolate 25EC	o
Chloropropylate 22EC	o
Binapacryl 48.5EC	o
Dicofol 40EC	o
Phenisobromolate 45EC	o
Chlorobenzilate 45EC	•
Binapacryl 35EC	•
CPCBS + chlorpropiren 30 + 20 WP	•
BPPS 30WP	•
Propargite 57EC	•
Criptoran 25WP	•

[a]Ten-day-old TN1 seedlings were sprayed at 0.75 kg ai/ha. Spray volume was 300 liters/ha. At 1 DAT, the plants in 4 replications were infested with mites of undetermined ages, at 20 mites/plant. [b]Recorded at 48 HAI. • = ≥80% mortality, o = 100% mortality. Fenbutatin-oxide 50WP and buprofezin 50WP produced <80% mortality.

In DS, six insecticides were evaluated as foliar spray against black bugs. Dicrotophos, profenofos + cypermethrin, and metamidophos were effective at 0.75 kg ai/ha. A mixture of profenofos + cypermethrin 40 + 4EC was effective even at 0.27 kg ai/ha. Of four granules, carbofuran was promising. All results agreed with those obtained in the previous year. In WS, the promising spray insecticides were evaluated at lower dosages. Dicrotophos, metamidophos, and monocrotophos at 0.5 kg ai/ha, profenofos + cypermethrin at 0.27 kg ai/ha, and carbofuran at 0.5 kg ai/ha were confirmed to be still effective.

Granules. Five granular insecticides — cartap, carbaryl + diazinon, isazophos, carbofuran, and UC 54229 — were broadcast into flooded ricefields. All were effective against BPH and GLH up to 7 DAT.

Seedbox treatment. Seven granular insecticides applied into seedboxes caused very high adult GLH mortality: 91-100% at 2 DAT and 67-88% at 12 DAT (Table 17).

Insectistatics. Six insectistatics were evaluated against AW 5th instars with carbofuran (standard check insecticide). Except with DU 415155, mortality was low with the chemicals during the larval stage, but no insect reached an advanced stage. Six chemicals (DU 415155, LAB 141 305 I,

Table 17. Field evaluation of 7 insecticides against adult GLH by seedbox treatment. IRRI, 1985 WS.

Insecticide[a]	Mortality[b]			
	2	7	12	17
Carbosulfan 5G	o	•	•	+
Cartap 4G	•	•	•	+
Isazophos 3G	•	o	•	+
MIPC + phenthoate 3 + 3G	•	o	++	
Propaphos 5G	•	•	•	+
Chlorpyrifos 5G	•	•	++	
BPMC 4G	•	•	•	•

[a]Applied at 5 g ai into a box (60 X 30 X 3 cm) with about 5 liters soil 1 d before treatment. G = granules. [b]Recorded at 48 HAI at 2, 7, 12, and 17 DAT. + = ≥40%, ++ = ≥60%, • = ≥80%, o = 100% mortality.

Table 19. Insecticide LD_{50} values of BPH brachypterous males and females. IRRI insectary, Nov 1984.

Insecticide	Sex	Body weight (g)	LD_{50}[a]	
			µg/adult	µg/g
BPMC	Female	0.00220	0.0046 a	2.11 a
	Male	0.00084	0.0009 b	1.05 a
Carbofuran	Female	0.00220	0.0006 a	0.28 a
	Male	0.00084	0.0003 a	0.40 a
Diazinon	Female	0.00220	0.0140 a	6.35 a
	Male	0.00084	0.0023 b	2.80 a
Monocrotophos	Female	0.00220	0.0141 a	6.40 a
	Male	0.00084	0.0008 b	0.95 b

[a]Av of 3 replications, 20 adults/replication. Between sexes and for each insecticide, LD_{50} values followed by a common letter are not significantly different at 5% level.

LAB 149 5252 I, tritlumuron, DU 415 146, and HOE 522) are promising for suppressing AW.

Nine insectistatics were evaluated as foliar spray against RB 3d-instar nymphs. Although mortality was low at 9 DAT, DU 415 146, PH 60-51 (DU 415 155), chlorfluazuron (IKI 7899), and tritlumuron (SIR 8514) caused 63-95% mortality up to 12 DAT. Against 2d-instar nymphs of BPH, GLH, and WBPH, none of five chemicals (methoprene, IKI 7899, LAB 153 959 I, HOE 522, and SIR 8514) showed better results than buprofezin in the laboratory. Buprofezin was evaluated at 12.5-125 g ai/ha in the field in WS. It was effective in suppressing BPH and WBPH nymphs even at 12.5 g ai/ha, but 75 g ai/ha was recommended as more practical. Buprofezin did not affect the natural enemies *Microvelia douglasi atrolineata*, *Cyrtorhinus lividipennis*, and spiders.

Susceptibility of BPH and GLH to insecticides. BPH field populations collected at IRRI in March and October showed low sensitivity to carbofuran, chlorpyrifos, and chlorpyrifos + BPMC. BPH was

Table 18. LD_{50} (µg/g, 24 h) values of BPH brachypterous adult females and GLH adult females at 6 temperatures. IRRI phytotron, Feb-Aug 1985.

Temperature (°C)	LD_{50} (µg/g)						
	BPMC	Carbaryl	Carbofuran	Cypermethrin	Deltamethrin	Diazinon	Malathion
				BPH[a]			
18	4.68 a	4.12 a	1.19 a	0.24 a	0.40 a	12.13 a	37.43 a
21	2.59 b	4.64 a	0.85 ab	0.15 a	0.53 a	8.36 a	23.95 a
24	1.92 b	3.91 a	0.74 abc	0.29 a	0.46 a	8.46 a	27.02 a
27	1.30 b	3.78 a	0.37 bc	0.33 a	0.57 a	6.76 a	14.38 a
30	1.70 b	4.08 a	0.39 bc	0.42 a	0.55 a	7.05 a	13.95 a
33	0.61 b	1.67 b	0.21 c	0.39 a	0.59 a	4.92 a	9.08 a
				GLH[a]			
18	6.85 a	4.38 a	3.42 a	0.14 b	0.12 b	36.20 a	11.83 a
21	7.00 a	5.38 a	2.88 ab	0.21 ab	0.27 b	27.61 b	12.05 a
24	4.40 ab	4.54 a	2.03 bc	0.14 b	0.54 ab	23.78 b	12.25 a
27	3.49 b	5.62 a	1.61 bc	0.25 ab	0.75 a	19.04 b	9.62 ab
30	2.30 b	3.70 a	1.68 bc	0.58 a	0.75 a	19.10 b	9.31 ab
33	1.66 b	4.41 a	1.17 c	0.57 a	0.71 a	19.36 b	6.99 b

[a]Av of 3 replications, 20 insects/replication. In a column and within a species means followed by a common letter are not significantly different at the 5% level by DMRT.

tested for reaction to contact and foliar sprays. GLH collected at IRRI in October showed less sensitivity to MIPC and chlorpyrifos + BPMC. Relative resistance ratios of field-collected to insecticide-free greenhouse BPH populations at IRRI in March-July were 0.98-1.27 with carbaryl, 1.75-2.09 with malathion, and 2.76-2.96 with carbofuran by topical application. LD_{50} values of seven insecticides applied topically to BPH and GLH adult females are shown in Table 18. LD_{50} value varied according to insecticide and pest species at different temperatures. The difference in LD_{50} values for adult BPH brachypterous males and females was shown by monocrotophos (Table 19).

Table 20. Field evaluation of 7 granular insecticides to prevent RTV on TN1 by seedbox treatment. IRRI, 1985 WS.

Insecticide[a]	Rate (g ai/box)	Hills (%) showing RTV symptoms at 65 DT
Cartap 4G	5	12 a
Propaphos 5G	5	15 ab
Carbosulfan 5G	5	21 abc
Isazophos 3G	5	25 abc
MTMC + phenthoate 3 + 3G	5	27 abcd
BPMC 4G	5	32 bcd
Chlorpyrifos 5G	5	33 bcd
Control		44 d

[a]Insecticide was applied to each box (30 X 60 X 3 cm).

Tungro prevention on susceptible cultivars and lines. *Seedbox treatment.* Although GLH mortality on transplanted rice was 80-100% up to 5 DT in the field (Table 17), RTV infection was high. It was minimum (12%) in cartap and 44% in untreated plots (Table 20).

Seedbox or wet seedbed treatment and foliar spray combination. Of 8 treatments, cartap seedbox and foliar spray combination caused the highest GLH mortality (55-78%), low GLH populations (0.3-3.5/10 sweeps), and the lowest (51.8%) RTV infection at 65 DT. Wet seedbed and foliar spray combination were less effective than seedbox and foliar spray combination (Table 21).

Dipping and foliar spray combination. Mixtures of deltamethrin and buprofezin were tested in WS (Table 22) and DS (Table 23). When untreated plots got 58% RTV infection in DS and 75% in WS, the best treated plots showed 7 and 22%. The treatments were not sufficient to prevent RTV despite significant yield increases of 28-89% in DS and 30-60% in WS.

Foliar spray and broadcast granular insecticide. Wet seedbeds were covered with nylon mesh to protect them from GLH attack at IRRI. The effect of either spray or broadcast granular insecticides was evaluated after transplanting in three field trials. All treatments with 4 conventional sprays, 4 synthetic pyrethroids, and 5 granular insecticides caused more than 70% RTV infection, indicating that 2-5 applications of insecticides causing GLH mortality could not prevent RTV by either method.

Table 21. Field evaluation of seedbox and wet seedbed treatment plus foliar sprays to prevent RTV on IR22. IRRI, 1985 DS.

Insecticide	Application[a]	GLH adults (no./10 sweeps)		Hills (%) showing RTV symptoms at 65 DT
		7 DT	12 DT	
Cartap 4G	Seedbox + FS	0.3 a	0.8 ab	51.8 a
Isazophos 3G	Seedbox + FS	0.0 a	1.8 b	63.5 ab
PHC 2G	Seedbox + FS	0.5 a	0.8 ab	72.6 bc
Diazinon 5G	Seedbox + FS	0.5 a	0.0 a	73.3 bc
Cartap 4G	Seedbed + FS	0.5 a	1.8 ab	81.3 bc
Isazophos 3G	Seedbed + FS	0.8 a	0.3 a	84.5 bc
PHC 2G	Seedbed + FS	1.5 ab	0.3 a	85.1 c
Diazinon 5G	Seedbed + FS	0.8 ab	0.8 ab	80.6 b
Treated control	FS	2.3 b	1.9 b	82.2 bc
Untreated control	–	8.5 c	13.4 c	81.7 bc

[a]Applied in seedbox and seedbed at 100 g formulated material/box (60 X 30 X 3 cm) 1 d before transplanting. Foliar spray (FS) of cypermethrin (50 g ai/ha) and deltamethrin (12.5 g ai/ha, 3 times).

Table 22. Field evaluation of mixtures of deltamethrin with buprofezin to prevent RTV on IR22. IRRI, 1985 WS.

Insecticide[a]	Rate (kg ai/ha)	GLH adults + nymphs (no./10 sweeps)			Hills showing RTV symptoms (%) at 60 DT	Yield (t/ha)
		29 DT	43 DT	57 DT		
Deltamethrin + buprofezin	0.06 + 0.10	1.8 ab	19.3 ab	3.3 a	40.7 b	2.6 bc
Deltamethrin + buprofezin	0.09 + 0.75	3.0 b	15.8 ab	4.8 a	25.7 ab	2.9 ab
Deltamethrin + buprofezin	0.13 + 0.50	0.5 a	16.0 ab	5.0 a	28.6 ab	2.8 ab
Deltamethrin + buprofezin	0.13 + 0.75	0.8 a	18.3 ab	5.3 a	26.7 ab	3.1 ab
Deltamethrin + buprofezin	0.13 + 0.10	1.0 a	23.0 b	5.8 a	26.5 ab	3.0 ab
Deltamethrin	0.13	0.8 a	15.3 ab	4.8 a	21.7 a	3.2 ab
Deltamethrin	0.25	2.0 ab	21.5 b	5.5 a	29.2 ab	3.2 ab
BPMC	0.75	3.0 b	21.5 b	5.0 a	30.8 ab	2.9 ab
Maximum protection[b]		0.8 a	10.3 a	3.5 a	17.2 a	3.6 a
Untreated control		12.0 c	59.0 c	12.0 b	74.9 c	2.0 c

[a]Seedling roots were soaked in each solution for 2 min. Each solution was sprayed at 10 and 20 DT. Diazinon 20EC (0.75 kg ai/ha) was sprayed against LF in all plots at 66 DT. [b]Maximum protection = isazophos 3G (5 g ai/seedbox) at 1 d before transplanting, deltamethrin (0.125 kg ai/ha) sprayed at 5 DT. MIPC (0.75 kg ai/ha) at 2 wk after transplanting (WT), monocrotophos (0.75 kg ai/ha) at 3 WT, acephate (0.75 kg ai/ha) at 4 WT, and diazinon 20EC (0.75 kg ai/ha) at 10 WT.

Table 23. Field evaluation of a coded insecticide (mixtures of deltamethrin with buprofezin) to prevent RTV on IR22. IRRI, 1985 DS.

Insecticide	Rate (kg ai/ha)	Application[a]				GLH adults + nymphs (no./10 sweeps)			Hills (%) showing RTV symptoms at 66 DT	Yield (t/ha)
		1	2	3	4	40 DT	56 DT	68 DT		
S 534 11.78EC	0.24	X	X	X	–	2 b	5 ab	11 bc	7.2 a	3.4 a
S 534 11.78EC	0.24	–	X	X	X	5 cd	5 ab	17 e	7.5 a	3.4 a
S 534 11.78EC	0.24	X	X	–	X	3 bc	8 de	11 bc	26.8 b	2.4 bcd
S 534 11.78EC	0.24	X	X	X	X	2 b	6 bc	10 b	13.4 ab	3.3 ab
S 534 11.78EC	0.12	X	X	X	–	5 d	9 e	21 f	23.1 ab	2.3 cd
S 534 11.78EC	0.12	–	X	X	X	4 bcd	6 bc	12 cd	9.8 ab	2.9 abc
S 534 11.78EC	0.12	X	X	X	X	3 bc	4 a	8 a	19.3 ab	3.1 abc
BPMC 50EC	0.75	X	X	X	X	3 bc	9 e	14 d	48.5 c	2.4 bcd
Maximum protection[b]	–					1 a	7 cd	10 b	10.3 ab	3.7 a
Control	–	–	–	–	–	19 e	23 f	39 g	57.6 c	1.8 d

[a]1 = dipping of whole seedlings for 15 min before transplanting; 2, 3, and 4 = sprayed at 10, 20, and 30 DT, respectively; X = treated. [b]Maximum protection = isazophos 3G (5 g ai/seedbox) at 1 d before transplanting, deltamethrin (0.125 kg ai/ha) sprayed at 5 DT, MIPC (0.75 kg ai/ha) at 4 wk after transplanting (WT), buprofezin 25WP (0.125 kg ai/ha) at 6 and 7 WT, diazinon 20EC (0.75 kg ai/ha) at 10 WT, and deltamethrin (0.125 kg ai/ha) at 2 wk before harvest.

Control and management of rice pests

Weeds

Agronomy Department

HERBICIDE SCREENING **178**
- Irrigated transplanted rice **178**
  - Preliminary screening **178**
  - Advanced trials at IRRI and BPI **178**
- Irrigated wet seeded rice **179**
  - Preliminary screening **179**
  - Advanced trials at IRRI and BPI **179**
  - Control of annual and perennial weeds **180**
  - Method of butachlor application **180**
  - Time of herbicide application **180**
- Rainfed transplanted rice **181**
- Rainfed wet seeded rice **181**
- Upland rice **182**
- Deep water rice **182**

EFFECT OF OVERFLOWING WATER ON HERBICIDE PERFORMANCE **182**

REDUCING HERBICIDE PHYTOTOXICITY IN WET SEEDED RICE **184**

PERENNIAL WEEDS AND THEIR CONTROL **184**
- Irrigated transplanted rice **184**
- Wet seeded flooded rice **186**
  - Effect of cultivar, tillage, and herbicide **186**
  - Control of *S. maritimus* with herbicides applied at low volume **186**
- Rainfed transplanted rice **187**

WEED CONTROL IN WET SEEDED AND TRANSPLANTED RICE **189**

WEED CONTROL IN WATER SEEDED RICE **190**

CONTROL OF WILD RICE IN DEEP WATER RICE **190**

CULTURAL CONTROL METHODS **191**
- Effect of flooding time **191**
- Control of *Rottboellia cochinchinensis* **191**

INTEGRATED WEED MANAGEMENT **192**
- Effects of cultivar and cultivation **192**
- Effect of azolla **192**

177

HERBICIDE SCREENING

Research to identify herbicides for weed control in rice continued at IRRI; at the Maligaya, Bicol, and Visayas research stations of the Philippine Bureau of Plant Industry (BPI); and in a farmer's field in Nueva Ecija.

Echinochloa crus-galli ssp. *hispidula*, *E. glabrescens*, *Monochoria vaginalis*, and *Cyperus difformis* were common at all transplanted and broadcast-seeded lowland sites. *E. colona*, *Digitaria ciliaris*, *D. setigera*, and *Rottboellia cochinchinensis* were dominant in the upland fields.

Irrigated transplanted rice. *Preliminary screening*. All SC 0254 treatments were effective on the dominant *M. vaginalis* and *Scirpus maritimus* and gave significantly higher transplanted rice (TPR) yields than the untreated check (Table 1). SC 0254 gave significantly higher yields than the thiobencarb — 2,4-D check, but only when applied 6 d after transplanting (DT). None of the herbicides damaged TPR.

Advanced trials at IRRI and BPI. In dry season (DS) at IRRI, all herbicides except quinchlorac (coded BAS 514), pendimethalin, and oxyfluorfen gave significantly higher yields than the untreated check (Table 2). At Maligaya, treatment did not affect yield. At Bicol, pendimethalin and oxyfluorfen yields were similar to that of the untreated check.

Table 1. Effects of granular herbicides on weed control, crop tolerance, and yield of irrigated transplanted IR62.[a] IRRI, 1985 WS.

Treatment	Application		Weed weight (g/m²)			Rice yield (t/ha)
	Rate (kg ai/ha)	Time[b] (DT)	Broadleaf weeds	Grasses	Sedges	
SC 0254	0.75	6	0 a	0 a	7 a	3.1 a
SC 0254	1.0	6	0 a	0 a	15 ab	3.1 a
SC 0254	1.0	4	0 a	1 a	27 ab	2.9 ab
SC 0254	0.75	4	0 a	0 a	16 a	2.6 abc
Hand weeded check	Twice	15 + 30	3 ab	0 a	5 a	2.1 abc
Quinchlorac	0.1	10	27 b	0 a	102 bc	1.9 abc
S 53275	0.012	4	0 a	0 a	135 c	1.8 abc
Thiobencarb - 2,4-D check[c]	1.0-0.5	4	1 a	0 a	133 c	1.5 bcd
Quinchlorac	0.1	6	41 b	3 a	123 c	1.4 cd
S 53275	0.006	4	0 a	0 a	203 c	1.4 cd
Untreated check	–	–	9 ab	1 a	168 c	1.1 d

[a]Av of 3 replications. Visual toxicity rating at 2 wk after herbicide application was 0 in all cases. [b]DT = days after transplanting. [c]A spaced dash (–) means the 2 herbicides were applied as a proprietary mixture.

Table 2. Effect of granular herbicides applied before weed emergence (3-5 DT) on IR36 yield at 3 sites in the Philippines, 1985 DS.

Treatment	Rate (kg ai/ha)	Yield[a] (t/ha)		
		IRRI	Maligaya	Bicol
Hand weeded check[b]	–	4.2 ab	4.1 ab	5.5 a
Butachlor	1.0	3.7 abc	4.6 a	5.1 ab
Bensulfuron - methyl	0.05	4.2 ab	4.2 ab	4.6 bc
Piperophos - 2,4-D	0.3-0.2	3.6 abc	4.2 ab	5.2 ab
Naproanilide - thiobencarb	1.0-0.7	3.6 abc	4.4 ab	4.9 ab
Quinchlorac	0.3	3.4 bcd	4.0 b	5.1 ab
Pendimethalin	0.75	3.2 cd	4.3 ab	4.1 cd
2,4-D	0.8	4.3 a	4.1 ab	3.0 e
Oxyfluorfen	0.14	3.0 cd	4.4 ab	3.8 d
Untreated check	–	2.7 d	4.3 ab	3.7 d
CV (%)		15	7	9

[a]Av of 4 replications/site. [b]At 15 and 35 DT.

In wet season (WS) at IRRI and Maligaya, the treated and untreated plots gave comparable yields because weed infestation was low (Table 3). Oxyfluorfen was moderately toxic to rice at IRRI and gave markedly lower yield than most herbicides. At Bicol, several chemicals gave yields significantly lower than the hand weeded check and comparable to the untreated check. At Visayas, all treatments yielded significantly higher than the untreated check except quinchlorac, which did not control broadleaf weeds and sedges.

Irrigated wet seeded rice. *Preliminary screening.* All herbicides except S 53275 at 0.006 kg ai/ha gave significantly higher yield than the untreated check (Table 4). Most treatments were effective against the dominant grassy weeds without harming rice.

Advanced trials at IRRI and BPI. At IRRI, all herbicides except butachlor gave significantly higher yield than the untreated check in DS (Table 5). At Maligaya, all treatments except one gave comparable yields; butachlor + 2,4-D was extremely toxic to rice and gave significantly lower yield than the untreated check. At Bicol, only piperophos – 2,4-D, naproanilide – thiobencarb, and pendimethalin gave yields markedly higher than that of the untreated check.

In WS at all sites, most treatments did not differ in yield from the untreated control because weed populations were low (Table 6). Oxyfluorfen at

Table 3. Effect of granular herbicides applied before weed emergence (3-5 DT) on IR36 yield at 4 sites in the Philippines, 1985 WS.

Treatment	Rate (kg ai/ha)	Yield[a] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Bensulfuron - methyl	0.05	4.5 a	3.1 a	3.7 bcd	5.7 a
Hand weeded check[b]	–	4.4 a	3.1 a	4.7 a	4.7 b
Butachlor	1.0	4.3 ab	3.2 a	3.7 bcd	5.2 ab
Piperophos - 2,4-D	0.3-0.2	4.5 a	2.9 a	4.2 ab	4.7 b
Pendimethalin	0.75	4.6 a	3.0 a	3.8 bc	4.7 b
Naproanilide - thiobencarb	1.0-0.7	4.1 ab	3.1 a	4.2 ab	4.4 b
2,4-D	0.8	4.6 a	3.0 a	2.9 de	4.5 b
Quinchlorac	0.3	3.9 ab	3.3 a	4.2 ab	3.4 c
Oxyfluorfen	0.14	3.4 b	3.3 a	2.9 e	4.6 b
Untreated check	–	3.9 ab	3.5 a	3.0 cde	3.2 c
CV (%)		14	14	14	10

[a]Av of 4 replications/site. [b]At 15 and 35 DT.

Table 4. Effect of granular herbicides on weed control, crop tolerance, and yield of irrigated, broadcast-seeded, flooded IR62.[a] IRRI, 1985 WS.

Treatment	Application		Weed weight[c] (g/m²)		Visual toxicity rating[d]	Yield (t/ha)
	Rate (kg ai/ha)	Time (DAS)[b]	Broadleaf weeds	Grasses		
SC 0254	0.75	8	0 a	34 abc	0	3.9 a
SC 0254	1.0	6	0 a	0 a	0	3.6 ab
SC 0254	0.75	6	0 a	28 abc	0	3.4 abc
Thiobencarb - 2,4-D check	1.0-0.5	6	3 a	15 ab	4	2.5 abc
Quinchlorac	0.1	10	4 a	208 de	0	2.4 bc
SC 0254	1.0	8	30 a	83 bcde	4	2.2 bc
S 53275	0.012	6	5 a	84 cde	0	2.2 bc
Quinchlorac	0.18	10	74 a	24 bcd	0	2.1 c
S 53275	0.006	6	12 a	102 cde	2	0.2 d
Untreated check	–	–	40 a	278 e	0	0.2 d

[a]Av of 4 replications. [b]DAS = d after seeding. [c]No sedges grew. [d]Rated 2 wk after herbicide application on a scale of 0-10: 0 = no toxicity, 10 = complete kill.

Table 5. Effect of early postemergence (6-8 DAS) application of granular herbicides on yield of broadcast seeded, flooded IR36 at 3 sites in the Philippines, 1985 DS.

Treatment	Rate (kg ai/ha)	Yield[a] (t/ha)		
		IRRI	Maligaya	Bicol
Bensulfuron - methyl	0.05	5.7 a	5.4 a	3.5 d
Piperophos - 2,4-D	0.3-0.2	3.5 cd	5.2 a	5.2 a
Quinchlorac	0.3	4.4 b	4.9 a	4.4 abc
Naproanilide - thiobencarb	1.0-0.7	3.6 bcd	5.3 a	4.5 ab
Butachlor	1.0	2.9 de	5.0 a	4.4 abc
Oxyfluorfen	0.14	4.1 bc	4.7 a	3.5 d
Pendimethalin	0.75	3.6 bcd	4.2 a	4.5 ab
Thiobencarb - 2,4-D	1.0-0.5	3.5 cd	4.5 a	3.8 bcd
Butachlor + 2,4-D[b]	0.75 + 0.5	3.8 bc	2.3 b	4.2 bcd
Untreated check	–	2.6 e	4.4 a	3.6 cd
CV (%)		14	16	13

[a]Av of 4 replications/site. [b]A plus (+) means the chemicals were applied separately.

Table 6. Effect of early postemergence (6-8 DAS) application of granular herbicides on yield of direct seeded, flooded IR36 at 4 locations in the Philippines, 1985 WS.

Treatment	Rate (kg ai/ha)	Yield[a] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Naproanilide - thiobencarb	1.0-0.7	5.1 a	2.8 ab	3.7 a	2.8 ab
Bensulfuron - methyl	0.05	4.8 a	2.5 ab	3.2 ab	4.4 a
Piperophos - 2,4-D	0.3-0.2	4.6 a	3.0 a	3.3 ab	3.2 bc
Quinchlorac	0.3	4.4 a	2.4 ab	3.6 a	3.6 ab
Pendimethalin	0.75	4.0 ab	2.4 ab	3.4 ab	3.2 bc
Butachlor	1.0	4.7 a	1.2 c	3.2 ab	3.5 ab
Thiobencarb - 2,4-D	1.0-0.5	4.9 a	2.4 ab	2.8 ab	2.4 c
Oxyfluorfen	0.14	2.9 b	2.1 b	3.4 ab	3.7 ab
Butachlor + 2,4-D	0.75 + 0.5	4.6 a	1.1 c	2.8 ab	3.5 ab
Untreated check	–	4.5 a	2.2 ab	2.6 b	3.2 bc
CV (%)		21	22	17	18

[a]Av of 4 replications/site.

IRRI and butachlor and butachlor + 2,4-D at Maligaya were extremely toxic to rice and gave significantly lower yields than the untreated checks.

Control of annual and perennial weeds. Bensulfuron – methyl (coded DPX 5384) and butachlor followed by 2,4-D adequately controlled the annuals *E. crus-galli*, *E. glabrescens*, *C. difformis*, and *M. vaginalis*, and the perennial *S. maritimus* (Table 7). 2,4-D alone also controlled all weeds except *Echinochloa* spp. and gave significantly higher yield than the untreated check. Butachlor alone did not control *S. maritimus* and gave a yield similar to that of the untreated check.

Method of butachlor application. Degrees of butachlor incorporation were superimposed on water regimes (drained and flooded) at seeding. When averaged across water treatments, grain yields from all treated plots, regardless of application method, were significantly higher than yields from untreated plots (Table 8). The unincorporated treatments yielded markedly lower than the incorporated ones because they substantially reduced initial crop stand, especially on flooded plots. Deep incorporation gave best weed control and highest tiller number at 53 d after seeding (DAS).

Time of herbicide application. Butachlor alone

Table 7. Effect of herbicides on annual and perennial weeds and yield of broadcast seeded, flooded IR36.[a] IRRI, 1985 DS.

Treatment	Application		Weed biomass (g/m²)		Yield (t/ha)
	Rate (kg ai/ha)	Time[b]	Annual[c]	Perennial[d]	
Butachlor fb 2,4-D	0.75 fb 0.75	3 DBS fb 23 DAS	26 a	23 a	5.3 a
Bensulfuron - methyl	0.05	8 DAS	18 a	7 a	5.1 a
2,4-D	0.75	23 DAS	105 ab	43 a	4.6 a
Butachlor	0.75	3 DBS	16 a	159 b	1.7 b
Untreated check	–	–	138 b	163 b	1.2 b

[a]Av of 3 replications. [b]DBS = d before seeding, fb = followed by, DAS = d after seeding. [c]*Echinochloa crus-galli* ssp. *hispidula*, *E. glabrescens*, *Monochoria vaginalis*, and *Cyperus difformis*. [d]*Scirpus maritimus*.

applied 3 d before seeding (DBS) gave the best crop stand (Table 9). Butachlor + 2,4-D severely reduced rice stand, enhancing proliferation of *S. maritimus* on the 3 DBS treatment and *E. glabrescens* on the 6 DAS treatment. However, yields did not differ among treatments because weed populations were low.

Table 8. Weed control, crop tolerance, and yield of broadcast seeded, flooded IR36 as affected by mode of butachlor application at 3 DBS.[a] IRRI, 19[illegible] DS.

Treatment[b]	Weed biomass (g/m²)	Rice stand count (no./m²)		Grain yield (t/ha)
		15 DAS	53 DAS	
No incorporation	100 ab	74 c	559 b	4.4 b
Shallow incorporation	146 bc	116 a	648 ab	5.3 a
Deep incorporation	78 a	99 b	748 a	5.2 a
Application at 6 DAS	97 ab	74 c	649 ab	4.3 b
Untreated check	170 c	87 bc	631 ab	2.2 c

[a]Av of 4 replications and 2 water regimes at seeding. [b]Butachlor was applied at 0.75 kg ai/ha.

In another trial, 2,4-D was toxic to rice when applied 3 and 1 DBS but safe at 6 DAS (Fig. 1). Butachlor was safe as a preseeding treatment but reduced crop stand by about 30% (not significantly) as a postseeding treatment. Regardless of application time, bensulfuron – methyl did not damage rice, effectively controlled *Echinochloa* spp. and *S. maritimus*, and gave significantly higher rice yields than the other treatments.

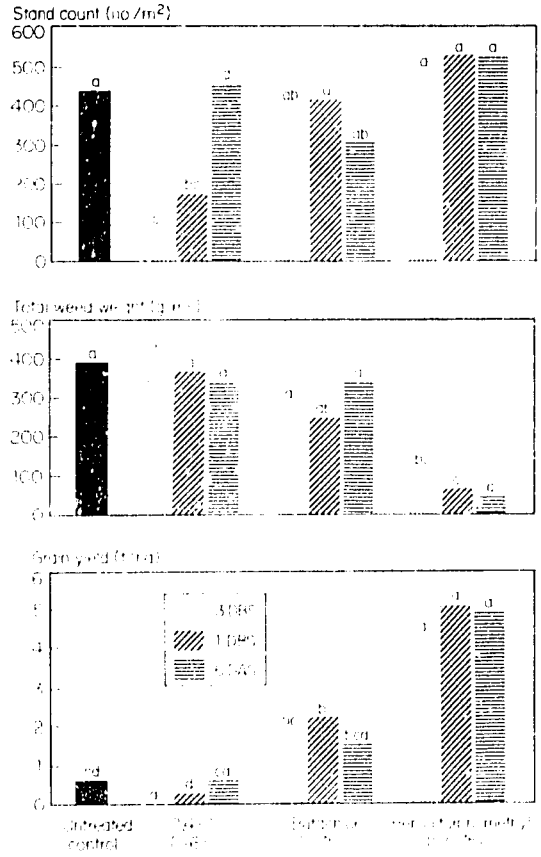
Rainfed transplanted rice. In preliminary screening, SC 0254 controlled *Echinochloa* spp. and *Leptochloa chinensis* and gave yields comparable to that with hand weeding and significantly higher than untreated checks (Table 10). None of the herbicides damaged rice.

Rainfed wet seeded rice. In preliminary screening, no granular herbicides damaged rice, and all treatments yielded significantly higher than the untreated check (Table 11). Quinchlorac was very effective on the grasses and SC 0254 on the sedges.

Table 9. Effect of butachlor, applied alone and with 2,4-D before and after seeding, on weed control, crop establishment, and yield of broadcast seeded, flooded IR36.[a] IRRI, 1985 WS.

Treatment	Application		Weed biomass (g/m²)		Seedling count (no./m²)	Grain yield (t/ha)
	Rate (kg ai/ha)	Time	Grasses[b]	Sedges[c]		
Butachlor	1.0	3 DBS	38 a	4 b	116 a	2.9 a
Butachlor	1.0	6 DAS	32 a	50 c	74 b	3.3 a
Butachlor + 2,4-D	0.75 + 0.5	3 DBS	36 a	147 d	43 bc	1.7 b
Butachlor + 2,4-D	0.75 + 0.5	6 DAS	136 b	40 c	33 c	2.5 a
Butachlor fb 2,4-D	1.0 fb 0.8	3 DBS fb 20 DAS	49 ab	0 a	75 b	3.5 a
Butachlor fb 2,4-D	1.0 fb 0.8	6 DAS fb 20 DAS	54 ab	0 a	82 ab	3.1 a
Untreated check	–	–	87 ab	7 b	83 ab	2.0 ab

[a]Av of 4 replications. [b]*Echinochloa crus-galli* ssp. *hispidula* and *E. glabrescens*. [c]*Scirpus maritimus*.



1. Effect of herbicides applied before and after seeding on crop stand, weeds, and yield of direct seeded, flooded IR62 rice, IRRI, 1985 DS. Within a parameter, treatments with a common letter were not significantly different at the 5% level by DMRT.

Upland rice. Except for dinitramine, all herbicides gave weed biomass similar to that of the untreated check (Table 12). No yield was obtained because drought occurred during the crop's reproductive stage.

Deep water rice. Postemergence herbicides for weed control in deep water rice were tested at Phu Khao Thong, Thailand, in 1984 WS. Herbicides were sprayed 9 d after emergence (DE). The main weed was *E. colona*. 2,4-D + propanil, thiobencarb + propanil, and oxadiazon + propanil appeared most effective for control of *Echinochloa* spp. (Table 13). These treatments and ioxynil + 2,4-D also had the lowest weight of sedges and broadleaf weeds. Grain yields were unaffected by any treatment.

EFFECT OF OVERFLOWING WATER ON HERBICIDE PERFORMANCE

In a farmer's field in Guimba, Nueva Ecija, Philippines, butachlor failed to control weeds because, according to the farmer, heavy rain had fallen soon after application and the herbicide was lost in the water that overflowed from the field.

In a series of experiments conducted in small plots (30 m²) at IRRI, butachlor was applied to TPR as an emulsifiable concentrate at 1.0 kg ai/ha into 2.0 cm water. There was no loss in weed control or reduction in yield when water was allowed to flow out for 30 min from 2 to 24 h after

Table 10. Effect of granular herbicides on weed control, crop tolerance, and yield of rainfed transplanted IR62.[a] IRRI, 1985 WS.

Treatment	Application		Weed weight (g/m²)			Yield[a] (t/ha)
	Rate (kg ai/ha)	Time (DT)[b]	Broadleaf weeds	Grasses	Sedges	
SC 0254	0.5	6	0 a	3 ab	0 a	3.4 a
SC 0254	1.0	6	0 a	0 a	1 ab	3.2 ab
SC 0254	1.0	4	1 a	0 a	2 abc	3.0 ab
Quinchlorac	0.18	6	2 ab	7 ab	11 cd	3.0 ab
Hand weeded check	Twice	15 + 30	0 a	6 ab	2 abc	3.0 ab
SC 0254	0.75	4	0 a	0 a	1 ab	2.8 ab
S 53275	0.012	4	0 a	0 a	34 d	2.5 bc
Quinchlorac	0.1	6	19 c	2 ab	6 abc	2.5 bc
Thiobencarb - 2,4-D check	1.0-0.5	4	0 a	0 a	17 bcd	2.5 bc
S 53275	0.006	4	1 a	2 ab	11 cd	2.4 bc
Untreated check	–	–	6 b	23 b	18 bcd	2.1 c

[a]Av of 3 replications. [b]DT = d after transplanting.

Table 11. Effect of granular herbicides on weed control, crop tolerance, and yield of rainfed, wet seeded, lowland IR62.[a] IRRI, 1985 WS.

Treatment	Application		Weed weight (g/m²)			Visual toxicity rating[b]	Yield (t/ha)
	Rate (kg ai/ha)	Time (DAS)	Broadleaf weeds	Grasses	Sedges		
S 53275	0.006	8	1 ab	47 abc	12 bc	0	3.0 a
Quinchlorac	0.1	8	4 b	12 ab	94 d	0	2.8 ab
SC 0254	0.75	6	0 a	26 abc	1 a	0	2.7 ab
SC 0254	1.0	6	0 a	72 c	2 a	0	2.5 ab
S 53275	0.006	6	0 a	62 bc	16 bc	1	2.5 ab
SC 0254	1.0	8	0 a	85 b	17 bc	0	2.4 ab
Quinchlorac	0.18	8	1 ab	8 a	55 cd	0	2.3 ab
Thiobencarb 2,4-D	1.0-0.5	6	0 a	60 abc	37 bcd	1	2.1 ab
SC 0254	0.75	8	0 a	65 bc	7 ab	1	2.0 b
Untreated check	–	–	1 ab	88 b	48 cd	0	1.2 c

[a]Av of 3 replications. [b]Rated 2 wk after herbicide application on a scale of 0-10: 0 = no toxicity, 10 = complete kill.

Table 12. Effect of herbicides applied before weed emergence (3 DAS) on weed control in upland IR36 rice.[a] IRRI, 1985 WS.

Treatment	Rate (kg ai/ha)	Total weed weight[b] (g/m²)
Hand weeded check[c]	–	14 a
Dinitramine	1.5	110 b
Pendimethalin	2.0	142 bc
Oxadiazon	1.0	171 bc
Propanil[d]	2.0	172 bc
Thiobencarb	3.0	177 bc
Oxyfluorfen	0.4	215 bc
Butralin	2.0	234 bc
Butachlor	2.0	242 bc
Untreated check	–	294 c

[a]Av of 4 replications. [b]Sampled at 51 days after emergence (DE). [c]At 16 and 34 DE. [d]Applied at 10 DE.

herbicide application compared with control plots. There was an increase in weed density and weed weight but no reduction in yield when water flowed out for 30 min at 0.5 h after herbicide application (Table 14). There was an increase in weed density but no increase in weed weight or reduction in yield when water flowed out for 30 min at 1 h after application.

When the water flowed out for 30 min at 0.5-2 h after treatment from the treated plot to an adjacent untreated plot, excellent weed control was obtained in both plots, and yields were no lower than those in a treated plot where no flowing out had occurred (Table 15). This indicates that herbicide moved in the water from the treated plot to the adjacent untreated plot.

Table 13. Postemergence herbicides used on deep water rice in Thailand. 1984 WS.

Treatment	Application rate (kg ai/ha)	Dry weight of weeds (g/m²)		
		Echinochloa spp.	Total grasses	Others
2,4-D	0.75	174 e	298 f	18 bc
Propanil	2.0	67 bcd	122 de	17 bc
2,4-D + propanil	0.33 + 1.67	31 a	34 a	0 a
Molinate + propanil	1.0 + 1.0	46 ab	70 abc	7 ab
Thiobencarb - propanil	2.0	34 a	54 ab	9 ab
Butachlor + propanil	0.8 + 1.5	61 abc	84 bcd	3 a
Ioxynil - 2,4-D	1.0	76 bcd	111 de	0 a
Ioxynil - 2,4-D - propanil	1.0	81 cd	104 cde	5 ab
Bromoxynil + propanil	1.0 + 1.0	75 bcd	115 de	9 ab
Oxadiazon + propanil	0.8 + 1.5	34 a	37 a	0 a
Bifenox + propanil	1.5 + 1.5	44 ab	52 ab	3 a
Untreated check	–	96 d	125 e	27 c

Table 14. Weed density, weed weight, and grain yield as affected by herbicide treatment and flowing out of water at different times after treatment. IRRI, 1985.

Treatment[a]	Time of flowing out (h after herbicide application)	Weed density (no./m²)	Weed weight (g/m²)	Grain yield (t/ha)
Butachlor	–	54 a	22 a	2.5 a
Butachlor	0.5	242 cd	40 bc	2.6 a
Butachlor	1.0	178 bcd	23 ab	2.7 a
Butachlor	1.5	84 abc	22 a	2.9 a
Butachlor	2.0	80 ab	26 ab	2.8 a
No herbicide	–	278 d	72 c	1.0 b

[a]1.0 kg ai/ha.

REDUCING HERBICIDE PHYTOTOXICITY IN WET SEEDED RICE

A series of experiments was conducted to try to reduce the toxicity of butachlor to wet seeded rice (WSR).

Application at 3 DBS resulted in better weed control, less stand reduction, and higher yields than when application was at 6 DAS. No differences in weed control and yield were observed between granular and emulsifiable concentrate formulations when they were applied at 3 DBS. At 6 DAS, however, better weed control and higher yields were obtained when the emulsifiable concentrate was used.

In another experiment, thorough incorporation of butachlor into the soil before seeding resulted in less toxicity but a lower level of weed control than when it was surface applied or lightly incorporated.

Better weed control and less toxicity were observed when the herbicide was applied at 3 DBS than when it was applied at 6 DAS regardless of application method. The time of application is important in reducing butachlor toxicity.

There were stand reductions when butachlor was applied at 3 DBS if the rice seeds were underwater for 2 DAS.

A number of herbicides applied alone and in combination performed as well as butachlor applied at 3 DBS in controlling weeds and giving good yields without causing crop damage (Table 16).

PERENNIAL WEEDS AND THEIR CONTROL

Irrigated transplanted rice. Research on the long-term effect of tillage level (conventional, minimum, and zero) and cultivar (IR34, IR40, and IR42) on weed shift continued in 1985 DS (23d crop) and WS (24th crop). Conventional tillage was one plowing and two harrowings, minimum tillage was one harrowing, and zero tillage was cutting and removing rice and weed debris.

In the 23d crop, reduced tillage markedly increased *Paspalum distichum* biomass, significantly reducing yield in the zero tillage plots (Fig. 2). Tillage and cultivar did not affect *S. maritimus* and annual weed biomass. However, IR40 had significantly more *P. distichum* and yielded significantly less than IR34 and IR42.

In the 24th crop grain yield and total weed biomass were the same among tillage levels (Fig. 3). The significant *P. distichum* and annual weed decrease with conventional tillage was negated by a marked *S. maritimus* increase. Although weed infestation did not differ among cultivars, IR42 yielded significantly lower than IR34 and IR40.

Table 15. Weed weight and grain yield in butachlor-treated and untreated plots as affected by flowing out of water at different times after treatment. IRRI, 1985.

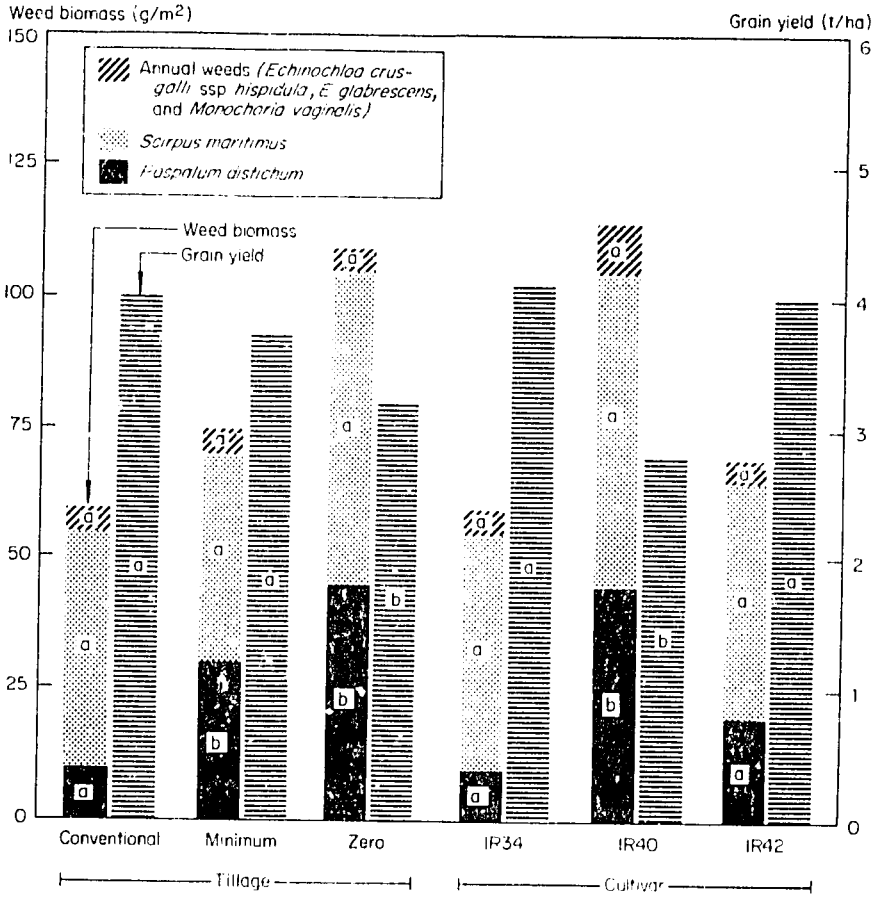
Treatment[a]	Time of flowing out (h after herbicide application)	Weed weight (g/m²)		Grain yield (t/ha)	
		Treated plot	Untreated plot	Treated plot	Untreated plot
Butachlor	–	1 a	–	3.7 a	–
Butachlor	0.5	21 b	18 a	3.7 a	3.7 a
Butachlor	1.0	6 ab	18 a	3.6 a	3.5 a
Butachlor	1.5	20 b	19 a	3.8 a	3.7 a
Butachlor	2.0	9 b	8 a	3.9 a	3.8 a
No herbicide	–	152 c	–	2.5 b	–

[a]1.0 kg ai/ha.

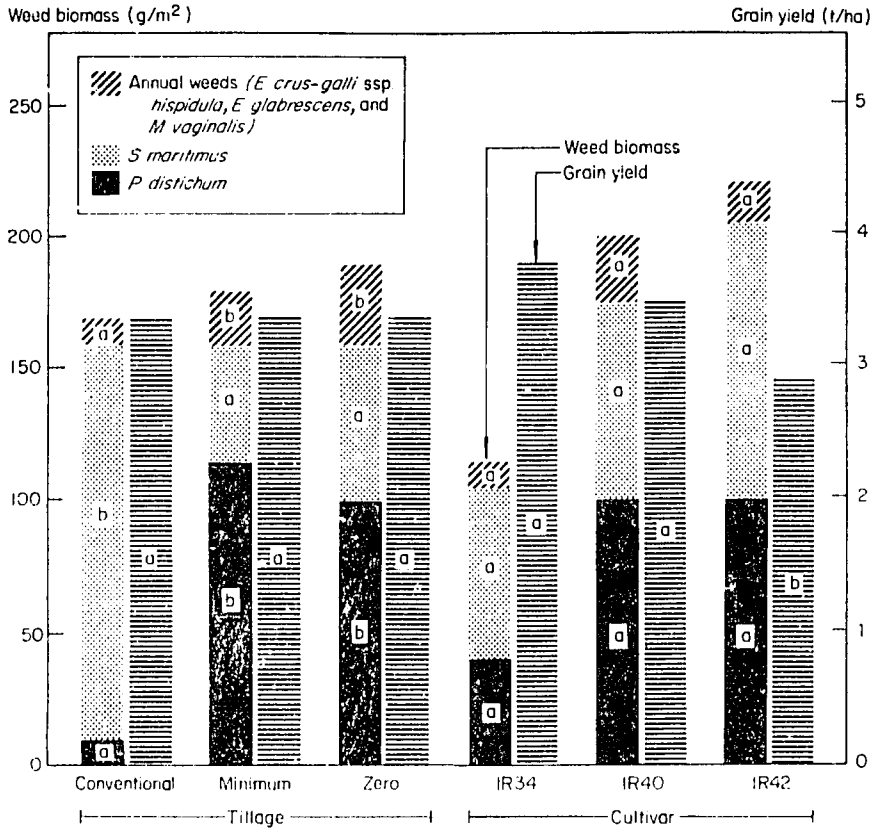
Table 16. Plant height, weed weight, and yield of broadcast seeded, flooded IR58 as affected by different herbicide treatments. IRRI, 1985 DS.

Treatment	Rate (kg ai/ha)	Time of application	Plant height 11 DAS (cm)	Weed weight[a] (g/m^2) 45 DAS	Yield (t/ha)
Butachlor	0.75	3 DBS	17 cd	54 a	3.3 a
Butachlor	0.75	6 DAS	15 e	141 b	1.1 b
Bensulfuron - methyl	0.04	6 DAS	18 bc	39 a	3.0 a
Propanil	3.0	15 DAS	18 bc	39 a	2.5 a
Butachlor + bensulfuron - methyl	0.5 + 0.04	6 DAS	18 bc	30 a	3.4 a
Bensulfuron - methyl + quinchlorac	0.04 + 0.30	6 DAS	18 bc	13 a	3.2 a
Bensulfuron - methyl + dimepiperate	0.04 + 2.0	6 DAS	18 bc	20 a	3.2 a
Bensulfuron - methyl fb propanil	0.04 fb 1.5	6 DAS fb 15 DAS	17 cd	17 a	3.1 a
Propanil fb propanil	1.0 fb 1.0	15 DAS fb 21 DAS	18 bc	38 a	3.0 a
Propanil fb 2,4-D	1.5 fb 0.5	15 DAS fb 21 DAS	19 ab	47 a	2.7 a
Pretilachlor + CGA 123,407 fb 2,4-D	0.3 fb 0.5	3 DAS fb 21 DAS	19 ab	17 a	3.3 a
Hand weeded	–	24 + 42 DAS	20 a	3 a	2.7 a
Unweeded	–	–	18 bc	163 b	1.3 b

[a]Based on transformed data.



2. Weed biomass and grain yield in the 23d crop as affected by tillage and cultivar. IRRI, 1985 DS. Within a parameter, items with a common letter are not significantly different at the 5% level by DMRT.



3. Weed biomass and grain yield in the 24th crop as affected by tillage and cultivar. IRRI, 1985 WS. Within a parameter, items with a common letter are not significantly different at the 5% level by DMRT.

Wet seeded flooded rice. *Effect of cultivar, tillage, and herbicide.* The study on the long-term effect of cultivar (IR36 and IR29723-143-3-2-1), tillage (1, 2, and 3 harrowings), and herbicide (bensulfuron – methyl, propanil + 2,4-D, and untreated check) continued in DS (3d crop) and WS (4th crop). Each harrowing treatment was preceded by one plowing. Bensulfuron – methyl (0.05 kg ai/ha) was applied at 10 DAS and propanil + 2,4-D (1.5 + 0.5 kg ai/ha) tank-mixed was applied at 15 DAS.

In the 3d crop, cultivar did not affect the stand of any weed type (Fig. 4). The higher yield of IR29723-143-3-2-1 is its inherent trait. Three harrowings significantly reduced the *P. distichum* population but did not affect *S. maritimus*, annual weeds, or grain yield. Bensulfuron – methyl and propanil + 2,4-D markedly reduced *S. maritimus* and annual weeds, significantly increasing grain yield.

In the 4th crop, cultivar and tillage again had no effect on *S. maritimus* and annual weed population (Fig. 5). Although three harrowings reduced *P. distichum* stand, yield did not increase. The herbicides adequately controlled *S. maritimus*, significantly increasing yield. However, propanil + 2,4-D failed to control the annual weeds and gave significantly lower yields than bensulfuron – methyl.

Control of S. maritimus *with herbicides applied at low volume.* In DS, the dimethylamine salt (amine), isobutyl ester (IBE), and isopropyl ester (IPE) formulations of 2,4-D were applied with the low-volume Micronherbi, Birky, and VLV-50 and the conventional hydraulic knapsack sprayers to control *S. maritimus*.

When 2,4-D amine was used, Micronherbi and Birky plots had lower weed dry weights than the conventional sprayer plots, whereas VLV-50 plots and the conventional sprayer plots had similar dry

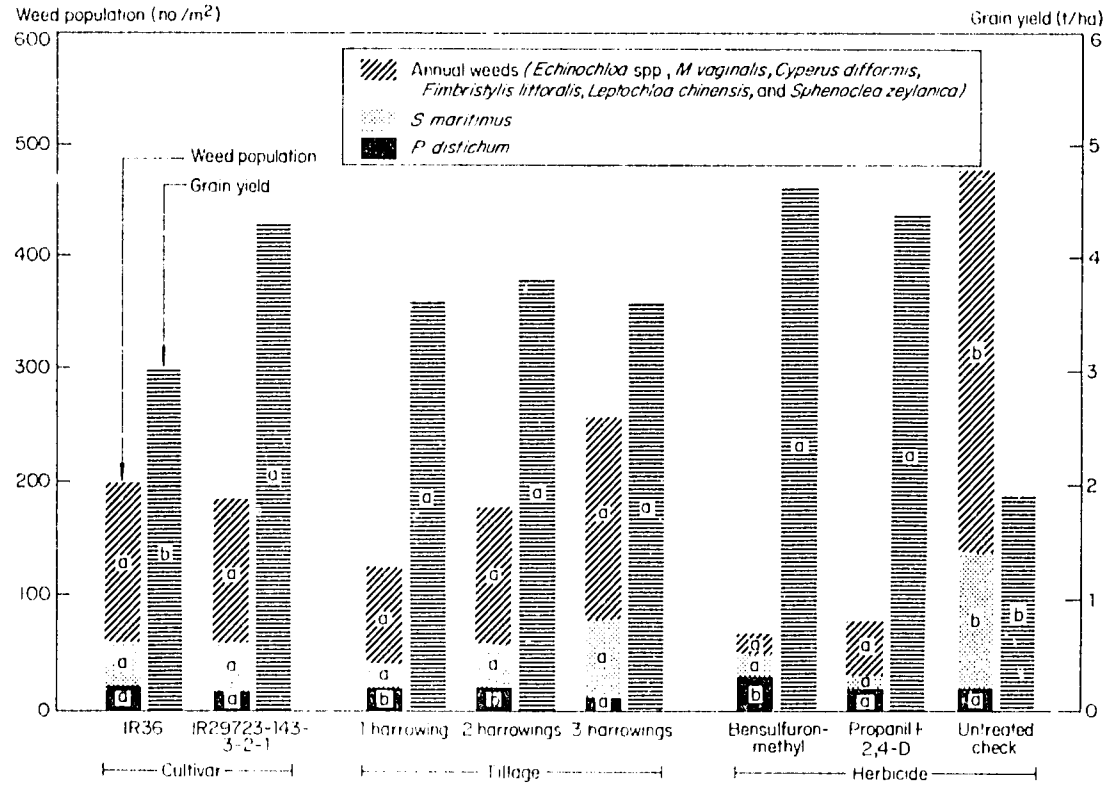
weight (Fig. 6). With 2,4-D IPE and IBE, the different sprayers performed similarly in controlling the weed. Averaged over 3 formulations and 4 sprayers, the dry weight of *S. maritimus* was significantly lower at 1.0 kg/ha than at 0.5 kg/ha. Grain yield was not affected by 2,4-D formulation, rate, and sprayer type, possibly because of the low level of weed infestation.

In WS, bensulfuron – methyl, bentazon, and 2,4-D IBE were used at various rates. At half and full recommended rates, they controlled *S. maritimus* better than at the lowest rate. 2,4-D and bensulfuron – methyl gave similar dry weight of the weed regardless of sprayer type. With bentazon, Micronherbi performed the poorest. Sprayer type and herbicide rate did not affect grain yield of WSR IR58, but the kind of herbicide did. Bensulfuron – methyl gave higher yields than did 2,4-D and bentazon.

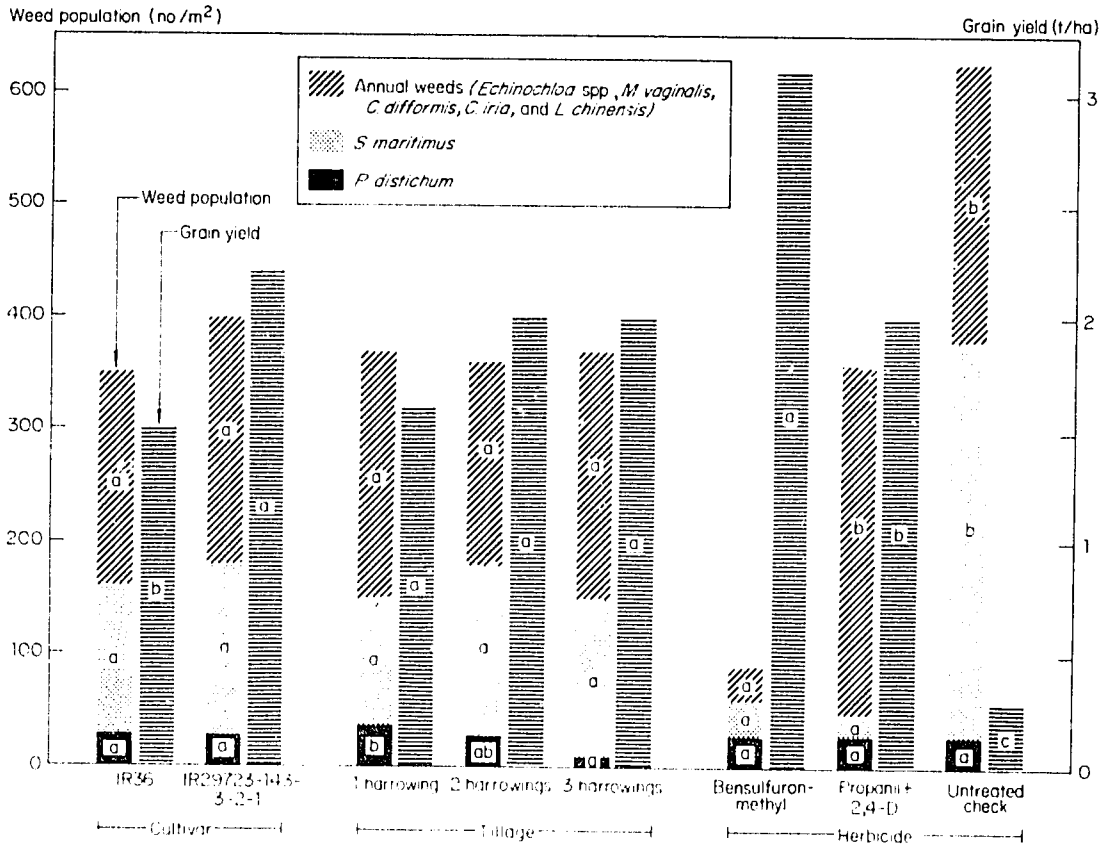
Rainfed transplanted rice. Two experiments in WS evaluated the activity of herbicides applied with low-volume sprayers on *S. maritimus*. One trial compared 2,4-D amine and IBE, and another trial compared bensulfuron – methyl, bentazon, and 2,4-D IBE.

In the first trial, the 2,4-D formulations gave similar weed dry weight at 61 DT at each of the application rates. A significant difference in rates was observed only with 2,4-D amine, where 0.5 kg/ha was inferior to 1.0 kg/ha. 2,4-D IBE was equally effective at both rates. Averaged over two rates and two formulations, the Birky plots gave the lowest *S. maritimus* dry weight and the highest grain yield. Grain yield from the VLV-50 plots was similar to that from the Birky plots.

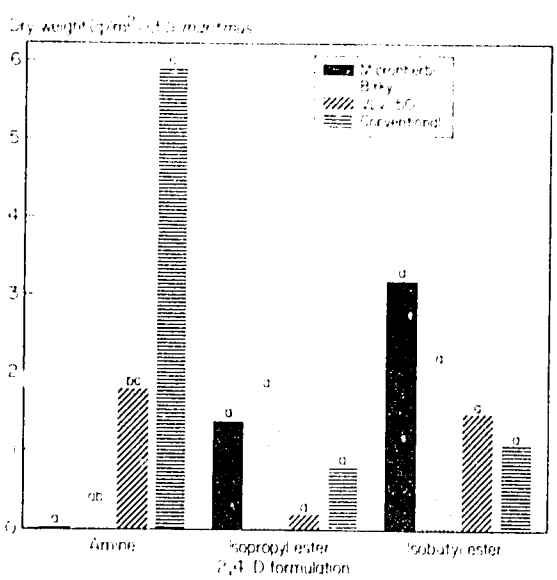
In the second trial, bensulfuron – methyl and 2,4-D reduced *S. maritimus* density better than bentazon, but only bensulfuron - methyl gave a grain yield significantly higher than that of the other plots (Table 17). Increasing herbicide level significantly reduced *S. maritimus* density for the three herbicides. Highest grain yield came from the



6. Weed population and grain yield in the 3d crop as affected by cultivar, tillage, and herbicide. IRRI, 1985 DS. Within a parameter, items with a common letter are not significantly different at the 5% level by DMRT.



5. Weed population and grain yield in the 4th crop as affected by cultivar, tillage, and herbicide. IRRI, 1985 WS. Within a parameter, items with a common letter are not significantly different at the 5% level by DMRT.



6. Effect of 2,4-D formulation and sprayer type on the dry weight of *Scirpus maritimus* at 55 DAS and grain yield of wet seeded irrigated IR58. IRRI, 1985 DS. Bars having a common letter are not significantly different at the 5% level by DMRT.

Table 17. Effect of herbicides, herbicide rate, and sprayer type on the density of *Scirpus maritimus* and grain yield of rainfed transplanted IR58.[a] IRRI, 1985 WS.

Treatment	Density of *S. maritimus* (no./m²)	Grain yield (t/ha)
Herbicide		
2,4-D	23 a	2.4 b
Bentazon	44 b	2.2 b
Bensulfuron - methyl	28 a	3.2 a
Herbicide level		
¼ recommended	50 c	2.2 b
½ recommended	29 b	2.8 a
Recommended	16 a	2.8 a
Sprayer type		
Micronherbi	25 a	2.5 a
Birky	25 a	2.7 a
VLV-50	33 ab	2.7 a
Conventional	43 b	2.7 a

[a]Av of 3 replications. For each herbicide, herbicide level, and sprayer type, mean separation is by DMRT at the 5% level.

plots sprayed with herbicide at half or full recommended rate. Micronherbi and Birky treatments reduced *S. maritimus* density better than the conventional knapsack sprayer. Grain yield was unaffected by sprayer type.

WEED CONTROL IN WET SEEDED AND TRANSPLANTED RICE

A long-term trial was conducted to determine the effect of different weed control treatments on TPR and WSR and to follow changes in the weed spectrum. The major weed species in the unweeded check plots in decreasing order of importance in the first crop were *M. vaginalis*, *C. difformis*, and *E. glabrescens*. By the second crop, *C. difformis* comprised a minor component of the weed flora. By the third crop, *E. glabrescens* was the major weed (summed dominance ratio, 51.2-56.8%) but *M. vaginalis* still accounted for about 40% of the weed flora. By the fifth crop, *E. glabrescens* completely dominated the weed flora, having summed dominance ratios of 78.8% for TPR and 89.6% for WSR.

There was an increase in weed weight in the unweeded check plots with increase in cropping (Table 18). In the first crop of TPR, where infestation was light, weed weight was not reduced significantly by the weed control treatments used. In the second, third, and fourth crops, weed weights were significantly lower in the treated plots than in the check. In the fifth crop, where weed pressure was intense, herbicides failed to suppress the weeds. In WSR, all the weeding treatments significantly reduced weed weights in all crops.

In the first crop, yields in all treatments were significantly higher in TPR than in WSR. In the other crops, yield differences of 1.0 t/ha or less between planting methods were not significant.

In the first crop, weeds did not cause a significant yield reduction in TPR. But thereafter, uncontrolled weed growth caused a significant yield reduction. In WSR, uncontrolled weed growth

Table 18. Effect of crop establishment and weed control methods on weed growth and rice yield.[a] IRRI, 1985.

Weed control method	Weed weight at 45 DT or DAS (g/m²)		Grain yield (t/ha)	
	Transplanted	Wet seeded	Transplanted	Wet seeded
	First crop			
Unweeded check	20.5 a	78.7 b	4.0 a	1.7 b
Hand weeded, 15 and 35 DT or DAS	8.1 a	21.7 a	3.7 a	2.3 a
Butachlor (1.0), 3 DT or 3 DBS	2.5 a	10.7 a	3.9 a	2.8 a
Thiobencarb - 2,4-D (1.0), 3 DT or 3 DBS	0.1 a	20.6 a	4.1 a	2.2 ab
	Second crop			
Unweeded check	117.5 b	153.7 b	1.4 b	1.5 b
Hand weeded	11.0 a	15.3 a	3.2 a	2.9 a
Butachlor	13.8 a	16.8 a	3.1 a	2.8 a
Thiobencarb - 2,4-D	32.9 a	41.9 a	3.3 a	2.1 ab
	Third crop			
Unweeded check	320.9 b	228.9 b	2.1 b	1.8 b
Hand weeded	7.4 a	6.9 a	4.7 a	3.7 a
Butachlor	25.2 a	34.6 a	4.2 a	4.5 a
Thiobencarb - 2,4-D	41.3 a	79.0 a	4.8 a	4.1 a
	Fourth crop			
Unweeded check	484.7 b	465.5 b	0 c	0 b
Hand weeded	33.7 a	18.9 a	2.7 a	1.4 a
Butachlor	185.9 a	186.6 a	1.9 b	0.8 ab
Thiobencarb - 2,4-D	206.2 a	271.0 a	1.3 b	0.5 b
	Fifth crop			
Unweeded check	666.4 b	1080.4 b	0 c	0 c
Hand weeded	7.7 a	8.0 a	3.5 a	2.4 a
Butachlor	347.4 ab	403.1 a	1.5 b	1.2 b
Thiobencarb - 2,4-D	506.5 b	386.7 a	0.9 b	0.6 bc

[a]In a column, within each crop, means followed by the same letter are not significantly different at the 5% level.

caused a significant yield reduction in all crops. By the fourth crop in both types of rice culture, weed growth in the untreated check was so great that no yield was obtained.

Yield increases in the first three crops were due to the application of herbicides and hand weeding, and differences among weed control methods were not significant. By the fourth crop, however, herbicides did not control weeds as well as hand weeding, and yields in the herbicide-treated plots were significantly lower than in the hand weeded plots but significantly higher than in the unweeded checks.

WEED CONTROL IN WATER SEEDED RICE

In some parts of the Philippines, farmers broadcast pregerminated rice seeds directly into water to protect them from birds and rats and to control grassy weeds. Plots in which rice was water seeded were flooded with 5-10 cm water until 10 DAS, when the plots were drained for 3 d to improve root anchorage. At 14 DAS the plots were reflooded with 5-10 cm water. Conventional (seeds sown on puddled soil and plots flooded to a depth of 1-2 cm at 5 DAS) hand weeded and untreated checks were included for comparison.

The major weed species in the experimental area were *E. glabrescens* and *M. vaginalis*. Water seeding reduced the growth of grassy weeds; however, it did not significantly reduce weed weight at crop flowering (Table 19).

In another experiment, the total weed weight in plots flooded for 8 DAS was 57% less than that in a conventionally seeded plot.

The best weed control with herbicides was obtained with bensulfuron – methyl and pretilachor + safener applied at 3 DBS and 6 DAS and with butachlor and thiobencarb applied at 6 DAS.

Crop stand and plant height were not affected by water seeding in untreated plots. All herbicide treatments except bensulfuron – methyl applied at 3 DBS and 6 DAS and pretilachlor + safener applied at 6 DAS caused reductions in crop stand or plant height.

The grain yield of the hand weeded check was not affected by the method of crop establishment. Weeds caused a significant yield reduction in conventionally seeded plots but not in water seeded plots. Except for plots treated with thiobencarb at 3 DBS, yields of herbicide-treated plots were not significantly different from that of the hand weeded check. The crop compensated for stand reduction by producing more tillers.

CONTROL OF WILD RICE IN DEEP WATER RICE

Previous experiments had demonstrated that tillage can reduce wild rice that emerges following the opening rains. A field experiment in 1984 WS (Table 20) included row sowing and the use of pregerminated seed. Row sowing increased the local population of the cultivar LMN111, thus increasing its competitive ability, and allowed

Table 19. Effect of weed control treatment on weed weight, crop stand, plant height, and yield of water seeded IR60 rice. IRRI, 1984-85 DS.

Treatment	Herbicide rate (kg ai/ha)	Time of application	Weed weight at crop flowering (g/m²)	Crop stand at 14 DAS (no./m²)	Plant height (cm) 21 DAS	Yield (t/ha)
Thiobencarb	1.5	6 DAS	49 abc	249 cd	23 bc	5.2 a
Hand weeded check	–	21 + 35 DAS	22 ab	–	–	5.1 a
Hand weeded check (conventional)	–	21 + 35 DAS	26 abc	–	–	5.0 a
Pretilachlor + safener	0.4	6 DAS	16 a	365 bc	25 ab	5.0 a
Bensulfuron - methyl	0.05	3 DBS	22 ab	337 bc	25 ab	5.0 a
Pretilachlor + safener	0.4	3 DBS	38 abc	156 de	19 d	4.9 a
Butachlor	0.75	6 DAS	34 abc	222 d	22 c	4.8 a
Butachlor	0.75	3 DBS	70 bcd	122 e	18 d	4.6 a
Bensulfuron - methyl	0.05	6 DAS	11 a	456 ab	26 a	4.6 a
2,4-D	0.8	30 DAS	52 bcd	–	–	4.3 ab
2,4-D	0.8	3 DBS	111 de	413 ab	22 c	4.2 ab
Untreated check (water seeded)	–	–	73 cde	411 ab	26 a	4.0 abc
Thiobencarb	1.5	3 DBS	190 e	44 f	18 d	3.6 bc
Untreated check (conventional)	–	–	107 de	533 a	26 a	2.9 c

Table 20. Number of wild rice *Oryza rufipogon* and LMN111 plants, and grain yield of LMN111 for different cultural treatments.[a] Pitsanulok, Thailand, 1984 WS.

Treatment	Date	Plants/m² at 6 wk after sowing		LMN111 yield (t/ha)
		Wild rice	LMN111	
1 Broadcast	31 May	109 b	167 ab	0.46 bc
2 Row sowing, 50 cm apart	31 May	131 b	152 ab	0.27 c
3 Row sowing, 50 cm, weeded between rows	31 May	176 a	187 a	1.01 ab
4 Broadcast	12 Jun	38 c	107 bc	1.26 a
5 Row sowing, 50 cm apart	12 Jun	44 c	146 ab	1.08 ab
6 Row sowing, 50 cm, weeded between rows	12 Jun	35 cd	154 ab	1.63 a
7 Broadcast pregerminated seed	18 Jul	8 e	46 c	1.64 a
8 Broadcast dry seed	19 Jul	12 de	71 c	1.44 a

[a]Monthly rainfall: May, 240 mm; June, 83 mm; July, 162 mm; August, 406 mm.

mechanical destruction of wild rice plants in the interrow space by hoeing.

Early sowing treatments had the most wild rice plants and the lowest yields. Early weeding in treatment 3 improved yield. Late tillage in conjunction with delayed sowing markedly decreased wild rice, but one early weeding between rows in treatment 6 still improved yield. Treatments 7 and 8 gave relatively high yields, but sowing in mid-July risks submergence of the crop. Pregerminated seed was used for the final sowing, when the soil was expected to be saturated. But the soil dried, and establishment was no better than that for dry seed. As few as 20 wild rice plants/m² substantially reduced yield.

CULTURAL CONTROL METHODS

Effect of flooding time. *M. vaginalis* was best controlled by flooding at 4 DAS; *E. crus-galli* at 2, 6, and 8 DAS; and *S. maritimus* at all postseeding floodings (Table 21). Seeding into water (0 DAS) reduced rice stand, increased weed population, and decreased panicle number. However, grain yields did not differ significantly among flooding treatments.

Control of *Rottboellia cochinchinensis*. The effect of rototillage at different time intervals (2, 3, 4, 5, or 6 wk) on *R. cochinchinensis* emergence was studied in a fallow field at IRRI from August 1983 to July 1985. Rototilling the soil every 2-3 wk eliminated *R. cochinchinensis* in less than 2 yr. Less frequent rototillings took longer to reduce the population.

The decline in *R. cochinchinensis* population was accompanied by an increase in the density of other species such as *Digitaria* spp., *Eleusine indica*, *Portulaca oleracea*, *Murdannia nudiflora*, and *C. rotundus* so that the total weed population was not reduced after 2 yr regardless of the frequency of rototillage.

Table 21. Effect of flooding time on weed control, crop stand, and yield of broadcast seeded, flooded IR36.[a] IRRI, 1985 WS.

Flooding time (DAS)	Biomass (g/m²)			Crop stand (no./m²)		Grain yield (t/ha)
	Broadleaf weeds[b]	Grasses[c]	Sedges[d]	Seedlings	Panicles	
0	5 b	204 d	57 b	36 c	224 b	3.2 a
2	29 d	83 a	15 a	98 a	313 ab	3.4 a
4	2 a	123 c	19 a	69 b	350 a	3.7 a
6	7 b	60 a	30 a	76 ab	288 ab	3.6 a
8	26 d	98 ab	30 a	94 a	255 ab	2.8 a
10	16 c	103 bc	5 a	101 a	260 ab	2.8 a

[a]Av of 3 replications. [b]*Monochoria vaginalis*. [c]*Paspalum distichum* and *Echinochloa crus-galli* ssp. *hispidula*. [d]*Scirpus maritimus*.

Table 22. Effect of weed control method on rice and weed growth under upland conditions.[a] IRRI, 1985 WS.

Treatment[b]	Application time[c]	Weed count (no./m²) at 31 DE	Rice stand count (no./m²) at 31 DE	Total weed weight (g/m²) at 50 DE	Tillers (no./m²) at 50 DE
Butachlor (1.0)	PE	148 abc	78 c	245 bcd	554 b
Butachlor (2.0)	PE	129 ab	80 bc	275 cd	502 b
Butachlor (1.0) fb IRC	PE fb 14 DE	173 bc	72 c	185 b	624 ab
Butachlor (1.0) fb 1 HW	PE fb 21 DE	138 ab	66 c	204 bc	739 a
IRC fb butachlor (1.0)	14 DE fb 19 DE	106 a	76 c	312 de	468 b
IRC + HW along rows	14 DE	185 c	62 c	301 de	473 b
IRC	14 DE	156 bc	68 c	299 de	453 b
1 HW	21 DE	162 bc	106 a	250 bcd	536 b
2 HW	14 DE fb 35 DE	184 c	76 c	63 a	747 a
Untreated check	–	244 d	97 ab	350 e	443 b

[a]Av of 4 replications and 3 cultivars. [b]Figures in parentheses are application rates in kg ai/ha. IRC = interrow cultivation with lithao, HW = hand weeding. [c]PE = preemergence.

INTEGRATED WEED MANAGEMENT

Effects of cultivar and cultivation. The individual and combined effects of cultivar, chemical, and cultural method on weed control and crop establishment were evaluated.

At 31 DE, all treated plots had fewer weeds compared with the untreated check (Table 22). Plots with interrow cultivation followed by butachlor (1.0 kg ai/ha) had the least number of weeds, but were comparable to plots with butachlor 1.0, butachlor 2.0, and butachlor 1.0 followed by 1 hand weeding. One hand weeding at 21 DE gave the highest rice stand count, comparable to that of the untreated check.

Although no treatment reduced the total weed weight at 50 DE as well as two hand weedings, preemergence application of butachlor 1.0 followed by interrow cultivation was the next best treatment, comparable to butachlor 1.0, butachlor 1.0 followed by 1 hand weeding, and 1 hand weeding. Tiller number was highest in plots hand weeded twice, but this was comparable to butachlor 1.0 followed by interrow cultivation and butachlor 1.0 followed by 1 hand weeding.

IR43 and UPLRi-7 plots had more tillers and lower total weed weights than Kinandang Patong plots. Moreover, tiller number was highly correlated with total weed weight for the three cultivars.

No grain was produced because of drought at the reproductive stage of the crop.

Table 23. Fresh weight of *Azolla caroliniana* 20 d after application[a] of different herbicides. IRRI, 1984.

Treatment	Application rate (kg ai/ha)	*A. caroliniana* fresh weight (g/m²)
Butachlor	1.0	77 ef
2,4-D	0.8	148 ef
Thiobencarb	1.0	520 b
Thiobencarb - 2,4-D	1.2	289 cde
Piperophos - 2,4-D	1.0	191 defg
Butachlor - 2,4-D	1.25	32 fg
Pendimethalin	0.75	160 efg
Molinate - simetryn - MCPB	0.93	0 g
Naproanilide - thiobencarb	1.7	198 defg
Oxyfluorfen	0.14	238 def
Oxadiazon	0.75	489 bc
Hand weeded check	–	735 a
Unweeded check	–	787 a

[a]All herbicides applied at 4 d after transplanting except oxadiazon at 3 d before transplanting.

Effect of azolla. A trial was conducted to see if herbicides could be used in conjunction with azolla for weed control.

None of the herbicides tested reduced the N content of azolla, but all significantly reduced the fresh weight of azolla at 20 d after herbicide application (Table 23). Complete kill of azolla was caused by molinate – simetryn – MCPB, while thiobencarb caused the least damage — 30% reduction in weight compared with the hand weeded check. The only other herbicide to cause less than 50% reduction in weed weight was oxadiazon.

Irrigation water management

Water Management, Agricultural Economics, and Plant Breeding Departments

IMPROVING OPERATIONAL EFFICIENCY OF A PUMP-BASED IRRIGATION SYSTEM **194**
- Rainfall, cropping calendar, and pumping cost **194**
- Designed and actual service area potentials **196**
- Effective use of rainfall **196**
- Factors contributing to low irrigation coverage **197**
- Water distribution equity **199**
- Rice yields and water productivity **200**

FINANCIAL VIABILITY OF LCPIS **201**
- Productivity **201**
- Labor use **201**
- Purchased inputs **201**
- Benefits of irrigated rice **201**
- Distribution of benefits **203**
- Systemwide benefits **204**
- Irrigation fee payment **205**

FORECASTING DRY SEASON WATER SHORTAGES **205**

STRATEGIES FOR IMPROVING RICE PRODUCTION IN FLOOD-PRONE ENVIRONMENTS **207**
- Extent of flooding **207**
- Flood avoidance strategies **208**
- Strategies to minimize flood damage **208**
  - Use of alternative varieties **208**
  - Improving drainage rate **209**
  - Flood protection **209**
- Water management requirement **209**

BANGLADESH COLLABORATIVE RESEARCH **209**

IMPROVING OPERATIONAL EFFICIENCY OF A PUMP-BASED IRRIGATION SYSTEM

Water Management Department

Maintaining high operational efficiency is crucial for pump-based irrigation systems because of the high cost of energy needed to run them. Water users in these systems pay a much higher irrigation service fee than in run-of-the-river or reservoir-backed systems. Low efficiency not only limits the growth of pump-based irrigation but also threatens to close down existing systems because of the cost.

A collaborative research project between the Philippine National Irrigation Administration (NIA) and IRRI, conducted from 1981 to 1985 in the Libmanan-Cabusao Pump Irrigation System (LCPIS), Camarines Sur, focused on developing effective means to improve the system's operational efficiency and to increase benefits from its use. Implications of this research are relevant to pump-based irrigation systems in general.

Rainfall, cropping calendar, and pumping cost. The rainfall pattern based on records for 5 yr from 7 stations within the LCPIS command area of about 4,000 ha is shown in Figure 1. Although the total yearly rainfall was moderately high (2,140 mm/yr), weekly rainfall during January-June was low, generally less than 30 mm. Typhoons brought in much of the rain. Although historically November is the month with most typhoons, followed by October, three typhoons occurred in July 1983 and one in July 1982.

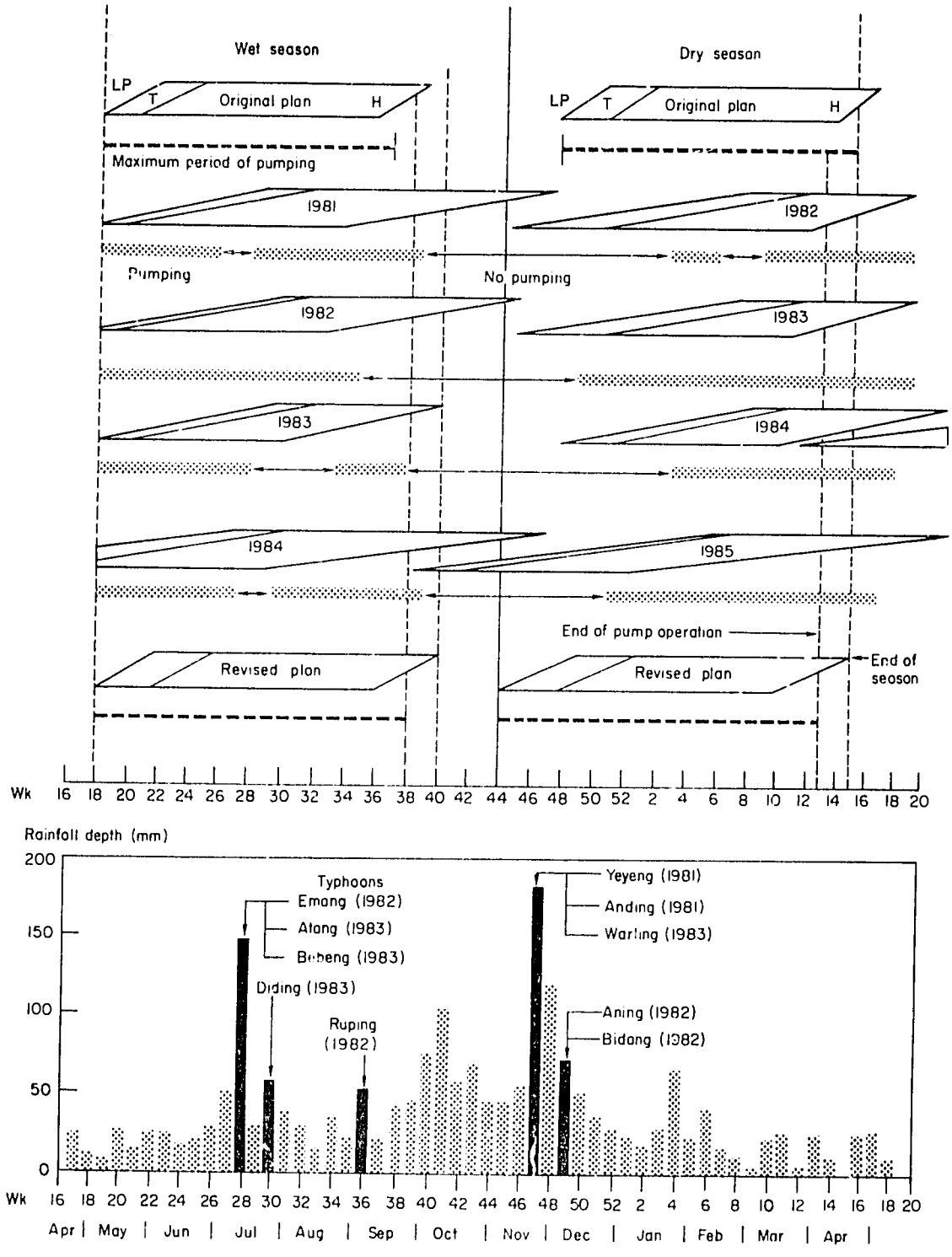
The system's planned cropping calendar, developed in 1981, and the actual cropping calendars that farmers followed during 1981-85 are also shown in Figure 1. The original calendar provided for a 22-wk wet season (WS) starting the first week of May and a 20-wk dry season (DS) starting the last week of November. The period allowed for land soaking and land preparation was 7 wk for WS and 6 wk for DS. The turnaround time between the completion of harvesting of the WS crop and the start of land preparation for DS was 8 wk. But farmers' actual cropping practices varied greatly. WS and DS overlapped during two of the four crop years studied. WS lasted from 22 to 37 wk and DS from 25 to 34 wk. Delayed planting stretched the time between the start of land preparation and completion of transplanting from 13 to 22 wk in WS and from 14 to 22 wk in DS, instead of the 7 wk in WS and 6 wk in DS that were envisioned.

Delayed planting is undesirable for two main reasons: 1) it forces the system to extend pumping operation at higher cost and to distribute the water at lower efficiency for portions of the total service area; and 2) late-planted fields in WS suffer more risk of typhoon damage in October and November. During the extended period, the pumping cost for each hectare served and water loss are higher because the area needing irrigation at that time is smaller and noncontiguous, but the system has to operate at its normal capacity to be able to deliver water where it is needed.

A survey of 102 farmers categorized into 3 classes — early (40 farmers), middle (23), and late transplanters (39) — showed that over 85% of farmers who transplanted early in WS did so to avoid crop damage by typhoons. However, about 8% of the early farmers indicated their reason was to be able to grow a second crop before DS, avoiding the payment of irrigation service fees. The reasons given by the middle and late transplanters to justify their delayed start were either lack of timely irrigation water, excessive water in the field (in waterlogged areas), or lack of capital.

Pump operation in LCPIS was extended every year in DS to serve the late-planted rice areas (Fig. 1), but at high cost because heavy pumping is needed in April (DS pumping schedule terminates at the end of March) when rainfall is very low. Late planting of a large area every DS was responsible for major cost escalations (Table 1). In 1984 DS, when about 69% of the total service area was planted late, pumping during the extended period required as much as 40% of the total energy cost for the season. In the other DSs, costs of extension ranged from 22 to 27% of total.

To improve the system's economic viability, 1) its operational schedule should be followed strictly in both seasons, and no extension of pumping schedule should be allowed; 2) farmers' organization and the system management should strive together to convince the farmers of the critical need to reduce pumping costs for the system's economic viability, and of the benefits,



1. Five-year (1981-85) average weekly rainfall and typhoon occurrences in LCPIS. Top shows planned and actual cropping calendars in WS and DS during those years. LP = land preparation. T = transplanting, H = harvest.

Table 1. Pump usage, area planted, and energy (electric power) cost.[a] LCPIS, Philippines, 1981 WS to 1985 DS.

Year	Area irrigated during pumping extension[b]		Total pump usage (pump-h)	Unit cost of energy ($/pump-h)	Total energy cost ($)	Energy cost per unit irrigated area ($/ha)	Pump usage during extension[b] (pump-h)	Energy cost due to extension of pump operation[b]	
	ha	% of total						$	% of total
					Wet season				
1981	1,076	64	3,031	14	43,434	25	160	2,240	5
1982	1,267	62	2,859	16	45,774	24	0[c]	0	0
1983	558	37	3,512	13	45,656	30	0[c]	0	0
1984	618	41	2,753	16	44,048	30	54	864	2
					Dry season				
1982	1,458	89	2,479	16	39,664	24	673	10,768	27
1983	1,026	55	4,844	11	53,284	28	1,060	11,660	22
1984	912	69	2,250	15	33,750	25	902	13,530	40
1985	834	51	2,704	17	45,968	27	683	11,611	25

[a]Exchange rates: $1.00 = ₱7.90 (1981), $1.00 = ₱8.54 (1982), $1.00 = ₱11.11 (1983), $1.00 = ₱16.70 (1984), $1.00 = ₱20.00 (1985); [b]Calculation based on "revised plan" calendar. [c]No pumping was needed because of rainfall.

both for themselves and for the system, of practicing a cropping calendar in tune with the system's pumping calendar; and 3) water allocation-distribution should be improved to make irrigation water available to all water users early in each season so that they are able to plant on time.

The cropping calendar originally adopted in LCPIS had certain weaknesses that created maintenance problems and contributed to off-schedule planting by farmers. First, there was only a 2-wk gap between the end of pumping for DS and the start for WS. This small gap encouraged some farmers to plant late in DS because the risk of their crop being substantially damaged by water stress during the 2-wk period was relatively low. The short gap was also not enough for repairs and maintenance. Furthermore, the short gap encouraged some farmers to grow three rice crops during the year, with a higher risk of crop damage by typhoon. Farms with delayed crops and those growing three crops were the ones most in need of an extension of pumping.

Therefore, a revised cropping calendar and a supporting pump operation schedule were developed (Fig. 1). The revised cropping plan allows WS one extra week to complete harvesting, but DS starts earlier (1 Nov) and benefits from the usually high rainfall during the month for land soaking and land preparation. Transplanting, however, is to be completed by the first week of January, as in the original plan. The pumping schedule goes to the end of March so that the whole month of April, usually the driest month of the year, may be reserved for repairs and maintenance.

Designed and actual service area potentials. LCPIS was designed to irrigate 3,916 ha with 4 pumps operated simultaneously for 24 h/d during periods of peak water demand. But 444 ha could not be irrigated because they were higher than the water level in the canals; power for the pumps was available for only 17 h/d; and siltation decreased the carrying capacity of the main canal so that only three pumps could be used simultaneously.

Assuming no rainfall during the peak demand period, the practically irrigable area with 3 pumps operating for 17 h/d is estimated as 2,382-2,758 ha, depending on area location. It was assumed that the average water delivery efficiency between the pumphouse and the service area is 80%, which is reasonable considering the low water conveyance losses in canals dug in heavy clay.

Effective use of rainfall. Effective use of rainfall is critically important for the system to minimize pumping. The effectiveness of rainfall is influenced by both the system manager — through his decision to withhold pumping — and the farmers' management of the ricefield spillway, the lowest portion of the dike, to hold rainwater in the field. The farmers' and the manager's efforts complement each other to establish a rainfall storage capacity in the system in general and in the fields in particular. The rainfall storage capacity in the fields, also called freeboard, is the difference between the spillway height and the water depth.

For LCPIS, rainfall below 50 mm was found to be 100% effective. For rainfall greater than 50 mm, effective rainfall (ER) was found related to rainfall (RF) through the following regression equation, which is significant at the 1% level:

$$ER = 97.67 - 0.94\,(RF) + 0.0024\,(RF)^2$$
$$(r^2 = 0.46;\ Fc = 12.13^{**})$$

where ER is in percent and RF in millimeters. These relationships are useful in developing a pumping suspension schedule to allow maximum use of rainfall within the service area.

In an experiment to assess the effective use of rainfall in the various parts of LCPIS, ER was determined at the head, middle, and tail parts of the system for three consecutive seasons starting in 1982 WS. Freeboard was measured daily in 54 selected fields at each of the 3 locations, and ER was computed using the following formulas:

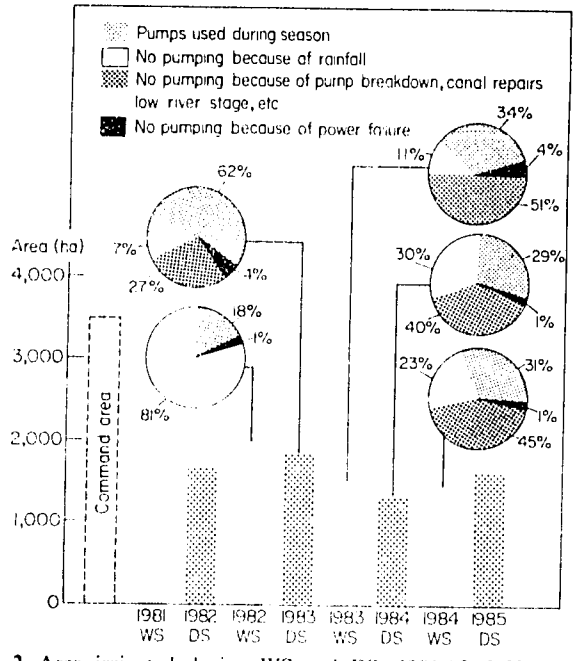
- For RF < freeboard, $ER = 100\%$
- For RF > freeboard, $ER = \dfrac{\text{freeboard}}{\text{RF}} \times 100\%$

In DS, farmers in the middle and tail portions of the system maintained significantly higher spillway heights, resulting in higher freeboards than those in the head portion of the system (Table 2). These farmers also had a significantly higher ER. The reason for the difference is that irrigation water supply in DS is less in areas more distant from the source and hence distant farmers are more meticulous about the use of rainwater. The 93% ER value in the tail area is indicative of the

Table 2. Average spillway height, freeboard, and effective rainfall in 3 sections of LCPIS, Philippines, 1982 and 1983.[a]

Section	Spillway height (mm)	Freeboard (mm)	Effective rainfall (%)
	1983 DS		
Head	58.1 b	35.7	43.7 b
Middle	83.0 a	52.4	77.5 a
Tail	75.0 a	64.4	93.1 a
	1982 and 1983 WS		
Head	66.8 b	44.1	73.9 a
Middle	69.3 b	39.7	59.8 b
Tail	88.3 a	63.1	75.8 a

[a]Within a season, column means followed by the same letter are not significantly different at the 5% level.

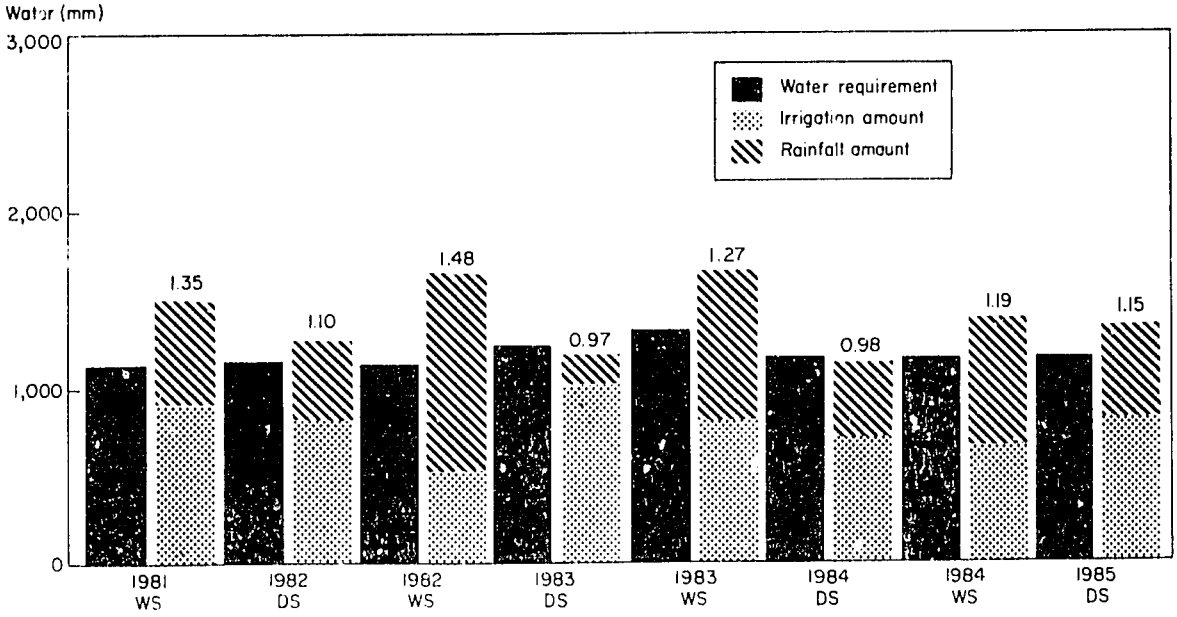


2. Area irrigated during WS and DS, 1981-85, LCPIS, Camarines Sur, Philippines. The pie graphs show percentage of periods of pump use and nonuse due to various reasons.

significant scope available to improve the effective use of rainfall by controlling water supplies to areas such as the head section where irrigation supplies are abundant and consequently rainwater use is low (ER = 47%).

Factors contributing to low irrigation coverage. The irrigated area in LCPIS during the 8 seasons of 1981-85 fluctuated between 1,325 ha in 1984 DS and 2,032 ha in 1982 WS (Fig. 2). The two major factors contributing to the seasonal variation in irrigated area were the total water supply and the water delivery rate.

Rainfall and pumped water constitute the total water supply in LCPIS during both seasons. With optimum timing and rate of supply to the service area, irrigation deliveries can be made to only supplement rainfall, thus minimizing pumping costs. The water delivery rate from the pumps is determined by the number of pumps that are operated simultaneously and by the related water stage that can be maintained at the canal network for delivery to the fields. Since power to operate the pumps is available only during 17 h/d because of other demands, the optimum scheduling of pump operation, in terms of both number of pumps and time of starting, requires skillful management.



3. Seasonal water requirement for rice and water supplies from irrigation and rainfall. LCPIS, Camarines Sur, Philippines. The relative water supply value is given on top of the bars.

Seasons with low service area are associated with frequent and prolonged pumping interruptions because of technical problems such as pump breakdown, canal breach or low water in the river at the pump suction end (Fig. 2). In 1982 WS, when the irrigation achievement was highest, there was no pumping interruption when irrigation water was needed. But in 1983 WS, when only 1,501 ha were irrigated, about 77% of the nonpumping period was due to technical problems. Similarly, 57% of the nonpumping in 1984 DS was caused mostly by 2 pumps remaining out of order for about half the season.

The highest difference in service area among the DSs was between 1983 and 1984 (Fig. 2). Although 1983 DS received much less rainfall (Fig. 3), a greater amount of pumped water during the season, facilitated by fewer pumping interruptions due to technical problems, sustained the water needs of the cropped area. The primary factor responsible for a higher area coverage in 1983 DS was the higher average flow rate maintained in the main canal (3.19 m^3/s), which enabled quicker and more effective delivery of water to the fields, particularly during the land preparation time when the area that could be prepared each week was strongly and positively correlated with the water delivery rate (Annual report for 1984). The average flow rate was only 1.28 m^3/s in 1984 DS (Table 3).

Among the WSs, the greatest difference in irrigated area occurred between 1982 WS (2,032 ha) and both 1983 WS and 1984 WS, each of which had an irrigated area of 1,501 ha. Rainfall was significantly higher in 1982 WS (1,142 mm) than in 1983 WS (852 mm) or 1984 WS (730 mm) (Fig. 3). Most 1983 WS rainfall occurred during three typhoons in July and was largely wasted as runoff. The high incidence of technical problems, forcing suspension of pumping in 1983 WS (Fig. 2), did not allow enough irrigation water to be supplied into the system to bring total irrigation coverage close to the 1982 WS level. Among the three seasons,

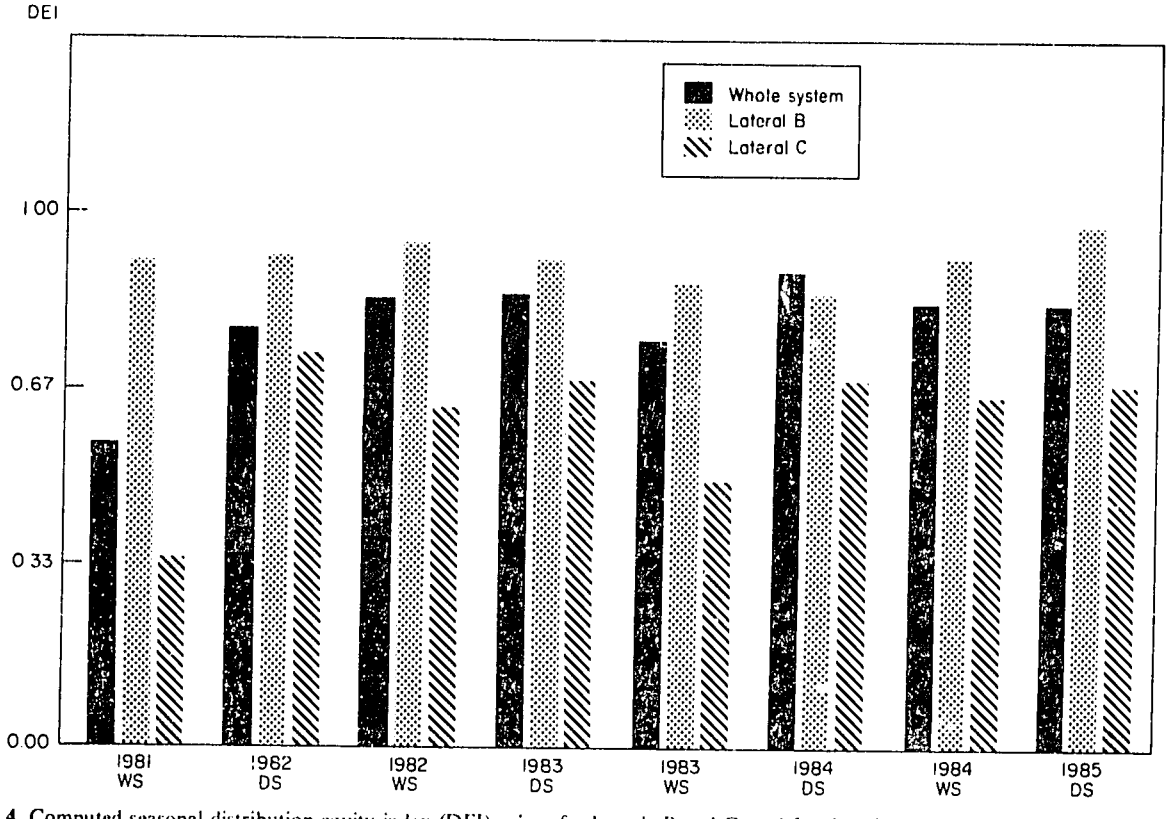
Table 3. Seasonal average water delivery rates. LCPIS, Philippines, 1981 WS to 1985 DS.

Season	Av flow (m^3/s)
1981 WS	1.84
1982 DS	1.23
1982 WS	2.43
1983 DS	3.19
1983 WS	2.51
1984 DS	1.28
1984 WS	2.71
1985 DS	3.32

1984 WS had not only the least rainfall but also the least pumped water (652 mm), resulting in a significantly lower relative water supply (Fig. 3). As in 1983 WS, pumping in 1984 WS was constrained by technical problems (Fig. 2), contributing the water supply shortage in the fields.

Water distribution equity. To improve water distribution equity in LCPIS, a sectionwise rotation in lateral method of water allocation-distribution was introduced in 1982 DS. The method required designing water delivery schedules in defined sections of a lateral so that each section had the exclusive right to use the canal flow during specified and fixed periods within a week. Laterals B and C, where the method was introduced, were divided into three and four sections, respectively (Annual report for 1982). The distribution equity index (DEI), which measures the water distribution equity achieved during a season based on the proportion of area actually irrigated relative to area targeted, improved significantly in lateral C, which serves about 60% of the LCPIS command area (Fig. 4). In 1983 WS, when pumping interruptions due to technical problems were very high, DEI for lateral C was only 0.49. Fluctuations of DEI in lateral B were small, primarily because of its relatively small service area (500 ha) and favorable topography. Also, lateral B enjoys a more reliable water supply from the main canal because it is the closest major lateral to the pumphouse (lateral A serves a very small area). DEI for the entire system was maintained at a fairly high level from 1982 DS (Fig. 4).

Equitable water distribution is desirable not only from the social perspective but also because it promotes efficient utilization. The sectionwise rotation in lateral method, if practiced meticulously, can minimize the water wastage that often occurs in the area served by the headend portions of canals. Strict adherence to the given schedule, which is possible only through the joint cooperation of farmers and system personnel, is the key to achieving a high degree of water distribution equity as well as high water use efficiency.

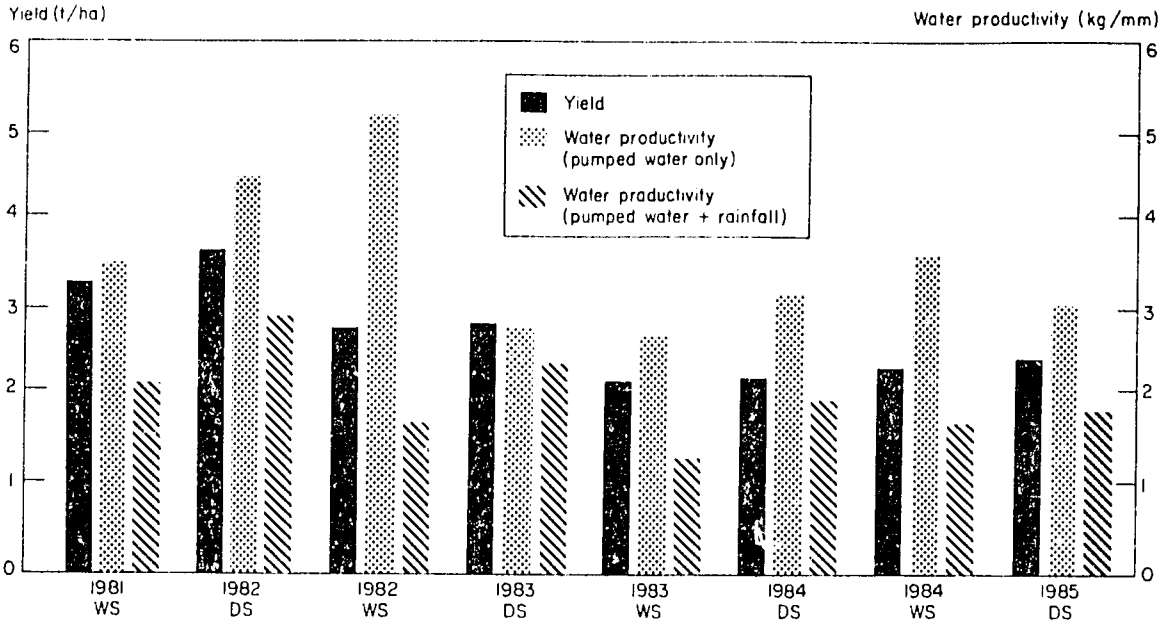


4. Computed seasonal distribution equity index (DEI) values for laterals B and C, and for the whole of LCPIS, Camarines Sur, Philippines, 1981-85.

During 1982-85 DS, the rotational schemes in laterals B and C were implemented with moderate success. With more supervision from system personnel and farmer organization leaders, significantly greater success could be achieved. One major problem, however, is that if pumping is interrupted due to technical problems, it becomes difficult to reestablish the schedule when pumping is resumed, because at that time all farmers need water. Furthermore, such interruptions cause users to lose confidence in the reliability of the newly adopted method, and force them to seek their own solutions, which may be detrimental to the system as a whole. The tailend farmers are the worst sufferers from such a problem. The low DEI for lateral C in 1983 WS (Fig. 4) was most likely caused by this problem.

A unique advantage of implementing the rotational scheme of water allocation-distribution is that, because water right is exclusive to a given section on any given day, canal supervision can easily determine whether any illegal diversion of water is taking place and where. By applying social pressures with the help of system personnel or farmer organization leaders, concerned farmers can expect to remedy the situation. Tailend farmers are the major beneficiaries of this advantage. The system as a whole gains because larger irrigation coverage becomes possible. Analysis of individual turnout service area data from past years indicates a strong positive correlation between the area planted to rice with irrigation and the relative frequency of no-water-delivery condition during unscheduled periods. Likewise, a strong negative correlation was found between the area planted and the relative frequency of no-water-delivery during the scheduled periods.

Rice yields and water productivity. Average yields, computed from crop-cuts taken from a grid system consisting of 108 sample farmers, and water productivity are shown in Figure 5. The highest average yield (3.62 t/ha) was achieved in 1982 DS and the lowest (2.15 t/ha) in 1983 WS. In general, typhoons and consequent flooding suppressed WS yields, whereas DS yields were affected by water shortages and rodent infestations in some parts of the service area. In 1982 WS and 1984 WS, the water productivity values computed with pumped water only were much higher than those computed with pumped water plus rainfall, because the proportion of rainfall to pumped water was higher than in other seasons (Fig. 5).



5. Seasonal rice yields and water productivity computed for pumped water as well as pumped water plus rainfall. LCPIS, Camarines Sur, Philippines, 1981-85.

FINANCIAL VIABILITY OF LCPIS

Agricultural Economics and Water Management Departments

The benefit of the irrigation investment on rice production in LCPIS was determined by sampling 92 irrigated and 43 rainfed farms in 1981-84. Data on input use and yields of first (planted Jun-Jul) and second (planted Dec-Jan) rice crops were assembled through postharvest interviews of farmers.

Productivity. Irrigation led to higher yields and a higher proportion of farms planted to rice than in the rainfed situation (Table 4). Over the 3-yr evaluation period, the mean first and second rice crop yields were significantly higher for flood-free irrigated farms than for rainfed farms: flood-free irrigated farms produced an average 2.6 t/ha for the first crop season and 3.0 t/ha for the second compared with 1.7 t/ha for the first crop season and 1.6 t/ha for the second on rainfed farms. The productivity of flood-prone and rainfed farms was similar for the first crop, but flood-prone farms recorded higher yields in the second season, when moisture stress tended to be a problem with the late second season crop maturity.

In addition to yield gains, cropping intensity (measured as the percentage of rice area planted) was higher under irrigated than rainfed rice production, particularly for the second rice crop.

Labor use. Flood-free irrigated farms used significantly higher labor inputs (74 d/ha) than flood-prone irrigated (57 d/ha) or rainfed (63 d/ha) farms for the first rice crop (Table 5). Components of labor use for crop establishment and harvesting were higher on flood-free than on rainfed farms. For the second crop, total labor inputs averaging about 63 d/ha did not differ significantly among systems. However, flood-free irrigated farms spent significantly more time on harvesting and threshing; rainfed farms spent more time on land preparation.

Purchased inputs. Irrigated and rainfed farms applied similar fertilizer rates (Table 6). Mean fertilizer rates across farms ranged from 29 to 43 kg N/ha, 13 to 17 kg P/ha, and 9 to 14 kg K/ha. Although rates did not vary between farm types, the extent of adoption differed greatly. Over 70% of irrigated flood-free farms applied N compared with 41-52% of rainfed farms in the first and second seasons. Trends are similar for the use of P and K fertilizer, with flood-free farmers having the highest adoption rate.

Almost all farmers applied pesticides regardless of water regime. There was no significant difference in the value of pesticides applied between seasons or among landscape positions.

Benefits of irrigated rice. One measure of the utility of irrigation is to compare the benefits of irrigated rice with those of rainfed rice (Table 7).

Table 4. Yields and cropping intensity on irrigated and rainfed farms, CY 1981-84, LCPIS, Philippines.[a]

	First season				Second season		
	Irrigated		Rainfed		Irrigated		Rainfed
	Flood-free	Flood-prone			Flood-free	Flood-prone	
	Yield (t/ha)				*Yield (t/ha)*		
1981	3.30 a	2.08 ab	1.60 b	1982	3.44 a	2.13 b	2.03 b
1982	2.54 a	2.28 ab	1.74 b	1983	2.80 a	2.26 a	0.85 b
1983	2.06 a	1.35 a	1.67 a	1984	2.85 a	3.20 a	1.76 b
Mean	2.60 a	1.87 b	1.72 b	Mean	3.02 a	2.51 b	1.56 c
	Cropping intensity (% area planted)				*Cropping intensity (% area planted)*		
1981	90	42	59	1982	89	83	45
1982	92	92	59	1983	97	95	49
1983	76	82	45	1984	88	81	46
Mean	86	81	54	Mean	92	86	47

[a]Means followed by the same letter within rows within a group are not significantly different at the 5% level by DMRT.

Table 5. Labor use by activity on irrigated and rainfed farms for first and second crop, LCPIS, Philippines, 1981-84.

Activity	Labor use (labor d/ha)					
	First crop			Second crop		
	Irrigated		Rainfed	Irrigated		Rainfed
	Flood-free	Flood-prone		Flood-free	Flood-prone	
Seedbed preparation	1	1	1	1	1	1
Land preparation	17	15	16	15	13	19
Crop establishment	19*	18*	14	17	17	15
Fertilizer and chemical application	4	3	3	4	3	3
Care and cultivation	10	6	12	8	7	8
Harvesting and threshing	23*	14	17	23*	18	17
Total	74*	57	63	68	59	63

Table 6. Comparative fertilizer and pesticide use on irrigated and rainfed farms for first and second crops. LCPIS, Philippines, 1981-84.

Input	Irrigated				Rainfed	
	Flood-free		Flood-prone			
	First	Second	First	Second	First	Second
Fertilizer						
Quantity applied (kg/ha)						
N	43	40	34	29	30	38
P	17	17	16	13	13	16
K	14	13	10	9	12	14
Rate of adoption (% of users)						
N	73	77	59	61	41	52
P	46	42	32	26	15	25
K	33	27	15	10	10	19
Pesticides						
Amount spent ($/ha)	11	9	10	9	10	7
Rate of adoption (% of users)	99	98	100	98	96	92

Table 7. Estimated net benefit/ha[a] per year, with and without comparison, LCPIS, Philippines, 1981-84.

Item	Irrigated		Rainfed
	Flood-free	Flood-prone	
	First season crop		
Area planted (%)	86	81	54
Total value of output[b] ($)	224	152	93
Total cost of production ($)	178	146	86
Farmer's net income ($)	46	6	7
Net benefits/ha[c] ($)	39	0	
	Second season crop		
Area planted (%)	92	86	47
Total value of output[b] ($)	278	215	73
Total cost of production ($)	202	164	75
Farmer's net income ($)	76	51	(2)
Net benefits/ha[c] ($)	76	51	
Total annual net benefits ($) derived from irrigation	115	51	

[a]Assumed exchange rate $1 = ₱20.00. [b]Calculated at local price of $100/t. [c]Irrigated net income-rainfed net income.

The annual benefit in the flood-free areas was estimated at $115/ha (at local prices), two-thirds of which was due to the second season crop and one-third to the first season crop. The farmer benefits generated a surplus over and above the irrigation fee of $60/ha per year.

Flood-prone irrigated farms, on the other hand, which frequently experienced flooding during the first season, derived benefit from irrigation only during the second season. In the low-lying areas, irrigation did not generate a benefit in the first season, although it generated about $50/ha more than rainfed farms in the second season.

An alternative measure of irrigation benefits is a before-and-after analysis, where the difference between the net income of farms before and after the project is considered as the net benefit due to irrigation. By this approach, irrigation did not generate an added benefit over the system for the first rice crop, but it generated a net value of $26/ha for the second (Table 8).

These estimated benefits are less than the benefits calculated via the with-and-without comparative approach for two reasons: 1) 25% of the samples representing the "after" situation remained rainfed although they were within the designed command area; and 2) the differences in the time periods of analysis created a downward bias in the "after" situation because several typhoons depressed yields.

Table 8. Estimated net benefits/ha[a] per yr before and after comparison, LCPIS, Philippines, 1981-84.

Item	Before	After
First season crop		
Area planted (%)	62	74
Total value of output[b] ($)	129	168
Total cost ($)	94	137
Farmer's net income ($)	35	31
Net benefits/ha ($)	(4)	
Second season crop		
Area planted (%)	21	78
Total value of output[b] ($)	38	202
Total cost ($)	32	170
Farmer's net income ($)	6	32
Net benefits/ha ($)	26	
Total annual net benefits ($) derived from irrigation	22	

[a]Assumed exchange rate $1 = ₱20.00. [b]Calculated at local price of $100/t.

The analyses reported in Tables 7 and 8 are the direct benefits from increased rice production. Systemwide benefits not reflected in the figures are, e.g., the indirect benefits from extra employment because of increased cropping intensity and increased labor use per crop when compared with rainfed rice production. These potentially large indirect benefits are currently being estimated.

Distribution of benefits. The increase in real income associated with irrigation was not equally shared among factors of production (Table 9). The percentage share of current inputs in the first

Table 9. Comparative distribution of output among factors of production and earners, with and without irrigation, LCPIS, Philippines, 1981-84.

	Distribution (%) of output					
	Irrigated					
	Flood-free		Flood-prone		Rainfed	
	First season	Second season	First season	Second season	First season	Second season
Rice output	100	100	100	100	100	100
Factor payments						
Current inputs	34	28	42	29	25	27
Capital	19	18	22	19	22	24
Labor	27	24	30	25	33	38
Land	11	13	18	15	13	13
Operator's surplus	9	17	-12	12	7	-2
Earner's share						
Hired laborers	21	19	22	18	21	24
Current input earners	34	28	43	29	25	27
Other earners	13	12	18	15	16	16
Landlord	11	13	18	15	13	14
Operators	21	28	-1	23	25	19

season increased from 25 to 34% and that of operator's surplus from 7 to 9% upon conversion of rainfed land to irrigated flood-free conditions. On the other hand, the percentage shares of capital, labor, and land decreased. Similar trends occurred in the second season, except that the operator's surplus increased substantially with irrigation.

The negative operator's share among flood-prone farms during the first season further confirmed the fact that flood-prone farms received little if any benefit from irrigation during the first season. The majority of output was captured by current inputs (42%). The reverse was true during the second season, when the operator's surplus increased from -2% for rainfed to 12% for flood-prone ricelands.

In terms of earner's share, Table 9 shows that, of the proportionate share of output in the first season, only earnings of current inputs increased (25 to 34%) when a rainfed farm was converted to an irrigated flood-free farm; the shares of other earners were similar. In the second season, however, the operator's share increased from 19 to 28% of output. Therefore, most of the benefit from irrigation during the first season was captured by current input earners; during the second season, the operators benefited most. Trends were similar for flood-prone farms in the second season.

Systemwide benefits. The economic viability of LCPIS was evaluated using the direct benefits earned by rice grown in different water regimes in the command area, and considering the capital investment, operation, and maintenance cost of the system. Benefits were estimated at three levels of assumed rice yield. Good yields were taken as the average yield of the first year of the project — a year when no typhoons hit the standing crop. The poor yield scenario was the last year of project evaluation, when severe typhoon damage occurred. The average yield was the mean over the 3 yr in which data were collected. Project benefits on this basis ranged from $193,000 to $533,000/yr and not surprisingly were extremely sensitive to the assumed rice yield. We will conduct further research on yield expectations and system benefits.

The economic efficiency of the system was evaluated in terms of the benefit-cost ratio (B:C) and internal rate of return (IRR). These were estimated at two levels of cost: 1) full cost, which includes the cost of loan amortization for the capital investment cost, plus operation and maintenance (O&M) cost; and 2) partial cost, consisting of only O&M.

The computed B:C and IRR at full cost at all levels of benefits showed low values. They were B:C 0.1 to 0.2, and 4% or less IRR (Table 10). Factors contributing to this situation were unusually high capital investment and high operating costs (electricity), lower than expected yields, and smaller benefited area. The projected investment was $2.29 million, but actual cost was $3.22 million, or $927/ha. Likewise, estimated O&M costs were $7.5/ha, while actual costs were about $23/ha.

On a partial cost basis, the project may be marginally viable. The B:C was 1.5 for intermediate yield and 2.2 for high yield. Similarly, under favorable assumptions, the IRR values were

Table 10. Estimated annual direct benefits, benefit-cost ratios (B:C), and internal rates of return (IRR). LCPIS, Philippines, 1981-84.

Item	Level of benefits		
	High	Intermediate	Low
Benefits ($/ha per yr)	154	101	56
Total project benefits ($)	532,870	349,286	193,314
		At full cost	
B:C	0.24	0.16	0.10
IRR (%)	4.16	1.4	0.001
		At partial cost	
B:C	2.20	1.50	0.90
IRR (%)	38.40	28.50	15.20

greater than the 18% interest charge on the project.

A constraint to greater profitability is the inherently low yields in LCPIS and in Bicol in general. While mean yields in LCPIS were less than 3 t/ha, irrigated rice yields in Central Luzon, the "rice bowl" of the Philippines, exceeded 4 t/ha. The causes of low yields in Bicol are partly technical and partly economic: the region is a hot-spot for tungro and other diseases, and has a high incidence of typhoons and floods. Our calculations suggest that the level of the N applied is profitable, given climatic uncertainty, crop N response, and prices. Constraints experiments conducted by the IRRI Agronomy Department (Annual reports for 1982 and 1983) demonstrated that yields could be increased by up to 1 t/ha using higher input levels, particularly fertilizer. In general, however, the higher yielding but higher cost technology was not clearly more profitable than that of the farmers.

Irrigation fee payment. An issue of central concern to NIA is the low rate of irrigation fee payment in LCPIS. Several models were developed, and farmer- and crop-oriented factors that were hypothesized to influence fee payment were examined. No systematic relationship between fee payments and determinants of payment was identified.

FORECASTING DRY SEASON WATER SHORTAGES

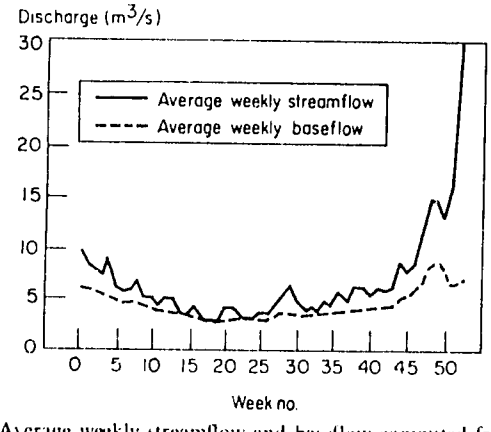
Water Management Department

In most diversion irrigation systems, the programmed area for DS irrigation has to be determined using average values of streamflow late in DS, when water is likely to be in short supply. If actual streamflows are below average, then irrigation system managers face the challenge of meeting the water requirements of the cropped area with a lower water supply. Analysis of available streamflow records of two small rivers — the Tigman and Hinaguianan — serving irrigation systems in Camarines Sur showed that actual discharges fell below the average about 65% of the time, increasing the risk of water shortages if average values are used to determine the programmed area. Research in 1985 was focused on determining how early in DS it is possible to predict whether flows will be above or below average later.

For developing the relationship among streamflows at different times, analysis of baseflow, or sustained runoff, is more desirable than using actual flow because unpredictable flash floods lasting for short durations have little utility for irrigation, and the river level soon reverts to its baseflow condition. Furthermore, streamflow is usually characterized by a skewed distribution, with more flows being below average because of the effect of occasional large storms.

To derive the baseflow, discharges associated with small flash floods following storms must first be removed from the record, leaving a smoother baseflow discharge curve. Figure 6 shows the average baseflow curve for the Tigman River over 9 yr, typical of small river catchments with a smooth exponential shape compared with the more erratic actual discharge rate.

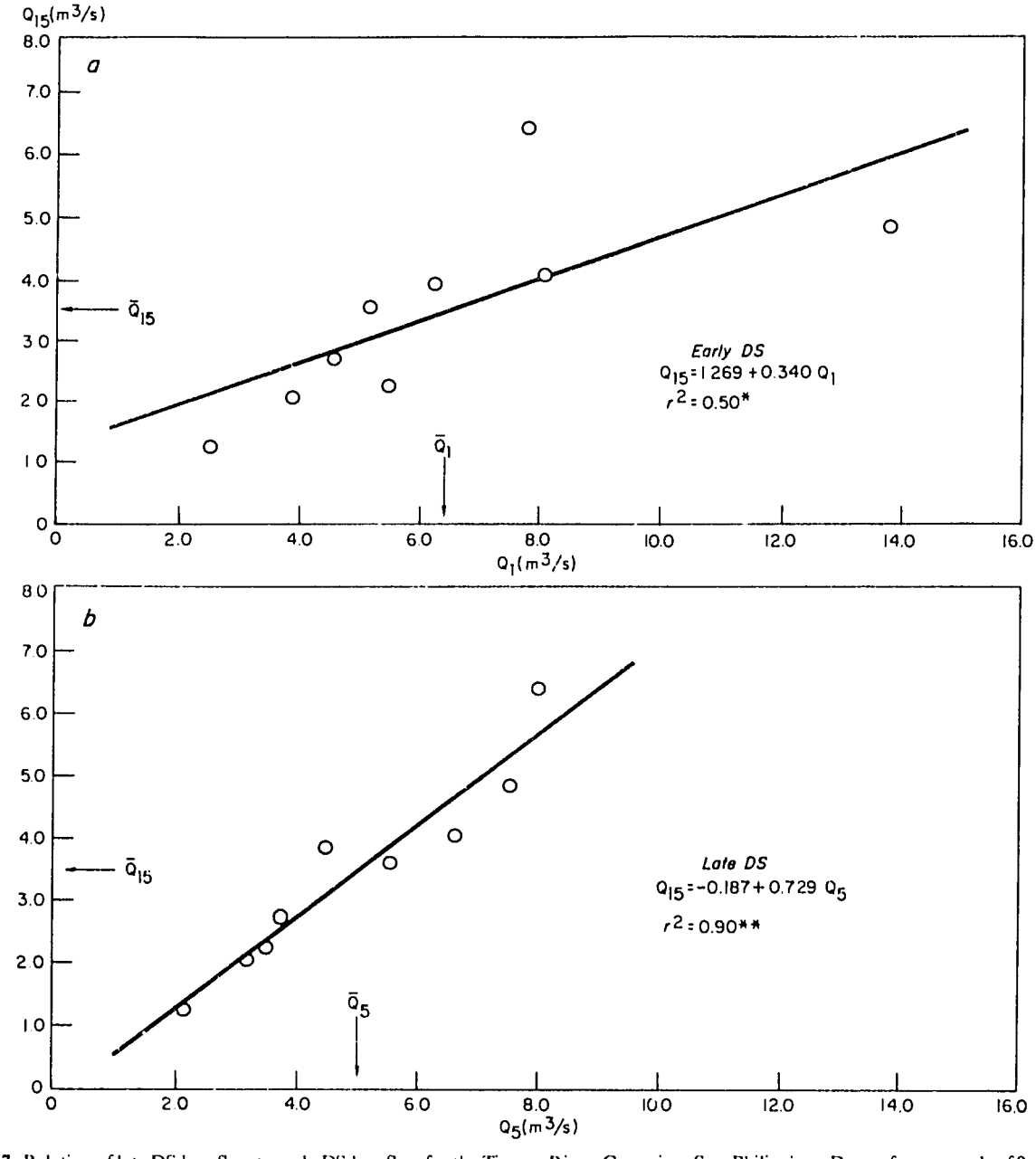
The analysis of streamflow records of both rivers indicates that it is not possible to predict with confidence late DS discharges using average baseflows before week 5 (early February) because the end of the rainy season varies. Nevertheless, below average discharges in week 1 are a warning of water shortages if rains do not persist. Figure 7a shows that in the Tigman River, flows in week 1 were below average in 6 of the total 9 years. Of the 6 years, 4 were still below average in week 15, close to the end of DS, while the other 2 years had flows in week 15 that were within +10% of the average. Even though the regression is significant at the 5% level for the Tigman River data and not significant for the other river, the data from week 1 may be



6. Average weekly streamflow and baseflow computed from records for 9 yr (1976-84) of the Tigman River, Camarines Sur, Philippines.

used to obtain a first indication of the likelihood of a water shortage, and possibly early enough to allow irrigation managers to discourage marginal areas from planting. In both irrigation systems, land preparation continued up to week 8.

Once the main rains finished (week 5 in the sample catchments), it was possible to predict with considerable certainty the expected baseflow for both rivers in subsequent weeks using average weekly baseflow values. Figure 7b shows that there is a high correlation between baseflows in weeks 5 and 15. In 4 of the 5 years when weekly baseflows were below average in week 5, they were also below average in week 15 (mid-April), which is normally



7. Relation of late DS baseflow to early DS baseflow for the Tigman River, Camarines Sur, Philippines. Drawn from records of 9 yr (1976-84). Q1, Q5, and Q15 are baseflows for the 1st, 5th, and 15th weeks of the year, respectively. The 9-yr mean value of each is indicated by a bar on top, e.g., $\bar{Q}_1$.

the period of greatest demand for water. Average baseflow in week 5 could be used to predict baseflow in week 15 with a 99% confidence interval. The same level of confidence applies for both river systems when week 5 data are used in predicting baseflow conditions from week 6 through week 19, which is normally after the end of the main DS cultivation (Table 11).

This technique has the potential to provide irrigation system managers with several weeks of lead time in determining whether there may be a water shortage and how severe it is likely to be. They could therefore develop water distribution strategies that are suited to the expected water conditions. Typical strategies involve some form of rotation, either by laterals or sections within a lateral. A further potential use of the technique is possible if irrigation deliveries are made to different sections of a system sequentially. Programming land preparation in blocks would allow cultivation over a limited area and its extension when it becomes apparent that water shortages are unlikely. In the case of the two rivers, all years that had above average flows as early as week 1 also had above average flows for the remainder of DS. This tends to indicate the low risk involved in extending the programmed area, using week 1 data, to include land that could not be irrigated in an average year. This would help to maximize the use of water in both favorable and unfavorable years.

STRATEGIES FOR IMPROVING RICE PRODUCTION IN FLOOD-PRONE ENVIRONMENTS

Water Management and Plant Breeding Departments

Farmers in flood-prone environments are significantly worse off economically than those in flood-free areas. The former suffer crop losses when flooding occurs and hesitate to make investments in fertilizers and other inputs under the high risk condition; thus they have lower yields even in relatively better seasons. The impact of flooding on rice production throughout the Bicol River Basin under both irrigated and rainfed conditions was assessed following typhoon Saling in October 1985, and ways to improve rice production in flood-affected areas were analyzed.

Extent of flooding (*Water Management*). Following the 18-19 Oct typhoon (Saling), which resulted in 200-300 mm rainfall within 24 h, some 33,000 ha of riceland in low-lying portions of the basin were flooded. Most of the area was flooded to approximately 1 m and drained within 7-10 d of the storm, but about 5,500 ha experienced severe floods lasting 7-14 d, with water reaching depths of 1-1.25 m. The worst affected area was 2,500 ha that remained flooded for more than 1 mo and experienced depths of 1.5-2.5 m.

The flood associated with typhoon Saling was typical. The maximum river stage at Santo

Table 11. Degree of predictability of weekly average baseflows in 2 rivers in Camarines Sur, Philippines, 1976-84.

Weeks[a] correlated	Tigman River			Hinaguianan River		
	Regression relationship	R^2	N	Regression relationship	R^2	N
15 & 19	$Q_{19} = 1.065 + 0.496\ Q_{15}$	.90**	9	$Q_{19} = 0.145 + 0.77\ Q_{15}$	.85**	9
9 & 19	$Q_{19} = 1.020 + 0.385\ Q_9$	.94**	9	$Q_{19} = 0.172 + 0.649\ Q_9$	.78**	9
5 & 19	$Q_{19} = 1.075 + 0.341\ Q_5$	.72**	9	$Q_{19} = 0.282 + 0.452\ Q_9$	.65**	9
1 & 19	$Q_{19} = 1.685 + 0.170\ Q_1$	.45*	9	$Q_{19} = 0.591 + 0.146\ Q_1$	.07	9
9 & 15	$Q_{15} = 0.007 + 0.768\ Q_9$	.89**	9	$Q_{15} = 0.021 + 0.858\ Q_9$	.95**	9
5 & 15	$Q_{15} = -0.187 + 0.729\ Q_5$	.90**	9	$Q_{15} = 0.203 + 0.565\ Q_9$	.71**	9
1 & 15	$Q_{15} = 1.269 + 0.340\ Q_1$	.50*	9	$Q_{15} = 0.442 + 0.295\ Q_1$	.20	9
5 & 9	$Q_9 = -0.018 + 0.918\ Q_5$	.82**	9	$Q_9 = 0.182 + 0.686\ Q_9$	.81**	9
1 & 9	$Q_9 = 1.509 + 0.476\ Q_1$	.56*	9	$Q_9 = 0.335 + 0.463\ Q_1$	.37	9
1 & 5	$Q_5 = 1.703 + 0.512\ Q_1$	.67**	9	$Q_5 = 0.359 + 0.571\ Q_1$	.33	9
49 & 19	$Q_{19} = 1.918 + 0.081\ Q_{49}$	.61*	8	$Q_{19} = 0.546 + 0.101\ Q_{49}$	.50	7
49 & 15	$Q_{15} = 1.83 + 0.166\ Q_{49}$	.63*	8	$Q_{15} = 0.523 + 0.136\ Q_{49}$	.63*	7
49 & 9	$Q_9 = 2.48 + 0.202\ Q_{49}$	.57*	8	$Q_9 = 0.617 + 0.152\ Q_{49}$	.52	7
49 & 5	$Q_5 = 3.42 + 0.173\ Q_{49}$	.40	8	$Q_5 = 0.834 + 0.121\ Q_{49}$	.28	7
49 & 1	$Q_1 = 5.54 + 0.095\ Q_{49}$	.05	8	$Q_1 = 1.132 + 0.112\ Q_{49}$	.13	7

[a]First 7 days of the year = week 1.

Domingo was 8.97 m, a level that has been reached 5 times in the past 11 yr, a recurrence interval of 2.2 yr. Floods exceeding 8.0 m, the generally accepted level at which widespread crop damage can be expected, have been recorded 9 times in the 11-yr period. Only 2 years in this period had no flood, but 1979 and 1983 had both early and late floods. All floods occurred between July and December as the direct result of a typhoon. Floods in early WS have not exceeded the 9.0-m stage because water levels in the main rivers are still low. However, they are associated with widespread crop damage because the entire area is under cultivation at that time. Typhoons in the later part of WS result in comparatively larger floods because rainfall in the preceding months has already caused water in the main rivers to rise above DS levels. The three most devastating floods (river stage exceeding 9.5 m at Santo Domingo) occurred in September-December and resulted in inundation of much wider areas than was experienced after typhoon Saling.

Flood avoidance strategies (*Water Management*). Many of the flood-prone areas were not cultivated before modern varieties (MV) came because traditional photoperiod-sensitive varieties could be harvested only after the main flood season. The high risk of flood damage and low yield potential made traditional varieties unattractive to farmers in flood-prone areas.

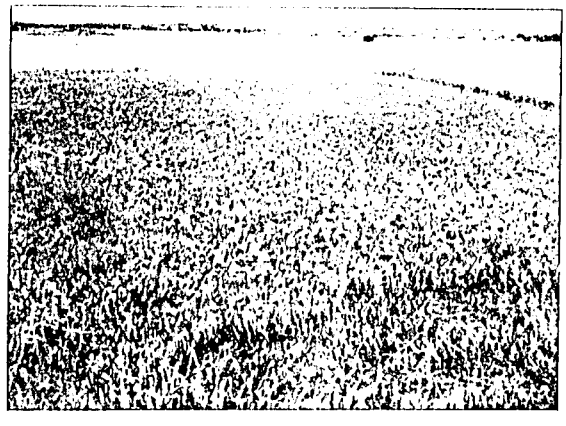
The most effective strategy for minimizing the risk of flooding damage to the WS crop is to harvest it by early October. The actions needed for this are to start the WS crop early, e.g., in May, and grow a short-duration MV that can be harvested before October (Fig. 8). (Historically, the most typhoon-prone month is November, followed by October.) Harvesting by early October reduces the risk of damage from a flood caused by a 9.0-m or higher water stage in the Bicol River from 5 in 11 yr to 2 in 11 yr. Similarly, the risk of damage from a flood of 8.0 m or higher is reduced from 82 to 45%.

To have a WS crop transplanted by May, a dependable supply of irrigation water is often necessary because rainfall in April-May is often inadequate for proper land preparation and transplanting. Farmers in rainfed areas often must wait too long for the right amount of rainfall before they can start field operations. Irrigated farms therefore have a big advantage over rainfed farms. Farms located at the headend of gravity irrigation systems and those with access to shallow tubewell water generally receive a more timely and reliable supply of water, especially during the early part of the season, than those located in the tailends.

Strategies to minimize flood damage (*Plant Breeding and Water Management*). *Use of alternative varieties.* In anticipation of a major flood, varietal trials were conducted in 1985 WS in the Bicol River Basin area. Thirteen lines with varying degrees of flood tolerance and elongation capability and 2 checks (IR36 and IR64) were established at 11 sites in 5 clusters. The clusters included areas in two gravity irrigated systems, a communal low-lift pump system, a privately owned shallow tubewell system, and a rainfed environment. Each cluster had two or three trials. All varieties were planted concurrently with the farmer's planting time.

The 4 short duration entries harvested before the typhoon at 6 of the 11 sites yielded an average 3.8 t/ha (range: 2.4-6.7 t/ha), whereas the average of the after-typhoon yields of 2 sites was 1.5 t/ha (range: 0.6-2.3 t/ha). At the remaining three sites, the short duration varieties were completely destroyed by typhoon Saling.

Lodging of taller varieties decreased yields, while rice harvested later than in the surrounding fields was damaged by rats, birds, and work animals. Short duration varieties at three sites and long duration varieties at four sites were damaged by



8. Photograph of ricefields taken 5 d after typhoon Saling hit, showing in background previously harvested fields that had been transplanted early, and in foreground a late-planted mature crop that has been submerged.

animals, and their yields are not included in the estimate.

Long duration varieties harvested at 5 sites before the typhoon yielded an average 3.0 t/ha (range: 0.5-5.4 t/ha). The average yield from 3 sites harvested after the typhoon was 1.7 t/ha (range: 0.8-3.3 t/ha). At three sites, the typhoon completely destroyed some of the long duration varieties.

At all sites where flooding lasted longer than 7 d, crops in the field were totally lost because of the very rapid rise and the high turbidity of the floodwater. Varieties with faster elongation capacity could not cope with floodwater reaching 1-3 m deep within 12-18 h after the rain stopped. Once plants were submerged, the high water turbidity due to sediment load prevented any underwater photosynthetic and respiratory activities.

The following are preliminary conclusions:

- Flood escape by the use of early or very early maturing varieties was possible at sites that had access to irrigation water for early crop establishment.
- Where escape was not possible, submergence-tolerant varieties outperformed both entries with stem elongation capacity and those without tolerance for deep water.
- Some submergence-tolerant lines were found attractive for further trial.

Improving drainage rate. Floodwater recession rate is critical to the degree of crop loss sustained. Rates measured in 1985 were 8 cm/d for the first 5 d, followed by around 6 cm/d. Clogging of drains and of the Bicol River itself by water hyacinth contributed to the declining rate of floodwater recession. In areas of adequate drainage infrastructure where floodwater receded to 50 cm or less within 5 d, there was relatively little damage to standing crops.

In areas where recession was delayed, several factors affected drainage, including lower density of drains; sinuous and inefficient natural drains; reduced conveyance capacity of drains due to siltation, erosion, and weeds; and impoundment behind embankments due to inadequate number of culverts, poor culvert design, and poorly designed flapgates in the coastal protection dike. At least 10,000 ha appear to have been flooded for longer periods than necessary because existing drainage facilities were inadequate, especially in the lower portions of the basin.

Flood protection. Initiatives to reduce flooding of the basin have included coastal protection dikes and straightening of the lower portion of the Bicol River. Proposed measures include additional diversion channels and one upstream reservoir. In the central part of the basin, however, natural low-elevation conditions result in prolonged flooding that is not likely to be eliminated. The combination of high intensity rainfall and flat valley bottoms is conducive to waterlogging, and there is no prospect for any upstream flood protection reservoirs.

Water management requirement (*Water Management*). Because early planting is the most promising strategy for avoiding flood damage, there is a constant need to focus on ways to enable flood-prone farmers to obtain sufficient water for land preparation in the first part of WS. In gravity irrigation systems there is potential for improving water distribution through more efficient and equitable system management strategies, but this can be achieved only with the strong interest of the system managers and of functional, responsive farmer organizations. In rainfed areas the potential to increase the use of privately owned shallow tubewells appears high, but there is a need to assess the cost effectiveness of the investments required for such facilities. Rainfed farmers are increasingly using small low-lift pumps to obtain water from creeks and ponds so as to advance their WS cropping schedule. Development of strategies to make better use of these local water bodies to speed up land preparation is a high research priority.

BANGLADESH COLLABORATIVE RESEARCH

Water Management Department

Collaborative research with the Bangladesh Rice Research Institute (BRRI) and the Bangladesh Water Development Board (BWDB) started in 1982 with the major objective of increasing irrigation effectiveness and crop production in two types of irrigation systems: the large-scale Ganges-Kabodak (G-K) Irrigation System (phase I services over 40,000 ha) and the North Bangladesh Tubewell Irrigation System, which consists of 378 deep tubewells. The field research was conducted in 9

tertiary canal areas, representing the headend, middle, and tailend conditions within the G-K system, and in 12 selected tubewell areas of the other system.

The research followed the action research methodology, which involves systematic diagnostic analysis of the problems, applying the most promising solution for each problem, and evaluating its effect. The continuing evaluation allowed improvements in the specific research design for each season, as one season's results were used in planning actions for the next.

The field research was focused on three aspects of water management and related crop production: 1) improving reliability of irrigation water delivery to farmers' fields and developing suitable procedures for improving efficiency of water use; 2) conducting field trials with selected components of modern technology and selected cropping patterns with a view to recommending practices that will increase crop production as well as farmer income; and 3) promoting farmer organization development to sustain benefits from the results of the first two activities. A multidisciplinary team of BRRI scientists and BWDB professionals, in collaboration with IRRI's Water Management Department, planned and conducted the research

The results of recent research at one of the two sites are reported in the section on Cooperative Programs.

Soil and crop management

Soil characterization

Soil Chemistry/ Physics and Multiple Cropping Departments

LOWLAND PROBLEM SOILS IN SOUTH AND SOUTHEAST ASIA **212**

INFLUENCE OF WATER REGIME ON CHEMICAL KINETICS OF SOIL AND ON RICE GROWTH **212**

RESIDUAL EFFECTS OF LIME AND MANGANESE DIOXIDE ON RICE GROWTH AND YIELD **213**

MICROBIAL BIOMASS IN FLOODED RICE SOILS **213**

AREA AND DISTRIBUTION OF ACID UPLAND SOILS IN SOUTHEAST ASIA **214**

LOWLAND PROBLEM SOILS IN SOUTH AND SOUTHEAST ASIA

Soil Chemistry/Physics Department

Based on recent surveys, maps, publications, and discussions with national soil survey organizations, the extent of problem soils (saline, sodic, acid sulfate, and organic) in South and Southeast Asia was estimated to be over 58 million ha (Table 1). The area of uncultivated land suited to rice production using adverse soil-tolerant varieties is smaller, though, because some parts of this land — saline and sodic soils in dry areas without irrigation, severe acid sulfate soils, and very deep organic soils with low bearing capacity — have no potential for rice cultivation. Nevertheless, the area that could be cultivated is more than 25% of the total area currently under rice cultivation in tropical Asia.

INFLUENCE OF WATER REGIME ON CHEMICAL KINETICS OF SOIL AND ON RICE GROWTH

Soil Chemistry/Physics Department

Ricefields undergo alternate flooding and drying if the water supply is not ensured by irrigation. A greenhouse study revealed that the effect on yield (IR54) of intermediate soil drying followed by resubmergence depended not only on the N content but also on the Zn- and S-supplying capacity of the soil.

Keeping standing water on rice soils during the growth period usually results in higher grain yields than alternate flooding and drying because of concomitant heavy N loss by nitrification and denitrification and decrease in the Fe, N, P, K, Ca, and Mg content of the soil solution. But if soils are Zn- or S-deficient and not supplemented with chemical fertilizer, yield decreases can be limited by a short drying period 4-8 wk after transplanting (WT).

In drum experiments irrigated with demineralized water, floodwater depth (10-40 cm) had no significant effect on nutrient uptake and grain or straw yield of IR42, but both tiller and panicle numbers were higher at 10 cm floodwater. Soil solution and floodwater kinetics followed the same pattern, independent of floodwater depth. Concentration of elements in the soil solution was always higher than in the floodwater.

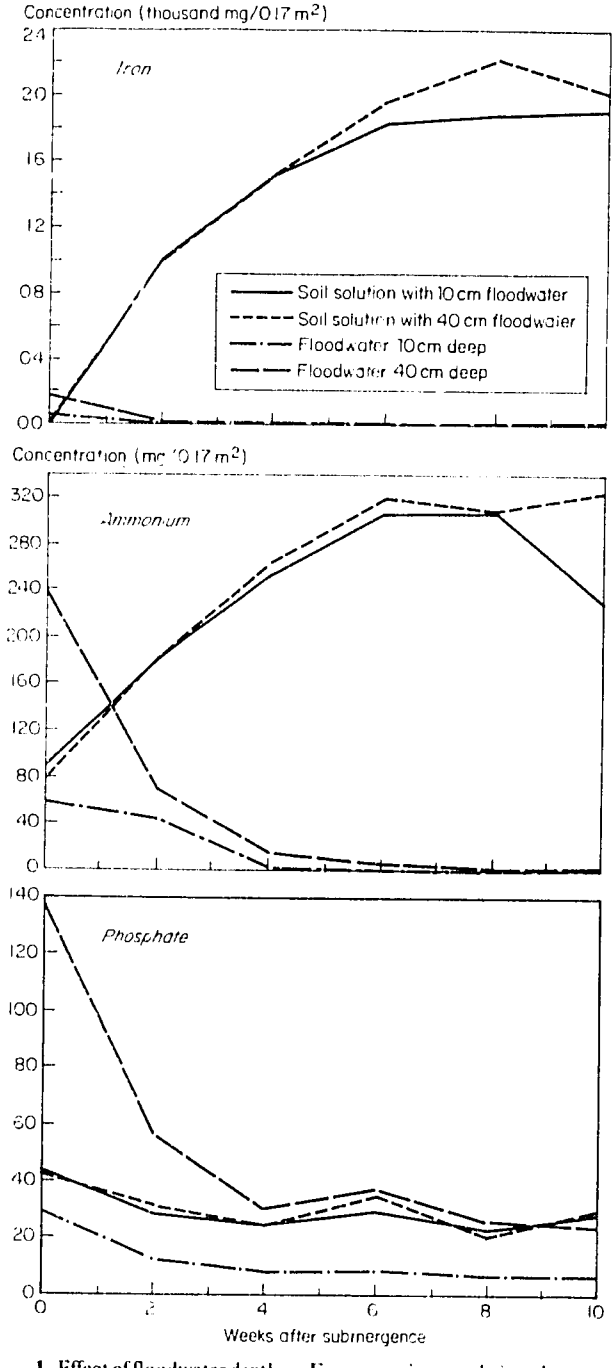
A floodwater depth of 40 cm did not change the concentration of elements in the soil solution or in the floodwater. As a result, the amount of nutrients in the floodwater was 4 times that at 10 cm floodwater depth (Fig. 1).

Table 1. Estimates of areas of problem soils in South and Southeast Asia.[a]

Country	Area (million ha)									
	Saline		Sodic		Acid sulfate		Organic		Total	
Bangladesh	1.4				0.1	(0.1)	0.4		1.9	(0.1)
Brunei							0.2	(0.2)	0.2	(0.2)
Burma	1.2	(1.0)							1.2	(1.0)
Kampuchea	0.1	(0.1)			0.3	(0.3)			0.4	(0.4)
India	5.5	(2.8)	2.5	(2.5)					8.0	(5.3)
Indonesia	u				u		27.1	(10.0)	27.1	(10.0)
Malaysia	u				0.8		2.9	(0.2)	3.7	(0.2)
Pakistan	6.2	(2.6)[b]	4.3						10.5	(2.6)
Philippines	0.4								0.4	
Sri Lanka	0.1	(0.1)[b]	0.1				0.1	(0.1)	0.3	(0.2)
Thailand	0.3		0.3	(0.3)	0.2		0.1		0.9	(0.3)
Vietnam	1.0	(0.1)			2.6	(2.6)	0.2	(0.1)	3.8	(2.8)
Total	16.0	(9.5)[b]	7.2		4.0	(3.0)	31.0	(10.6)	58.4	(23.1)

[a]u = unmapped or overlapping with other problem soil types. The extent of potential areas for growing rices tolerant of adverse soils is given in parentheses. From these areas have been excluded areas generally unsuitable for rice cultivation, saline soils that are desalinized by rainfall in the rice growing season, saline sodic soils in dry areas without possibility of irrigation, severe acid sulfate soils (strong jarosite formation in topsoil), and deep organic soils (>1 m deep). [b]Saline and sodic areas are combined.

Aside from plant uptake (rice, algal), the concentrations of Fe^{2+}, Mn^{2+}, and NO_3^- are clearly governed by redox-reactions, while the kinetics of other nutrients in the floodwater are related to solubility, sorption or desorption, and pH.



1. Effect of floodwater depth on Fe, ammonium, and phosphate in the soil solution and floodwater above Maahas clay (pH 6.0, organic C 2.11%, clay 52%). IRRI, 1985.

Water and nutrient conservation can be increased by avoiding high floodwater levels and seepage. Water should be removed from ricefields by evaporation rather than by floodwater runoff, except where toxins have accumulated and percolation is necessary.

RESIDUAL EFFECTS OF LIME AND MANGANESE DIOXIDE ON RICE GROWTH AND YIELD

Soil Chemistry/ Physics Department

In a field experiment in Balza, Albay, Philippines, we tested the residual effects of applied lime and MnO_2 on an acid sulfate soil (Sulfaquept, pH 3.9, organic C 1.0, ECe 2.3 dS/m). Susceptible rice variety IR21015-136-1-2-3 was grown one season after the application of either 5 t lime/ha or 50 kg MnO_2, or both.

Plant analyses at 8 WT showed higher N, Ca, and Fe content of the leaves in limed plots regardless of MnO_2 treatment.

Grain yields revealed a residual effect of liming regardless of MnO_2, but straw yields did not (Table 2). The difference was mainly due to higher sterility in the unlimed plots. Mn showed a significant interaction with lime, resulting in highest yields.

MICROBIAL BIOMASS IN FLOODED RICE SOILS

Soil Chemistry/ Physics Department

The increased interest in the role of soil microorganisms in rice soils, especially with regard to N-release pattern, emphasized the need to develop simple methods for determining the size of the microbial population in flooded soils.

Freezing core samples with liquid N for 5 h followed by 12-d incubation yielded the same CO_2-C flushes as fumigation with chloroform.

In submerged rice soils, the microbial biomass comprising bacteria, fungi, and algae contains 3-7% of the soil organic C in Aquepts and Aquolls on the IRRI farm, which is greater than reported values for temperate grasslands and much higher than reported for other cereals.

This high biomass production seems to be one crucial property of submerged rice soils with regard to soil fertility and soil health.

Table 2. Residual effects of applied lime and MnO_2 in an acid sulfate soil, 1 season after application, 3 replications. IRRI, 1985.

Treatment		Grain yield (t/ha)				Straw yield (t/ha)			
		1	2	3	$\bar{X}$	1	2	3	$\bar{X}$
No lime	No MnO_2	3.46	3.50	3.57	3.51 c	3.99	4.45	4.70	4.38 a
No lime	With MnO_2	3.61	3.35	3.05	3.34 c	4.05	3.95	4.02	4.01 b
With lime	No MnO_2	4.02	3.81	3.34	3.72 b	3.79	4.22	4.06	4.02 b
With lime	With MnO_2	4.38	4.09	4.44	4.30 a	4.17	4.61	4.84	4.54 a
			F-computed						
Treatment			9.84*				5.41^{ns}		
Lime			19.29**				0.62^{ns}		
Manganese			2.27^{ns}				0.41^{ns}		
Lime X manganese			7.98*				15.21**		

AREA AND DISTRIBUTION OF ACID UPLAND SOILS IN SOUTHEAST ASIA

Multiple Cropping Department

Acid uplands in most of Southeast Asia are a vast land resource that can accommodate expanded agriculture to meet the increasing demand for food. Expansion has spontaneously been done by many farmers in the hinterlands. Upland rice alone is grown annually on close to 3 million ha of acid upland soils in the region.

However, the stability of crop production under present farm management technology is generally low because of inherently adverse soil properties. These soils are in an advanced stage of weathering and are strongly leached, hence low in natural fertility. They are especially deficient in P. There is an apparent lack of technology — improved cultivars, suitable crop management practices, and cropping systems — to exploit fully the extensive land resource of acid upland soils.

An acid upland soil in this study has a pH of 5.5 or lower, generally less than 10 ppm available P, and low exchangeable bases — characteristics of soils that are strongly leached and have a high degree of phosphate fixation due to Fe or Al. Most acid upland soils commonly have hues of 5YR and 7.5YR, i.e., reddish. They tend to develop even

Table 3. Distribution of FAO soil units interpreted as dominantly acid upland soils in the countries of Southeast Asia.[a] 1985.

Country	Distribution (million ha)														
	Af	Ah	Ao	Ap	Bf	Fh	Fo	Fr	Fx	Lc	Lf	Lo	Nd	Nh	Total
Burma	1.8	3.0	19.8	0.5	2.2	–	–	1.0	–	1.1	2.1	–	3.4	0.4	35.3
Indonesia															
Kalimantan	1.3	7.3	11.9	–	0.1	2.6	1.3	0.4	0.6	0.4	–	1.2	0.2	0.2	27.5
Sumatra	3.4	6.5	9.6	1.0	0.4	0.5	2.2	–	0.4	0.9	–	0.4	0.9	0.2	26.4
Other islands	2.0	6.4	7.7	1.7	0.8	2.9	1.0	0.2	–	4.3	–	1.0	0.7	0.1	28.8
Kampuchea	1.7	0.4	3.9	–	0.9	–	0.1	0.2	–	–	–	–	0.1	7.3	14.6
Laos	1.5	1.7	13.1	0.1	–	–	–	–	–	0.2	–	–	1.0	–	17.6
Malaysia															
Peninsular	2.4	0.4	4.8	0.9	–	–	0.1	0.1	–	0.3	–	–	0.8	–	9.8
Sarawak/Sabah	1.2	4.7	8.6	–	–	0.6	0.2	–	–	0.2	–	0.2	0.8	–	16.5
Philippines	–	–	5.5	–	–	–	–	–	–	–	–	1.2	5.5	–	12.3
Thailand	4.1	1.7	15.6	–	–	0.1	0.1	–	–	1.0	–	–	2.4	–	25.0
Vietnam	3.2	1.1	10.2	0.5	0.5	0.1	0.6	0.8	–	0.6	–	–	1.3	–	18.9
Total	22.6	33.2	110.7	4.7	4.9	6.8	5.6	2.7	1.0	9.0	2.1	4.0	17.2	8.2	232.7
% of total	9.7	14.3	47.6	2.0	2.1	2.9	2.4	1.2	0.4	3.9	0.9	1.7	7.4	3.5	100.0

[a]Derived by planimetry from the mapping units of the FAO-UNESCO *Soil map of the world for Southeast Asia*, subsequently adjusted into individual soil units using the mapping unit composition rules. See Table 4 for soil unit designations.

more acidic soil reactions (pH 4.0-5.0) when used for annual crops under normal management. Moreover, they occur mostly on sloping landforms ranging from gently undulating to hilly to mountainous terrain. They are therefore subject to considerable runoff and erosion unless appropriate control measures are taken.

We measured by planimetry the areas of soil mapping units (SMU) of acid upland soils on the *FAO-UNESCO soil map of the world for Southeast Asia*, particularly those known to have a high probability of pH less than 5.5. The area of each SMU was further disaggregated by applying the mapping unit composition rules that specify the proportion of area occupied by dominant, associated, and inclusion soils. The final area of a soil unit was determined by summing all areas attributed to the unit, whether dominant, associated, or inclusion (Table 3). Orthic Acrisols is the dominant acid upland soil unit in the region, covering over 110 million ha or 47% of the gross area of all soil units considered.

Available chemical data from sample soil profiles in the legend of the *FAO-UNESCO soil map of the world for Southeast Asia* indicate that most soil units identified as acid upland soils range in pH from about 4.0 to > 5.5. To account for this variability, we allocated the areas to three pH classes on the basis of the information (Table 4). The probability that soil pH is < 5.0 for Ferralsols and Acrisols, for example, is high, while Nitosols and Luvisols are commonly less acidic (pH > 5.0).

Table 5 shows the distribution of two pH classes for the countries of Southeast Asia. All have large areas of acid upland soils, of which 118 million ha or 63% is estimate to have a pH < 5.0, i.e., highly acid.

Table 4. Percentage area of soil mapping units representing tropical acid upland soils allocated to 3 surface soil pH classes with increasing acidity (FAO-UNESCO *Soil map of the world*).

Soil unit	Code	Frequency (%) of given surface soil pH		
		> 5.5	5.0-5.5	< 5.0
Ferric Acrisols	Af	10	30	60
Humic Acrisols	Ah	20	30	50
Orthic Acrisols	Ao	10	30	60
Plinthic Acrisols	Ap	10	30	60
Ferralic Cambisols	Bf	50	25	25
Humic Ferralsols	Fh	20	20	60
Orthic Ferralsols	Fo	10	20	70
Rhodic Ferralsols	Fr	10	20	70
Xanthic Ferralsols	Fx	10	20	70
Chromic Luvisols	Lc	50	30	20
Ferric Luvisols	Lf	30	40	30
Orthic Luvisols	Lo	50	44	20
Dystric Nitosols	Nd	30	50	20
Humic Nitosols	Nh	40	40	20

Table 5. Distribution of acid upland soils in Southeast Asia, 1985.

Country	Total land area (million ha)		Estimated area[a] of acid upland soils		Estimated area (million ha) with[b]	
			million ha	%	pH 5.0-5.5	pH < 5.0
Burma	61.1		28.9	47.3	11.3	17.6
Indonesia	216.9		67.6	31.2	24.0	43.6
Kalimantan	65.1	22.9			7.8	15.1
Sumatra	65.7	22.1			7.8	14.3
Other islands	86.1	22.6			8.4	14.2
Kampuchea	18.1		6.1	33.7	2.1	4.0
Laos	23.2		15.6	67.2	5.4	10.2
Malaysia	44.8		22.5	50.2	8.1	14.4
Peninsular	15.9	8.6			3.1	5.5
Sarawak/Sabah	28.9	13.9			5.0	8.9
Philippines	30.8		9.6	31.2	4.9	4.7
Thailand	51.0		21.5	42.2	8.0	13.5
Vietnam	32.4		16.2	48.4	5.8	10.4
Total	478.3		188.0	39.3	69.6	118.4

[a]Based on planimetry, subsequently adjusted using the mapping unit composition rules, FAO-UNESCO *Soil map of the world*, Vol IX – Southeast Asia, 1979. [b]See Table 3 for the allocation of the proportion of soil unit area in each pH class.

Soil and crop management

Management of soil and fertilizer nitrogen

Agronomy Department

COMPARISON OF TOTAL N LOSS AND AMMONIA VOLATILIZATION USING SIMPLE TECHNIQUES **218**
- ^{15}N balance in microplots **221**

POTENTIAL N LOSS, ^{15}N BALANCE, AND YIELD IN WET SEEDED FLOODED AND TRANSPLANTED RICE **222**
- Floodwater nitrogen **222**
- ^{15}N balance **224**
- Grain yield **224**

^{15}N BALANCE AND FERTILIZER N EFFICIENCY IN UPLAND RICE **224**

EFFECTIVENESS OF A UREASE INHIBITOR IN LOWLAND RICE **227**

VARIETAL DIFFERENCE IN SOIL N UTILIZATION **227**

EVALUATION OF EXPERIMENTAL N SOURCES **229**

ALTERNATIVE TECHNOLOGY FOR INCREASING N EFFICIENCY IN LOWLAND RICE **230**

N USE EFFICIENCY AT LOW APPLICATION RATES **232**

N MANAGEMENT FOR EARLY MATURING RICE **233**

INCREASING EFFICIENCY OF APPLIED N IN LOWLAND RICE OF DIFFERENT MATURITY **234**

INTEGRATED N MANAGEMENT IN LOWLAND RICE **235**
- Biofertilizers **235**
- Commercial fertilizers **235**

N FERTILIZER MANAGEMENT UNDER SIMULATED RAINFED LOWLAND CONDITIONS **237**

COMPARISON OF TOTAL N LOSS AND AMMONIA VOLATILIZATION USING SIMPLE TECHNIQUES

In collaboration with the Commonwealth Scientific and Industrial Research Organization (CSIRO), total N loss determined by ^{15}N balance techniques, and NH_3 loss determined from measurements of NH_3 concentration and windspeed at a given height above the floodwater were obtained at Mabitac, Laguna, in 1985 dry season (DS). N losses were also compared for a range of management practices and fertilizer application rates.

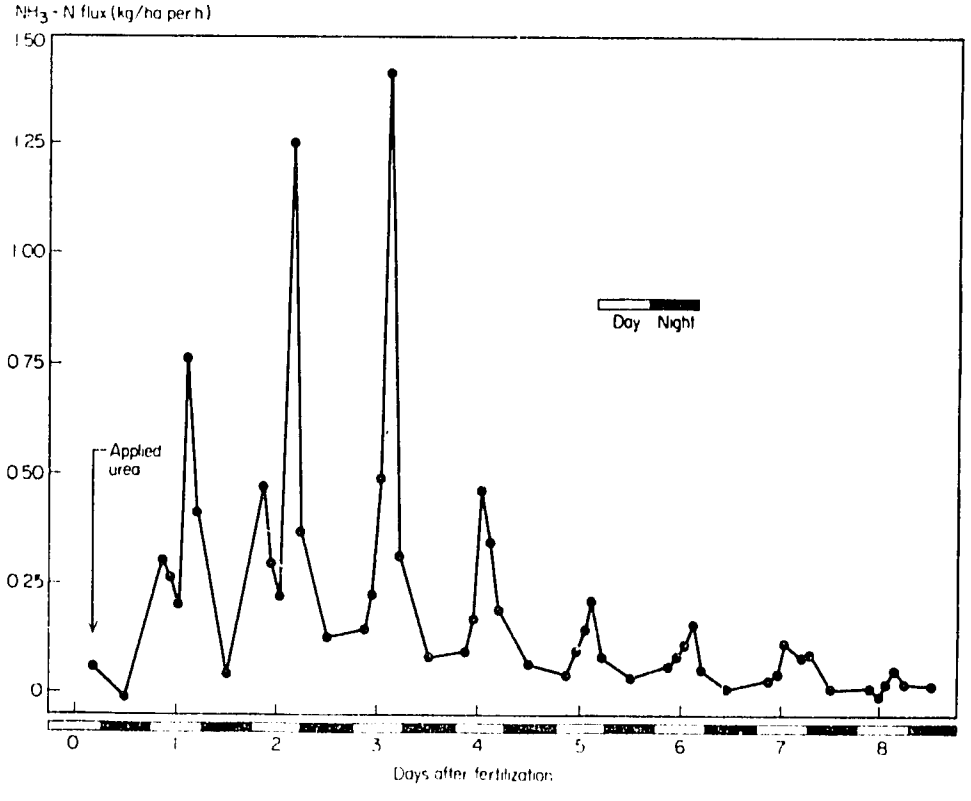
High rates of NH_3 volatilization were observed between 1400 and 1600 h on the 3 days following surface application of urea into the floodwater at 80 kg N/ha (Fig. 1). These periods coincided with daytime fluctuations in the concentration of ammoniacal N in the floodwater (Fig. 2). Maximum values of windspeed and floodwater temperature (Fig. 3) and floodwater pH (Fig. 4) occurred at about this time.

The total N loss in the circular plot from ^{15}N balance studies after 30 d was 55% (Table 1). Of this, 31% was lost by NH_3 volatilization during the first 8 d after fertilization (Table 2). Since leaching and runoff were negligible, the difference of 24% was the maximum loss in the circular plot due to nitrification-denitrification.

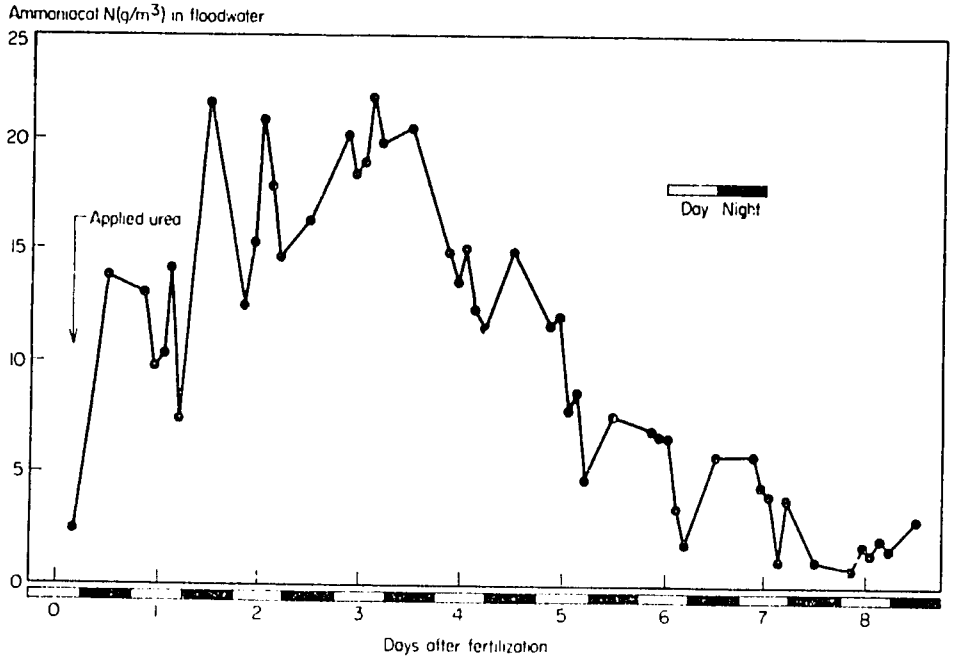
The measured flux density of NH_3 has been correlated with the product of windspeed and the difference in NH_3 concentration in the floodwater and in the air at 0.8 m. The resultant equation for the flux F (in kg N/ha per h) is

$$F = 0.0357 \times 10^{-3}\, \bar{u}_{0.8}\, (\bar{c}_{H_2O} - \bar{c}_b) \qquad (n = 48;\ r = 0.74)$$

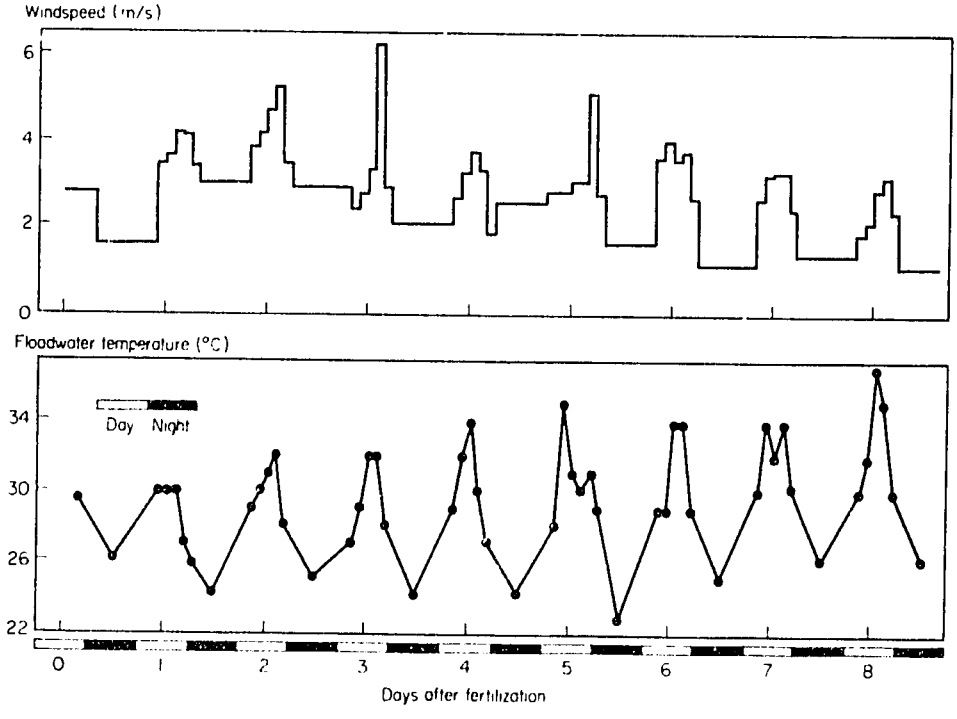
where $\bar{c}_{H_2O}$ is the mean concentration of NH_3 in the floodwater (g N/m^3) and $\bar{c}_b$ the mean background



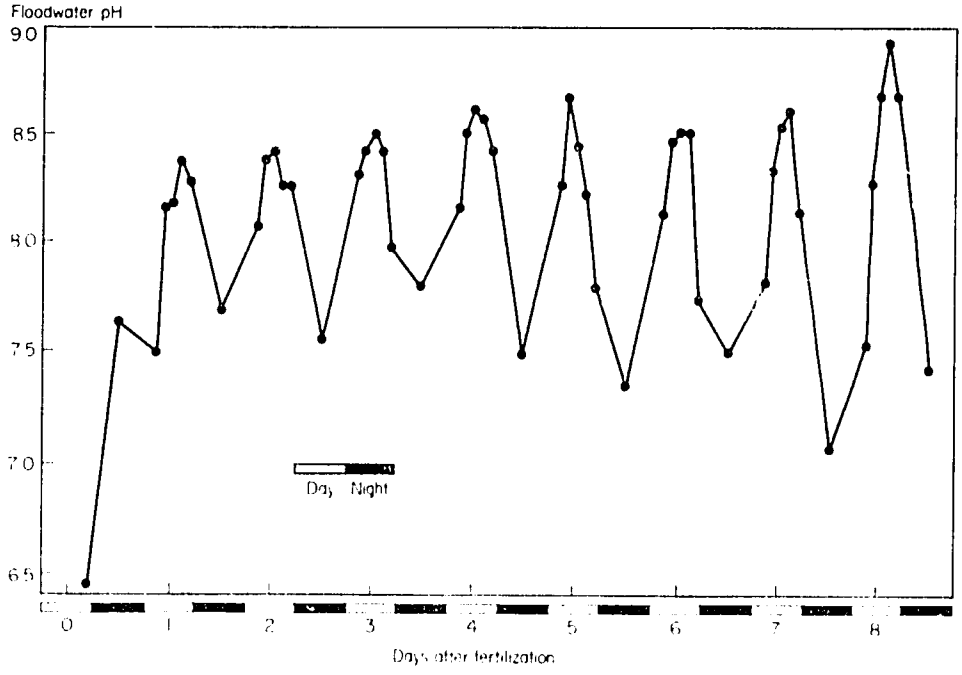
1. NH_3 fluxes from the circle as measured by simplified aerodynamic technique. Mabitac, Laguna, Philippines, 1985 DS. The vertical ammonia flux density F (in μg N/m^2 per s) was calculated from $F = 0.091\, \bar{u}_{0.8}\bar{c}_{0.8}$ where $\bar{u}_{0.8}$ is the mean windspeed (in m/s) at a height of 0.8 m and $\bar{c}_{0.8}$ is the excess concentration of NH_3 (in μg N/m^3) over the background NH_3 concentration measured at a height of 0.8 m at the center of a fertilized circle with a 25-m radius. The fluxes were then converted to kg/ha per h.



2. Ammoniacal N concentration in floodwater in a fertilized circle during measurement of NH_3 fluxes. Mabitac, Laguna, Philippines, 1985 DS.



3. Diurnal fluctuations in windspeed and floodwater temperature in a fertilized circle. Mabitac, Laguna, Philippines, 1985 DS.



4. Diurnal fluctuations in floodwater pH in a fertilized circle. Mabitac, Laguna, Philippines, 1985 DS.

Table 1. Recovery of ^{15}N-labeled fertilizer at 30 d after transplanting (DT) in soil and plant as affected by application method and water depth. Mabitac, Laguna, Philippines, 1985, late DS.

^{15}N recovery	53 kg N/ha			80 kg N/ha			
	Researchers' split[a]		Farmers' split[b]	Researchers' split[a]		Farmers'	
	Without water	With 5 cm water		Without water	With 5 cm water	Split[b]	Circle[c]
Plant	24	14	15	26	14	15	14
Exchangeable N	11	5	7	18	7	11	10
Nonexchangeable N + roots	32	27	20	24	21	15	21
Unaccounted for	33	54	60	32	58	59	55
Total[d]	67 (±8)	46 (±4)	40 (±1)	68 (±3)	42 (±3)	41 (±2)	45

[a]2/3 urea broadcast and incorporated basally, 1/3 topdressed 5-7 d before panicle initiation (DBPI). [b]2/3 urea topdressed at 10 DT, 1/3 at booting. [c]Unreplicated. [d]N source was urea. Figures in parentheses are standard errors.

Table 2. Relation between total N loss and NH_3 volatilization. Mabitac, Laguna, Philippines, 1985, late DS.

Application method	Application rate (kg/ha)	Water depth (cm)	Total N loss (%)	NH_3 loss (%)	Estimated nitrification-denitrification loss[a] (%)
Researchers' split[b]	53	0	33	6	27
Researchers' split[b]	53	5	54	22	32
Farmers' split[b]	53	5	60	27	33
Researchers' split[b]	80	0	32	7	25
Researchers' split[b]	80	5	58	27	31
Farmers' split[c]	80	5	59	31	28
Farmers' split[d]	80	5	55	31	24

[a]By difference. [b]2/3 basal + 1/3 at 5-7 DBPI. [c]2/3 at 10 DT + 1/3 at booting. [d]Circular plot.

concentration of NH_3 in the atmosphere at 0.8 m (g N/m^3). This equation has been used to predict NH_3 loss from the different management treatments.

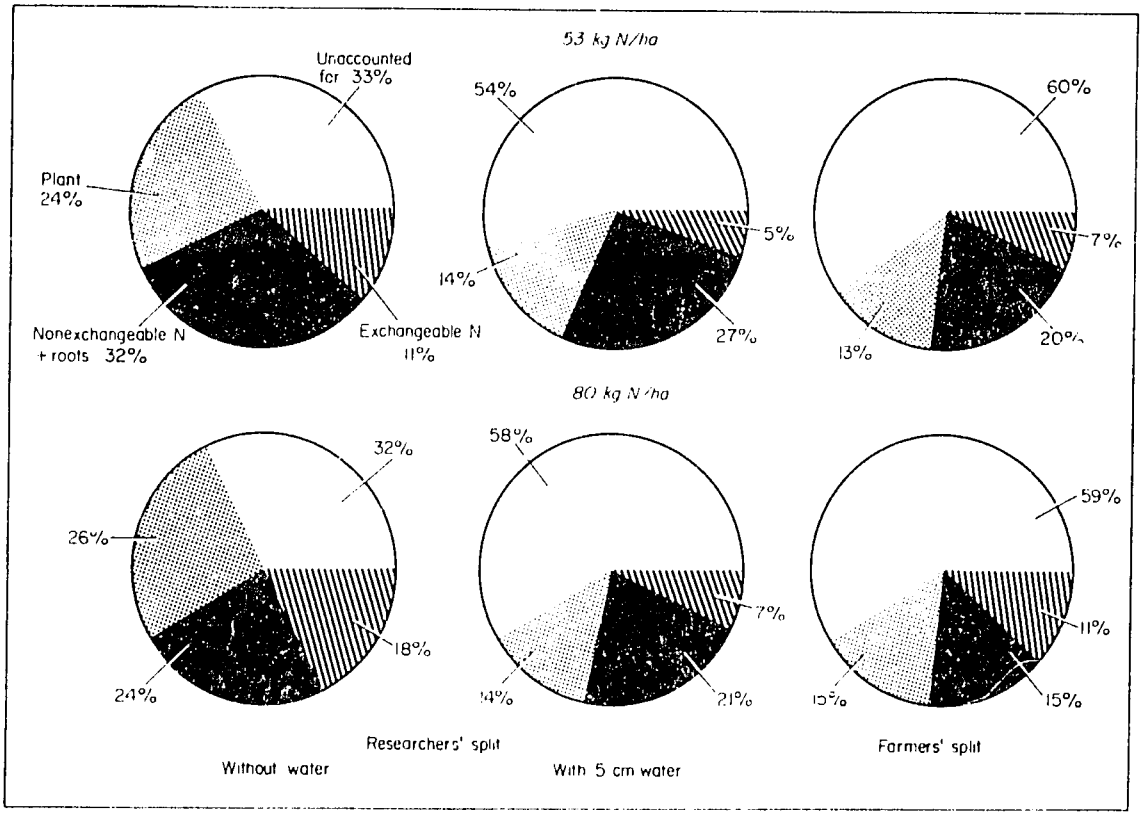
^{15}N balance in microplots. Highest total ^{15}N recoveries at 30 d after transplanting (DT) of 67% with 53 kg N/ha and 68% with 80 kg N/ha were obtained with the researchers' split without standing water (Table 1). Fertilizer incorporation in the presence of standing water decreased ^{15}N recovery by 21-26%. ^{15}N recovery was lowest when fertilizer was topdressed as farmers' split.

Total N loss as predicted from unaccounted-for was N ranged from 54 to 60% when N applied as researchers' split with 5 cm standing water or farmers' split (Fig. 5). The least percentage of unaccounted-for N and the highest plant recovery of 24-26% were obtained with researchers' split without standing water. Standing water during fertilizer incorporation decreased plant recovery by 10%. Where there was more contact between soil and fertilizer, exchangeable N increased from 5-11% to 11-18% and nonexchangeable N + root increased from 20 to 32% with 53 kg N/ha and from 15 to 24% with 80 kg N/ha.

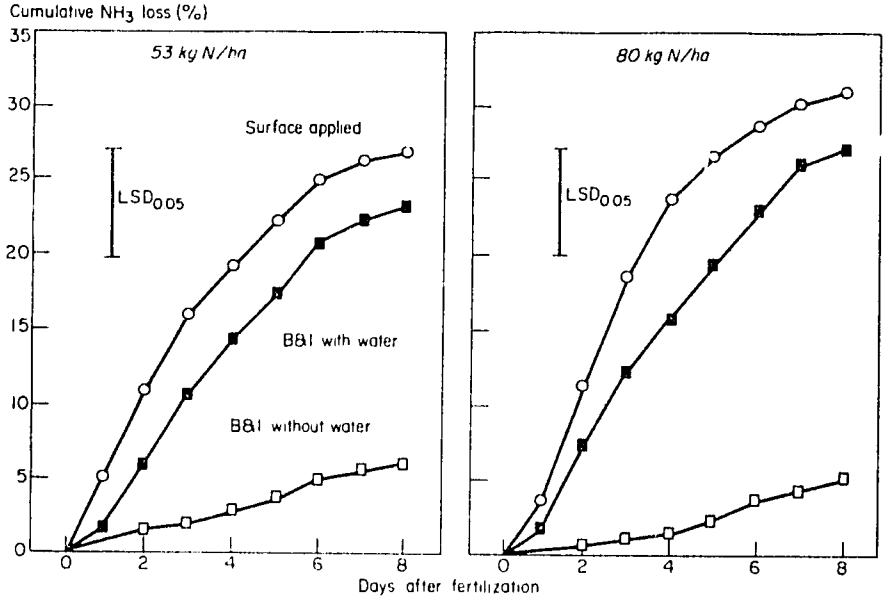
Figure 6 shows the cumulative loss due to NH_3 volatilization for three methods and two rates of fertilizer application. Volatilization was maximum when urea was surface applied (farmers' split), and was lowest when urea was incorporated into the soil without standing water. Within a method, losses at the two rates of application were comparable.

Total N losses after 30 d for the two rates were about 60% when urea was surface applied (Table 2). Total loss was reduced to about half (32-33%) when urea was incorporated into the soil without standing water. Losses other than as NH_3 were probably caused by nitrification-denitrification.

The implied nitrification-denitrification losses were all about 30%, more than N loss as NH_3, irrespective of method or rate of application.



5. Balance of ^{15}N-labeled urea at 30 DT with different methods of application and water depths. Mabitac, Laguna, Philippines, 1985, late DS.



6. Cumulative NH_3 loss as affected by fertilizer management. Mabitac, Laguna, Philippines, 1985 DS. B&I = broadcast and incorporated.

The yield response of IR60 to N fertilizer was almost 2 t/ha more than that of the unfertilized control (Table 3). Applying 80 kg N/ha gave an average yield of 5.4 t/ha, and applying 120 kg N/ha increased the average yield to 5.8 t/ha. However, the yields did not significantly differ.

POTENTIAL N LOSS, ^{15}N BALANCE, AND YIELD IN WET SEEDED FLOODED AND TRANSPLANTED RICE

In a cooperative project with the International Fertilizer Development Center (IFDC), the effects of crop establishment method on potential N loss and recovery of applied N were evaluated during DS at the Maligaya Rice Research and Training Center (MRRTC), Nueva Ecija, Philippines.

Using the ^{15}N balance method, fertilizer N use efficiencies after different application methods in wet seeded (WSR) and transplanted rice (TPR) were compared. Floodwater N contents were monitored to determine potential N loss through volatilization.

Floodwater nitrogen. The equilibrium vapor pressure of NH_3 (pNH_3) in floodwater was used as an indicator of volatilized N. Broadcasting and incorporating N before seeding or transplanting generally gave similar pNH_3 to TPR and WSR flooded rice (Fig. 7). In both crop establishment methods, 2/3 urea broadcast and incorporated (B&I) into mud and 5 cm water introduced 4 d later resulted in lower floodwater pNH_3 than did urea B&I with 5 cm standing water. Vapor pressure of NH_3 was high for 5 d after N was B&I in 5 cm standing water. $(NH_4)_2SO_4$ as the N source gave higher pNH_3 values than did urea.

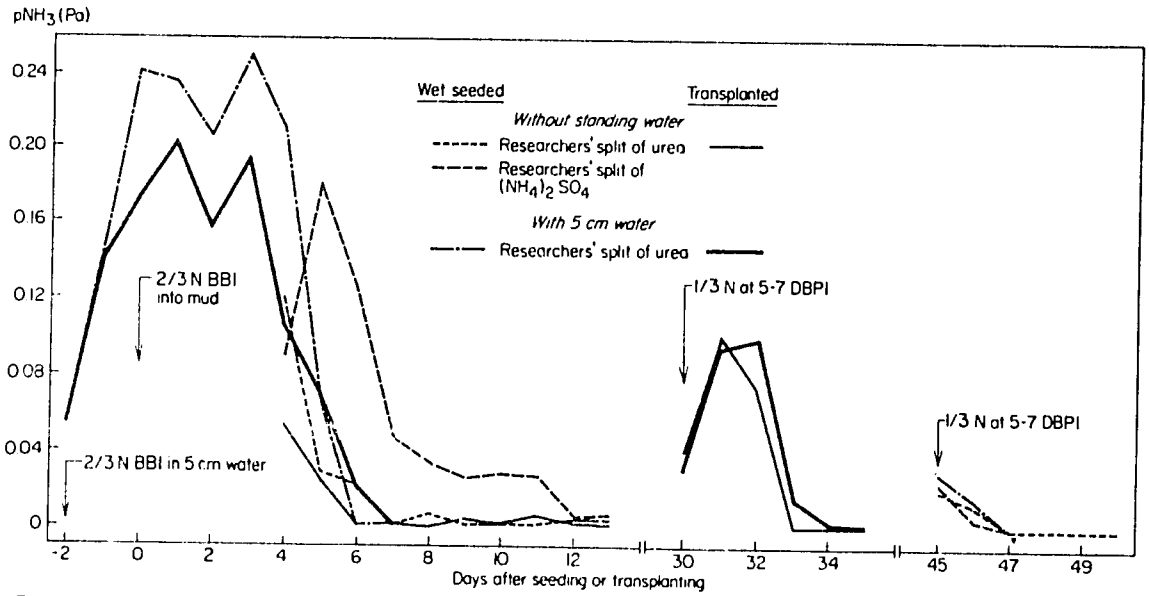
Floodwater pNH_3 values were higher in TPR than in WSR with topdressing of 1/3 urea at 5-7 d before panicle initiation (DBPI).

Under the farmers' method of N application,

Table 3. IR60 grain yield as affected by method of N application and water depth. Mabitac, Laguna, Philippines, 1985 DS.

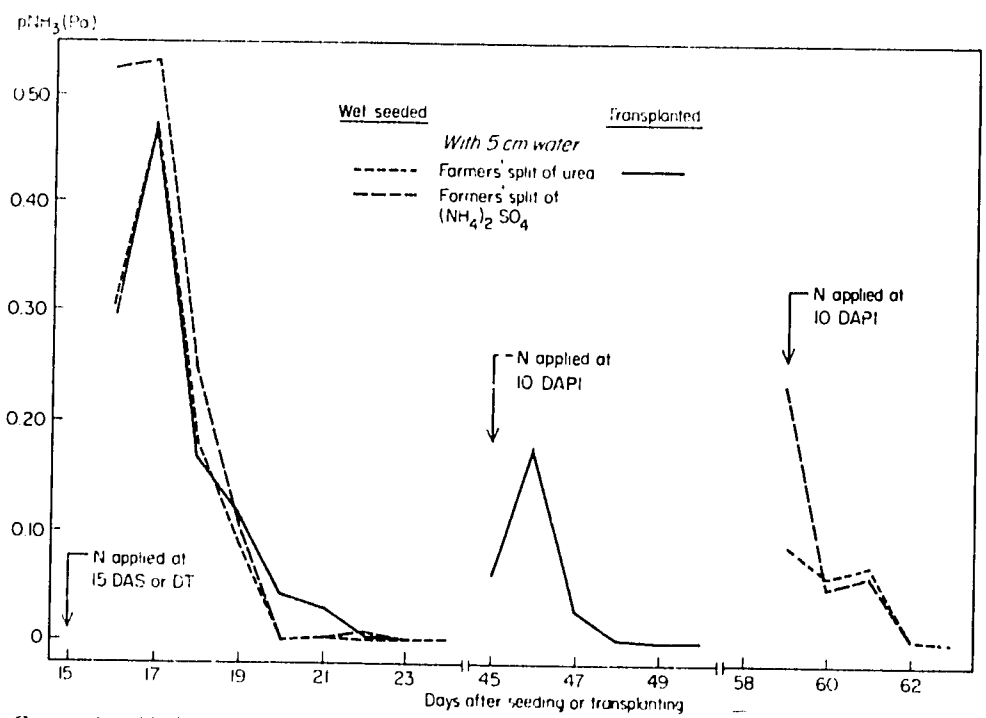
Treatment	Rate (kg N/ha)	Water depth (cm)	Grain yield (t/ha)
Unfertilized control	0	–	3.9 c
Researchers' split[a]	80	0	5.6 ab
Researchers' split[a]	80	5	5.2 b
Farmers' split[b]	80	5	5.4 ab
Researchers' split[a]	120	0	5.8 ab
Researchers' split[a]	120	5	5.8 ab
Farmers' split[b]	120	5	5.9 a
Farmers' split[b] in circle (unreplicated)	120	5	5.0

[a]2/3 basal + 1/3 at 5-7 DBPI. [b]2/3 at 10 DT + 1/3 at booting.



7. Corrected equilibrium vapor pressure of floodwater NH_3 at 1400 h after applying N by researchers' split using 2 water managements with 2 rice establishment methods. Values corrected over the unfertilized control. MRRTC, Nueva Ecija, Philippines, 1985 DS. BBI = basal, broadcast and incorporated. DBPI = d before panicle initiation.

pNH_3 values in WSR and TPR did not significantly differ (Fig. 8) but were appreciably higher than with the researchers' split. When fertilizer was applied at 15 d after seeding (DAS) or at 15 DT, pNH_3 values remained high for about 3 d and then declined rapidly. Lower pNH_3 values

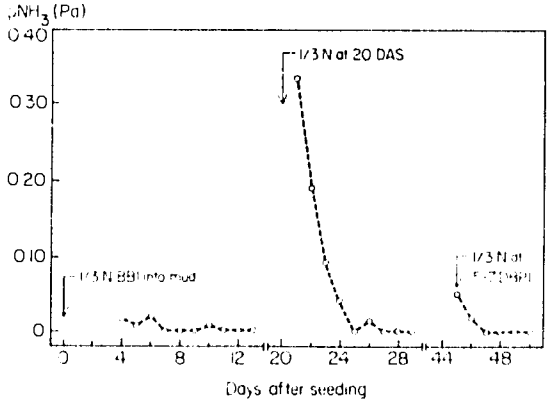


8. Corrected equilibrium vapor pressure of floodwater NH_3 at 1400 h after applying N by farmers' split (1/2 at 15 DAS or DT + 1/2 at 10 DAPI) under two rice establishment methods. Values corrected over the unfertilized control. MRRTC, Nueva Ecija, Philippines, 1985 DS. DAS = d after seeding, DAPI = d after panicle initiation.

were observed at 10 d after panicle initiation (DAPI).

$(NH_4)_2SO_4$ initially gave higher pNH_3 values than did urea. When urea was applied in 3 equal split doses, very low values were obtained at seeding and at 5-7 DBPI (Fig. 9). Applying N at 20 DAS resulted in high floodwater pNH_3, suggesting greater susceptibility to volatilization loss.

Floodwater measurements were also taken at 0600 h. Floodwater pNH_3 was very low even when ammoniacal N was high, since floodwater pH and temperature, which influence pNH_3 values, were low at the sampling time.



9. Corrected equilibrium vapor pressure of floodwater NH_3 after applying N in 3 split doses in wet seeded rice. Values corrected over unfertilized control. MRRTC, Nueva Ecija, Philippines, 1985 DS.

^{15}N balance. In TPR, N losses from farmers' and researchers' splits were comparable (33-39%). Improved water management at the time of basal fertilizer N incorporation did not improve plant recovery of applied ^{15}N urea (Fig. 10).

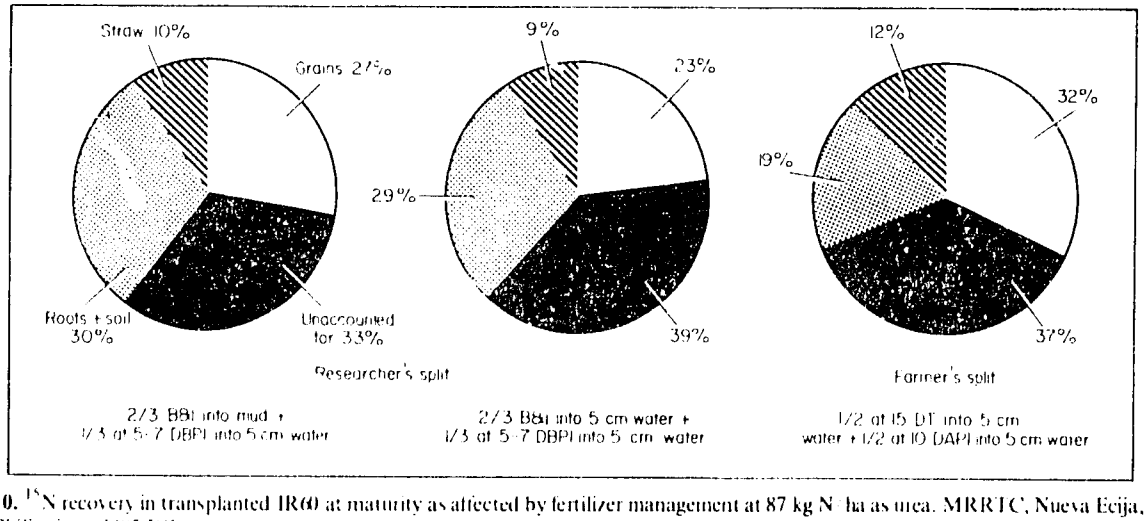
Preliminary results indicate that the magnitude of N losses were less from flooded WSR than from TPR. Losses were less with $(NH_4)_2SO_4$ than with urea (Fig. 11). Basal deep placement of urea completely eliminated N loss.

Grain yield. N application to either WSR or TPR produced significantly higher yields than no fertilizer (av yield difference of 1.7 t/ha) (Table 4). With N, TPR yielded higher than WSR, although the yield differences were not significant between researchers' split without standing water and farmers' split. A significant difference in yield was noted with researchers' split with 5 cm water: the presence of standing water at seeding time caused many seedlings to die.

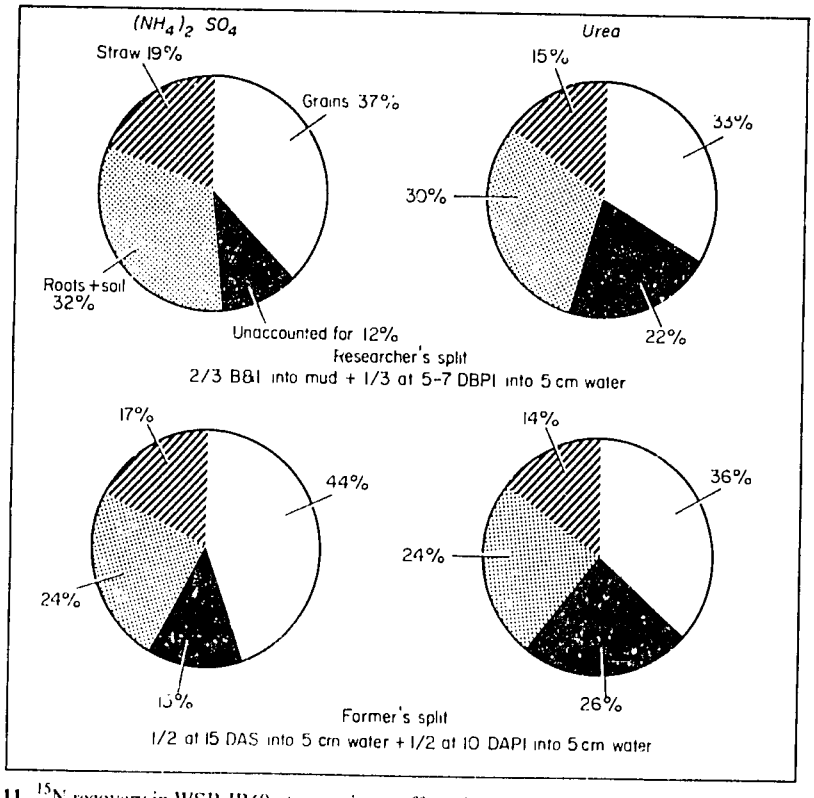
In WSR, point placement of urea supergranules (USG) produced low grain yields because the crop lodged at early flowering.

^{15}N BALANCE AND FERTILIZER N EFFICIENCY IN UPLAND RICE

^{15}N-labeled urea was used in 1984 WS to measure the effect of fertilizer application method on N loss in upland rice. IR43 was grown on an Alfisol. The highest ^{15}N recovery was 87% (56% was by straw+



10. ^{15}N recovery in transplanted IR60 at maturity as affected by fertilizer management at 87 kg N/ha as urea. MRRTC, Nueva Ecija, Philippines, 1985 DS.



11. ^{15}N recovery in WSR IR60 at maturity as affected by source of N at 87 kg/ha. MRRTC, Nueva Ecija, Philippines, 1985 DS.

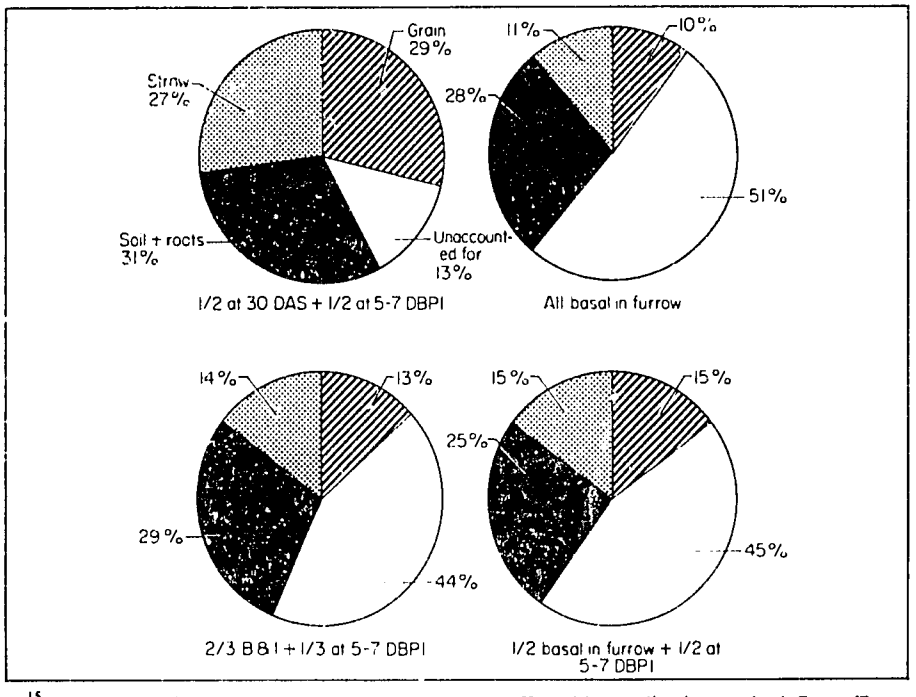
grains and 31% by soil + roots) when 1/2 N was topdressed 30 DAS and after first weeding and 1/2 topdressed at 5-7 DBPI (Fig. 12). Two-thirds B&I + 1/3 at 5-7 DBPI and 1/2 basal in furrows + 1/2 at 5-7 DBPI gave similar ^{15}N recoveries of 55-56%.

The lowest ^{15}N recovery was 49%, when fertilizer was applied basal in furrow and covered with dry soil. The results indicate that, under upland conditions, fertilizer should be applied when moisture is sufficient and roots are established.

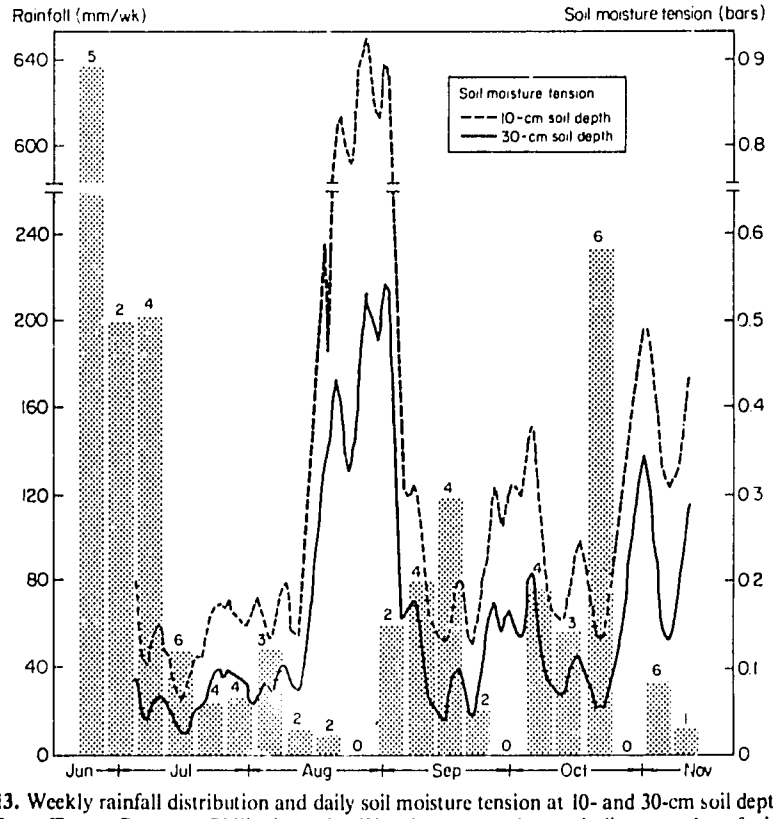
Table 4. Grain yield of IR60 as affected by crop establishment method and fertilizer management at 87 kg N/ha. MRRTC, Nueva Ecija, Philippines, 1985 DS.

Fertilizer management[a]	N source[b]	Water depth during N application (cm)					Grain yield[c] (t/ha)	
		Basal	15 DAS or DT	20 DAS	5-7 DBPI	10 DAPI	WSR	TPR
No fertilizer N (no standing water)							4.8 d	4.5 d
No fertilizer N (with 5 cm water)							4.5 d	4.4 d
Researchers' split	PU	0			5		6.2 abc	6.7 ab
Researchers' split	PU	5			5		5.9 c	6.8 a
Farmers' split	PU		5			5	6.3 abc	6.4 abc
3-split application	PU	0		5	5		6.5 abc	
Point placement	USG	0					5.9 c	
Researchers' split	AS	0			5		6.4 abc	
Farmers' split	AS		5			5	6.1 bc	

[a]Researchers' split = 2/3 B&I + 1/3 at 5-7 DBPI; farmers' split = 1/2 topdressed at 15 DAS or DT + 1/2 topdressed at 10 DAPI; 3-split = 1/3 B&I + 1/3 at 20 DAS + 1/3 at 5-7 DBPI; point placement = hand placement at 10-12 cm depth on a 20 cm X 20 cm spacing before seeding. [b]PU = prilled urea, USG = urea supergranules, AS = $(NH_4)_2SO_4$. [c]CV = 6.8%.



12. ^{15}N recovery of fertilizer at harvest of upland IR43 as affected by application method. Santo Tomas, Batangas, Philippines, 1984 WS.



13. Weekly rainfall distribution and daily soil moisture tension at 10- and 30-cm soil depth. Santo Tomas, Batangas, Philippines, 1985 WS. Numbers on the bars indicate number of rainy days.

The experiment was repeated in 1985 WS to determine the yield response of IR43 to different fertilizer practices under upland conditions. Figure 13 shows the weekly rainfall distribution and soil moisture tension. Severe moisture stress just before the crop reproductive stage and slight moisture stress during ripening caused low yields in all plots. Fertilizer application increased yields from 1.9 to 2.7 t/ha, but different application methods had no significant effects on grain yield.

EFFECTIVENESS OF A UREASE INHIBITOR IN LOWLAND RICE

Urease inhibitors offer the attractive possibility of increasing N use efficiency and grain yield through inhibition of urea hydrolysis in the soil without requiring a change in the farmer's application practice. In trials at IRRI, the inhibitor phenyl phosphorodiamidate (PPD) delayed urea hydrolysis and reduced the buildup of ammoniacal N in the floodwater (Fig. 14).

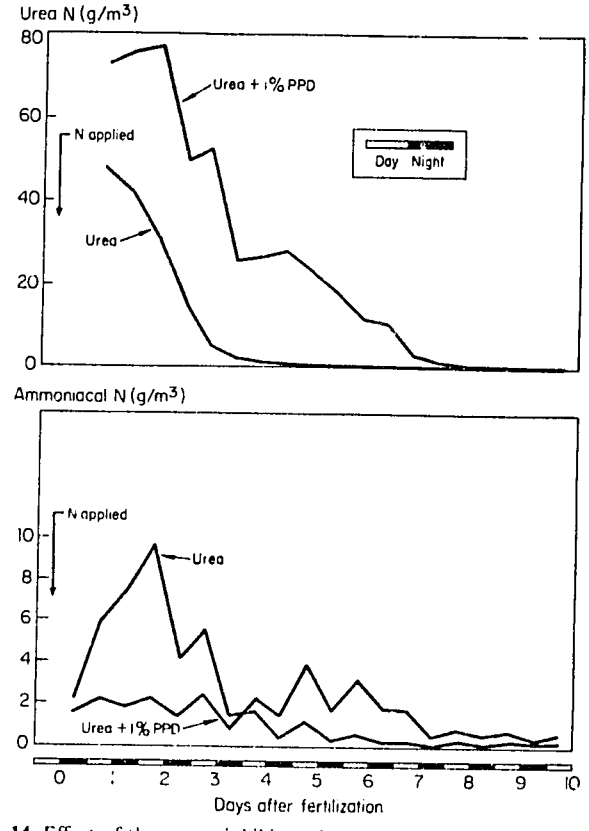
Urea with and without 1% PPD was broadcast into the floodwater at either 18, 28, or 38 DT. PPD was effective in reducing N loss as determined by ^{15}N balance. The added ^{15}N-labeled urea not recovered in the plant and soil and presumably lost as N gases was significantly less with PPD at 2 and 4 wk after N application (Table 5). N loss decreased as the time of N application was delayed. However, PPD, used at different times of N application, did not significantly increase the yield of 5.2 t/ha.

In another study, urea amended with 2% PPD was evaluated at 4 N rates (Table 6). IR58 responded significantly to both urea and urea + 2% PPD broadcast into 5 cm of floodwater 2/3 at 18 DT and 1/3 at 5-10 DAPI, but the slight yield increase with PPD (0.2 t/ha) was not significant.

VARIETAL DIFFERENCE IN SOIL N UTILIZATION

Cooperative studies with the University of California, Davis, USA, continued to evaluate the ability of modern varieties to efficiently utilize soil N, a major N source in most lowland rice soils.

Twenty-four varieties or lines were grown in six replications at IRRI from 1983 to 1984. ^{15}N-depleted $(NH_4)_2SO_4$ was used to distinguish between soil- and atmosphere-derived N and fertilizer N in the rice plant.



14. Effect of the urease inhibitor phenyl phosphorodiamidate (PPD) on floodwater urea N and ammoniacal N. IRRI, 1984 DS. Urea was applied to floodwater at 28 DT.

At 30 DT and at panicle initiation (PI), the dry matter, total N, percentage of N derived from fertilizer, and dry matter to fertilizer N ratio of varieties or lines were evaluated. At harvest, three additional parameters were used: panicle weight, panicle weight to total N ratio, and panicle weight to fertilizer N ratio. Thus a variety or line

Table 5. Effect of phenyl phosphorodiamidate (PPD) and timing of N application on unrecovered ^{15}N, presumably gaseous N loss, at 2 and 4 wk after N application. IRRI, 1984 DS.

Treatment	Time of N application (DT)	Unrecovered ^{15}N (%)	
		2 wk	4 wk
Urea	38	12 bc	8 ab
Urea + 1% PPD	38	0 a	2 a
Urea	28	16 c	20 b
Urea + 1% PPD	28	8 b	6 a
Urea	18	35 d	34 c
Urea + 1% PPD	18	16 c	18 b

Table 6. Influence of N rate and treatment on grain yield of IR58. Pila, Laguna, Philippines, 1985 DS.

Treatment	Grain yield (t/ha)
N rate	
0	3.9
30 kg N/ha	4.8
60 kg N/ha	5.8
90 kg N/ha	6.4
120 kg N/ha	6.7
N treatment	
Urea, 5 cm water (N_1)	6.0
Urea + 2% PPD, 5 cm water (N_2)	6.2

Analysis of variance

Source	*df*	*Mean square*
N rate	4	16.350**
0 vs treated	(1)	40.646**
Among treated	(3)	8.251**
N treatment	2	1.497**
N_1 vs N_2	(1)	0.184^{ns}

producing high grain yield with minimum N fertilizer used would have a high panicle weight to fertilizer N ratio. The opposite would be true for a variety strongly responsive to N fertilizer, or of low efficiency in utilizing soil- and atmosphere-derived N.

Considering 5 yield and N-uptake efficiency parameters at harvest — dry matter : total N, dry matter : fertilizer N, panicle weight, panicle weight : total N, and panicle weight : fertilizer N — over the 3 seasons, there were statistically significant differences in 14 of 15 instances among rices, and in 13 of 15 instances with duration means. These parameters were used to rank individual varieties and lines with respect to N uptake efficiency.

The variety or line having the highest value for a particular parameter was ranked 1, and so on up to 24. The results suggest reasonable consistency among varieties and lines as well as from season to season. Short duration varieties and lines tended to rank low, although IR19728-9-3-2-1-2 ranked high in 1984 DS. By giving the five yield and N-uptake parameters equal weight, cumulative rankings for each season were obtained, from which an overall ranking for the three seasons was made (Table 7). Among 110-d varieties and lines, IR13429-150-3-2-1-2, IR18349-135-2-3-2-1, and IR21912-56-3-1-2-2 ranked high for all parameters in all seasons. Among >120-d maturity varieties and lines, IR13540-56-3-2-1, IR21912-131-3-3-2-2, and IR15323-78-1-3-1 performed exceptionally well, while short duration varieties IR8608-167-1-2 and IR9752-1-2-1 consistently ranked low.

Of the four released varieties that were included in the trial, IR26 and IR42 performed at about the same level, but neither ranked high.

The breeding line IR13429-150-3-2-1-2 had the highest total and fertilizer N harvest index values and produced the highest average grain yield for three seasons (Table 8). Most of the 100-d varieties were low yielders. On the other hand, IR2863-38-1 in the 120- to 135-d maturity group appeared to be an excellent gatherer of soil N but produced low grain yield, implying it is a poor N utilizer for grain production, i.e., it has a high protein content.

In 1985 DS and wet season (WS), the performances of the 24 entries were tested in 2 soils of contrasting soil N content. One site at the Bureau of Plant Industry station in Maligaya, Muñoz, Nueva Ecija, had a soil N content of 0.08%. At IRRI, the soil N content was 0.12% (Table 9).

Table 7. Cumulative rankings of varieties or lines based on 5 yield and N-uptake parameters. IRRI, 1983-84.

Variety or line	1983 WS	1984 DS	1984 WS	Overall
100-d maturity				
IR8455-78-1-3-3	21	18	20	20
IR8608-167-1-2	24	24	24	24
IR9729-67-3	15	11	16	17
IR9752-1-2-1	23	23	22	23
IR19729-5-1-1-3-2	19	15	23	21
IR15429-268-1-2-1	22	20	19	22
IR19728-9-3-2-3-3	16	4	18	13
IR19735-2-3-2-1	18	20	21	18
110-d maturity				
IR36	12	17	13	14
IR50	20	12	7	16
IR13429-150-3-2-1-2	5	1	1	1
IR13427-40-2-3-3-3-3	17	22	17	18
IR13240-82-2-3-2-3-1	6	14	3	9
IR25588-32-2	14	13	15	15
IR18349-135-2-3-2-1	2	3	2	2
IR21912-56-3-1-2-2	3	6	8	5
120- to 135-d maturity				
IR13540-56-3-2-1	7	9	5	5
IR21912-131-3-3-2-2	1	8	6	3
IR26	11	19	12	12
IR2863-38-1	7	16	10	11
IR42	13	10	9	10
IR8192-200-3-3-1-1	10	2	14	7
IR11248-148-3-2-3-3	3	5	11	8
IR15323-78-1-3-1	9	7	3	4

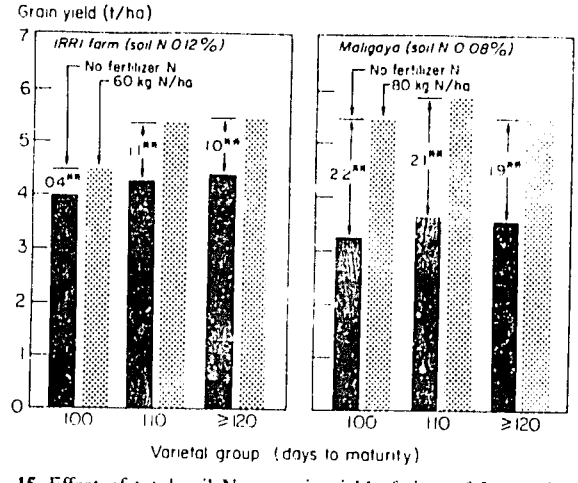
Table 8. Total and fertilizer N harvest index values and grain yield of rices that showed highest and lowest N use efficiency, with rankings. 1985 IRRI-U.C. Davis cooperative experiment, 1983-84.

Rank[a]	Variety or line	Duration (d)	Mean total N harvest index[b]	Mean fertilizer N harvest index[b]	Grain yield (t/ha)			
					1983 WS	1984 DS	1984 WS	Mean
						Highest ranking		
1	IR13429-150-3-2-1-2	110	0.74	0.74	5.4	6.3	4.4	5.3
2	IR18349-135-2-3-2-1	110	0.68	0.69	5.7	5.3	4.1	5.0
3	IR21912-131-3-3-2-2	>120	0.71	0.66	4.7	5.7	3.7	4.7
4	IR15323-78-1-3-1	>120	0.63	0.63	4.6	6.7	4.0	5.1
5	IR21912 56-3-1-2-2	110	0.64	0.67	4.9	6.3	4.0	5.1
5	IR13540-56-3-2-1	>120	0.68	0.69	4.3	5.6	3.8	4.5
						Lowest ranking		
23	IR9752-1-2-1	100	0.69	0.68	4.1	4.8	3.8	4.2
24	IR8638-167-1-2	100	0.65	0.67	3.6	5.2	3.7	4.1

[a]Based on N utilization. [b]Av of 1983 WS and 1984 DS and WS.

Table 9. Properties of soils at IRRI and MRRTC, 1985 cropping season.

Soil property	IRRI	MRRTC
pH (1:1)	7.1	5.8
CEC (meq/100 g)	40	36
Total N (%)	0.12	0.08
Available Olsen P (ppm)	40	3
Exchangeable cations (meq/100 g)		
Na	1.32	0.67
K	1.23	0.29
Ca	32	28
Mg	12	17
Available Katyal and Ponnamperuma Zn (ppm)	nil	0.93



15. Effect of total soil N on grain yield of rices of 3 growth durations. 1985.

Without N fertilizer, rice grain yields were higher at sites with high soil N values (Fig. 15), but with N, yield differences were higher on the Maligaya soil. N response was lowest with short duration rices on soil high in total N. Distinct varietal differences exist in fertilizer N response on soil high in total N. On the other hand, dependence on fertilizer N is high and uniform in soil low in N, irrespective of rice variety or growth duration.

EVALUATION OF EXPERIMENTAL N SOURCES

The search for cost-effective slow-release N fertilizers and their application methods was continued. Super 60/urea gave no higher yields than PU applied either as researchers' split or as farmers' split at IRRI. Osmocote, however, gave grain yields comparable to the other slow-release fertilizer, sulfur-coated urea (SCU) (Table 10).

Urea-formaldehydes (ureaforms) are slow-release N compounds. Chemists at IFDC developed a simpler manufacturing process that produces shorter molecular chains of urea than do commercial processes. Experimental ureaforms with either 5 or 10% paraformaldehyde (PFA) added to urea were evaluated in a farmer's field in Pila, Laguna, Philippines.

Grain yield of IR58 without applied N was 2.9 t/ha. Yield with the two ureaforms was comparable to that of the researchers' split of urea. But yields with ureaform and prilled urea (PU) were significantly less than with hand-placed USG.

Guanylurea sulfate, an experimental slow-release N source, was also evaluated because of

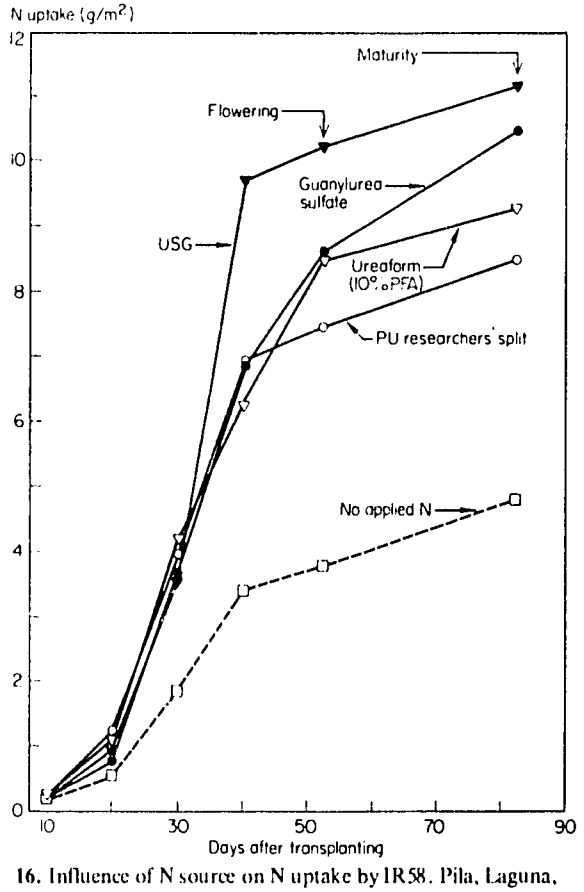
Table 10. Effect of urea source and application method on grain yield of IR64. IRRI, 1985, late WS.

Urea source[a]	N rate (kg/ha)	Application method[b]	Grain yield[c] (t/ha)
–	0	–	2.0 d
PU	58	1/2 at 10 DT + 1/2 at 10 DAPI (farmers' split)	2.7 c
PU	58	2/3 B&I without water + 1/3 at 5-7 DBPI (researchers' split)	3.0 bc
SCU	58	All basal, B&I without water	3.6 a
SCU	58	All basal, B&I with 5 cm water	3.6 a
USG	58	All basal, hand point placement	3.9 a
Super 60/urea	58	All basal, B&I without water	3.4 ab
Super 60/urea	58	Full dose at 10 DT	2.8 c
Osmocote (3-4 mo formulation)	58	All basal, B&I without water	3.6 a
Osmocote (3-4 mo formulation)	58	Full dose at 10 DT	3.5 ab
Osmocote (5-6 mo formulation)	58	All basal, B&I without water	3.8 a
PU	87	2/3 B&I without water + 1/3 at 5-7 DBPI	3.6 a

[a]Super 60/urea = 75% super 60 (2,4,6-triamino 1,3,5-triazine) + 25% urea. [b]Topdressing at 10 DT and before or after panicle initiation with 5 cm standing water. [c]CV = 12%.

previous promising results in the greenhouse at IFDC. However, grain yield was not significantly greater for guanylurea sulfate than for PU (Table 11).

Uptake of N by IR58 was markedly increased with N application (Fig. 16). It was greatest with USG and slightly greater with ureaform and guanylurea sulfate than with PU. Uptake of N was comparable for the ureaforms with 5 and 10% PFA.



16. Influence of N source on N uptake by IR58. Pila, Laguna, Philippines, 1985 DS.

ALTERNATIVE TECHNOLOGY FOR INCREASING N EFFICIENCY IN LOWLAND RICE

In an experiment to demonstrate alternative technologies for increasing fertilizer N use efficiency in lowland rice using traditional variety Binato and elite breeding line IR29723-143-3-2-1, yield responses to fertilizer source, application rate, and method were comparable. All treatments gave good yields of the elite line but low response to fertilizer N because of high soil fertility. The yields of Binato did not reach more than 3.3 t/ha with any treatment.

Even when N was not applied, grain yields of modern rices were higher than those of traditional rices by 2.7 t/ha in DS and by 1.4 t/ha in WS (Table 12). Results suggest that the potential yield

Table 11. Influence of N source on grain yield response of IR58. Pila, Laguna, Philippines, 1985 DS.

N source[a]	Grain yield (t/ha)			
	58 kg N/ha	87 kg N/ha	116 kg N/ha	Mean
PU, researchers' split	4.4 ab	4.8 b	5.5 a	4.9 b
USG, DP	4.9 a	5.6 a	5.8 a	5.4 a
Ureaform (5% PFA), B&I	4.3 b	5.0 b	5.4 a	4.9 b
Ureaform (10% PFA), B&I	4.3 b	5.0 b	5.5 a	4.9 b
Guanylurea sulfate, B&I	4.8 ab	5.1 ab	5.5 a	5.1 ab
PU, researchers' split with poor water control	4.5 ab	4.8 b	5.3 a	4.9 b

[a]Researchers' split = 2/3 B&I without standing water + 1/3 at 5-7 DBPI, DP = deep placement, PFA = paraformaldehyde, poor water control with approximately 2 cm water during incorporation.

Table 12. Effect of urea source, application rate, and method on grain yield of traditional variety Binato and modern cultivar IR29723-143-3-2-1. IRRI, 1985.

Urea source[a]	N rate (kg/ha)		Application method[b]	Grain yield[c] (t/ha)	
	Binato	IR29723-143-3-2-1		Binato	IR29723-143-3-2-1
			Dry season		
–	0	0	No fertilizer N	2.7 ab	5.4 b
PU	29	58	Farmers' split	2.4 abc	6.2 ab
PU	29	58	Researchers' split	3.0 ab	6.7 a
SCU	29	58	BBI	2.9 ab	6.2 ab
USG	29	58	Hand point placement	3.2 a	6.8 a
USG	26	56	Point placement by press wedge	2.3 abc	5.9 ab
PU	29	58	Band placement by plunger/auger	2.2 abc	6.0 ab
PU	58	87	Farmers' split	2.3 abc	6.2 ab
PU	58	87	Researchers' split	2.4 abc	6.4 ab
SCU	58	87	BBI	1.9 bc	6.2 ab
USG	58	87	Hand point placement	1.3 c	6.8 a
USG	58	71	Point placement by press wedge	2.1 abc	6.1 ab
PU	58	87	Band placement by plunger/auger	1.9 bc	6.5 ab
PU	80	120	Researchers' split	2.1 abc	6.8 a
			V mean	2.3	6.3
			Wet season		
–	0	0	No fertilizer N	2.2 ab	3.6 d
PU	29	29	Farmers' split	2.3 ab	4.6 abc
PU	29	29	Researchers' split	2.7 a	4.3 c
SCU	29	29	BBI	2.1 abc	4.5 bc
USG	29	29	Hand point placement	1.4 def	4.4 c
USG	26	29	Point placement by press wedge	1.0 ef	4.8 abc
PU	29	29	Band placement by plunger/auger	1.7 bcd	5.1 ab
PU	58	58	Farmers' split	1.1 def	4.4 c
PU	58	58	Researchers' split	0.8 f	5.1 ab
PU	58	58	BBI	1.0 ef	4.6 abc
USG	58	58	Hand point placement	1.5 cde	5.1 ab
USG	58	46	Point placement by press wedge	1.3 def	5.2 a
PU	58	58	Band placement by plunger/auger	1.2 def	4.8 abc
PU	80	120	Researchers' split	1.2 def	4.9 abc
			V mean	1.5	4.7

[a]PU = prilled urea, SCU = sulfur-coated urea, USG = urea supergranules. [b]Farmers' split = 1/2 at 10 DT + 1/2 at 10 DAPI. Researchers' split = 2/3 B&I into mud + 1/3 topdressed at 5-7 DBPI. BBI = basal, broadcast and incorporated. [c]For each season, means in a column followed by a common letter are not significantly different at the 5% level. CV = 14%.

of modern rices, at least in good soils, is higher than that of traditional varieties under limited resources such as fertilizer N.

Low yields of the traditional variety were due to severe lodging that started during heading.

N USE EFFICIENCY AT LOW APPLICATION RATES

The yield response of rice to urea source and application method at low fertilizer rates was studied in DS and WS. Grain yield in DS was low because rices were planted on 25 Mar, which is late for the DS crop.

No interaction was observed between variety and fertilizer treatment. Hence, data were averaged for the two varieties used.

PU applied at 29 kg N/ha gave comparable grain yields regardless of application method in both seasons. Point-placed USG at 29 kg N gave the same yield (3.8 t/ha) as PU applied as farmers' split at 58 kg N/ha.

At 58 kg N/ha, hand point placement of USG

Table 13. Grain yield of rice as affected by urea source and application method. IRRI, 1985, late DS and WS.

Urea source	N rate (kg/ha)	Application method[a]	Grain yield[b] (t/ha) DS	Grain yield[b] (t/ha) WS
–	0	–	3.0 e	2.7 g
PU	29	Farmers' split	3.5 d	3.5 ef
PU	29	Researchers' split	3.7 d	3.4 f
USG	29	Hand point placement	3.8 cd	3.8 cde
PU	29	Band placement by plunger/auger machine	3.7 d	3.5 ef
PU	29	Single dose at 5-7 DBPI	3.6 d	3.7 def
PU	58	Farmers' split	3.8 cd	3.7 def
PU	58	Researchers' split	4.1 bc	4.1 bc
USG	58	Hand point placement	4.4 ab	4.5 a
PU	58	Band placement by plunger/auger machine	4.5 a	4.0 bcd
PU	58	1/2 at 20 DT + 1/2 at 5-7 DBPI	4.2 ab	4.1 bc
PU	58	1/2 at 30 DT + 1/2 at 5-7 DBPI	4.2 ab	4.2 ab

[a]Farmers' split = 1/2 at 10 DT + 1/2 at 10 DAPI. Researchers' split = 2/3 B&I into mud before transplanting + 1/3 top-dressed at 5-7 DBPI. [b]Av of 4 replications and 2 rice varieties (IR58 and IR28150-84-3-3-2). CV = 8.2% in DS and 8.1% in WS.

Table 14. Field duration, productivity, and brown rice protein content of 5 varieties and 9 early maturing IR lines as affected by rate and method of N application. IRRI, 1985 DS.

Entry	Field duration[a] (d)	Grain yield[b] (t/ha): No N	116 kg N/ha: Urea split	116 kg N/ha: SCU	116 kg N/ha: USG	150 kg N/ha urea split	Av yield: t/ha	Av yield: kg/ha per day	Brown rice protein (%)
IR8	106	4.3 abc	6.9 def	6.7 ef	6.3 d	6.9 cd	6.2	59	7.4
IR36	93	4.4 abc	6.3 f	6.5 f	6.3 d	6.2 d	5.9	64	8.3
IR42	109	4.2 abc	6.8 ef	6.8 def	6.7 cd	6.9 cd	6.3	58	8.4
IR58	84	3.9 c	7.8 abcd	7.5 abcde	7.2 bcd	7.0 bcd	6.7	79	9.2
IR64	95	4.1 abc	8.5 a	8.3 a	8.2 a	8.0 a	7.4	78	8.4
IR13540-56-3-2-1	96	5.0 a	8.0 abc	7.3 bcdef	7.1 cd	6.8 d	6.8	71	8.3
IR29658-43-3-2-1	88	4.2 abc	7.4 bcde	7.6 abcde	7.4 abc	7.1 abcd	6.7	76	8.4
IR29658-69-2-1	88	4.3 abc	7.5 bcde	7.2 cdef	6.9 cd	7.0 bcd	6.6	75	8.8
IR31802-48-2-2-2	90	4.9 ab	7.7 abcde	8.2 ab	7.0 cd	7.8 abc	7.1	79	8.7
IR31851-63-1-2-3-2	88	4.3 abc	7.2 bcdef	7.6 abcde	7.4 abc	7.8 abc	6.9	78	9.2
IR31868-64-2-3-3-3	90	4.2 abc	7.1 cdef	6.8 def	7.1 cd	6.9 cd	6.4	71	8.6
IR32429-47-3-2-2	88	4.9 ab	8.1 ab	7.9 abc	8.1 ab	7.9 ab	7.4	84	8.8
IR32429-68-3-3-3	90	3.8 c	7.1 cdef	7.7 abcd	7.3 abc	7.8 abc	6.7	75	8.5
IR32429-122-3-1-2	88	4.0 bc	7.0 def	7.6 abcde	7.1 cd	6.9 cd	6.5	74	8.2

[a]Does not include 18 d in the seedbed. [b]Av of 4 replications. CV = 10%.

Table 15. Field duration, productivity and brown rice protein content of 5 varieties and 9 early maturing IR lines as affected by rate and method of N application. IRRI, 1985 WS.

Entry	Field duration[a] (d)	Grain yield[b] (t/ha)					Av yield		Brown rice protein (%)
		No N	58 kg N/ha			90 kg N/ha urea split	t/ha	kg/ha per day	
			Urea split	SCU	USG				
IR8[c]	107	2.8 f	3.3 g	3.4 d	3.1 e	3.5 e	3.2	30	7.0
IR36	93	4.1 bc	5.2 bcd	5.5 c	5.5 bcd	5.6 bc	5.2	56	8.4
IR42	118	4.4 bc	4.9 def	5.5 c	5.2 bcd	5.0 d	5.0	42	8.1
IR58	83	3.5 de	4.6 ef	5.3 c	4.9 d	5.2 cd	4.7	57	9.3
IR64	100	4.6 b	6.4 a	6.5 a	6.2 a	6.3 a	6.0	60	7.5
IR29658-43-3-2-1	92	4.4 bc	5.3 bcd	5.4 c	5.7 ab	5.5 bcd	5.3	57	7.9
IR29658-69-2-1	92	4.6 b	5.6 bc	5.6 bc	5.8 ab	5.7 bc	5.5	60	8.3
IR31802-48-2-2-2	93	4.1 bc	5.7 b	5.9 bc	5.8 ab	5.8 abc	5.5	59	8.2
IR31851-63-1-2-3-2	90	4.3 bc	5.0 cdef	5.8 bc	5.4 bcd	5.7 bc	5.2	58	8.6
IR31868-64-2-3-3-3	97	5.2 a	5.6 bc	6.1 ab	6.2 a	5.7 bc	5.8	59	7.8
IR32429-47-3-2-2	90	3.9 cd	5.1 bcde	5.6 bc	5.3 bcd	5.5 bcd	5.1	57	8.3
IR32429-68-3-3-3	90	4.4 bc	5.5 bcd	5.9 bc	5.6 bc	5.9 ab	5.4	60	8.0
IR32429-122-3-1-2	92	4.2 bc	5.5 bcd	5.8 bc	5.6 bc	5.8 abc	5.4	59	7.7
IR39422-18-1-2-2	83	3.1 ef	4.5 f	5.4 c	5.0 cd	5.4 bcd	4.7	56	8.8

[a]Does not include 18 d in the seedbed. [b]Av of 4 replications. CV = 7.9%. [c]Affected by virus diseases.

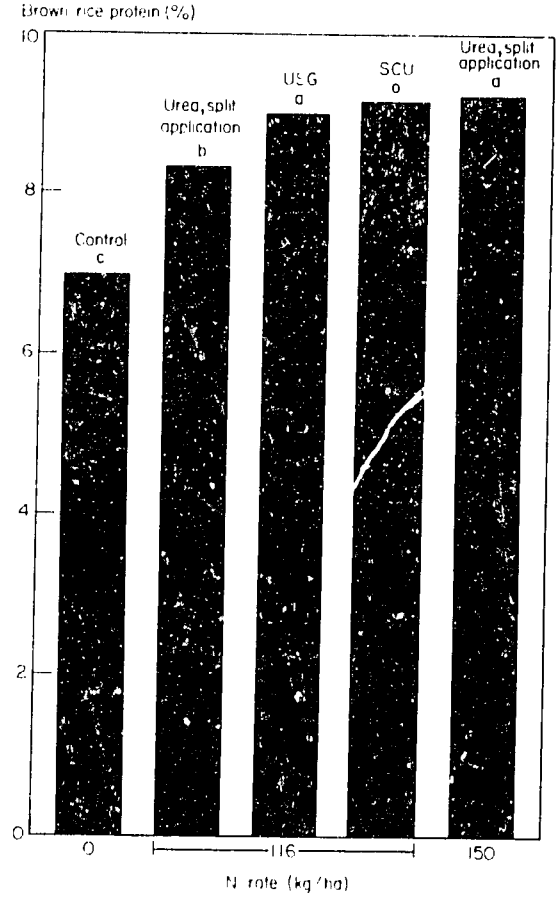
gave significantly higher yield than did farmers' split application of PU (Table 13). Machine-placed PU was also significantly superior to farmers' split in DS but gave comparable yields in WS. In WS, researchers' split gave significantly higher yields than farmers' split.

N MANAGEMENT FOR EARLY MATURING RICE

The productivity, brown rice protein content, and lodging resistance of early maturing elite breeding lines as affected by application method and N rate were evaluated.

IR64 yielded the highest (8.5 t/ha) when urea was split-applied at 116 kg N/ha in DS (Table 14) and 6.5 t/ha when SCU was applied at 58 kg N/ha in WS (Table 15). IR64 also gave the highest average yields of 7.4 t/ha in DS and 6.0 t/ha in WS. However, the earlier maturing IR32429-47-3-2-2 gave the highest productivity of rough rice (84 kg/ha per day) in DS compared with 78 kg/ha per day for the medium duration variety IR64 and 64 kg/ha per day for IR36.

In DS and WS, the very early maturing IR58 consistently gave the highest brown rice protein content (Table 14, 15). Proper fertilizer management may thus increase protein content. Single basal incorporation of SCU and deep placement of USG significantly increased brown rice protein content over the researchers' split (Fig. 17). These findings are consistent with results in the last 5 yr.



17. Effect of urea source, application method, and application rate on brown rice protein content (av of 14 rices). IRRI, 1985 DS. Bars with a common letter are not significantly different at the 5% level.

INCREASING EFFICIENCY OF APPLIED N IN LOWLAND RICE OF DIFFERENT MATURITY

In DS and WS, the farmers' practice of applying urea gave yields significantly lower than or comparable to the improved method and timing of application (2/3 B&I without water + 1/3 at 5-7 DBPI) and deep placement of USG (Table 16, 17). Yields when urea was basally incorporated with 2 cm standing water were comparable to those without free water. Results suggest that N fertilizer may be broadcast and incorporated with 2 cm standing water in soil with high CEC, like Maahas clay (Andaqueptic Haplaquoll), or when water is not immediately withdrawn before fertilizer application.

Broadcasting and incorporating 2/3 N in saturated soil + 1/3 N at 5-7 DBPI gave yields comparable to those obtained with deep-placed USG using either an early or a medium maturing variety. Deep placement of N may be done from 0 to 20 DT. In low fertility soils, deep placement

Table 16. Effects of water depth and urea application method on grain yield of early maturing IR58 (102 d) and late maturing IR29723-143-3-2-1 (135 d). IRRI, 1985 DS.

Urea source	N rate (kg/ha)	Application method[a]	Grain yield[b] (t/ha)	
			IR58	IR29723-143-3-2-1
–	0	No fertilizer N	2.7 g	4.4 e
PU	58	1/2 at 10 DT + 1/2 at 10 DAPI	3.9 f	6.0 cd
PU	58	Single dose at 20 DT	5.0 de	6.3 bcd
PU	58	Single dose at 5-7 DBPI	4.5 ef	5.9 d
PU	58	2/3 B&I without water + 1/3 at 5-7 DBPI	5.2 cde	6.5 bcd
PU	58	2/3 B&I with 2 cm water + 1/3 at 5-7 DBPI	5.0 de	6.7 bcd
USG	58	Hand point placement at 0 DT	6.0 bc	7.1 ab
USG	58	Hand point placement at 10 DT	5.9 bc	6.7 bcd
USG	58	Hand point placement at 20 DT	5.5 cd	6.8 abc
USG+PU	58	1/2 at 0 DT as USG + 1/2 at 5-7 DBPI as PU	5.4 cd	6.7 bcd
USG	116	Hand point placement at 0 DT	7.0 a	7.0 ab
PU	116	2/3 B&I without water + 1/3 at 5-7 DBPI	6.6 ab	7.6 a

[a]Topdressing at 10 DT and before or after panicle initiation was done with 5 cm standing water. [b]CV = 8.4%.

Table 17. Effects of water depth and urea application method on grain yield of early maturing IR58 (98 d) and late maturing IR29723-143-3-2-1 (132 d). IRRI, 1985 WS.

Urea source	N rate (kg/ha)	Application method[a]	Grain yield[b] (t/ha)	
			IR58	IR29723-143-3-2-1
–	0	No fertilizer N	3.5 d	3.9 e
PU	58	1/2 at 10 DT + 1/2 at 10 DAPI	4.4 c	4.8 cd
PU	58	Single dose at 20 DT	4.9 bc	5.3 abc
PU	58	Single dose at 5-7 DBPI	4.9 bc	4.7 d
PU	58	2/3 B&I without water + 1/3 at 5-7 DBPI	4.9 bc	5.4 ab
PU	58	2/3 B&I with 2 cm water + 1/3 at 5-7 DBPI	4.6 bc	5.6 a
USG	58	Hand point placement at 0 DT	5.0 ab	5.0 bcd
USG	58	Hand point placement at 10 DT	5.1 ab	5.2 abcd
USG	58	Hand point placement at 20 DT	4.9 bc	5.1 abcd
USG+PU	58	1/2 at 0 DT as USG + 1/2 at 5-7 DBPI as PU	4.8 bc	5.4 ab
USG	87	Hand point placement at 0 DT	5.5 a	5.3 abc
PU	87	2/3 B&I without water + 1/3 at 5-7 DBPI	5.0 ab	5.6 a

[a]Topdressing at 10 DT and before or after PI was done with 5 cm standing water. [b]CV = 7.5%.

should commence shortly after transplanting to encourage early tillering. Further studies using different soils, however, are needed to ascertain wider adaptability of these findings.

INTEGRATED N MANAGEMENT IN LOWLAND RICE

Biofertilizers. The sixth (DS) and seventh (WS) consecutive crops were grown at IRRI (Table 18) and in a farmer's field in Victoria, Laguna (Table 19), to evaluate integrated N management using combinations of organic and inorganic fertilizer sources. In WS at IRRI, *Sesbania rostrata* as green manure was tested as an alternative N fertilizer source.

Fresh rice straw at both sites and rice straw compost in the farmer's field proved superior to the control in DS. In WS, however, fresh rice straw or rice straw compost gave yields no higher than the control. In DS in the farmer's field, PU and USG performed comparably with fresh rice straw and rice straw compost. Inorganic sources proved superior to fresh rice straw or rice straw compost at IRRI.

Sesbania, when incorporated into the soil as green manure, gave yields comparable to those with PU and significantly higher than those with fresh rice straw and the control (Table 18). In the farmer's field, azolla gave yields higher than those with rice straw compost or fresh rice straw and comparable to those with USG. The same trend was observed at IRRI in DS.

Combining organic sources with PU or USG consistently gave yields higher than the control and, in most cases, comparable to that with PU or USG. In the farmer's field in DS, fresh rice straw or rice straw compost with PU performed better than PU alone.

Commercial fertilizers. The extent to which inorganic fertilizer may be replaced by organic nutrient sources was evaluated in farm trials using three soils of different physical and chemical properties (Table 20). Soil at IRRI was deficient in N and Zn; at MRRTC and in a farmer's field in Pangasinan it was low in N, P, K, and Zn. A

Table 18. Effect of supplementary N fertilizer source on grain yield of IR36. IRRI, 1985.

N source[a]	Grain yield[b] (t/ha)	
	DS (6th crop)	WS (7th crop)
No fertilizer N (control)	3.5 e	2.7 de
Single sources		
PU, best split	6.2 ab	3.6 ab
USG	6.1 ab	3.9 a
Fresh azolla, soil incorporated	6.5 a	3.4 abc
Fresh rice straw, soil incorporated	4.5 cd	2.3 e
Rice straw compost, soil incorporated	4.0 de	3.0 cd
Fresh *Sesbania*, soil incorporated	–	3.3 bc
Combined sources[c]		
Fresh azolla + PU, best split	6.2 ab	3.6 ab
Fresh rice straw + PU, best split	4.9 c	3.0 cd
Rice straw compost + PU, best split	4.9 c	3.4 abc
Fresh azolla + USG	6.1 ab	3.7 ab
Fresh rice straw + USG	5.6 b	3.5 abc
Rice straw compost + USG	5.6 b	3.2 bc

[a]All treatments applied at equal N rates. For best split application, 2/3 urea was B&I at planting and 1/3 top-dressed at 5-7 DBPI. N rate = 58 kg N/ha in WS and 116 kg N/ha in DS. [b]CV is 8% in DS and 10 in WS. [c]For combined applications, 29 kg N/ha each of organic and inorganic sources in WS, and 58 kg N/ha in DS.

Table 19. Effect of supplementary N fertilizer source on grain yield of IR36. Victoria, Laguna, Philippines, 1985.

N source[a]	Grain yield[b] (t/ha)	
	DS (6th crop)	WS (7th crop)
No fertilizer N (control)	4.2 e	2.8 d
Single sources		
PU, best split	5.2 d	3.8 ab
USG	5.9 abcd	4.0 a
Fresh azolla, soil incorporated	6.2 ab	4.0 a
Fresh rice straw, soil incorporated	5.3 cd	3.2 bcd
Rice straw compost, soil incorporated	5.2 d	3.0 cd
Combined sources[c]		
Fresh azolla + PU, best split	5.9 abcd	4.1 a
Fresh rice straw + PU, best split	6.6 a	3.6 abc
Rice straw compost + PU, best split	6.2 ab	4.0 a
Fresh azolla + USG	6.0 abcd	3.8 ab
Fresh rice straw + USG	5.7 bcd	3.7 ab
Rice straw compost + USG	6.1 abc	4.0 a

[a]All treatments applied at equal N rates. For best split application, 2/3 urea was B&I at planting and 1/3 top-dressed at 5-7 DBPI. N rate = 58 kg N/ha in WS and 116 kg N/ha in DS. [b]CV is 9% in DS and 11% in WS. [c]For combined applications, 29 kg N/ha each of organic and inorganic sources in WS, and 58 kg N/ha in DS.

Table 20. Some physical and chemical properties of soils at 0-20 cm depth. IRRI, MRRTC, and farmer's field in Pangasinan, Philippines, 1985 WS.

Soil property[a]	IRRI	MRRTC	Farmer's field
pH (1:1)	6.9	6.3	7.6
Organic C (%)	1.40	1.73	1.34
CEC (meq/100 g)	40	37	41
Total N (%)	0.13	0.13	0.10
Total P (ppm ods)	517	246	206
Available Olsen P (ppm ads)	13	5	3
Exchangeable K (meq/100 g ads)	1.36	0.20	0.09
Available Katyal and Ponnamperuma Zn (ppm ods)	0.25	0.46	0.08
Exchangeable cations (meq/100 g ads)			
Na	1.60	0.69	0.33
Mg	17	14	32
Ca	31	36	23
Particle size (%)			
Sand	17	5	5
Silt	34	43	51
Clay	49	52	44
Texture	Clay	Silty clay	Silty clay
Soil series	Maahas clay	Maligaya silty clay	San Manuel silty clay

[a]ads = air-dried soil, ods = oven-dried soil.

commercial compost was used as the organic fertilizer source.

The researchers' split application of PU with or without added P and K gave the highest yields (Table 21). In the farmer's field and at MRRTC, combining 75% PU and 25% organic fertilizer produced yields comparable to those with PU alone. At IRRI, however, substituting 25% PU with organic fertilizer produced a yield 1 t/ha less than with PU alone. Furthermore, yield increased as the amount of PU in the combination increased. Organic fertilizer, when applied as the primary N source even with applied P and K inorganic sources, produced yields no better than that of the unfertilized control.

These preliminary results show that organic sources partially substituted for inorganic fertilizer in the trials at MRRTC and in Pangasinan.

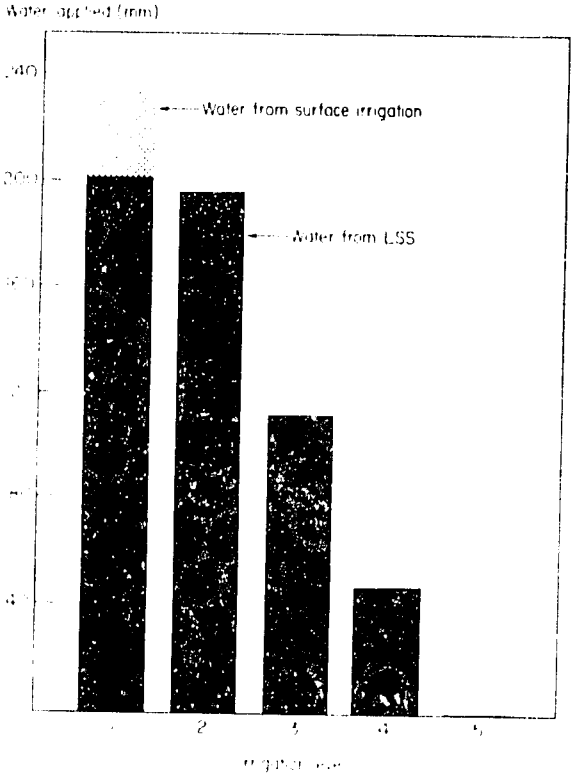
Table 21. Grain yield of IR64 and fertilizer cost as affected by source of fertilizer. IRRI, MRRTC, and farmer's field in Pangasinan, Philippines, 1985 WS.

Fertilizer source[a]	Yield[b] (t/ha)			Cost of fertilizer[c] ($/ha)
	IRRI	MRRTC	Farmer's field	
Unfertilized control	3.7 cd	3.0 d	3.7 c	–
Control + PK	3.4 d	2.7 d	3.7 c	102
Control + PKZn[d]	3.6 cd	2.8 d	4.1 bc	130
25% PU + 75% commercial organic fertilizer	4.1 c	3.3 cd	4.4 b	754
50% PU + 50% organic fertilizer	4.7 b	3.8 bc	4.3 b	556
75% PU + 25% organic fertilizer	4.9 b	4.0 ab	5.0 a	352
All PU without PK[e]	5.9 a	4.4 a	4.9 a	45
All PU with PK[e]	6.0 a	4.3 ab	5.1 a	147
All organic fertilizer without PK	3.8 cd	3.1 d	4.2 bc	887
All organic fertilizer with PK	3.8 cd	3.1 d	4.2 bc	964

[a]Fertilization rate: N = 60 kg/ha, P = 26 kg/ha, K = 50 kg/ha. [b]CV = 8.8% at IRRI, 12.2% at MRRTC, and 7.5% in the farmer's field. [c]Cost of fertilizer material ($/kg) as of Aug 1985: $ZnSO_4 \cdot 7\ H_2O$ = $0.78, PU (46-0-0) = $0.34, ordinary superphosphate = $0.23, muriate of potash (0-0-60) = $0.25, commercial organic fertilizer = $0.12. Conversion rate as of Jun 1985: $1 = ₱17.19. [d]Twenty kg Zn as $ZnSO_4$. [e]Used researchers' split: 2/3 PU without standing water before final harrowing + 1/3 PU topdressed at 5-7 DBPI.

N FERTILIZER MANAGEMENT UNDER SIMULATED RAINFED LOWLAND CONDITIONS

Rice yield response to different fertilizer management techniques was evaluated using the line source sprinkler system (LSS) at five irrigation levels and eight N treatments. IR60 was the test variety. P at 13 kg ha and K at 25 kg/ha were basally applied.



18. Total water applied from line source sprinkler system (LSS) and surface irrigation during stress period. IRRI, 1985 DS.

The field was surface irrigated starting at 3 DT to about 2 cm water depth for seedling establishment. The total water supplied through LSS is given in Figure 18. Irrigation level (L) 1 represented continuously flooded rice; it received the same amount of water from LSS as did L2, but surface irrigation was needed to maintain 5-cm continuous flooding. At 8 DT, the standing water at L2-L5 was allowed to dry by evapotranspiration and percolation. Irrigation by LSS, which was positioned between L1 and L2, started at 14 DT and was used 3 times a week until the end of the vegetative period. L2-L4 received a decreasing amount of water from LSS during the stress period. L5, the most stressed treatment, did not receive water from LSS.

Pan evaporation was used to determine water to be applied by LSS. The whole field was reflooded to about 5 cm from 38 DT to 10 d before harvest.

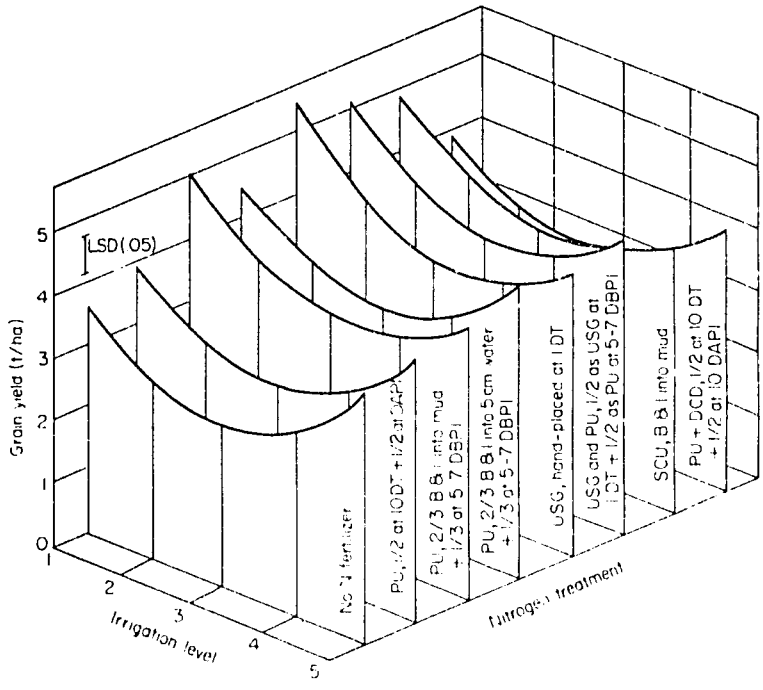
Continuously flooded plots received the highest amount of water (Fig. 18). L2, 3, 4, and 5 received 196, 113, 48, and 0 mm of water from LSS, respectively. The degree of soil cracking increased with increasing water stress. Alternate wetting and drying cycles in L2-L4 were also observed.

Under continuous flooding (L1), the highest yield (5.3 t ha) was obtained with deep-placed USG (Table 22). However, this was not significantly higher than that of the researchers' split of PU (2/3 B&I into mud + 1/3 at 5-7 DBPI). Split application of PU or PU + dicyandiamide at 10 DT and at 10 DAPI gave significantly lower yields than researchers' split of PU or deep-placed USG. At L1-L4, the researchers' split generally gave higher yields than incorporation of N into 5 cm standing water, but yields did not significantly differ. When irrigation water was withheld starting

Table 22. Grain yield of IR60 as affected by irrigation level and N treatment. IRRI, 1985 DS.

N treatment[a]	Yield (t/ha)				
	1	2	3	4	5
No N fertilizer	3.5 d	3.3 c	2.5 d	2.6 c	4.2 a
PU, 1/2 at 10 DT + 1/2 at 10 DAPI	3.8 cd	3.4 c	2.7 cd	3.2 bc	4.2 a
PU, 2/3 B&I into mud + 1/3 at 5-7 DBPI	5.0 ab	4.4 ab	3.4 abc	3.8 ab	4.3 a
PU, 2/3 B&I into 5 cm water + 1/3 at 5-7 DBPI	4.5 bc	3.9 bc	3.2 abc	3.7 ab	4.7 a
USG, hand-placed at 1 DT	5.3 a	4.8 a	3.8 a	3.5 ab	4.7 a
USG and PU, 1/2 as USG at 1 DT + 1/2 as PU at 5-7 DBPI	5.1 ab	4.6 a	3.5 ab	4.0 a	4.8 a
SCU, B&I into mud	4.8 ab	4.3 ab	3.4 abc	3.7 ab	4.3 a
PU + DCD[b], 1/2 at 10 DT + 1/2 at 10 DAPI	3.8 cd	3.5 c	2.9 bcd	3.2 bc	4.3 a

[a]Fertilizer was applied at 58 kg N/ha. [b]DCD = dicyandiamide.



19. Effect of irrigation level and N (58 kg/ha) treatment on grain yield of IR60, IRRI, 1985 DS.

at 10 DT during the vegetative stage (L5), N application regardless of source and method gave no significant increase in grain yield over the no-N fertilizer treatment.

Regardless of N treatment, L3 gave the lowest yield (Fig. 19). This is attributed to alternate wetting and drying, which caused substantial loss of both applied and native N. N losses at L2 and L4 were probably less. Yields at L5 approached those of the continuously flooded plots, perhaps the result of high mineralization of applied and native N after reflooding. Furthermore, the yield of the unfertilized plot was comparable to that of the fertilized plots at L5.

Results suggest that in areas where water supply from rains is limited but soil is relatively fertile, high grain yields can still be attained with modest amounts of N fertilizer. Rice plants require water during the initial seedling establishment, and continuous flooding during the reproductive and ripening periods. But continuous flooding is improbable in most rainfed rice areas in South and Southeast Asia.

Soil and crop management

Nitrogen fixation and azolla management

Soil Microbiology, Entomology, and Training and Technology Transfer Departments

BACTERIAL NITROGEN FIXATION **240**
- Chemotaxonomic characteristics of N_2-fixing *Pseudomonas* from rice roots **240**
- *Azospirillum lipoferum* Str Rif^R inoculation **240**
- Standardization of rice plant-associated ARA **240**
- Plant ARA and growth characteristics of short and long duration varieties **241**
- Varietal differences in associative N_2 fixation **241**
- N_2 fixation, microbial population, and straw application **241**
- ^{15}N dilution techniques **242**

PHOTODEPENDENT NITROGEN FIXATION **243**
- Blue-green algae collection **243**
- Standardization of ARA measurements **243**
- Occurrence of N_2-fixing BGA in rice soils **244**
- Composition of soil-based inocula **244**
- Composition and biomass of BGA from ricefields **244**
- Fate of inoculated BGA **245**
- Agricultural practices to enhance BGA growth **245**
- Invertebrate fauna in floodwater **246**

AZOLLA-*ANABAENA* SYMBIOSIS **246**
- Azolla collection and distribution **246**
- Response of azolla to high temperature **246**
- Growth in the field **246**
- Azolla growth under rice **247**
- Nutrient content of azolla **247**
- Method of P fertilizer application **247**
- Culture of rice and azolla in wide-narrow row spacing **248**

AZOLLA INSECT PESTS **248**
- Confirmed insect pests and their distribution **248**
- Life cycle and prevalence of four pyralid moths **248**
- Standing biomass and yield loss **250**
- Standing plus harvested biomass and yield loss **251**
- Production biomass and yield loss **251**

AZOLLA APPLIED RESEARCH **252**
- Rice yield response to azolla **252**
- Azolla growth trials **253**

239

Soil Microbiology Department

Chemotaxonomic characteristics of N_2-fixing *Pseudomonas* from rice roots. Deoxyribonucleic acid (DNA) base composition, ubiquinone, and cellular fatty acid analyses of some bacterial isolates from rice were made in collaboration with H. Kuraishi of the Tokyo University of Agriculture and Technology. DNA GC content of *Pseudomonas* was 65% in strain H8 and 67% in KLH76. Several isolates of *Pseudomonas* had ubiquinone Q10 as the major isoprenoid. Rhizobia, mostly from *Sesbania* spp., *Azospirillum amazonense*, *Alcaligenes latus*, *Xanthobacter autotrophicus*, and some strains of *Azospirillum lipoferum* and *A. brasilense*, also had Q10. *Herbazopirillum seropedicae*, Enterobacteriaceae, Azotobacteriaceae, and some strains of *A. brasilense* had Q8. All strains of *Pseudomonas* tested had straight chain fatty acids C18:1 (63-85% of total fatty acids) and C18:0 and C16:0 (<10% to trace). Among hydroxy fatty acids, 3-OH C14:0 was present in large amounts (22-37%) in all strains of *Pseudomonas*. Fatty acid contents and ubiquinone type suggest that *Pseudomonas* strains from rice belong to a new species of group 4 of Komagata's classification. An unidentified N_2-fixing rice isolate, SGBP (slow-growing black pigmented) did not contain 3-OH fatty acid C14:0 but had 3-OH C12:0 and 2-OH C14:0, suggesting that it differs from *Pseudomonas* strains.

***Azospirillum lipoferum* Str Rif^R inoculation.** *A. lipoferum* 34H, resistant to streptomycin and rifampicin, was inoculated through peat as the carrier into Maahas clay in pots in the greenhouse 10 d before rice varieties OS4 and Hua-chou-chi-mo-mor (Hua) were transplanted. The inoculated bacteria were detected by antibiotics in Congo red agar plates and were further checked by fluorescent antibody reaction and acetylene-reducing activity (ARA). Inoculated bacteria could survive in the soil and around the roots and stems of both varieties, but declined progressively and became absent from the soil and stems of both varieties at heading. The control treatment (inoculated boiled cells) had no antibiotic-resistant bacteria

Inoculation enhanced flowering and grain production of both varieties. In Hua, inoculation increased the dry weight of roots by 81%, leaves by 24%, and submerged culm and leaf sheath by 23%. The increases in OS4 were 45% for roots, 12% for leaves, and 38% for submerged culm and leaf sheath (Table 1). Inoculation increased grain yield by 18% for Hua and 11% for OS4. Total N uptake also increased 20% in OS4 and 7.2% in Hua.

The effect of inoculation on N_2 fixation associated with the rice plant was studied by in situ acetylene reduction assay, $^{15}N_2$ incorporation, and ^{15}N dilution. ARA was not affected by inoculation at two early stages but was significantly lower in the inoculated plants at heading. There were also no significant differences in $^{15}N_2$ incorporation and ^{15}N dilution between control and inoculated treatments.

It is unlikely that the yield and total N increases in both varieties due to inoculation were attributable to the enhancement of N_2 fixation.

Standardization of rice plant-associated ARA. Our modified method measures the ARA of the excised plant in the dark at a constant temperature to avoid the effects of climatic conditions in the field. The sampling time (0800, 1100, and 1600 h) did not influence 6-h ARA when sampling was made from 3 varieties for 3 consecutive days. A modified plant sampling procedure for ARA assay

Table 1. Dry matter yield responses of rice to inoculation with *Azospirillum lipoferum*. IRRI, 1985.

Variety	Treatment	Dry weight (g/pot)					N (mg/pot)
		Root	Straw	Submerged culm and leaf sheath	Grain	Total	
OS4	Control	5.5	36.3	5.8	35.7	83.3	638
	Inoculated	8.0*	40.6*	8.0*	39.5*	96.1*	765*
Hua	Control	2.6	32.0	3.5	40.4	78.5	719
	Inoculated	4.7*	39.9*	4.3	47.8*	96.7*	770

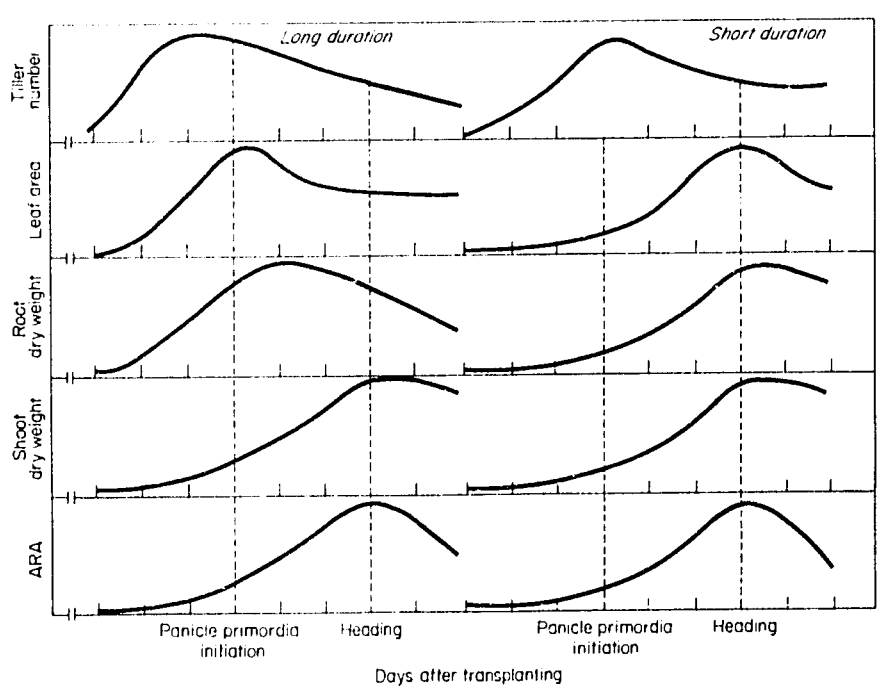
was used in 1985 dry season (DS). Two plants per block from 3 blocks for 3 consecutive days (total of 18 plants/variety) were sampled at heading. Selection of rice hills with average tiller number could minimize plant-to-plant ARA variation.

Plant ARA and growth characteristics of short and long duration varieties. Plant ARA and other plant characteristics (root and shoot dry weights, tiller number, and leaf area) over a growth cycle were determined by sampling plants of 8 long and 8 short duration varieties from 21 d after transplanting (DT) until about 20 d after heading at 10-d intervals (Fig. 1). The trends of ARA and shoot dry weight were similar in both groups, showing a peak at heading, followed by a sharp decline of ARA and gradual decline of shoot dry weight. Leaf area and root dry weight trends were similar among short duration varieties, with peaks at heading. Root dry weight and leaf area of long duration varieties declined before heading. Maximum tillering occurred after panicle initiation in the short duration varieties, and before in the long duration varieties.

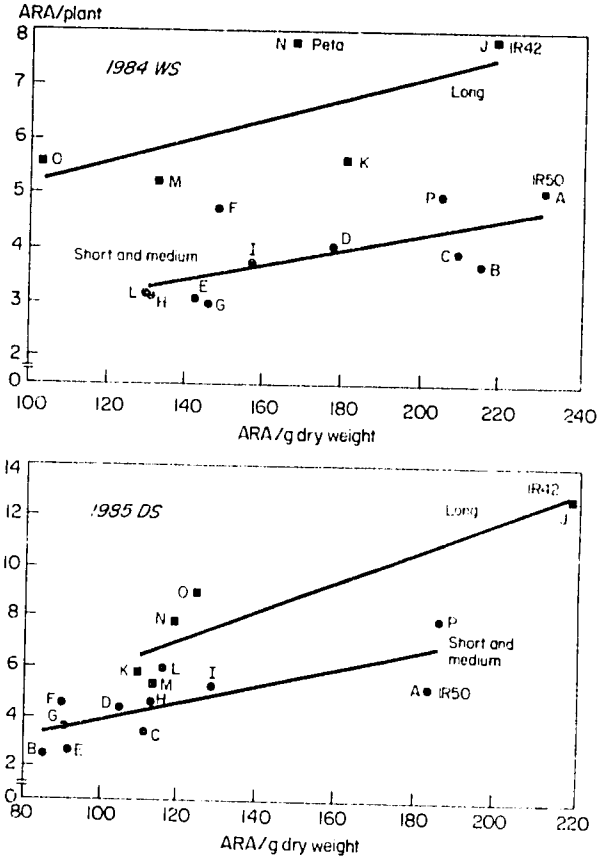
Varietal differences in associative N_2 fixation. Using the standardized method, the ARA of N_2 fixation of 16 rice varieties was studied during 1984 wet season (WS). The F values for both groups increased from the vegetative stage to heading. The CV of ARA among blocks also tended to decrease toward heading.

Differences in ARA per plant and per unit plant dry weight among varieties of short and long duration groups were significant in both seasons (Fig. 2). Plant ARA significantly correlated with root, shoot, and total plant biomass at heading, and with total plant biomass at harvest. Generally, the higher the plant biomass, the higher was the ARA, with some exceptions. Traditional varieties like Peta and Rodjolele had high plant biomass but low ARA. Although IR50 had short growth duration and produced lower biomass, its ARA was similar to that of some long duration varieties with high biomass. In both seasons, IR42 among the long duration group and IR50 among the short duration group had the highest ratios of ARA to their plant biomass.

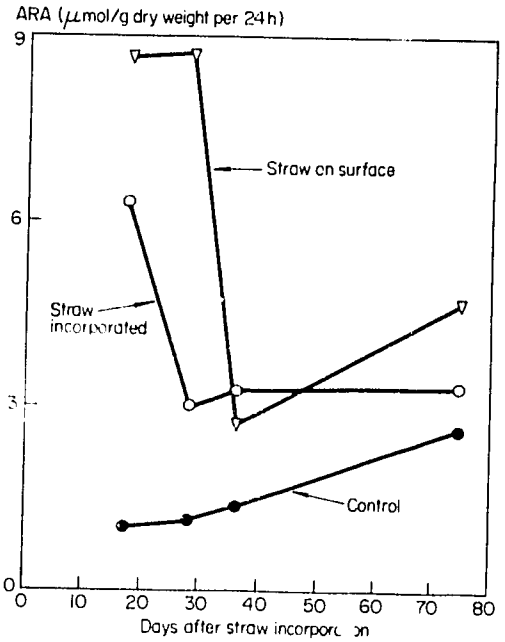
N_2 fixation, microbial population, and straw application. In 1983, a field experiment was started on the effects of straw incorporation on N_2 fixation associated with plant and soil bacterial populations



1. Trends of rice plant acetylene reducing activity (ARA) and plant characteristics in long and short duration varieties. IRRI, 1984 WS.



2. ARA per plant vs ARA per g dry weight of plant. Long duration varieties (■): J = IR42, O = Rodjolele, P = IR20, N = Peta, L = IR13540-56-3-2-1, K = IR22082-4-1-2, F = IR18349-135-2-3-2-1, and M = IR15314-30-3-1-3; short duration varieties (●): A = IR50, I = IR13420-45-82-2-3-2-3-1, D = IR36, G = IR31802-48-2-2-2-3189, C = IR9729-67-3, E = IR21912-56-3-1-2-2, and B = IR19728-9-3-2-3-3. IRRI, 1984 WS and 1985 DS.



3. ARA of nonrhizospheric soil with and without straw application. IRRI, 1985 DS.

and rice plant growth. In 1985 DS, surface application of straw was added as a treatment.

Surface application of straw showed significantly higher ARA in the soil at early stages of application (Fig. 3). In general, straw application stimulated the populations of total and N_2-fixing heterotrophic bacteria and photosynthetic purple nonsulfur bacteria in the soil. The population of the last, in particular, was significantly higher in the surface-applied straw treatment in several samplings throughout the rice growth cycle (Table 2). The surface layer of soil (0-1 cm) had higher average populations of heterotrophs and N_2 fixers than the subsurface layer (1-15 cm) in the control and straw-treated plots (Table 3).

^{15}N dilution techniques. To determine the dependence of rice N nutrition on soil N or biologically fixed N, ^{15}N contents were measured in rice plants grown in flooded soil with ^{15}N-labeled $(NH_4)_2SO_4$. Two series of concrete pots were used. In series A of 1984 WS, 16 varieties were placed in 4 groups based on growth duration. Rodjolele in group 3 and TKM6 in group 4 gave the lowest ^{15}N in their grains, compared with Palawan and N22 as references. In series B in 1984 WS, significant differences were observed in two out of four groups. IR42 and Hua-chou-chi-mo-mor had the lowest ^{15}N content in the grains.

Table 2. Population of photosynthetic purple nonsulfur bacteria in the surface layer (0-1 cm) of soil. 1985 DS.

Days after straw application	Population (log cells/g dry soil)		
	Control	Straw incorporated	Straw surface-applied[a]
-2	3.10	3.62*	3.62*
10	3.04	3.52*	5.35* (6.0)
20	2.44	2.66	4.25* (4.56)
34	3.11	3.76	4.35* (5.41)
54	2.89	3.23	3.07
90	3.01	3.23	4.22*

[a]Values in parentheses are log number of cells/g dry straw.

Table 3. Population of total and N_2-fixing heterotrophs in surface (0-1 cm) and subsurface (1-15 cm) layers of soil after straw application.[a] IRRI, 1985 DS.

Treatment	Population (log cells/g dry soil)			
	Total heterotrophs		N_2-fixing heterotrophs	
	Surface	Subsurface	Surface	Subsurface
Control	6.41	5.96	4.71	4.30
Straw incorporated	6.45	6.02	4.73	4.42
Straw surface-applied	6.72	6.09	5.35	4.61

[a]Based on average population at 2 d before straw application and 10, 20, 34, 54, and 90 d after straw application.

In series A in 1985 DS, 10 varieties were laid out in a balanced incomplete block design with 4 varieties in each block (concrete pot) (Table 4). IR9729-67-3 and IR58 had higher ^{15}N than IR31917-31-3-2 and IR15314-30-3-1-3. Among 6 experiments from 1982 to 1985, the largest difference in ^{15}N in grains of test varieties was 25% lower than that in the reference varieties.

The natural abundance of ^{15}N in grains was also studied. Because the ^{15}N isotope ratio in available soil N varies with depth, well-mixed soil was put in pots, and rice varieties were planted in them. The pots were placed in a rice canopy. The ^{15}N isotope ratios were analyzed in cooperation with T. Yoneyama of the National Institute of Agricultural Resources, Japan. The $\delta^{15}N$ values (in parts per thousand) in grains were 5.2 for IR18349-135-2-3-2-1, 6.0 for Hua-chou-chi-mo-mor, 6.0 for IR50, 6.1 for IR42, 6.45 for OS4, and 6.5 for Rodjolele (SE = 0.17).

Table 4. Atom percent excess (APE) of ^{15}N in grains of plot A. IRRI, 1985 DS.

Variety or line	Growth duration (d after transplanting)	APE ^{15}N (%)
IR9729-67-3	86	0.540
IR58	86	0.538
IR36	86	0.528
IR13540-56-3-2-1	100	0.506
IR42	113	0.502
OS4	86	0.500
Hua-chou-chi-mo-mor	86	0.492
IR15314-30-3-1-3	105	0.482
IR22082-4-1-2	100	0.473
IR31917-31-3-2	105	0.467
SE		0.022

PHOTODEPENDENT NITROGEN FIXATION

Soil Microbiology Department

Blue-green algae collection. The current blue-green algae (BGA) collection comprises 150 strains, mostly from ricefields (Table 5). Sixty-five strains from the ORSTOM collection in Senegal were transferred to IRRI in 1985. Short-term preservation in the dry state of nonaxenic material permitted their easy transport.

Standardization of ARA measurements. We studied the photodependent ARA of wetland soil samples and laboratory cultures of BGA in the presence of soil under a range of experimental conditions. We compared two methods of measurement under constant temperature (25 °C) and light intensity (20 klux). One method used undisturbed

Table 5. Number and origin of the collection of blue-green algae. IRRI, 1985.

Genus or type	Blue-green algae (no.)			
	Philippines	West Africa	Other	Total
Anabaena	5	13	18	36
Aphanothece	1	0	0	1
Aulosira	0	1	1	2
Calothrix	5	16	0	21
Cylindrospermum	1	3	0	4
Gloeotrichia	3	1	0	4
Fischerella	7	0	0	7
Nodularia	1	2	1	4
Nostoc	12	15	9	36
Scytonema	1	6	1	7
Tolypothrix	0	0	4	4
Nonfixing	0	9	0	9
Other	4	7	0	11
Total	40	72	34	150

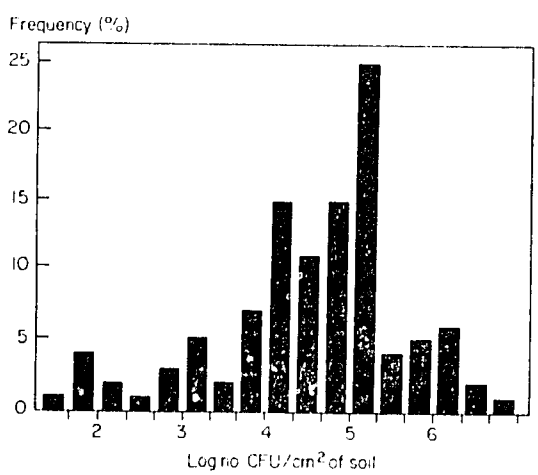
composite soil core samples and the other, composite samples obtained by collecting and mixing floodwater and the first millimeters of soil. In the second method, samples were gently shaken during incubation.

Frequently, results from the two methods did not differ significantly. Apparently, in soil-water samples the decrease in ARA because of increased water turbidity is balanced by an unknown process that could be better diffusion and recovery of gases than with undisturbed soil cores.

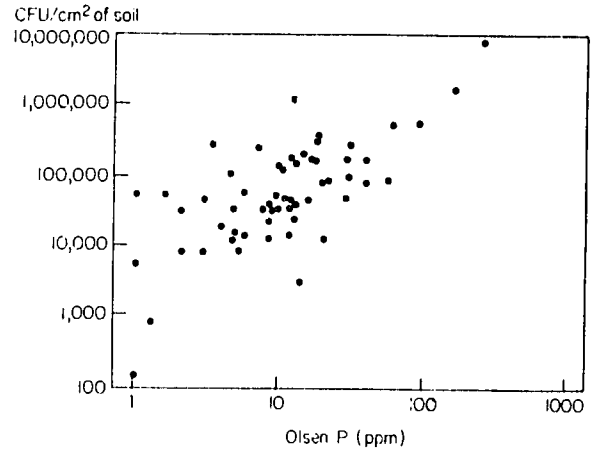
Samples comprising only floodwater and the first millimeters of soil are easier to collect than core samples; because they can be homogenized, their utilization permits more reproducible measurements of ARA.

Occurrence of N_2-fixing BGA in rice soils. A comprehensive bibliographic study and a survey of rice soils from 5 countries (Fig. 4) indicated that BGA are present in all rice soils. Densities ranged from a few dozen to more than 10^6 colony-forming units (CFU)/cm^2 of soil; the median was 8×10^4 CFU/cm^2. An abundance of heterocystous BGA in rice soils was positively correlated with soil pH and available P content (Fig. 5).

The field survey and bibliographic study showed that *Nostoc* spp., *Anabaena* spp., and *Calothrix* spp. are present in 80% or more of the rice soils studied. *Nostoc* was frequently the dominant genus and comprised 61% of the CFU of heterocystous BGA that we recorded. Other major taxa, in decreasing order of abundance, were unicellular



4. Density of heterocystous BGA in 109 rice soils sampled from 5 countries. 1985. CFU = colony-forming unit.



5. Abundance of heterocystous BGA in relation to available Olsen P of the soil ($R = 0.87^{**}$). IRRI, 1985.

BGA (20%), *Anabaena* (9%), *Calothrix* (7%), and *Fischerella* (2%).

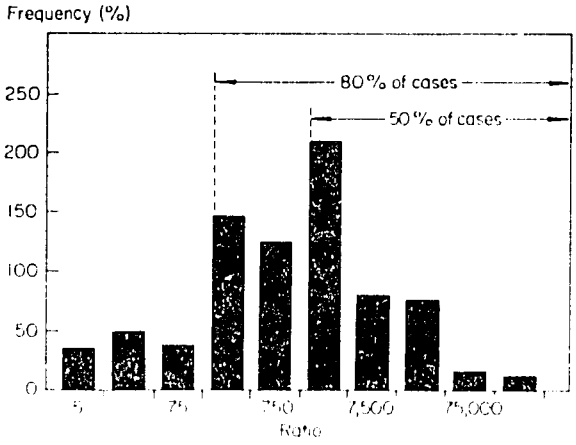
Among the 37 genera and 248 species of heterocystous BGA listed by Desikachary, about two-thirds have been recorded in ricefields, indicating that BGA found in flooded ricefields are not specific to those conditions.

Composition of soil-based inocula. The density of N_2-fixing BGA in 20 soil-based inocula ranged from 10^5 to 3×10^7 CFU/g dry weight. *Nostoc* was consistently the dominant genus in the multistrain soil-based inocula studied.

Most frequently the number of CFU of N_2-fixing BGA in the quantity of inoculum recommended for application (10 kg/ha) is considerably smaller than that of indigenous BGA. The ratio of indigenous to inoculated BGA was larger than 100 in 80% of the cases and larger than 1,000 in 50% (Fig. 6), indicating that inoculation is not the only possible way of utilizing BGA; emphasis should also be placed on agricultural practices that enhance indigenous BGA growth.

Composition and biomass of BGA from ricefields. Analysis of cultures and natural samples of N_2-fixing BGA showed that soil-grown and field samples have much higher ash contents and lower N contents than laboratory cultures (Table 6).

A positive correlation between P and N contents was observed for P values lower than 1% (Fig. 7). Field samples were P-deficient (<0.5%), indicating that P is a major limiting factor for BGA growth in ricefields.

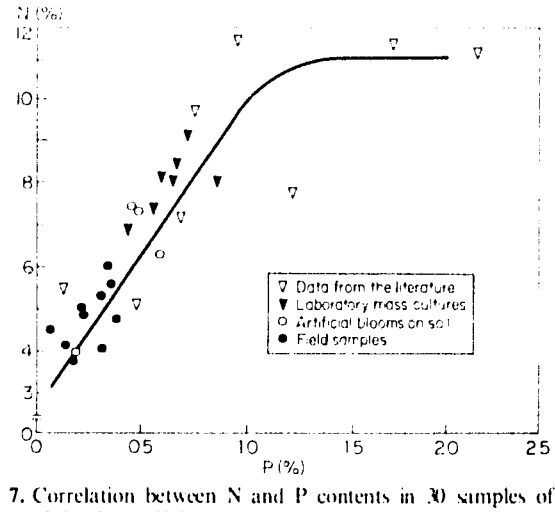


6. Ratio of indigenous N_2-fixing BGA to BGA in the recommended dose of inoculum (10 kg) calculated from enumeration of BGA in 120 rice soils from 6 countries and 20 inocula from 4 countries. IRRI, 1985.

Principal component analysis of the composition of strains grown under laboratory conditions indicated that composition is more influenced by the physiological state of the strain, especially its age, than by its taxonomical position.

Table 6. Average composition of cultures and field samples of N_2-fixing BGA from ricefields. IRRI, 1985.

	Laboratory cultures	Field samples
Ash (% dry weight)	5-9	30-70
N (% dry weight)	5-11	3-7
P (% dry weight)	0.7-1.0	0.2-0.5



7. Correlation between N and P contents in 30 samples of N_2-fixing BGA. IRRI, 1985.

Studies of BGA blooms and crusts showed that a visible growth of BGA usually corresponds to less than 10 kg N/ha, a dense bloom may correspond to 10-20 kg N/ha, and higher values (20-45 kg N/ha) occur only under artificial conditions such as in experimental microplots or in soil-based inoculum production plots.

Fate of inoculated BGA. In microplot greenhouse experiments in 1984, BGA inoculated in wetland soils rarely became dominant. In only a single case among 10, when grazers were controlled, did an inoculated strain of *Aulosira fertilissima* form a bloom; in the other cases, blooms of indigenous strains were observed.

In 1985, a similar experiment was conducted in newly flooded upland Maahas soil. The initial population of heterocystous BGA was about 10^3 CFU cm^2. Combinations of algal inoculation with various treatments of P and natural pesticide resulted in an N balance ranging from −17 to 134 kg N/ha (av 25 kg/ha) during a 2-mo submersion period (Table 7). The average balances in inoculated plots were higher than those in the corresponding noninoculated plots, but the differences were not statistically significant, whereas the effects of P and natural pesticide were highly significant.

Agricultural practices to enhance BGA growth. In a field experiment in an acidic soil (Luisiana), neither presoaking rice seedlings in BGA culture, nor BGA inoculation showed any statistically significant effect on grain yield.

A WS field experiment at IRRI indicated that split P application may be more efficient than basal

Table 7. Effect of P fertilizer, natural insecticide, molluscicide application, and BGA inoculation on N balance in upland Maahas soil submerged for 2 mo.[a] Microplot greenhouse experiment, IRRI, 1985.

Treatment			N balance (kg/ha)		
P	Neem	Endod	Noninoculated	Inoculated	Difference
−	−	−	−9	21	30
−	−	+	−17	−13	4
−	+	−	16	17	1
−	+	+	16	30	14
+	−	−	16	27	11
+	−	+	0	23	23
+	+	−	70	134	64
+	+	+	26	52	26

[a]Effect of P and pesticides both highly significant. Effect of inoculation not significant at the 5% level.

application in increasing photodependent ARA. Surface application of N fertilizer inhibited N_2 fixation more drastically than deep placement.

The slightly larger yield values in all inoculated plots were not statistically different from the control. The response to BGA inoculation was variable and small, and the experimental error was larger than the response.

Invertebrate fauna in floodwater. Invertebrate fauna was surveyed in six fields in India. Grazers comprised 68 of 82 taxa in farmers' fields and 50 of 77 taxa at the experiment station, which was irrigated by wells. The total number of taxa recorded was also lower in the experimental fields. Taxa described in Philippine ricefields sufficed to describe those in Indian ricefields. Ostracods were less dominant in irrigated experimental fields than in rainfed ricefields in the Philippines. At sites where pesticides might have been applied heavily, mosquito larvae and mollusks were dominant, but not ostracods.

AZOLLA-*ANABAENA* SYMBIOSIS

Soil Microbiology Department

Azolla collection and distribution. *A. filiculoides* collections from Colombia were added to the azolla collection. A total of 158 collections are now maintained. We received 11 lines of *Anabaena*-free azolla from natural populations, germinating sporophytes, or apex tissue culture (Table 8). A total of 200 collections were sent to 25 scientists in 13 countries upon their request. *A. microphylla* #418 was requested most often.

Response of azolla to high temperature. We tested the growth of azolla strains from Brazil (#307-315) at 22, 29, and 33 °C with 8 °C difference between day and night (12:12 h) under 20 klux light.

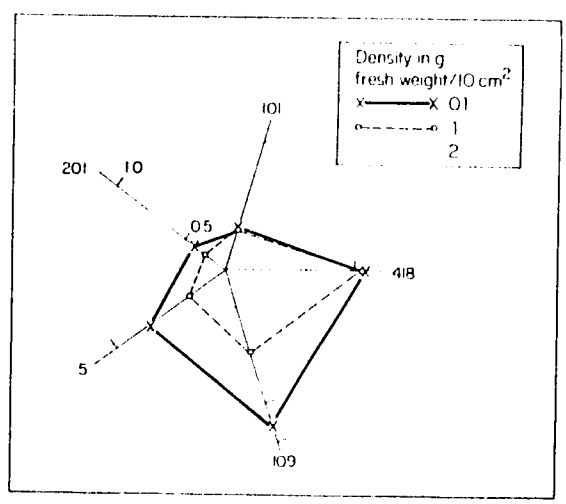
Azolla was grown up to 16 d. Except #315, all grew better at 29 and 33 °C than *A. filiculoides* #101 and *A. caroliniana* #301. Some strains like #308 and #309 produced at 33 °C biomass similar to that of *A. microphylla* #418. Azolla #309 and #310 are likely to be *A. mexicana* from their morphology of megasporocarps and microsporocarps. Growth of *Anabaena*-free *A. filiculoides* was compared with that of symbiotic *A. filiculoides* #101 at 22 and 33 °C. High temperature (33 °C) greatly reduced growth of *Anabaena*-free azolla and, to a greater extent, symbiotic azolla, suggesting that the low temperature tolerance of *A. filiculoides* is governed mostly by host-plant characteristics and, to a smaller extent, by symbiotic algae. The ARA of azolla grown for 2-4 d at high and low plant density at 33 °C and 29 °C was measured as a quick test for high temperature tolerance. High temperature at high plant density affected *A. microphylla* #418 least and *A. filiculoides* #101 most (Fig. 8).

Growth in the field. Azolla growth was studied at IRRI from January to May 1985. Strains used were mainly those from Brazil that had been tested for temperature response. Maximum biomass accumulated in January-February was plotted against that accumulated in April-May, a hotter period in which the growth was poorer (Fig. 9).

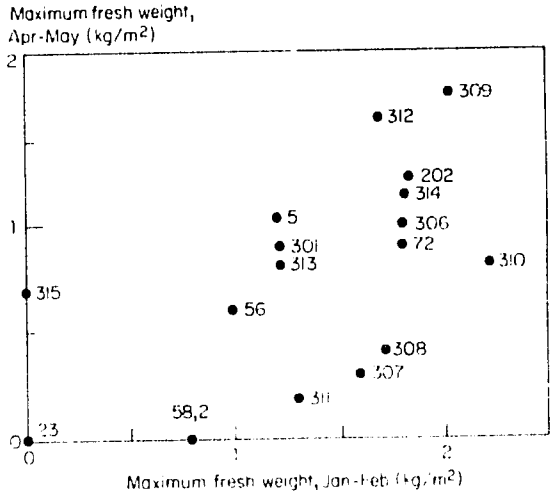
Table 8. *Anabaena*-free lines of azolla. IRRI, 1985.

Accession no.	Species	Parent accession no.	Method[a]
97	*A. pinnata*	2	T
112	*A. filiculoides*	Unknown	S
129	*A. filiculoides*	Unknown	–
130-131	*A. filiculoides*	Unknown	N
132-133	*A. filiculoides*	101	S
206	*A. mexicana*	201	S
425, 427, 429	*A. microphylla*	418	S

[a]T = from tissue culture, S = from germinating sporocarp, N = from natural population.



8. Ratio of average ARA at 2 and 4 d to ARA at 0 d grown at 37/29°C at 3 plant densities. IRRI, 1985.



9. Maximum fresh weight of field-grown azolla accessions in 2 periods. IRRI, 1985.

Strains #309 and #312 showed best performance in both periods. Most azolla achieved maximum biomass 5-7 wk after inoculation (WAI) of 0.1 kg fresh weight/ m^2. *A. pinnata* var. *imbricata* #5 grew faster than the 300 series. In June and September 1985, #309 and #310 gave the highest biomass, almost similar to that of *A. microphylla* #418.

Azolla growth under rice. A clear-cut relationship exists between growth of azolla and light intensity on its surface, expressed as:

$$\text{Dry weight (g/m}^2) = 9.50 + 0.30X \qquad (r = 0.902)$$

where X is average daily solar radiation (mWh/ cm^2 per d) during the 10 d before harvest of azolla. Azolla strains differ in ability to grow under shade, *A. microphylla* being more tolerant than *A. pinnata* var. *pinnata*.

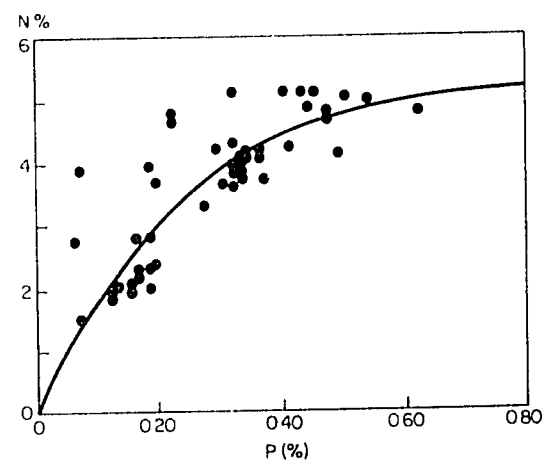
The presence of azolla depresses the increase of pH and O_2 concentration in floodwater during daytime by inhibiting the penetration of light and, hence, the photosynthetic activity of aquatic flora. Azolla density of 600-800 g fresh weight/ m^2 decreases light penetration by 90%.

Nutrient content of azolla. Analyses of azolla from various sites in the Philippines and from INSFFER trials showed tnat its N content is proportional to its P content where contents are below 0.4% P and 4% N (Fig. 10). When the P content is above 0.4%, increase of P does not increase N content. N content of azolla (123 samples) from ricefields in Leyte averaged 2.98% (median 2.93%, maximum 4.75%, minimum 2.02%). Only 4% of the samples had a N content higher than 4%. Their P content averaged 0.17% (median 0.16%, maximum 0.47%, minimum 0.07%). Only 4% of the samples had a P content higher than 0.4%. Three-fourths of the samples contained less than the critical P limit of 0.16%. Azolla in farmers' fields is thus deficient in P, low in N, and probably low in growth rate.

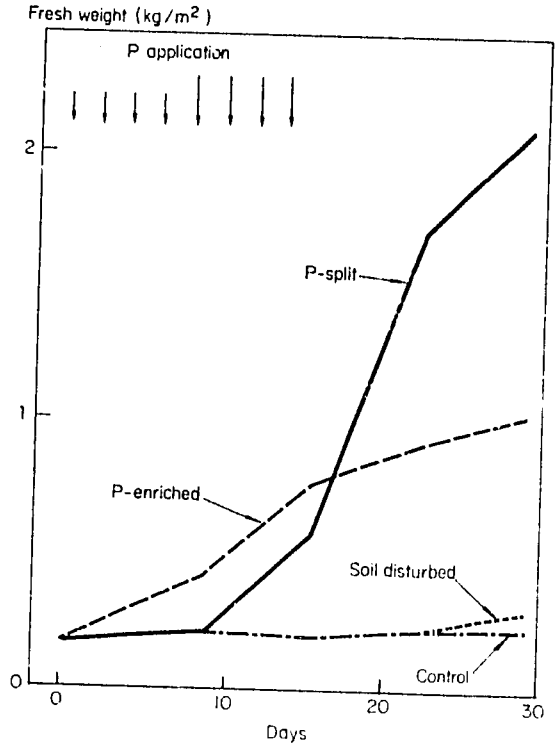
Method of P fertilizer application. In most soils, azolla is deficient in P, so it is necessary to use P fertilizer or soil P more efficiently. We compared 1) fertilizer P split application (6.55 kg P/ha = 10 times split), 2) inoculation of P-enriched azolla, 3) soil disturbance, and 4) no-P control. Enriched azolla (*A. microphylla* #418) received P fertilizer twice in the inoculum preparation field. At 2-d intervals, 10 kg P/ha was applied, and harvest was 2 d after final P application.

The azolla was then inoculated in the field. Because the biomass in the inoculum preparation field was 2 kg fresh weight/ m^2 and the inoculum rate was 0.15 g/ m^2, the amount of P received corresponded to 1.88 kg P/ha in the main field. The azolla thus enriched contained 1.2% P. The growth rate of P-enriched azolla was better for the first week than that of the split-P treatment. P-enriched azolla grew until its P content decreased to 0.2%. It yielded 1.0 kg fresh weight/ m^2 (Fig. 11).

Soil disturbance was aimed at releasing soil P to the floodwater; however, it neither increased floodwater P nor azolla growth.



10. N and P contents of azolla. IRRI, 1985.



11. Growth of azolla as affected by P application, pretreatment with P, and soil disturbance. July 1985.

Final N yields were 65 kg/ha in the split-P treatment and 18 kg/ha in the P-enriched treatment. The ratios of N yield to P applied were the same, showing that application of P only in the inoculum preparation field is a promising way to save P fertilizer.

Culture of rice and azolla in wide-narrow row spacing. Wide rows were alternated with narrow rows to allow more space for azolla grown at 25 hills/m^2. The experimental design resembled previous ones, except *A. microphylla* was inoculated (Table 9). The 13th crop was the final one.

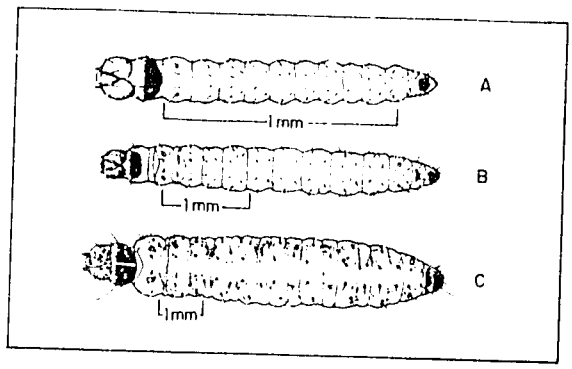
AZOLLA INSECT PESTS

Entomology Department

Confirmed insect pests and their distribution. One specimen of *Bagous affinis* Hustache (Col., Curculionidae) was collected on azolla in Banaue, Ifugao, Philippines, on 20 Jan. An *Elophila* species (caseworm) was identified as *Elophila nigralbalis* (Caradja). The larval and pupal stages of *Ephestiopsis vishnu* (spinning worm) are shown in Figures 12-14. Further distributions of 4 pyralid moths were newly confirmed: *E. vishnu* in Antique, Aklan, Negros Occidental, and southern Palawan; *Elophila enixalis* in Occidental Mindoro; *E. nigralbalis* in Occidental Mindoro, all four provinces of Panay, and Leyte; and *Elophila responsalis* in Aklan.

Life cycle and prevalence of four pyralid moths. *Ephestiopsis vishnu* required about 20 d from egg deposition to emergence and produced 246-370 eggs/pair, whereas 3 *Elophila* spp. required about 31-32 d and produced 44-478 eggs/pair (Table 10).

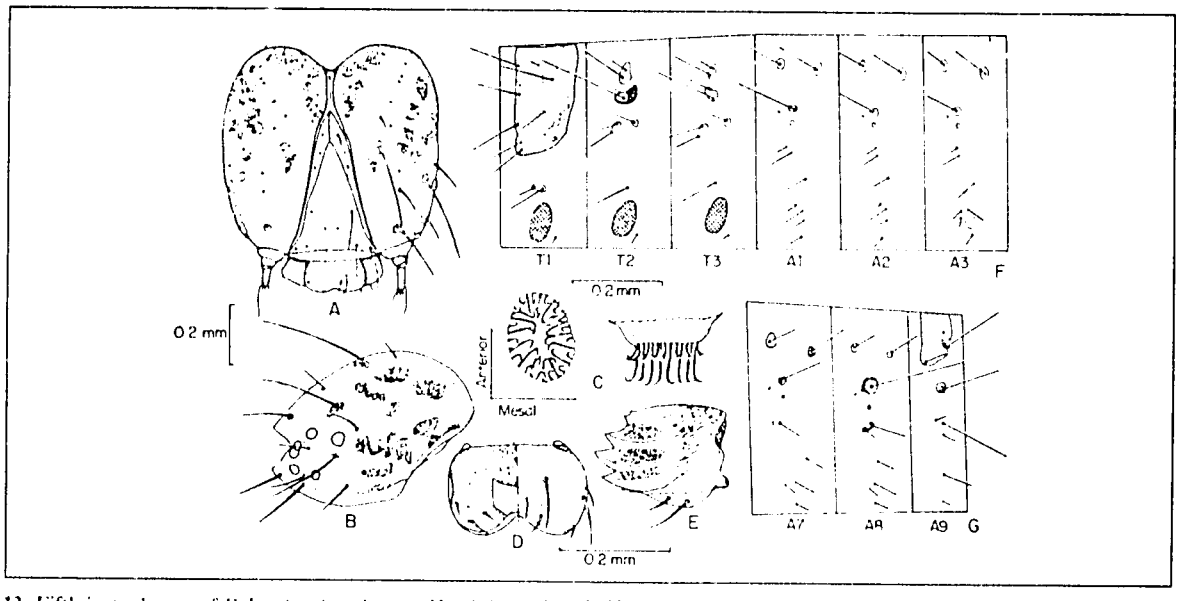
The seasonal prevalence of the four major pyralid moths at IRRI was surveyed. Daily adult



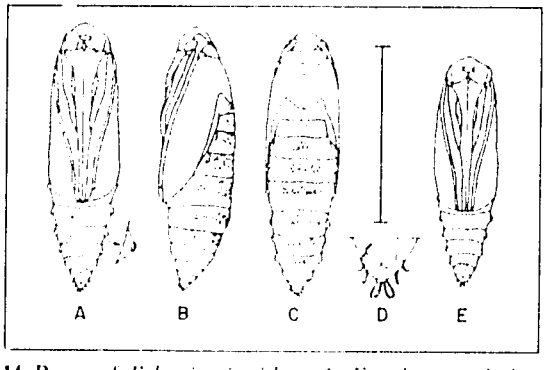
12. Larvae of *Ephestiopsis vishnu*. A. 1st instar. B. 2d instar. C. 5th (last) instar. IRRI, 1985.

Table 9. Dual culture of rice and azolla. IRRI, 1984 WS and 1985 DS.

Trial sequence	Rice varieties and crop duration	Chemical N applied (kg/ha)	Split ratio	Azolla incorporation		Rice grain yield (t/ha)		
				Number	N content (kg/ha)	No N	Chemical	Azolla
12th	IR56 Jun - Aug 84	60	1:1:1	4	83	3.7	4.4	4.4
13th	IR56 Nov 84 - Jan 85	60	1:1:1	4	62	3.4	4.4	4.3



13. Fifth-instar larvae of *Ephestiopsis vishnu*. A. Head, front view. B. Head, lateral view. C. Claw of proleg. D. Labrum. E. Mandible, inner view. F. Chaetotaxy, thorax to 3d abdominal segment. G. Chaetotaxy, 7th to 9th abdominal segments. IRRI, 1985.



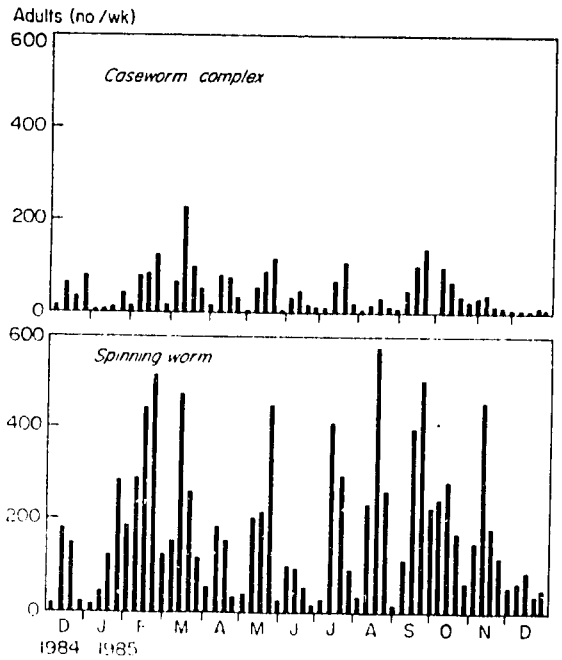
14. Pupae of *Ephestiopsis vishnu*. A. Female, ventral view. B. Female, lateral view. C. Female, dorsal view. D. Female, 10th segment, ventral view. E. Male.

light trap catches were recorded throughout the year in the same manner as in 1984. The highest catches were in caseworm complex in March and the spinning worm in February. There were usually more spinning worms than caseworms (Fig. 15); 12,406 adults of the 4 pyralid moths were collected in 1985, of which *Ephestiopsis vishnu* was 79.3% and the caseworms 20.7%. More females were collected than males except for *Elophila enixalis* (Table 11).

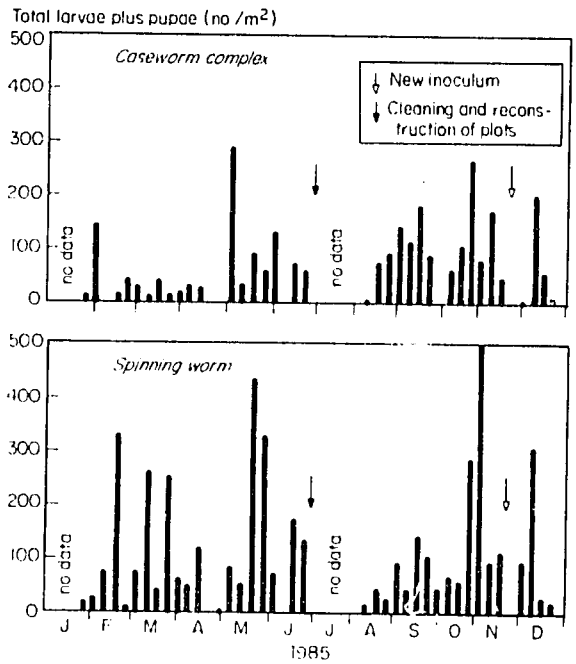
Weekly surveys were made of larval and pupal populations on standing biomass of untreated *A. microphylla* #418 and *A. pinnata* var. *imbricata* #5 at IRRI. On *A. microphylla*, caseworm complex

Table 10. Life cycle of 4 pyralid moths on *A. pinnata* var. *imbricata* at 27 ± 3°C. IRRI, 1985.

	Ephestiopsis vishnu	*Elophila enixalis*	*Elophila nigralbalis*	*Elophila responsalis*
Duration (d)				
Egg	3	4	5	5
Larva	12	21	20	20
Pupa	5	6	6	7
Total	20	31	31	32
Adult longevity (d)				
Male	3-4	2-7	1-4	1-6
Female	3-7	2-7	2-6	2-6
Eggs (no./pair)				
Av	310	252	236	344
Range	246-370	196-346	44-414	253-478



15. Light trap catches of caseworms *Elophila enixalis*, *E. nigralbalis*, and *E. responsalis* and of the spinning worm *Ephestiopsis vishnu*. IRRI, 1985.



16. Weekly larval and pupal samples of caseworms and the spinning worm on *A. microphylla* in untreated plots. IRRI, 1985.

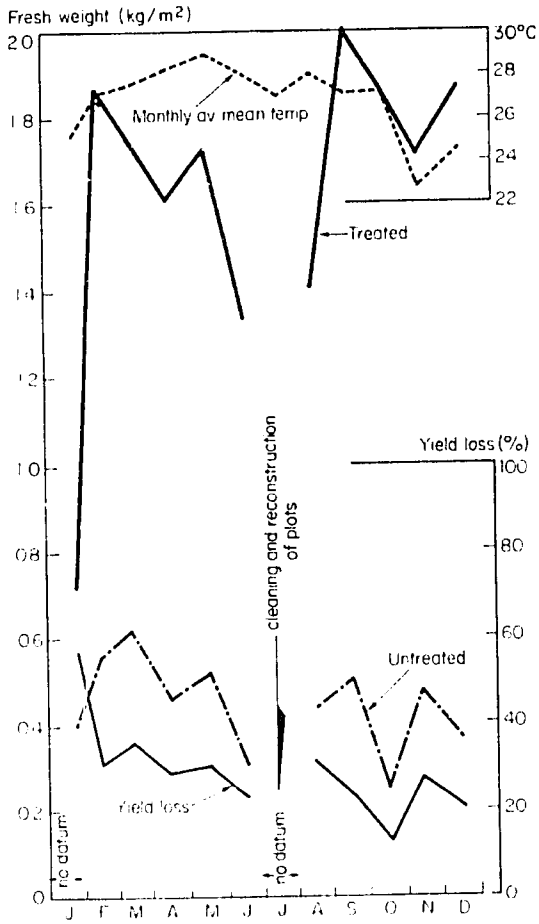
populations showed the highest peak in May and the next highest peak in October, whereas spinning worm appeared in October and May (Fig. 16). On *A. pinnata* var. *imbricata*, caseworm complex showed the highest peak in May-June and the second highest peak in October; spinning worm showed the same tendency. Both caseworm and spinning worm populations were frequently higher on *A. microphylla* than on *A. pinnata* var. *imbricata*.

Standing biomass and yield loss. Standing biomass in insecticide-treated and untreated plots of *A. microphylla* is illustrated in Figure 17. The biomass values, which fluctuated considerably, were not closely correlated with temperature and averaged 1.0 kg/m^2 per wk in treated plots and 0.46 kg/m^2 per wk in untreated plots. The estimated yield losses, averaging 53.7%, appear in Figure 18. With *A. pinnata* var. *imbricata*, standing biomass averaged 0.49 kg/m^2 per wk in treated plots and

Table 11. Species components and sex ratio of 4 pyralid moths collected at IRRI by a blue-black fluorescent tube light trap, 1985.

	Spinning worm *Ephestiopsis vishnu*	Caseworms		
		Elophila enixalis	*El. nigralbalis*	*El. responsalis*
Adults collected (no.)				
Male	4420	1499	49	17
Female	5421	848	90	62
Sex ratio[a]	81.5	176.7	54.4	27.4
Species components				
% each among 4 species	79.3	18.9	1.1	0.7
% each among 3 caseworms	–	91.5	5.4	3.1

[a]Males/100 females.



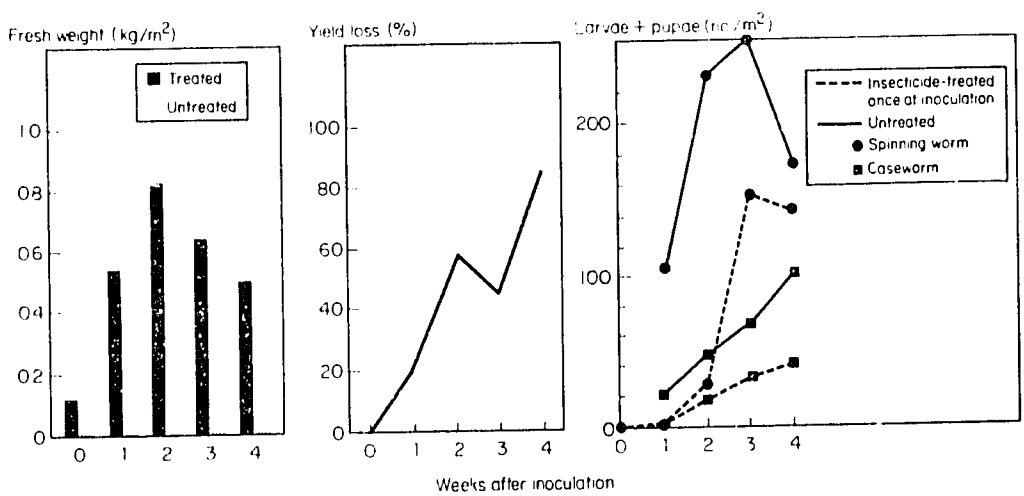
17. *Azolla microphylla* standing biomass in insecticide-treated and untreated plots and yield loss at IRRI from January to December 1985.

0.26 kg/m^2 per wk in untreated ones. Yield loss averaged 46%.

Table 12 summarizes the interactions among azolla standing biomass, pest populations, and yield loss caused by insect pests. Though the yield loss in standing biomass on *A. microphylla* was 53.7% and on *A. pinnata* var. *imbricata* 46.0%, *A. microphylla* produced at least 0.52 kg/m^2 per wk more in treated plots and 0.20 kg/m^2 per wk more in untreated plots than *A. pinnata* var. *imbricata*. In untreated plots, spinning worm averaged 111/m^2 on *A. microphylla* and 50/m^2 on *A. pinnata* var. *imbricata*, whereas caseworms averaged 78/m^2 and 61/m^2, respectively. Evidently there were more pyralid pests on *A. microphylla*.

Standing plus harvested biomass and yield loss. Standing plus harvested biomass was 1.81 and 0.46 kg/m^2 per wk in treated and untreated *A. microphylla*, and 0.79 and 0.26 kg/m^2 per wk in treated and untreated *A. pinnata* var. *imbricata*. The yield loss averaged 74.4% on standing biomass and 66.4% on harvested biomass (Table 12). In treated plots, *A. microphylla* produced more than *A. pinnata* var. *imbricata*.

Production biomass and yield loss. On the last day of the month, *A. microphylla* inoculum was divided into 2 groups: insecticide-treated (1 t fresh azolla mixed with 0.5 kg diazinon 10G formulation within plastic bags) and untreated. The azolla was inoculated in each plot (4-× 5-m) on the following day. Samples for production biomass and insect



18. Production biomass (av values for 8 mo) of *A. microphylla* and insect pest populations, IRRI, 1985.

Table 12. Standing biomass of 2 azolla species, larval and pupal populations of the spinning worm and caseworm complex, and yield loss. IRRI, Jan-Dec 1985.

Insecticide treatment	Biomass (kg fresh weight/m²)				Larvae + pupae (no./m²)				Estimated yield loss (%)			
	Standing		Harvested		Spinning worm		Caseworm		Standing biomass		Standing and harvested biomass	
	Av	Range	Av	Range	Av	Range	Av	Range	Av	Range	Av	Range
					A. microphylla							
Treated	1.002	0.593-1.442	0.811	0-1.065	0.0	-	0.0	-	53.7	5.5-89.7	74.4	42.8-95.1
Untreated	0.463	0.083-0.700	0.000	--	111.5	0-438.8	78.2	0-290.2				
					A. pinnata var. *imbricata*							
Treated	0.486	0.159-0.852	0.306	0-0.658	0.0	-	0.0	-	46.0	8.1-76.8	66.4	30.6-88.4
Untreated	0.263	0.063-0.416	0.000		50.0	0-250.1	60.9	0-378.6				

pest populations were taken weekly up to 4 WAI. Biomass was harvested 4 WAI. In treated plots, production biomass reached the maximum value 2 wk WAI and afterwards decreased; in untreated plots, it reached maximum 1 wk later and decreased rapidly to nothing 4 WAI (Fig. 18). Spinning worms and caseworm complex started to cause damage earlier and more severely in untreated than in treated plots. Yield loss in production biomass by insect pests averaged 20.3% at 1 WAI, 57.6% at 2 WAI, 54.3% at 3 WAI, and 84.7% at 4 WAI.

AZOLLA APPLIED RESEARCH

Training and Technology Transfer Department

Rice yield response to azolla. On-farm trials on *A. pinnata* were conducted in Leyte, Philippines, to evaluate its effects compared with those of chemical N fertilizers. The treatments were

- no azolla, no fertilizer;
- 43 kg N/ha best split, 2/3 basal and incorporated before transplanting, 1/3 topdressed at 5-7 d before panicle initiation (DBPI);
- fresh azolla inoculated at 500 g/m², incorporated after 10 d and again 20 d before transplanting; last incorporation was at 25 d after transplanting; and
- fresh azolla inoculated at 500 g/m², grown 20 d and incorporated before transplanting; 15 kg N/ha was topdressed at 5-7 DBPI.

During 1985 DS, trials were conducted at four sites: two each in the municipalities of Baybay and Hilongos. P was not applied. Response to N was significant at all four sites (Table 13). In Baybay, azolla grew poorly at both sites, resulting in no

Table 13. Effect of supplementary N source on grain yield of IR60. Baybay and Hilongos, Leyte, Philippines, 1985.

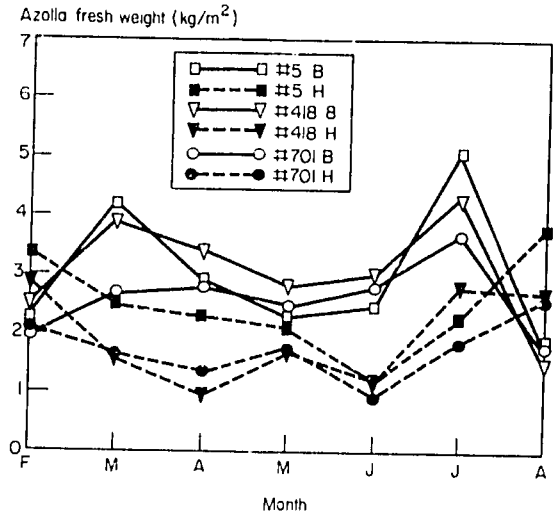
Source[a]	Grain yield (t/ha)					
	Dry season				Wet season	
	Baybay		Hilongos		Baybay[b]	Baybay and Hilongos[c]
	Site 1	Site 2	Site 1	Site 2		
No fertilizer, no azolla	3.6 b	3.3 b	3.4 b	2.8 c	2.8 b	3.3 b
45 kg N/ha as PU (best split)	4.8 a	4.4 a	5.2 a	4.5 a	3.8 a	4.2 a
A. pinnata alone, 3 incorporations	3.6 b	3.4 b	5.0 a	3.5 b	3.6 a	3.9 a
A. pinnata incorporated once, plus 15 kg N/ha as PU	4.1 b	4.1 a	5.2 a	4.1 ab	4.0 a	4.1 a
CV (%)	8.6	8.5	12.5	8.2	8.7	6.4

[a]PU = prilled urea. [b]Av of 3 replications at 1 site. [c]Av of 6 replications across sites.

significant yield increase. In Hilongos, azolla alone significantly increased yield. At site 1, the contribution of azolla appeared to be similar to that of 45 kg N/ha of prilled urea (PU). At site 2, the azolla contribution was significantly less than that obtained from 45 kg N/ha. At all 4 sites, a single incorporation of azolla at 20 d after inoculation, supplemented by 15 kg N/ha topdressed as urea, was equivalent or superior to 3 incorporations of azolla.

During 1985 WS, one trial in Baybay had three replications at one site, while the other trial was replicated six times across fields. In contrast to the result obtained in DS, the trial in Baybay showed that azolla incorporated 3 times significantly increased rice yield by 0.8 t/ha (Table 13). The yield obtained through azolla use was not significantly different from that with 45 kg N/ha applied as PU. A similar result was obtained from the multilocation trial, which was replicated across fields in both Baybay and Hilongos. In both types of trials during 1985 WS, a single incorporation of azolla grown for 20 d supplemented by a topdressed 15 kg N/ha gave yields equivalent to 3 azolla incorporations.

Azolla growth trials. The growth of three azolla species was studied in farmers' fields in Baybay and Hilongos. The initial inoculum was 500 g fresh azolla/m^2 quadrat. At 1 wk, the azolla was harvested. After determining the biomass, 500 g fresh weight was inoculated in a quadrat. Net azolla biomass accumulation was obtained on a monthly basis from February to August 1985. Solophos was added at 1.09 kg P/ha twice a week.



19. Growth of 3 species of azolla at Baybay (B) and Hilongos (H) in Leyte, Philippines, 1985. #5 = *A. pinnata* var. *imbricata*, #418 = *A. microphylla*, #701 = *A. pinnata* var. *pinnata*.

Across the two locations, *A. pinnata* var. *imbricata* #5 appeared to be most adapted during the period of observation (Fig. 19).

Azolla growth in Hilongos was poorer than in Baybay, despite the fact that field growth and response of rice was better. The N content of azolla in Hilongos ranged from 2.3 to 3.1%, whereas that in Baybay ranged from 3.3 to 4.8%. Unlike at IRRI, *A. microphylla* #418 was not best, perhaps because of low P fertility. *A. pinnata* var. *pinnata* seemed to be more suitable for less fertile soils.

Soil and crop management

Management of organic manures

Soil Chemistry/ Physics Department

DECOMPOSITION OF ^{14}C-LABELED RICE STRAW **256**

EFFECT OF INCORPORATION OF RICE STRAW, *AZOLLA MICROPHYLLA*, AND *SESBANIA ROSTRATA* ON NH_4^+-N RELEASE PATTERN IN FLOODED SOILS **257**

LONG-TERM EFFECTS OF STRAW AMENDMENTS ON SOIL FERTILITY AND RICE GROWTH **257**

255

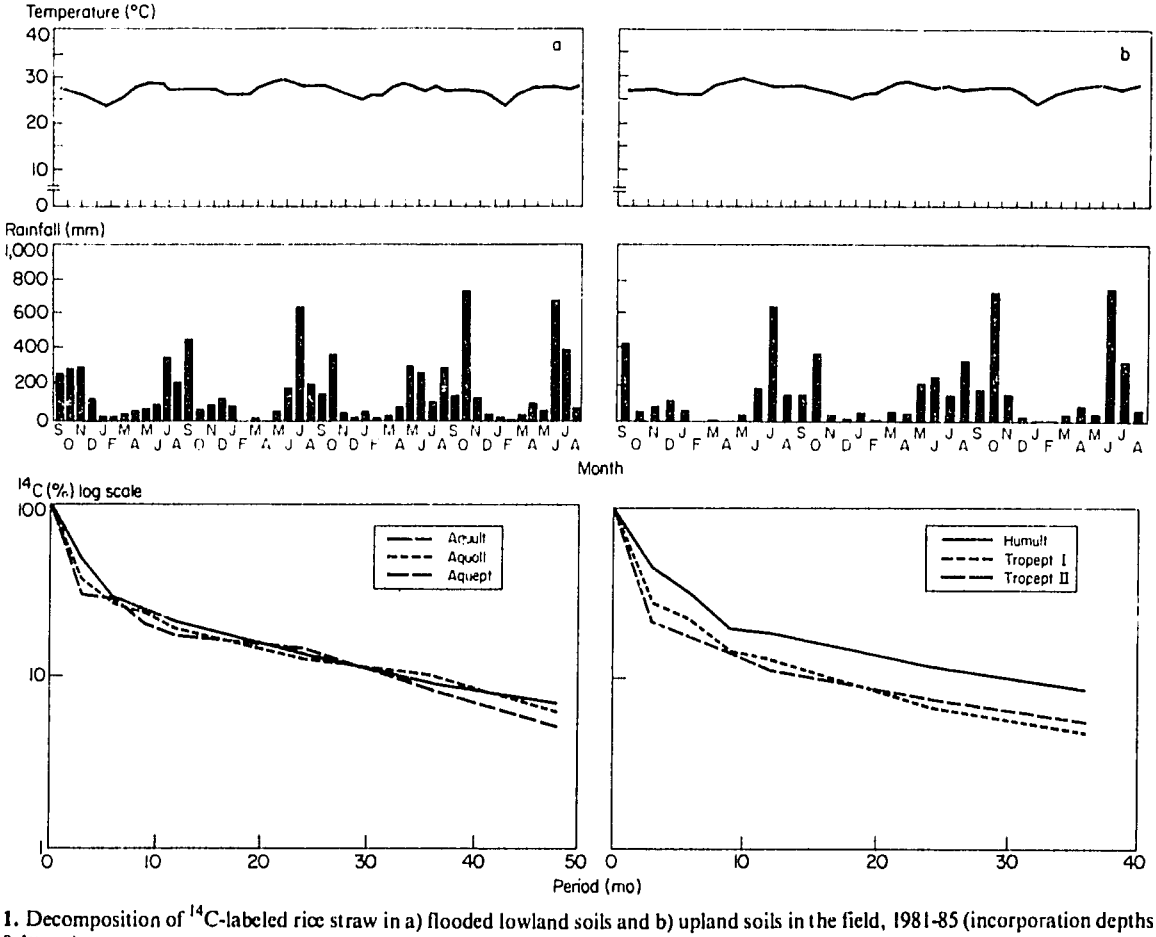
DECOMPOSITION OF ^{14}C-LABELED RICE STRAW

The decomposition of ^{14}C-labeled rice straw in different soils under submerged and drained conditions was investigated. To ensure equal environments, the following soils were sampled as monoliths and installed at the IRRI farm: Tropept (0.8% organic carbon [OC], 37% clay, pH 7.6), Tropept (0.8% OC, 43% clay, pH 6.0), Udult (2.1% OC, 46% clay, pH 4.8), Aquept (0.8% OC, 37% clay, pH 7.6), Aquoll (2.2% OC, 38% clay, pH 6.0), Aquult (2.1% OC, 46% clay, pH 4.8).

Chopped labeled straw (equivalent to 5 t/ha) was incorporated into the top 10 cm of the soil. Each particular treatment was replicated eight times. Soil cores were taken at appropriate times, and each year the entire soil was sampled down to 40 cm in 2 replications. Soil samples were freeze-dried, combusted, and analyzed for ^{14}C.

The decomposition pattern (Fig. 1) reveals that submergence retarded decay of ^{14}C-labeled rice straw only slightly in puddled neutral and alkaline soils. In the acid soil (Humult), no difference was found. Decomposition rates and patterns of all submerged soils were similar. A somewhat retarded mineralization occurred in the Aquult during the first weeks only.

Following the rapid mineralization losses of about 80% in the drained acid and all submerged soils, and 90% in neutral and alkaline drained soils during the first year, all decomposition curves showed a logarithmic function regardless of water regime. Apparently only the initial decomposition differs, and the remaining compounds and metabolites behave rather similarly, irrespective of initial soil properties and water regime. The half life of the more resistant residues and labeled metabolites is estimated to be about 2 yr only,



1. Decomposition of ^{14}C-labeled rice straw in a) flooded lowland soils and b) upland soils in the field, 1981-85 (incorporation depths 0-10 cm).

which is 3 to 4 times lower than the reported half life in drained soils of temperate zones, but comparable to other determinations for drained soils for the tropics.

The initial decomposition rate followed in the order of:

Tropepts > Humult = Aquoll = Aquept = Aquult

Incubation experiments with submerged soils under N_2 atmosphere resulted in highly retarded mineralization. Thus, submergence cannot be equated with anaerobic decomposition, even if redox potentials are below −50 mV.

Aside from the constant high soil temperature of 27-30 °C and a pH of 7, the constant low bulk density of puddled and flooded clayey soils (>0.6 g/cm^3), high microbial biomass (>3% of soil C), and enormous activities of aquatic invertebrates must contribute to rapid decomposition in submerged rice soils. The floodwater ecology might be as important as the soil edaphon.

EFFECT OF INCORPORATION OF RICE STRAW, *AZOLLA MICROPHYLLA*, AND *SESBANIA ROSTRATA* ON NH_4^+-N RELEASE PATTERN IN FLOODED SOILS

The established high initial mineralization rates of rice straw in submerged rice soils lead one to assume that incorporation of organic substrates having a high C to N ratio (C:N) causes a net immobilization of N in flooded soils as it does in drained soils. Low or even negative yield responses to straw amendments (Table 1) support this assumption.

In a greenhouse experiment we studied the effect of incorporating rice straw, azolla, and *Sesbania* on the soil solution kinetics in an Aquoll (1.8% OC, silty clay, pH 6.5, C:N 10, cation exchange capacity [CEC] 35.8 meq/100 g, Olsen P 27 mg/kg).

Table 1. Effect of 4 straw treatments on the grain yield of IR60 on Luisiana clay (pH 4.7) at Pangil, Laguna, Philippines, during the 12th crop, 1985 WS.

Straw management	Grain yield (t/ha)
Removed	3.0 a
Burned	2.9 a
Long straw	2.6 a
Chopped straw	3.0 a

Organic substrates were added at equivalent rates of 58 kg N/ha and 116 kg N/ha, both in the presence and in the absence of rice plants (IR36). All treatments received additionally 13 kg P/ha and 25 kg K/ha as inorganic fertilizers.

In both the presence and the absence of rice plants, neither soil solution pH, Eh, EC, HCO_3^- Na^+, Ca^{2+}, Mg^{2+}, nor Cu^{2+} was affected by any of the organic amendments.

Soil solution NH_4^+-N, however, was significantly altered by the materials. While straw decreased NH_4^+-N concentration below the control treatment, azolla and *Sesbania* increased it (Fig. 2, 3). The effects were more pronounced at the higher rate of application. There was no difference between azolla and *Sesbania* at the lower rate, but at the higher rate *Sesbania* provided more NH_4^+-N.

Without rice plants, the NH_4^+-N concentration reached a maximum at 60 d after flooding and remained approximately constant; with rice plants, the concentration decreased to very low levels after about 30 d because of N uptake by the plants.

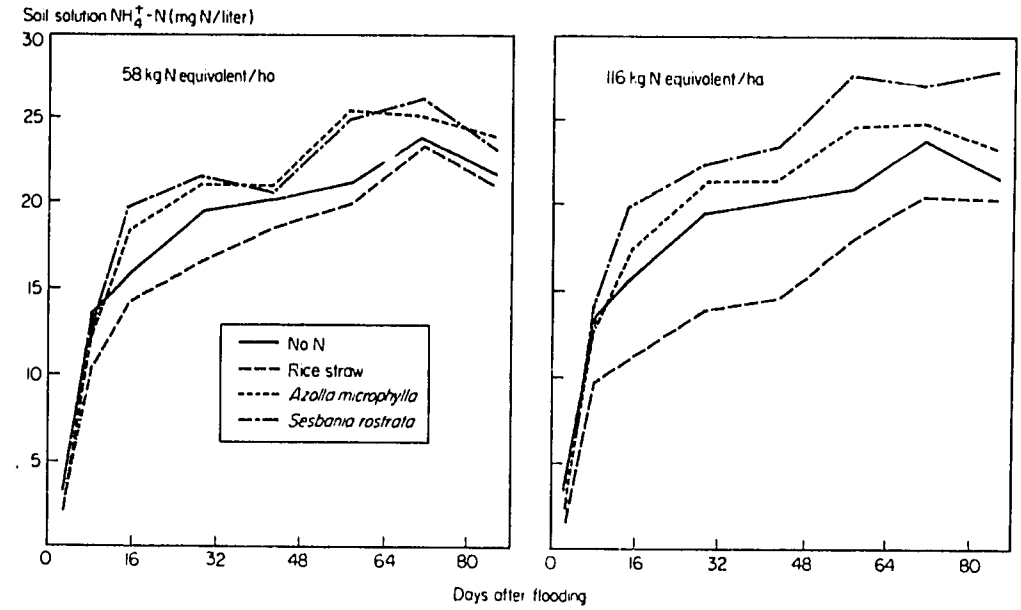
Unlike in upland soil, the immobilized N seems not to be released subsequently during the growth duration of IR36.

The soil solution concentrations of K^+, Fe^{2+}, Mn^{2+}, and $H_2PO_4^-$ increased more with straw than with azolla or *Sesbania* application. Only straw application severely depressed Zn^{2+} concentration in the soil solution, especially at the higher rate of application (Table 2).

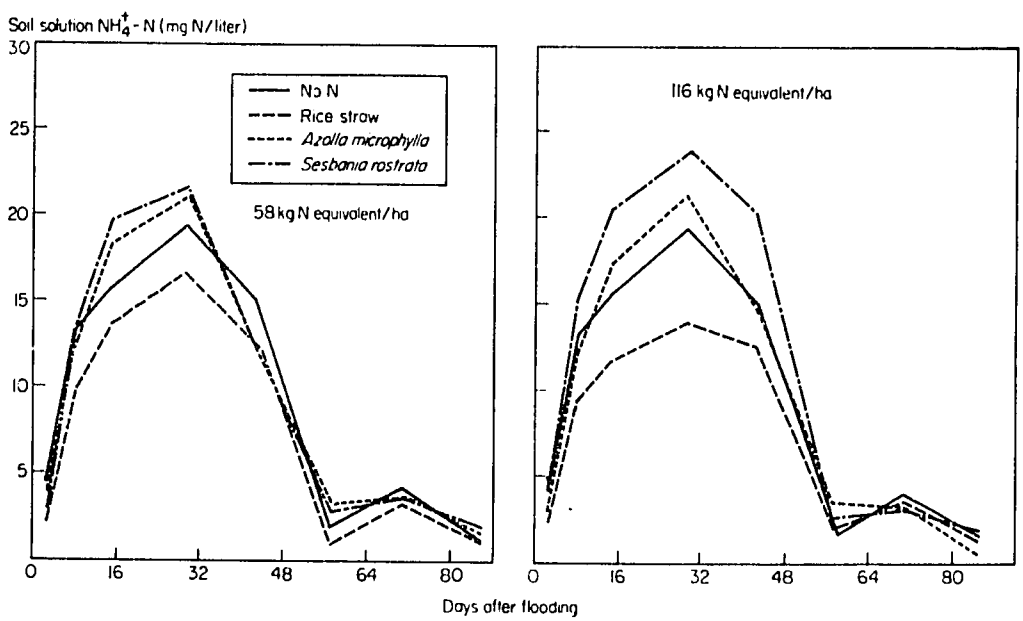
Grain and straw yields (Table 3) were lower than in the control for straw treatments, significantly so at the higher rate of application. Grain yields seemed to be depressed to the extent that soil N was immobilized by straw application. Addition of green manure increased N availability, resulting in improved plant growth and higher yield.

LONG-TERM EFFECTS OF STRAW AMENDMENTS ON SOIL FERTILITY AND RICE GROWTH

Long-term trials on straw amendments on Aquolls have been done at IRRI since 1972. In a dry fallow system with two rice crops per year, the treatments in experiment A are straw removed, straw burned and ash incorporated, long straw incorporated, and straw compost treated with single superphosphate and lime incorporated. In experiment B, straw incorporation is combined with three water



2. Changes in concentration of NH_4^+-N in soil solution of flooded Maahas clay without a rice crop as affected by incorporation of rice straw, *Azolla microphylla*, and *Sesbania rostrata* at N equivalents of 58 and 116 kg/ha. IRRI greenhouse, 1985.



3. Changes in concentration of NH_4^+-N in soil solution of flooded Maahas clay with a rice crop as affected by incorporation of rice straw, *Azolla microphylla*, and *Sesbania rostrata* at N equivalents of 58 and 116 kg/ha. IRRI greenhouse, 1985.

treatments: dry fallow, dry fallow + midseason drainage, and flood fallow with midseason drainage. Rice is planted directly after straw incorporation.

In all treatments the C content of the soil did not change significantly except for an initial drop in the straw removed and straw burned treatments during the first years. The initial soil C:N was 15.6 in

Table 2. Changes in concentration of Zn^{2+} in soil solution of an Aquoll as affected by incorporation of organic substrates equivalent to 116 kg N/ha. IRRI, 1985.

Organic material	Zn^{2+} concentration (mg/liter) at given days after flooding						
	3 d	8 d	15 d	29 d	43 d	57 d	71 d
None (control)	0.19	0.15	0.14	0.10	0.08	0.13	0.12
Rice straw	0.08	0.06	0.07	0.06	0.06	0.08	0.07
Azolla	0.19	0.10	0.12	0.08	0.06	0.09	0.06
Sesbania	0.17	0.18	0.12	0.06	0.08	0.09	0.06

Table 3. Grain and straw yields as affected by application of rice straw and *Sesbania rostrata*, each equivalent to 116 kg N/ha. IRRI, 1985.

Organic material	Grain yield (g/pot)	Straw yield (g/pot)
None (control)	40 b	62 b
Rice straw	32 c	49 c
S. rostrata	46 a	69 a

experiment A and 13.0 in experiment B. The N content in both experiments increased until a C:N of around 10 was established; thereafter no significant change took place (Table 4). Decrease in the C:N was enhanced by applying NPK fertilizer to the first 10 crops.

The addition of compost enriched with P significantly increased available P, but no difference was found with the other treatment.

Available K increased most (by 1.6 mmol/kg) when the ash of straw was incorporated, but differences among the treatments were not significant, most likely because of high K content of the irrigation water.

Seasonal incorporation of 5 t rice straw/ha for more than a decade has not improved fertility on Aquolls having an initial organic C content of about 2% and C:N of 10. Because in the soils studied the initial C:N was higher than 10, straw removal and burning caused a decline of C content during the first year, while straw incorporation maintained the original C content. After about 4 yr in all treatments, a C:N of 10 was established so that straw incorporation resulted in higher N content. Thereafter, C and N contents remained stable.

Water management seems to have no influence on these dynamics (Table 5), possibly because this soil is well buffered against excessive reduction. These results are in line with decomposition studies of ^{14}C-labeled rice straw on this soil.

Table 4. Effect of straw amendments on the C and N content of an Aquoll.[a] IRRI, 1972-84.

Treatment	1972	1973-75 mean	1982-84 mean	Δ means
		Carbon (%)		
Straw removed	2.05	1.82 ± 0.23	1.67 ± 0.07	-0.02
Straw burned	2.05	1.85 ± 0.15	1.74 ± 0.05	-0.11
Straw incorporated	2.05	2.07 ± 0.10	1.90 ± 0.05	-0.13
Straw compost	2.05	2.07 ± 0.06	1.98 ± 0.06	-0.09
		Nitrogen (%)		
Straw removed	0.132	0.126 ± 0.012	0.173 ± 0.007	+0.047
Straw burned	0.132	0.129 ± 0.019	0.179 ± 0.011	+0.043
Straw incorporated	0.132	0.141 ± 0.014	0.191 ± 0.007	+0.048
Straw compost	0.132	0.153 ± 0.006	0.202 ± 0.014	+0.047

[a] 2 rice crops a year, dry fallow.

Table 5. Effect of water management on the C and N content of an Aquoll, averaged for 2 straw treatments.[a] IRRI, 1972-84.

Treatment[b]	1972	1973-75 mean	1982-84 mean	Δ means
		Carbon (%)		
Dry fallow	1.95	1.81 ± 0.12	1.88 ± 0.03	+0.07
Dry fallow + msd	1.95	1.94 ± 0.02	2.08 ± 0.05	+0.14
Flood fallow + msd	1.95	1.97 ± 0.04	2.05 ± 0.03	+0.08
		Nitrogen (%)		
Dry fallow	0.150	0.153 ± 0.010	0.191 ± 0.007	+0.038
Dry fallow + msd	0.150	0.158 ± 0.016	0.211 ± 0.009	+0.053
Flood fallow + msd	0.150	0.165 ± 0.014	0.202 ± 0.003	+0.037

[a]2 rice crops a year. [b]msd = midseason drainage.

Table 6. Effect of straw treatment on the grain yield of rice on an Aquoll. IRRI, 26th cropping season, 1985 DS.

Treatment	Grain yield (t/ha)			
	IR36	IR58	IR60	Mean
Straw removed	3.8	3.8	4.3	4.0 b
Straw burned and ash incorporated	4.2	3.5	4.2	4.0 b
Straw incorporated	4.2	3.8	4.2	4.1 b
Straw compost incorporated	4.4	4.3	5.0	4.6 a

Drum or pot experiments on the effects of water management have to be evaluated carefully because artificially high rates of N fixation and C input by algae are likely, intensifying the reduction processes so that toxins are produced.

Differences in grain yield are not consistent over the years except with compost addition. Compost incorporation increased yield by about 0.5 t/ha (Table 6).

Soil and crop management

Management of other nutrients

Agronomy Department

RATE AND TIME OF PHOSPHORUS AND POTASSIUM APPLICATION **262**
POTASSIUM-ZINC INTERACTIONS IN LOWLAND RICE **262**
LONG-TERM FERTILITY TRIALS **264**
IRRI **264**
Bureau of Plant Industry stations **264**
Farmers' fields **265**
LONG-TERM TRIALS ON PHOSPHORUS SOURCES FOR DEEP WATER RICE **266**
INFLUENCE OF WATER MANAGEMENT ON SULFUR RESPONSE **267**
EVALUATION OF SULFUR SOURCES FOR LOWLAND RICE **268**
VARIETAL TOLERANCE FOR LOW SULFUR IN SOIL **269**
LONG-TERM SULFUR FERTILITY EXPERIMENT **270**

RATE AND TIME OF PHOSPHORUS AND POTASSIUM APPLICATION

Trials on the effects of rate and time of P and K application on rice yields were initiated in 1985 dry season (DS) in a farmer's field in Bugallon, Pangasinan, Philippines, where both elements were deficient. Table 1 shows the properties of the soils.

Grain yield responses to applied P (Table 2) and K (Table 3) were significant, but at the same fertilizer rate, different application methods gave comparable yields.

In DS and wet season (WS), K application without P gave lower yields than without Zn, suggesting that P is more limiting than Zn.

P applied at 45 kg/ha during the last harrowing gave the highest P response of 1.8 t/ha and was comparable to the same rate applied at 4 or 6 wk after transplanting (WT) in the loamy soil with available Olsen P of 1.5 ppm.

The results suggest that on this soil type, delaying application of 45 kg P/ha until 4 or 6 WT does not reduce yield compared with early basal application. This supports the farmers' practice, but a problem arises if only compound fertilizers are available.

Table 1. Properties of soils[a] used in P and K fertility trials. Bugallon, Pangasinan, Philippines, 1985.

Soil property	P trial	K trial
pH (1:1)	5.3	5.4
Organic C (%)	2.53	2.05
Total N (%)	0.21	0.18
Exchangeable bases (meq/100 g)		
Na	0.34	0.32
K	0.07	0.06
Mg	12	14
Ca	16	18
CEC (meq/100 g)	24	26
Fe (%, perchloric)	4.6	4.7
Available Olsen P (ppm)	1.5	1.2
Available Zn (ppm)	0.12	0.10
Particle size (%)		
Sand	25	17
Silt	48	52
Clay	27	31
Texture	Loam	Silty clay loam

[a]Mollisols; fine-loamy mixed isohyperthermic Typic Haplaquoll.

Table 2. Grain yield of IR36 as affected by rate and time of P application. Bugallon, Pangasinan, Philippines, 1985 DS.

Application time[a]	P rate (kg/ha)	Grain yield[b] (t/ha)
No P fertilizer	0	2.7 f
Last harrowing	5	3.2 ef
	15	3.3 ef
	45	4.5 a
Transplanting	5	3.4 def
	15	3.8 a-e
	45	4.2 abc
2 WT	5	3.4 def
	15	3.7 b-e
	45	4.1 a-d
4 WT	5	3.4 def
	15	3.5 cde
	45	4.3 ab
6 WT	5	3.5 cde
	15	3.8 a-e
	45	3.9 a-e

[a]WT = wk after transplanting. [b]CV (%) = 11.

Table 3. Grain yield of IR36 as affected by rate and time of K application. Bugallon, Pangasinan, Philippines, 1985.

Application time	K rate (kg/ha)	Grain yield[a] (t/ha)	
		Dry season	Wet season
Unfertilized control	0	2.2 b	1.7 d
No K fertilizer	0	2.7 b	1.9 cd
Basal	50	4.5 a	2.9 ab
	100	4.5 a	2.7 b
	150	4.6 a	3.2 a
	200	4.3 a	3.0 ab
Split (4 WT)	50	4.2 a	3.0 ab
	100	4.6 a	3.0 ab
	150	4.6 a	2.8 ab
	200	4.5 a	2.9 ab
Split (4 WT)	200 (no Zn)	4.3 a	2.7 b
	200 (no P)	2.3 b	2.2 c
Basal	200 (no Zn)	4.4 a	2.9 ab
	200 (no P)	2.4 b	2.3 c

[a]CV (%) = 10 for DS and 10 for WS.

POTASSIUM-ZINC INTERACTIONS IN LOWLAND RICE

Trials were continued in Bugallon and Mangatarem, Pangasinan, to evaluate the response of IR36 to K and Zn. Table 4 lists the soil properties.

Table 4. Properties of soils for trials on K-Zn interaction. Bugallon and Mangatarem, Pangasinan, Philippines, 1985.

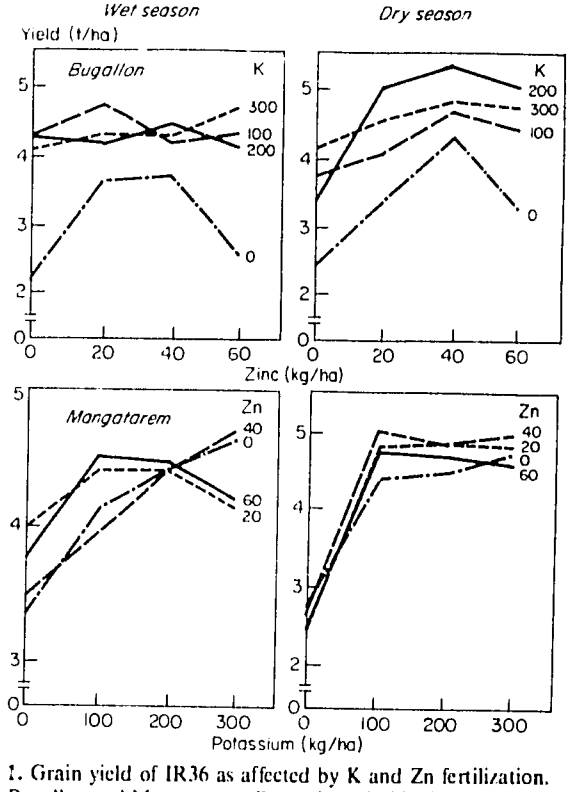
Soil property	Bugallon[a]		Mangatarem[b]	
	Topsoil	Subsoil	Topsoil	Subsoil
pH (1:1)	5.8	5.8	7.1	7.2
Organic matter (%)	3.4	2.4	2.2	1.9
Total N (%)	0.17	0.10	0.11	0.08
Available Olsen P (ppm)	0.65	0.46	1.6	1.3
Exchangeable cations (meq/100 g)				
Na	0.18	0.14	0.27	0.29
K	0.02	0.01	0.06	0.08
Mg	10	11	24	27
Ca	10.9	10.9	15.2	16.9
Ca/K	545	1090	253	211
Mg/K	520	1070	400	335
Ca/Mg	1.05	1.02	0.63	0.63
Ca + Mg/K	1065	2160	653	546
CEC (meq/100 g)	24	24	40	43
Fe (ppm, perchloric acid)	3.8	3.8	6.2	6.2
Available Zn (ppm, Katval and Ponnamperuma)	0.13	0.12	0.02	0.02
Particle size (%)				
Sand	27	28	9	8
Silt	46	43	48	44
Clay	27	29	43	48
Texture	Loam	Loam	Silty clay	Silty clay

[a]Fine loamy mixed isohyperthermic Typic Haplustoll. [b]Fine mixed isohyperthermic Aquic Haplustoll.

On Bugallon soil (pH 5.8), Zn application at all rates significantly increased yield in DS (Fig. 1). When Zn was applied with K, grain yields were significantly higher than without K. The highest yield was obtained with 200 kg K/ha in combination with 40 kg Zn/ha. In WS, Zn gave responses of over 1 t/ha without K, but K alone at 100 kg/ha increased yield by 2.1 t/ha; higher rates of K or added Zn gave no further significant yield increase.

At Mangatarem (pH 7.1), yield response to Zn was observed only with 100 kg K/ha (Fig. 1). In WS at the same K levels, yields did not significantly differ among Zn application rates. It was only on Bugallon soil that yield differences among Zn levels were recorded, although this soil had a higher level of available Zn than the Mangatarem soil.

In DS and WS, application of K alone produced a yield response. At Bugallon, the same trend was observed in WS, but Zn application was needed with K in DS to obtain highest yield. Response to Zn was due to the very low (<1.0 ppm) exchangeable Zn of the soils. More Zn is needed if Mg levels are high (Ca/Mg<2.0) or if (Ca + Mg)/K is high. Because of the imbalances of the soil nutrients, results varied between sites.



1. Grain yield of IR36 as affected by K and Zn fertilization. Bugallon and Mangatarem, Pangasinan, Philippines, 1985 DS and WS.

The 42d (DS) and 43d (WS) consecutive crops in the long-term fertility trials were planted at IRRI in 1985. In Maligaya, Bicol, and in the Visayas, 18 yr of cropping were completed.

IRRI. Significant N response was observed at IRRI. Without applied N, rice yield was comparable to that of the control. Applying N with P, K, or both gave yields not significantly higher than with N alone. All test rices responded similarly to fertilizer application. IR8 yielded as well as IR36 and IR29723-143-3-2-1.

In WS, however, IR8 was severely damaged by brown planthopper, and data were not included. Yield responses were similar to those observed on DS.

Replacing inorganic fertilizer N with rice straw compost by about 17% in DS and 40% in WS produced yields comparable to those obtained with inorganic sources alone (Table 5).

Bureau of Plant Industry stations. In Bicol, IR8 was excluded due to tungro infection in both seasons (Table 6). In DS, long maturing IR29723-143-3-2-1 outyielded IR36. Low yields of IR36 were caused by insufficient water supply during the early reproductive stage. N application significantly increased yields of IR29723-143-3-2-1. Yields from both rices were highest with NPK fertilizer, with K at 75 kg/ha applied in split doses. However, the small additional response to NPK over NP was not statistically significant.

Maligaya silty clay loam (Entic Pellustert) was highly responsive to NP and NPK fertilizer (Table 7). The DS yield of 9.8 t/ha with IR29723-143-3-2-1 was the highest for the past 18 yr. Even IR8 produced 8.8 t/ha, which was 2.4 t/ha higher than the yield of IR36. Significant response to N alone was obtained with IR29723-143-3-2-1 but not with IR8 and IR36. NK application was even inferior to N alone in the DS crop.

In WS, application of N or NK did not significantly increase yield unless P was also added. Results for both DS and WS show that after several years of cropping, N must be combined with P to increase yield.

In Santa Rita clay, low DS yields had been continuously obtained (Table 8). Insufficient water supply just before the reproductive stage has always been a problem. The 1985 DS crop was

Table 5. Effect of NPK fertilizer on yield of test rices in the 42d (DS) and 43d (WS) consecutive crops in the long-term fertility trial, IRRI, 1985.

Fertilizer (kg/ha)			Yield[b] (t/ha)		
N[a]	P	K	IR8[c]	IR36	IR29723-143-3-2-1
			Dry season		
0	0	0	3.6 b	3.8 b	3.6 b
140	0	0	7.0 a	6.6 a	6.7 a
0	13	0	4.1 b	3.9 b	3.6 b
0	0	25	3.8 b	3.8 b	3.4 b
140	13	0	6.6 a	6.0 a	7.0 a
140	0	25	6.7 a	6.4 a	6.6 a
140	13	25	6.9 a	6.8 a	7.3 a
140[a]	13	25	6.7 a	6.3 a	6.9 a
			Wet season		
0	0	0	–	3.7 b	3.1 b
60	0	0	–	5.2 a	5.1 a
0	13	0	–	3.9 b	3.5 b
0	0	25	–	3.7 b	3.2 b
60	13	0	–	4.9 a	5.1 a
60	0	25	–	5.0 a	5.1 a
60	13	25	–	5.4 a	5.5 a
60[d]	13	25	–	5.1 a	5.3 a

[a]Includes topdressing at 5-7 d before panicle initiation of 40 kg N/ha in DS and 20 kg N/ha in WS. [b]Within a season, figures in a column followed by a common letter are not significantly different at the 5% level by DMRT. CV (%) = 10 for DS and 12 for WS. [c]IR8 plants were severely damaged by brown planthopper in WS. [d]24 kg N/ha from rice straw compost.

Table 6. Effect of NPK fertilizer on yield of test rices in the long-term fertility trial. Bicol Experiment Station, Pili, Camarines Sur, Philippines, 1985.

Fertilizer (kg/ha)			Yield[b] (t/ha)	
N[a]	P	K	IR36	IR29723-143-3-2-1
		Dry season		
0	0	0	2.3 b	3.2 c
140	0	0	2.9 b	4.4 b
140	26	0	3.6 a	6.6 a
140	0	50	2.8 b	4.8 b
140	26	50	4.8 a	7.1 a
140	26	50+25	4.5 a	7.2 a
		Wet season		
0	0	0	3.3 ab	3.1 b
70	0	0	2.8 b	3.1 b
70	26	0	3.5 ab	4.1 a
70	0	50	2.8 b	3.2 b
70	26	50	3.0 ab	4.4 a
70	26	50+25	3.9 a	4.4 a

[a]Includes topdressing at 5-7 DBPI of 40 kg N/ha in DS and 30 kg N/ha in WS. [b]Within a season, figures in a column followed by a common letter are not significantly different at the 5% level by DMRT. CV (%) = 18 for DS and 17 for WS.

Table 7. Effect of NPK fertilizer on yield of test rices in the long-term fertility trial. Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines, 1985 DS and WS.

Fertilizer (kg/ha)			Yield[b] (t/ha)		
N[a]	P	K	IR8	IR36	IR29723-143-3-2-1
			Dry season		
0	0	0	2.4 c	1.8 c	2.4 d
140	0	0	3.4 c	1.6 c	5.3 c
140	26	0	6.9 b	5.6 b	8.1 b
140	0	50	3.0 c	1.4 c	4.2 c
140	26	50	8.8 a	6.4 ab	9.8 a
140	26	50+25	8.4 a	7.5 a	9.1 ab
			Wet season		
0	0	0	2.2 b	1.8 b	1.9 c
70	0	0	2.3 b	1.9 b	2.5 c
70	26	0	3.7 a	3.2 a	3.9 b
70	0	50	2.4 b	2.0 b	2.1 c
70	26	50	3.6 a	3.3 a	4.8 a
70	26	50+25	3.0 ab	2.7 a	4.7 a

[a]Includes topdressing at 5-7 DBPI of 40 kg N/ha in DS and 30 kg N/ha in WS. [b]Within a season, figures in a column followed by a common letter are not significantly different at the 5% level by DMRT. CV (%) = 13 for DS and 16 for WS.

planted early to avoid the later water supply shortage. Nevertheless, yields were still higher in WS. All test rices responded to N. N-P interaction was greater than N-K, giving yields comparable to or better than that with NPK.

Farmers' fields. The 18th and 19th crops in Luisiana, Laguna (Aquic Troporthent), and the 16th and 17th crops in Tanay, Rizal (Vertic Tropaquept), were grown in 1985 in farmers' fields. IR60 and IR29723-143-3-2-1 were used. On both soils, response to N applied either alone or in combination with P and K was observed.

With NPK, IR29723-143-3-2-1 gave the highest N response of 3.0-3.2 t/ha in both soils in DS (Table 9, 10). In WS, only IR60 gave a response to P. Grain yield response to K was noted only with IR29723-143-3-2-1 in calcareous (pH 7.1) Tanay soil, which contains 0.09[illegible] meq exchangeable

Table 8. Effect of NPK fertilizer on yield of test rices in the long-term fertility trial. Visayas Experiment Station, Hamungaya, Jaro, Iloilo, Philippines, 1985 DS and WS.

Fertilizer (kg/ha)			Yield[b] (t/ha)		
N[a]	P	K	IR8[c]	IR36	IR29723-143-3-2-1
			Dry season		
0	0	0	–	1.5 b	1.5 c
140	0	0	–	1.7 b	2.6 b
140	26	0	–	3.9 a	3.8 a
140	0	50	–	1.8 b	2.4 b
140	26	50	–	4.1 a	4.1 a
140	26	50+25	–	4.1 a	4.1 a
			Wet season		
0	0	0	2.3 d	2.0 c	2.9 c
140	0	0	3.7 c	2.7 bc	3.8 b
140	26	0	6.3 a	5.1 a	5.7 a
140	0	50	4.0 c	3.3 b	3.1 bc
140	26	50	5.4 b	5.0 a	5.9 a
140	26	50+25	5.2 b	5.2 a	5.7 a

[a]Includes topdressing at 5-7 DBPI of 40 kg N/ha in DS and 30 kg N/ha in WS. [b]Within a season, figures in a column followed by a common letter are not significantly different at the 5% level by DMRT. CV (%) = 13 for DS and 12 for WS. [c]IR8 was damaged by RTV in DS.

Table 9. Effect of NPK on yield of IR60 and IR29723-143-3-2-1 in the 18th (DS) and 19th (WS) consecutive crops. Luisiana, Laguna, Philippines, 1985.

Fertilizer treatment[a]	Yield[b] (t/ha)			
	Dry season		Wet season	
	IR60	IR29723-143-3-2-1	IR60	IR29723-143-3-2-1
Control	3.4 b	2.7 d	2.1 b	1.6 c
N	4.7 a	3.9 c	2.0 b	2.4 b
P	3.4 b	3.3 cd	2.1 b	2.0 bc
K	3.5 b	2.7 d	2.1 b	2.1 bc
NP	5.2 a	5.3 a	3.4 a	3.0 a
PK	4.0 b	3.0 d	2.2 b	2.1 bc
NK	4.9 a	4.5 b	1.9 b	2.3 b
NPK	5.0 a	5.9 a	3.5 a	2.8 a

[a]120 kg N/ha for DS and 60 kg N/ha for WS; 17.5 kg P/ha and 33 kg K/ha in both seasons. [b]CV (%) = 10 for DS and 13 for WS.

K/100 g soil as compared with the acidic (pH 4.3) Luisiana soil with 0.165 meq exchangeable K/100 g soil (Table 11).

LONG-TERM TRIALS ON PHOSPHORUS SOURCES FOR DEEP WATER RICE

Modern deep water rices grown on acid sulfate soils at Prachinburi, Thailand, respond to P, and some residual effects have been observed. A long-term experiment was initiated in 1984 to compare the response of deep water rice to small annual dressings of 8.8 kg P/ha as rock phosphate or triple superphosphate (TSP) with the residual effects of the equivalent of 35 or 8.8 kg P/ha as a single initial application in the first year.

The soil is classified as P-III a of the Maha Pot series. At the start of the experiment, the surface soil (0-20 cm) had a pH of 4.1, available P was 4 ppm (Bray II), and total P was 185 ppm. The whole area was sown with the deep water rice RD19 on 30 May 1984. P treatments and grain yields are shown in Table 12. Treatment differences showed early in the season. Plants on the zero-fertilizer P plots

Table 10. Effect of NPK on yield of IR60 and IR29723-143-3-2-1 in the 16th (DS) and 17th (WS) consecutive crops. Tanay, Rizal, Philippines, 1985.

Fertilizer treatment[a]	Yield[b] (t/ha)			
	Dry season		Wet season	
	IR60	IR29723-143-3-2-1	IR60	IR29723-143-3-2-1
Control	3.0 c	2.8 d	1.8 e	3.3 d
N	4.4 b	4.4 c	2.8 c	3.7 d
P	3.4 c	3.3 d	2.4 cd	3.5 d
K	2.8 c	2.6 d	1.9 de	3.3 d
NP	5.3 ab	4.5 bc	3.5 ab	4.3 bc
PK	3.4 c	2.9 d	2.3 cde	3.8 cd
NK	4.6 b	5.2 ab	3.2 b	4.5 b
NPK	5.9 a	5.8 a	4.0 a	5.4 a

[a]120 kg N/ha for DS and 60 kg N/ha for WS; 17.5 kg P/ha and 33 kg K/ha in both seasons. [b]CV (%) = 13 for DS and 10 for WS.

Table 11. Soil properties of control plots in long-term fertility trials, after 1984 WS.

Soil property	Luisiana soil	Tanay soil
pH (1:1)	4.3	7.1
Organic C (%)	1.66	1.90
Total N (%)	0.20	0.19
Available Olsen P (ppm)	2.3	4.1
Exchangeable bases (meq/100 g)		
Na	0.29	0.29
K	0.16	0.10
Mg	3	7
Ca	10	51
Fe (%, perchloric)	7.9	6.7
Available Zn (ppm)	4.9	0.002

Table 12. Grain yields and P content of the soil in a long-term P experiment with deep water rice. Prachinburi, Thailand, 1984 and 1985 WS.

Available P (kg/ha)	Source	1984 yield (t/ha)	Soil P[a] (ppm)	1985 yield (t/ha)
1. No P	--	2.9 a	3.4 b	1.4 d
2. Annually 8.8	TSP	3.3 a	8.5 b	2.2 bc
3. Annually 8.8	Rock	3.4 a	8.1 b	2.0 c
4. Initial 35	TSP	3.4 a	5.7 b	1.9 c
5. Initial 35	Rock	3.2 a	73.7 b	2.4 ab
6. Initial 140.8	TSP	3.2 a	30.3 b	2.0 c
7. Initial 140.8	Rock	3.5 a	842.5 a	2.6 a

[a]Bray II test for all soil samples taken after harvest, 1984.

were shorter than with other treatments and had less dry matter. The plants on the highest P levels showed unusually pale and broad leaves. These plots in particular were severely damaged by leaf-eating gryllids.

The grain yields for 1984 were not significantly different (CV = 10%). Soil P content after harvest was much higher for treatment 7, the maximum rate of rock phosphate, than for any other treatment, but the data had a very high CV (154%). After harvest, treatment 7 had a surface soil pH of 4.5, significantly higher than in the other treatments (pH 4.0–4.1, P 0.01, CV 4%).

Plant emergence was poor in 1985, but plant growth differed markedly among treatments. Grain yields reflected differences in soil P content at the end of the previous season and the addition of TSP in treatment 7.

INFLUENCE OF WATER MANAGEMENT ON SULFUR RESPONSE

The study on the effects of water management on S availability and plant uptake of IR36 was continued for another season in the greenhouse. The chemical characteristics and texture of the soils used are presented in Table 13.

Average numbers of tillers per hill, panicles per hill, and straw yields of the three soils were highest with predrying before continuous flooding (Table 14), followed by continuous flooding.

Mean grain yield over two seasons showed that predrying before continuous flooding produced the greatest response to S but was not significantly different from continuous flooding (Table 15). S responses were high in the Baenotan and Aguilar soils and lowest in the Botolan soil. Predrying

Table 13. Chemical characteristics and texture of 3 apparently S-deficient soils studied in the greenhouse, IRRI, 1984-85.

Soil	pH (1:1)	CEC (meq/100 g)	Total N (%)	Organic C (%)	Available P (ppm)		SO_4-S (ppm)	Total S (ppm)	Clay (%)	Soil texture
					Olsen	Bray				
Botolan, Zambales	6.8	14	.08	0.72	1.8	4	4	73	17	Loam
Bacnotan, La Union	6.1	14	.05	0.50	4.7	18	9	60	15	Sandy loam
Aguilar, Pangasinan	6.5	23	.15	1.59	4.5	10	14	–	21	Loam

Table 14. Effect of water management on tiller number, panicle number, and straw yield of IR36 grown in 3 Philippine soils. IRRI greenhouse, 1984-85.

Moisture regime[a]	Tillers per hill		Panicles per hill		Straw yield (g/pot)	
	1984 DS	1985 DS	1984 DS	1985 DS	1984 DS	1985 DS
M_1	33 a	34 a	32 a	31 a	41 a	34 a
M_2	28 b	30 b	30 ab	27 b	38 b	31 b
M_3	22 c	27 c	27 b	21 c	28 c	25 c

[a]M_1 = predrying, then continuous flooding, M_2 = continuous flooding, M_3 = predrying, then alternate drying and wetting.

Table 15. Grain yield of IR36 grown under 3 moisture regimes and 2 S levels. IRRI greenhouse, 1984-85.

Soil	Moisture regime[a]	S level (ppm)	Grain yield (g/pot)		
			1984 DS	1985 DS	Mean
Botolan, Zambales	M_1	0	50 def	38 de	44
		30	50 def	50 abc	50
	M_2	0	46 efg	50 abc	48
		30	56 cde	53 abc	54
	M_3	0	42 fgh	22 fg	32
		30	35 h	26 fg	30
Bacnotan, La Union	M_1	0	48 efg	46 bcd	47
		30	75 a	57 ab	66
	M_2	0	37 gh	46 cd	42
		30	71 ab	54 abc	62
	M_3	0	38 gh	24 fg	31
		30	50 def	26 fg	38
Aguilar, Pangasinan	M_1	0	40 fgh	47 bcd	44
		30	62 bc	60 a	61
	M_2	0	13 i	47 bcd	30
		30	59 cd	61 a	60
	M_3	0	46 efg	17 g	32
		30	54 cde	29 ef	42

[a]See footnote, Table 14.

followed by alternate drying and wetting produced the least response to S; this regime reduced the availability of both native and applied S. This is also reflected in the S uptake of the rice plants during 1984 (Table 16).

EVALUATION OF SULFUR SOURCES FOR LOWLAND RICE

Five S fertilizers — urea S (US), elemental S (ES), $(NH_4)_2SO_4$, $CaSO_4$, and S bentonite — were tested

Table 16. S uptake of IR36 grown in 3 soils under 3 moisture regimes[a] and 2 S levels. IRRI greenhouse, 1984.

Soil	S level (ppm)	S uptake (mg/pot)		
		M_1	M_2	M_3
Botolan, Zambales	0	28	24	18
	30	31	33	16
Bacnotan, La Union	0	21	14	14
	30	43	46	29
Aguilar, Pangasinan	0	16	7	25
	30	33	38	26

[a]See footnote, Table 14.

Table 17. Tiller number, straw yield, and grain yield of IR36 as affected by S source.[a] IRRI greenhouse, 1984.

S source	Tillers (no./pot)	Straw yield (g/pot)	Grain yield (g/pot)
Control	26 c	29 c	48 b
Urea S	38 a	38 ab	64 a
S bentonite	25 c	28 c	48 b
$CaSO_4$	35 b	36 b	57 a
Elemental S	33 b	35 b	59 a
$(NH_4)_2SO_4$	39 a	39 a	58 a

[a]Av of 11 sites.

Table 18. Residual effects of added S on tiller number, straw yield, and grain yield of IR36.[a] IRRI greenhouse, 1985.

S source	Tillers (no./pot)	Straw yield (g/pot)	Grain yield (g/pot)
Control	14 d	20 d	29 d
Urea S	23 a	36 a	46 a
S bentonite	18 c	26 bc	34 c
$CaSO_4$	19 bc	24 c	38 b
Elemental S	20 b	28 b	37 b
$(NH_4)_2SO_4$	19 bc	28 b	36 bc

[a]Av of 11 sites.

on 11 soils. Their residual effect on growth, straw, and rice grain yield was likewise evaluated.

On the first crop, $(NH_4)_2SO_4$ (24% S) and US (21% S) produced significantly more tillers per pot than the 3 other sources (Table 17). Tiller number and straw yield in S bentonite (90% S)-treated plants were the same as in the controls. US produced the highest grain yield, followed by ES (70% S), $(NH_4)_2SO_4$, and $CaSO_4$ (16% S), but at the same level of significance. S bentonite yielded the same as the control; this material is not a good source of S for lowland rice. Trends were similar in the residual crop (Table 18), with US producing the highest yields. S bentonite demonstrated some residual effects, producing significantly higher yield than the control. The performance of the different sources on the residual crop varied among the 11 soils (Fig. 2). Figure 3 shows the average relative yield increases due to the different sources on the applied and residual crop.

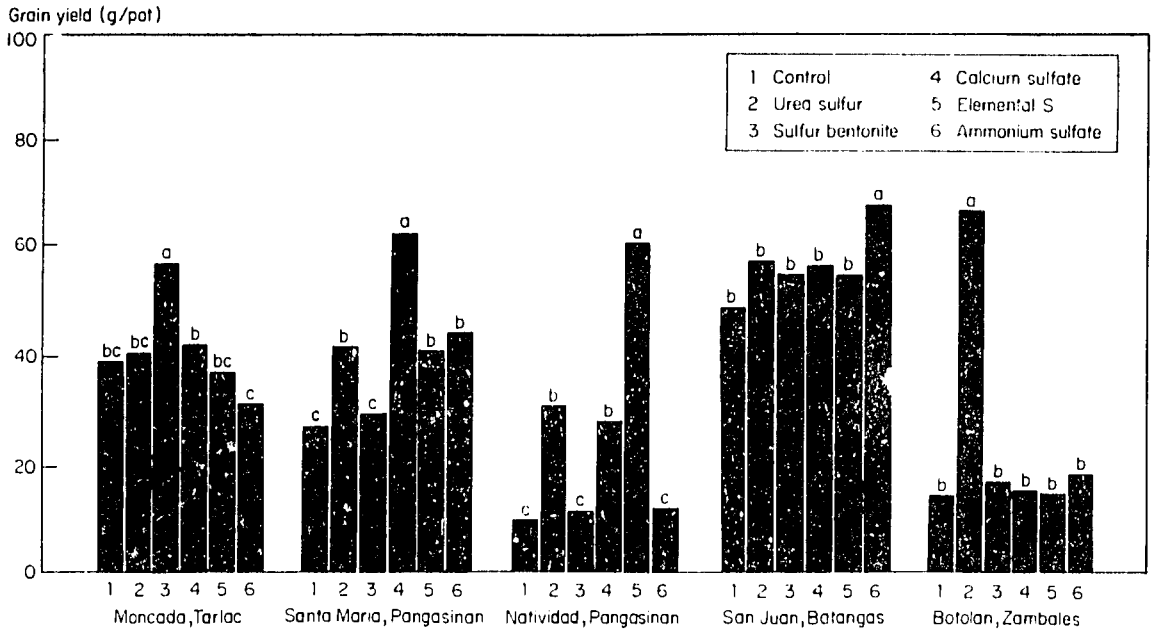
VARIETAL TOLERANCE FOR LOW SULFUR IN SOIL

Seventeen rices of varying maturity were evaluated in a greenhouse experiment to determine their tolerance for low S in soils. Sulfur was applied at 0, 1, and 10 ppm as $(NH_4)_2SO_4$. The soil used was taken from San Juan, Batangas, and had a pH of 6.8, organic C 1.44%, total N 0.14%, CEC 34.4 meq/100 g, SO_4^{-2}-S nil, and texture of silty clay loam.

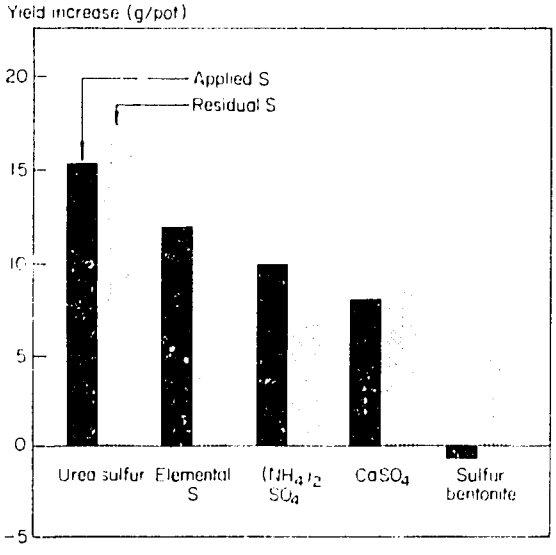
At 30 d after transplanting, yellowing of leaves and marked reduction in tiller number and plant height were observed among plants without S. With S, plant height increased in the range of 30-40% and tiller number increased significantly (Table 19).

IR20, IR30, and IR21820-154-3-2-2-3 showed no significant increase in grain yield with either 1 or 10 ppm S, suggesting that these cultivars are relatively tolerant of low S (Table 20). IR56, IR60, and IR19672-155-5-1-1-3 increased in yield not only at 1 ppm S but also at 10 ppm S. Ten of the cultivars tested did not respond to 1 ppm S but had increased grain yield at 10 ppm S, suggesting that they have relatively high S requirements. Of the 10, 7 are late maturing.

S content in straw and grain increased with the application of S only among early and medium maturing cultivars (Table 21). S content in straw of late maturing varieties decreased with the addition of S, possibly because of a dilution effect. When S is applied, very high biomass is produced, but uptake is not correspondingly increased. S uptake in straw and grain increased with the application of 10 ppm; the greatest increase occurred among the early maturing cultivars and the least among the late maturing.



2. Yield response of IR36 to residual S fertilizers. IRRI, 1985. Columns headed by a common letter are not significantly different at the 5% level by DMRT.



3. Average yield increase of IR36 with S fertilizers in soils from 11 sites in the Philippines. IRRI greenhouse, 1984-85.

Table 19. Effect of S on plant height and tiller number of rice varieties at harvest. IRRI greenhouse, 1985.

Variety	Plant height (cm)		Tillers (no./hill)	
	No S	10 ppm S	No S	10 ppm S
Early maturing				
IR30	77	111	5	11
IR36	76	109	6	11
IR56	79	118	7	13
IR60	82	108	5	11
IR13540-56-3-1	74	109	5	10
Medium maturing				
IR20	79	99	6	8
IR34	98	120	5	13
IR18348-36-3-3	83	122	7	17
Late maturing				
IR42	85	125	6	13
IR54	76	110	7	13
Syntha	145	191	5	9
Pelita I/I	110	122	6	14
IR21820-154-3-2-2-3	88	125	6	13
IR29723-143-3-2-1	107	140	6	10
IR2153-26-3-5-4	88	125	5	12
IR28222-9-2-2-2	110	135	6	12
IR19672-155-2-1-1-3	106	119	6	14

LONG-TERM SULFUR FERTILITY EXPERIMENT

Studies on the effects of continuous application of high analysis fertilizers (urea and TSP on IR64 on Maahas clay) continued at IRRI during 1985 DS and WS (6th and 7th crops). In the 6th crop, all but four treatments gave significant yield increases over the control (Table 22). NPK alone resulted in a significantly higher yield than NPK + Zn + S and

Table 20. Effect of S level on grain yield of rice varieties. IRRI, 1985.

Variety	Grain yield[a] (g/hill)		
	No S	1 ppm S	10 ppm S
	Group 1[b]		
IR20	46 a	58 a	61 a
IR30	67 a	72 a	95 a
IR21820-154-3-2-2-3	33 a	54 a	53 a
	Group 2[c]		
IR56	45 c	105 b	137 a
IR60	31 c	67 b	95 a
IR19672-155-2-1-1-3	50 b	64 ab	91 a
	Group 3[d]		
IR36	31 b	68 a	94 a
	Group 4[e]		
IR34	72 b	90 b	124 a
IR42	45 b	59 b	104 a
IR54	31 b	39 b	107 a
Syntha	59 b	62 b	226 a
Pelita I/I	54 b	74 b	111 a
IR29723-143-3-2-1	80 b	106 b	163 a
IR2143-26-3-5-4	34 b	58 b	111 a
IR18348-36-3-3	57 b	79 b	245 a
IR28222-9-2-2-2-2	54 b	70 b	191 a
IR13540-56-3-2-1	40 b	52 b	114 a

[a]In a row, figures followed by a common letter are not significantly different at the 5% level by DMRT. [b]No significant increase in yield at both S levels. [c]With significant increase in yield at both levels. [d]Without significant increase in yield between 1 and 10 ppm S. [e]With significant increase at 10 ppm S but not at 1 ppm S.

Table 22. Yield of 14 treatments in the long-term fertility trial with irrigated IR64 rice. IRRI, 1985 DS and WS.

Treatment[a]	Yield[b] (t/ha)	
	Dry season	Wet season
Control	3.1 d	3.3 ef
Zn	3.0 d	3.2 f
N + Zn	5.0 ab	4.0 bcde
P + Zn	3.0 d	3.8 cdef
K + Zn	2.7 d	3.4 def
NP + Zn	5.6 a	4.7 ab
PK + Zn	2.8 d	3.5 def
NK + Zn	5.0 ab	4.6 ab
NPK + Zn	5.2 ab	4.7 a
NPK	5.4 a	4.8 a
NPK + S	5.0 ab	4.7 a
NPK + Zn + S	4.6 bc	3.8 cdef
NPK + azolla + Zn	4.9 ab	4.4 abc
NPK + straw + Zn	4.0 c	4.1 abcd

[a]Zn as root dip in 4% ZnO solution. S as AS at 40 kg S/ha. [b]CV (%) = 10.3 in DS and 11.2 in WS.

NPK + straw + Zn. Moreover, the yield from NPK alone was comparable to those of NPK with Zn, NPK with S, and NPK with azolla and Zn. The same trends had been observed in the previous four seasons, indicating that N remains limiting and, despite the use of high analysis fertilizers with almost no S content, S deficiency is not yet apparent.

Table 21. S content and S uptake in straw and grain of rice varieties at harvest. IRRI, 1985.

Variety	Straw				Grain			
	Total S (%)		S uptake (mg/pot)		Total S (%)		S uptake (mg/pot)	
	No S	10 ppm S	No S	10 ppm S	No S	10 ppm S	No S	10 ppm S
			Early maturing					
IR36	.027	.063	8	54	.018	.062	5	58
IR60	.026	.056	11	33	.032	.071	10	67
IR13540-56-3-2-1	.022	.091	7	55	.051	.061	20	70
Mean[a]	.026	.063	12	47	.038	.064	17	69
			Medium maturing					
IR20	.029	.046	12	23	.032	.064	15	39
IR34	.125	.062	76	98	.051	.069	37	86
IR18348-36-3-3	.019	.065	11	120	.067	.062	38	152
Mean	.058	.058	33	80	.050	.065	30	92
			Late maturing					
IR42	.087	.048	75	67	.056	.063	25	66
Pelita	.142	.076	83	96	.074	.058	40	65
IR21820-154-3-2-2-3	.105	.050	43	32	.058	.056	19	29
IR28222-9-2-2-2-2	.107	.042	75	71	.038	.059	21	113
Mean[b]	.108	.063	79	91	.053	.058	27	73

[a]Mean values of 5 varieties. [b]Mean values of 9 varieties.

In 1985 WS, no significant yield increases were observed with Zn alone, Zn with K, and Zn with PK. The response to N, alone or in combination with P and K, was still significant, although lower than the corresponding DS values. The responses to NPK + S and NPK + Zn + S were lower than the response to NPK alone, suggesting that there is no benefit from the application of S. This could be attributed to the presence of adequate S in the irrigation water, which ranged from 16 to 23 ppm SO_4^{-2}-S.

Soil and crop management

Rice crop cultural practices

Agronomy Department

CONTINUOUS CROPPING 274
PLANT GROWTH REGULATOR STUDIES 274
Effect of chlormequat chloride in the field 274
15-day-old IR60 seedlings 274
15-day-old IR29723 seedlings 274
30-day-old seedlings 274
Effect of abscisic acid, Tachigaren, and B-995 274
EFFECTS OF CCC, WATER MANAGEMENT, AND NITROGEN APPLICATION METHOD 276
INTERCROPPING EARLY MATURING AND DEEP WATER RICE 277
EARLY MATURING RICES FOR PREFLOOD PRODUCTION IN DEEP WATER 277

CONTINUOUS CROPPING

The continuous cropping experiment continued to compare yield responses of broadcast seeded (BR) and transplanted (TPR) rice over four N rates.

Table 1 shows the average yield of 6 rices in the 67th and 68th crops. In dry (DS) and wet (WS) seasons, IR8 was damaged by tungro virus and brown planthopper (BPH).

In DS, transplanted medium-late maturing lines IR25587-133-3-2-2-2 and IR29723-143-3-2-1 yielded significantly more than when broadcast (Table 1). The advantage of TPR over BR was observed in IR25587-133-3-2-2-2 at 100 N, and in IR29723-143-3-2-1 at 0 and 150 N (Table 2). With early maturing IR36, IR58, and IR32429-47-3-2-2, yields of TPR and BR were similar. BR IR36 yielded 6.5 t/ha at 100 N.

Severe BPH was recorded in WS. The advantage of TPR over BR was generally observed at low N (Table 3).

PLANT GROWTH REGULATOR STUDIES

Research on the effects of synthetic plant growth regulators on rice continued in 1985 DS in field and greenhouse experiments.

Effect of chlormequat chloride in the field. In the field, chlormequat chloride (2-chloro-ethyl-trimethyl ammonium chloride or CCC) at 3.0 and 6.0 kg ai/ha was applied to IR60 and IR29723-143-3-2-1 at 10 d after seeding (DAS) in seedbeds, at tillering and at booting. Rices were transplanted at 15 and 30 days old. CCC did not significantly affect yield, although there were some small, statistically insignificant differences in some yield components depending on the rates and time of application, cultivar, and seedling age.

15-day-old IR60 seedlings. Applying CCC at 3.0 kg ai/ha at tillering and booting, and at 6.0 kg ai/ha at 10 DAS and tillering increased panicle weight and spikelet number of IR60 plants. Except in treatments with 3.0 kg at 10 DAS and 6.0 kg at tillering, spikelet sterility also increased.

15-day-old IR29723 seedlings. Panicle number in IR29723 increased with application of CCC at 3.0 kg ai/ha at all growth stages and at 6.0 kg ai/ha at booting; panicle weight increased with 3.0 kg and 6.0 kg at tillering and booting; spikelet number increased with 3.0 kg at all stages, and with 6.0 kg at tillering and booting; and grain-straw ratio increased with both rates and at all growth stages. Spikelet sterility was high with 3.0 kg ai/ha applied at 10 DAS and at booting.

30-day-old seedlings. Except for 100-grain weight and grain-straw ratio of 30-day-old seedlings, no other yield components were affected by the CCC treatment. CCC increased grain-straw ratio with 3.0 kg ai/ha applied at tillering and booting, and with 6.0 kg ai/ha at booting.

CCC affected more yield components in IR60 transplanted at 30 d and in IR29723 transplanted at 15 d. Panicle weight and spikelet number were the components most affected.

Effect of abscisic acid, Tachigaren, and B-995. Low temperature normally affects plant growth adversely. Greenhouse experiments examined the effect of abscisic acid (ABA), Tachigaren, and B-995 — each applied at 10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6} *M* — in minimizing low (16/12 °C) temperature stress

Table 1. Average grain yield of transplanted (TPR) and broadcast seeded (BR) rices at 4 N rates. Continuous cropping experiment, IRRI, 1985.

Variety or line	Yield[a] (t/ha)					
	Dry season (67th crop)			Wet season (68th crop)		
	TPR	BR	Difference	TPR	BR	Difference
IR8	3.2 c	3.0 c	0.2ns	0	0	–
IR36	5.1 a	5.4 a	0.3ns	3.9 a	3.7 a	0.2*
IR58	5.0 a	5.1 a	0.1ns	3.7 ab	3.8 a	0.1ns
IR25587-133-3-2-2-2	4.4 b	3.9 b	0.5**	3.7 ab	3.8 a	0.1ns
IR29723-143-3-2-2	4.5 b	3.8 b	0.7**	3.6 b	3.2 b	0.4**
IR32429-47-3-2-2	4.9 a	5.0 a	0.1ns	3.6 b	3.1 b	0.5**

[a]Av of 4 replications. 0 = no harvest because of severe RTV and BPH.

Table 2. Average grain yield of transplanted (TPR) and broadcast seeded (BR) rices at 4 N rates. Continuous cropping experiment (67th crop), IRRI, 1985.

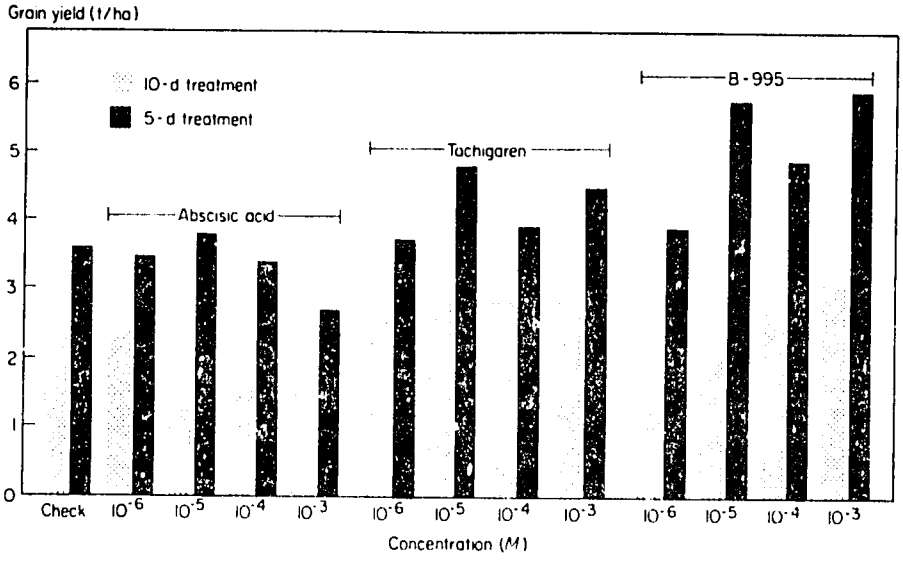
Variety or line	Yield[a] (t/ha)											
	0 N			50 N			100 N			150 N		
	TPR	BR	Difference	TPR	BR	Difference	TPR	BR	Difference	TPR	BR	Difference
IR8	2.8 c	2.7 b	0.1ns	3.6 b	3.2 b	0.4ns	3.6 c	2.9 d	0.7ns	2.6 d	2.9 b	0.3ns
IR36	3.6 ab	3.6 a	0.0ns	4.6 a	5.0 a	0.4ns	6.1 a	6.5 a	0.4ns	6.1 a	6.4 a	0.3ns
IR58	2.9 bc	3.5 a	0.6ns	5.0 a	4.8 a	0.2ns	6.0 a	6.2 ab	0.2ns	5.9 a	5.8 a	0.1ns
IR25587-133-3-2-2-2	4.1 a	3.6 a	0.5ns	4.7 a	4.3 a	0.4ns	5.1 b	4.3 c	0.8*	3.8 c	3.4 b	0.4ns
IR29723-143-3-2-1	3.6 ab	2.7 b	0.9*	4.6 a	4.2 a	0.4ns	5.2 b	4.8 c	0.4ns	4.7 b	3.5 b	1.2**
IR32429-47-3-2-2	3.2 bc	3.5 a	0.3ns	4.8 a	4.9 a	0.1ns	6.0 a	5.7 b	0.3ns	5.7 a	5.9 a	0.2ns

[a]Av of 4 replications.

Table 3. Average grain yield of transplanted (TPR) and broadcast seeded (BR) rices at 4 N rates. Continuous cropping experiment (68th crop), IRRI, 1985.

Variety or line	Yield[a] (t/ha)											
	0 N			30 N			60 N			90 N		
	TPR	BR	Difference	TPR	BR	Difference	TPR	BR	Difference	TPR	BR	Difference
IR36	3.1 a	2.6 bc	0.5*	3.9 a	3.4 ab	0.5*	4.3 a	4.3 a	0.0ns	4.4 a	4.4 a	0.0ns
IR58	3.3 a	3.3 a	0.0ns	3.0 c	3.1 bc	0.1ns	4.1 ab	4.3 a	0.2ns	4.3 a	4.4 a	0.1ns
IR25587-133-3-2-2-2	2.8 a	3.0 ab	0.2ns	3.4 abc	3.6 a	0.2ns	4.1 ab	4.2 a	0.1ns	4.4 a	4.4 a	0.0ns
IR29723-143-3-2-1	2.8 a	2.6 bc	0.2ns	3.6 ab	3.1 bc	0.5*	3.7 b	3.4 b	0.3ns	4.3 a	3.9 b	0.4*
IR32429-47-3-2-2	2.9 a	2.5 c	0.4*	3.2 bc	2.8 c	0.4*	3.9 ab	3.4 b	0.5*	4.2 a	3.9 b	0.3ns

[a]Av of 4 replications.



1. Effect of growth regulators and their concentration on yield of IR20654-R-R-R exposed at the 4-leaf stage to low (16/12 °C) temperature for 5 and 10 d. IRRI, 1985.

on IR20654-R-R-R. Five- and 10-d periods of exposure were compared.

Plant regulator treatments did not affect dry weight and tiller number but generally increased plant height and root length. Tachigaren at 10^{-4} and 10^{-5} *M* in the 10-d treatment and B-995 at 10^{-5} and 10^{-6} *M* in the 5-d treatment produced the tallest plants. ABA at 10^{-5} *M* in the 5-d exposure and B-995 at 10^{-4} *M* in the 10-d treatment produced the longest roots.

Regardless of plant growth regulator, the 5-d treatment consistently gave higher yields than the 10-d treatment (Fig. 1). At both exposures, Tachigaren and B-995 generally yielded higher than the untreated check. Highest yields were obtained with B-995 at 10^{-3} and 10^{-5} *M* in the 5-d exposure. Some ABA treatments yielded either as well as or lower than the untreated check.

None of the plant regulators used affected tiller number and dry weight of the rice seedlings exposed to temperature stress, but all influenced plant height and root length.

EFFECTS OF CCC, WATER MANAGEMENT, AND NITROGEN APPLICATION METHOD

With spraying of the growth retardant CCC at 1.5 kg ai/ha and midseason drying, prilled urea (PU) gave higher yields than urea supergranules (USG). Without CCC, however, PU performed better only with standard water management (Table 4). PU gave significantly higher yields than USG for medium and late maturing varieties but not for early maturing ones (Table 5). USG at 145 kg N/ha gave significantly lower yield than PU for medium and late maturing varieties because of more severe lodging that started during flowering. IR21820-154-2-2-3 and IR36 suffered from lodging. There were no significant responses to CCC application. IR29723-143-3-2-1 produced the highest average yield.

Table 4. Effect of plant growth retardant CCC, water management, and N source on grain yield, IRRI, 1985 late DS.

Water management	Urea source[a]	Yield[b] (t/ha)		
		Untreated	CCC-treated	Mean
Continuous flooding	PU	5.0 a	4.6 a	4.8
	USG	4.5 b	4.4 a	4.5
Midseason drying	PU	4.6 b	4.7 a	4.7
	USG	4.4 b	4.0 b	4.2
Mean		4.6	4.4	

[a]PU = prilled urea, USG = urea supergranules. N rate was 145 kg/ha. [b]Av of 6 IR varieties or lines and 4 replications.

Table 5. Effect of N application method (145 kg N/ha) on grain yield of early, medium, and late maturing IR rices. IRRI, 1985 late DS.

Maturity group	Yield[a] (t/ha)		
	PU	USG	Difference
Early	4.4 b	4.3 ab	0.14ns
Medium	4.6 b	4.1 b	0.50**
Late	5.2 a	4.5 a	0.63**

[a]Av of 2 CCC treatments, 2 water management treatments, and 4 replications.

Low grain yields in all treatments were caused by three successive typhoons that occurred at crop flowering to maturity.

INTERCROPPING EARLY MATURING AND DEEP WATER RICE

Previous trials at Huntra Experiment Station, Thailand, showed that under good growing conditions, a 40-50% increase in total grain production could be obtained by planting rows of an early maturing rice between rows of deep water rice.

Trials in farmers' fields during 1984 simplified establishment by broadcasting the early variety and then dropping seeds of deep water rice in rows either 75 cm or 100 cm apart. The intercrops were compared with broadcast monoculture of deep water rice and early maturing rice. Yields for three sites are given in Table 6. Poor establishment in the rows of deep water rice, early drought, bird damage to the early rice, and rat damage in deep water rice gave low yields and high variability, but the intercrops outyielded deep water rice monocultures at all three sites.

Table 7. Grain yields of rainfed early maturing (106 d) rices in farmers' fields at Wang Noi, Thailand, 1984 WS.

Entry	Mean yield (t/ha)
Khao Nai Neuong	2.6 a
IR15429-268-1-2-1	2.3 ab
SPRLR78002-124-1-2	1.9 abc
IR19774-23-2-2-1-3	1.6 abc
CNT BR79256-30-1	1.6 abc
IR19735-5-2-3-2-1	1.5 bc
IR19743-25-2-2-3-1	1.1 c
IR22097-41-4-3	1.0 c
CNT BR79041-8-2	1.0 c
IR9752-71-3-2	0.9 c
IR36	0.7 c

EARLY MATURING RICES FOR PREFLOOD PRODUCTION IN DEEP WATER

In 1984 WS flooding from heavy rain destroyed the first sowing at Wang Noi, Thailand, and the crop from a second sowing was affected by drought. The plants recovered well, but much of the grain was eaten by birds. Grain yields are shown in Table 7.

Table 6. Yields of monocultures of deep water rice and early maturing rice, and of components of intercrops with 2 row spacings of deep water rice at 3 sites in Thailand, 1984 WS.

Type of culture	Bang Ban		Phu Khao Tong		Wang Noi	
			Entries			
Early rice	IR19735-5-2-3-2-1		IR22097-41-4-3		IR22097-41-4-3	
Deep water rice	Puang Madeua		Khao Puang		PG56	
			Yield (t/ha)			
Monoculture early rice		1.0 b		1.2 b		1.6 a
Monoculture deep water rice		1.4 b		1.1 b		1.2 b
Intercrop, 75-cm rows						
Early rice	0.8		0.5		0.6	
Deep water rice	1.7		1.4		1.8	
Total		2.6 a		2.0 a		2.3 a
Intercrop, 100-cm rows						
Early rice	1.2		1.0		0.9	
Deep water rice	2.3		1.7		1.7	
Total		3.5 a		2.7 a		2.6 a
CV		35%		25%		12%

Table 8. Grain yields and emergence and harvest dates for preflood production of rainfed early maturing rices in deep water rice areas of Thailand, 1985 WS.

Entry or parameter	Huntra Experiment Station		Ban Sang farmer's field		Prachinburi Research Center		Prachinburi Township	
	Yield (t/ha)	Rank	Yield (t/ha)	Rank	Yield (t/ha)	Rank	Yield (t/ha)	Rank
IR9752-71-3-2	0.4	7	0.5	6	1.2	6	1.2	5
IR15429-268-1-2-1	0.8	4	0.5	5	1.6	5	1.8	1
IR19735-5-2-3-2-1	0.8	3	0.4	8	1.9	1	1.6	2
IR19743-25-2-2-3-1	0.9	1	0.7	1	1.7	2	1.5	3
IR19774-23-2-2-1-3	0.9	2	0.6	2	–	–	–	–
IR22097-41-4-3	–	–	0.4	7	1.6	4	1.0	6
Khao Nai Neuong	0.5	6	0.6	3	–	–	–	–
RD25	0.6	5	0.6	4	–	–	–	–
Hin Sorn 4	–	–	–	–	0.3	8	0.4	8
Hin Sorn 9	–	–	–	–	0.9	7	0.9	7
IR9729-65-3	–	–	–	–	1.7	3	1.2	4
Sown	3 May		10 May		23 Apr		25 Apr	
Emergence	10 May		17 May		2 May		5 May	
Harvest	20 Aug		30 Aug		9, 19 Aug		2, 9, 15 Aug	
Problems	Drought at panicle initiation (PI), dirty panicle, severe bird damage		Drought at PI, dirty panicle, severe bird and rat damage		Drought, rapid flood at harvest, severe rat damage at early stage		Severe bird damage	

During 1985 WS yields at four sites were very low because of drought, dirty panicle disease, rats, and birds (Table 8), but IR19743-25-2-2-3-1 ranked high at three sites.

In a farmer's field at Ban Sang, Ayutthaya, four entries were irrigated on four occasions to supplement rainfall. Although water was pumped until the field was flooded, drought stress still occurred. IR19735-5-2-3-2-1 yielded 2.65 t/ha; IR9752-71-3-2, 2.52 t/ha; IR36, 2.23 t/ha; and IR19774-23-2-2-1-3, 2.14 t/ha. There was heavy infestation of *Echinochloa colona*, which depressed rice growth.

Soil and crop management

Tillage and management of soil physical conditions

Soil Chemistry/Physics, Water Management, Agricultural Engineering, and Agronomy Departments

EFFECTIVE USE OF ENERGY AND WATER IN RICE-SOIL PUDDLING **280**
TILLAGE EFFECTS ON SOIL PHYSICAL PROPERTIES AND LOWLAND RICE YIELD **285**
PERCOLATION RATES IN LOWLAND RICE SOIL **286**
Percolation **286**
Percolation-organic matter interaction **287**
RESPONSE TO TILLAGE OF MUNGBEAN AFTER LOWLAND RICE **289**
DEEP CULTIVATION OF PUDDLED AND UPLAND SOILS FOR RAINFED MUNGBEAN **291**

EFFECTIVE USE OF ENERGY AND WATER IN RICE-SOIL PUDDLING

Soil Chemistry/Physics, Water Management, and Agricultural Engineering Departments

The need to minimize percolation by puddling is especially important in rice systems that are rainfed or partially irrigated. Puddling requires water and mechanical energy (usually from a draft animal or hand tractor). Current studies seek to determine whether effective puddling can be achieved using smaller inputs of water and energy than are traditional, and whether puddling implements and machines differ in their effectiveness and convenience. Puddling effectiveness is assessed in terms of seasonal percolation, the proportion of fine silt and clay particles that are detached from the soil aggregates, micromorphological changes in soil structure, and effects on rice growth and yield.

Experiments were carried out on two Vertic Tropaquepts of silty clay overlying clay loam, with topsoil having 22 meq Ca^{2+}/100 g and 13 meq Mg^{2+}/100 g. They 1) investigated effects and interactions of 3 levels each of water for land preparation and of mechanical energy imparted by a conventional (skid-supported) rototiller, 2) compared at 3 energy levels the puddling performance of skid-supported and floating rototillers (see section on Machinery Development and Testing) and carabao-drawn plow and harrow, and 3) measured the effects of percolation rate on soil structural changes and rice grain yield.

Three levels of prepuddling water — 50, 120, and 200 mm water depth — were applied to soil whose moisture content was about two-thirds of field capacity; farmers apply 200-600 mm. Each level brought surface soil to field capacity or slightly wetter. Compared to 50 mm, the 120 and 200 mm applications did not wet the soil appreciably beyond field capacity but rather increased the thickness of the surface layer that was brought to field capacity. Cultivation was thus undertaken at a water content only slightly wetter than field capacity and should be regarded as a wet rototilling rather than a puddling of supersaturated soil.

The three levels of cultivation energy input were achieved by operating one particular skid-supported power rototiller (SRT) for three time intervals. Assuming a 30% transfer of power from the 4 kW (6 hp) engine to the soil, the 3 time intervals corresponded to energy inputs of 5, 10, and 15 kJ/m^2 of ground area. These energies were roughly equal to those from one, two, or three passes of the carabao-drawn plow and harrow (P+H). The floating rototiller (FRT) was evaluated only for energy input of 15 kJ/m^2.

The presence of standing water affected puddling more than did energy input (Table 1). Water-dispersible silt-plus-clay, which was 13% prior to puddling, was increased to only 16-17% by cultivation at field capacity with the SRT. On plots that had 20 mm or more of standing water because of upwelling, the increase was to 28%. The implements differed in the ability to disaggregate saturated soil: the FRT and the P+H dispersed more material than the SRT. Operators found the FRT easier to maneuver and less prone to sink and stall than the SRT.

Cultivation decreased total soil porosity from 66% to about 61%; the decrease may have been less with standing water (Table 2). There were no differences in the effects on total porosity of the different energy inputs — either for the rototiller or the carabao-drawn plow (Table 3). On plots that were puddled under standing water and thus had soft soil 12 cm deep or deeper, soil bulk density, and hence total soil porosity, was measured using a new type of sampler (Fig. 1) designed to withdraw undisturbed horizons from soft mud.

Although cultivation had a relatively small effect on total porosity, it did cause large changes in pore size distribution. Before cultivation, the porosity contributed to the 0-15 cm layer by pores wider

Table 1. Effects of puddling implement, energy input, and soil-water content on percentage of water-dispersible silt-plus-clay for 0-10 cm soil depth. Vertic Tropaquept, IRRI, 1985.

Implement[a]	Soil water at cultivation[b]	Energy input (kJ/m^2)	Dispersible silt-plus-clay (%)
None	Precultivation	0	13 ± 1
SRT	FC	10	16 ± 1
SRT	FC	15	17 ± 1
SRT	≥ 20 mm	5, 10, 15	28 ± 2
FRT	≥ 20 mm	15	34 ± 4
P+H	≥ 20 mm	5, 10, 15	37 ± 2

[a]SRT = skid-supported rototiller, FRT = floating rototiller, P+H = plow and harrow. [b]FC = field capacity, ≥20 mm = 20 mm or more of standing water.

Table 2. Effects of puddling implement and water application on total porosity expressed as a percentage[a] at various soil depths.[b] IRRI, 1985.

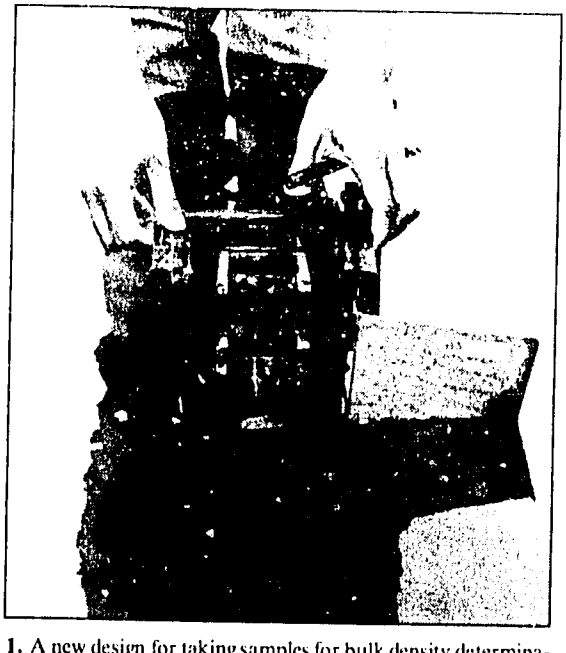
Applied water (mm)	Porosity (%) resulting from					
	Skid-supported rototiller measured at depth (cm) of			Plow and harrow measured at depth (cm) of		
	0-5	5-10	10-15	0-5	5-10	10-15
50	62	61	62			
120	64	62	62			
200	60	58	60			
Standing water[c]	63	65	64	63	60	61
SED	2	2	2			

[a]Precultivation total porosity = 66%, particle density = 2.40 t/m³. [b]Av of 3 energy treatments. Soil is a Vertic Tropaquept. [c]20 mm or more.

Table 3. Effects of puddling implement and energy input on total porosity expressed as a percentage[a] at various soil depths.[b] IRRI, 1985.

Energy (kJ/m²)	Porosity (%) resulting from					
	Skid-supported rototiller measured at depth (cm) of			Plow and harrow measured at depth (cm) of		
	0-5	5-10	10-15	0-5	5-10	10-15
5	62	62	63	64	62	62
10	62	62	61	63	61	61
15	63	61	62	63	58	61
SED	2	2	2	2	2	2

[a]Precultivation total porosity = 66%, particle density = 2.40 t/m³. [b]Av of all water treatments. Soil is a Vertic Tropaquept.



1. A new design for taking samples for bulk density determination in soft mud. IRRI, 1985.

than 50 μm was between 20 and 30%. This wide-pore porosity decreased to about 5% after cultivation at field capacity (Table 4), and to 3% (and possibly to 2% at 10-15 cm depth) after puddling under standing water. Effects of energy input were not significant — either for SRT or for P+H (Table 5) — but the plowing may have compacted the soil at 10-15 cm.

The effects of puddling on type and shape of pores were measured on thin soil sections using an image-analyzing computer at the Istituto per la Chimica del Terreno, Pisa, Italy. Only pores wider than 30 μm in two-dimensional cross-section are measured, and they are classified as rounded, irregular, or elongated. The last are the pores that facilitate percolation. Porosity contributed to the 5-15 cm layer by pores wider than 30 μm (regardless of shape) was decreased by puddling under standing water (Fig. 2); the number of pores per standard area was proportionally more affected (Fig. 3). The distribution of porosity among pores

Table 4. Effect of puddling implement and water application on percentage porosity contributed at various soil depths by pores[a] wider than 50 μm.[b] IRRI, 1985.

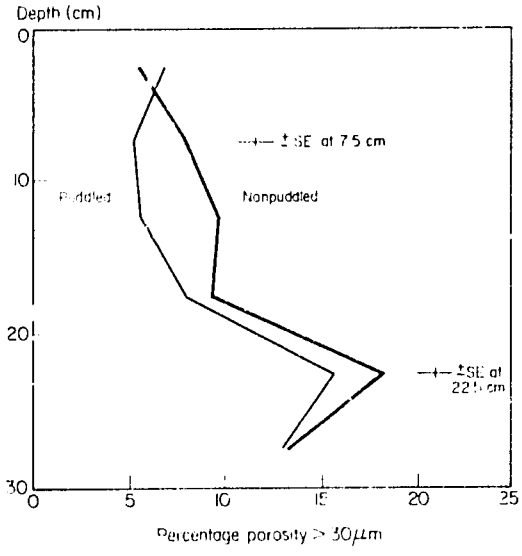
Applied water (mm)	Porosity (%) resulting from							
	Skid-supported rototiller measured at depth (cm) of				Plow and harrow measured at depth (cm) of			
	0-5	5-10	10-15	Mean	0-5	5-10	10-15	Mean
50	5.8	4.2	4.7	4.9				
120	4.0	4.6	4.0	4.2				
200	4.1	5.2	6.5	5.3				
Standing water[c]	4.0	2.2	2.6	2.9	3.8	3.5	1.7	3.0
SED	1.2	1.2	1.2	0.8				

[a]Porosity >50 μm prior to cultivation = 20-30%. [b]Av of 3 energy treatments. Soil is a Vertic Tropaquept. [c]20 mm or more.

Table 5. Effect of puddling implement and energy application on percentage porosity contributed at various soil depths by pores[a] wider than 50 μm.[b] IRRI, 1985.

Energy (kJ/m²)	Porosity (%) resulting from							
	Skid-supported rototiller measured at depth (cm) of				Plow and harrow measured at depth (cm) of			
	0-5	5-10	10-15	Mean	0-5	5-10	10-15	Mean
5	5.8	4.3	4.8	5.0	2.7	5.2	0.8	2.9
10	3.2	3.1	3.9	3.4	4.7	3.5	2.3	3.5
15	3.9	4.3	4.1	4.1	4.0	1.7	2.0	2.6
SED	1.1	1.1	1.1	0.8	1.1	1.1	1.1	0.8

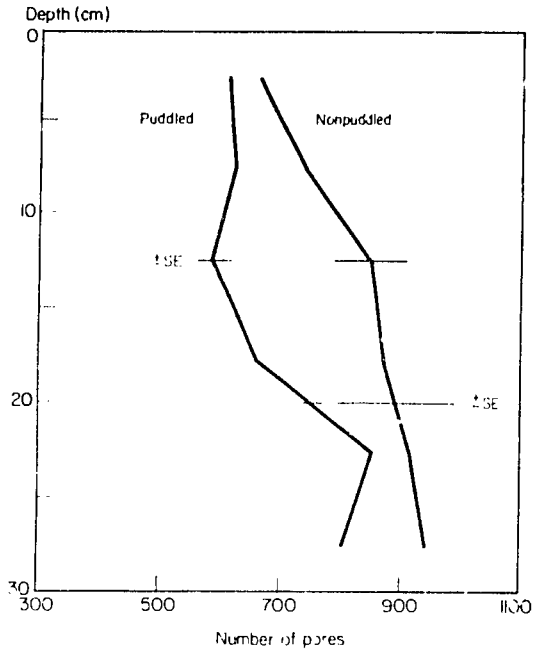
[a]Porosity >50 μm prior to cultivation = 20-30%. [b]Av of all water treatments. Soil is a Vertic Tropaquept.



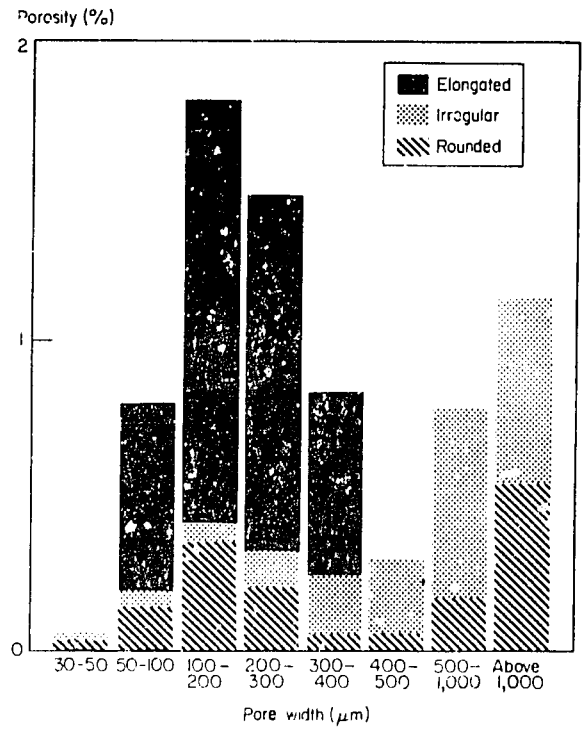
2. Variation with depth in puddled and nonpuddled soil of the porosity contributed by pores wider than 30 μm (from 2-dimensional sections). IRRI, 1985.

of different shapes and sizes in the 0-5 cm layer of puddled soil (Fig. 4) shows that the elongated pores dominated the areal porosity (though they were in fact fewer in number). Averages of puddled and nonpuddled plots for porosity in the 3 shape classes in the more disturbed surface soil (0-20 cm) and the less disturbed deeper soil (20-30 cm) (Table 6) show that porosity in all shape categories in the 0-20 cm layer was less in puddled soil, but below 20 cm there was no statistical or practical difference. The decreased porosity in puddled surface soil was associated with a lower water infiltration rate.

Measurements on thin-section samples taken just before rice harvest showed that porosity — especially of elongated pores — increased between transplanting and harvest in the 0-20 cm layer and decreased in 20-30 cm on both puddled and nonpuddled plots (Table 7). This phenomenon is illustrated more clearly in Table 8, where the totals of porosity (from Table 7) for puddled and non-



3. Variation with depth in puddled and nonpuddled soil of the number per standard area of pores wider than 30 μm (from 2-dimensional sections). IRRI, 1985.



4. Percentage porosity in various size and shape categories for puddled soil at 0-5 cm depth (from 2-dimensional sections). IRRI, 1985.

puddled plots are supplemented by results for one particular puddled plot that had high infiltration because of its exposed plot perimeter and deep water table. We hypothesize that the changes in porosity were caused by migration of clay and silt particles from the 0-20 to the 20-30 cm layer. This hypothesis is supported by our observation in thin soil sections from 20-25 cm depth: the wider pores showed yellowing that is characteristic of clay migration. The hypothesis may be tested quantitatively if it is assumed that the two-dimensional measures of porosity may be converted to three dimensions by simple 3/2-power-law scaling, and that soil material leaving the 0-20 cm layer does not penetrate deeper than 30 cm. Within the precision of the data, these assumptions are valid in that the computed three-dimensional porosities (not shown

Table 6. Effect of puddling on the percentage porosity contributed in various shape categories and in 2 soil depth layers by pores wider than 30 μm (from 2-dimensional sections, after puddling and before transplanting). IRRI, 1985.

Treatment	Porosity (%)				Infiltration[a] (mm/d)
	Rounded	Irregular	Elongated	Total	
		0-20 cm depth			
Nonpuddled	1.4	2.0	4.8	8.1	8.4
Puddled	1.2	1.7	3.5	6.4	4.7
SED	0.3	0.3	0.6	0.8	2.2
		20-30 cm depth			
Nonpuddled	3.0	2.6	10.2	15.8	
Puddled	2.1	2.5	9.7	14.3	
SED	0.3	0.3	2.0	2.1	

[a]By double-ring infiltrometer.

Table 7. Comparison, for puddled and nonpuddled soil, of changes between rice transplanting and harvest in percentage porosity contributed in various shape categories and in 2 soil depth layers by pores wider than 30 μm (from 2-dimensional sections). IRRI, 1985.

Sampled at	Porosity (%)							
	Puddled				Nonpuddled			
	Rounded	Irregular	Elongated	Total	Rounded	Irregular	Elongated	Total
				0-20 cm depth				
Transplanting	1.2	1.7	3.5	6.4	1.4	2.0	4.8	8.1
Harvest	1.8	1.8	4.0	7.6	2.2	2.0	6.3	10.5
SED	0.3	0.3	0.8	1.0	0.3	0.3	0.8	0.8
				20-30 cm depth				
Transplanting	2.1	2.5	9.7	14.3	3.0	2.6	10.2	15.8
Harvest	2.3	2.7	7.2	12.2	2.0	2.1	10.1	14.2
SED	0.3	0.5	1.8	2.0	0.4	0.3	1.0	1.8

Table 8. Effects of water infiltration rate on changes, between rice transplanting and harvest, in percentage porosity contributed in 2 soil depth layers by all pores wider than 30 μm, for puddled and nonpuddled soil (from two-dimensional sections). IRRI, 1985.

Sampled at	Porosity (%)		
	Puddled, low infiltration	Nonpuddled	Puddled, high infiltration[a]
		0-20 cm depth	
Transplanting	6.4	8.1	6.4
Harvest	7.6	10.5	9.6
SED	1.0	0.8	1.0
		20-30 cm depth	
Transplanting	14.3	15.8	14.3
Harvest	12.2	14.2	8.4
SED	2.0	1.8	2.0
Calculated loss (mm depth) of soil from 0-20 cm	1.0 ± 0.8	2.2 ± 0.8	2.8 ± 0.8
Calculated gain (mm depth) of soil in 20-30 cm	1.1 ± 1.0	0.9 ± 1.1	3.0 ± 1.0
Soil migration (mm depth)	1.0 ± 0.6	1.6 ± 0.7	2.9 ± 0.7
Infiltration (mm/d)	5 ± 1	8 ± 2	14 ± 4
Migration ÷ infiltration (mm depth/mm per day)	0.20 ± 0.14	0.20 ± 0.10	0.21 ± 0.06

[a]Resulting from deep water table and exposed plot perimeter.

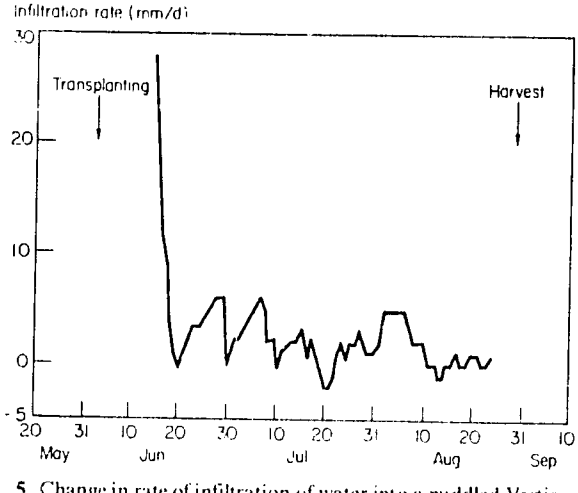
in Table 8) were consistent with measured values from water-release characteristics, and that the calculated losses of soil material were equal to the calculated gains. If the average of the loss and gain is assumed to represent the amount of migrated material (represented as mm depth), then there is a remarkable though perhaps fortuitous constancy (Table 8) in the ratio of soil migration to seasonal average infiltration.

Measurements of the effects on water infiltration of puddling implements and cultivation energy showed no correlation between infiltration and either the total or the wider-than-50 μm porosity (as derived from bulk density and water-release characteristics) or the water-dispersible silt-plus-clay. But infiltration was affected by cultivation energy: for the SRT, seasonal average infiltration was 6 mm/d at 5 kJ/m^2 and only 1 mm/d at

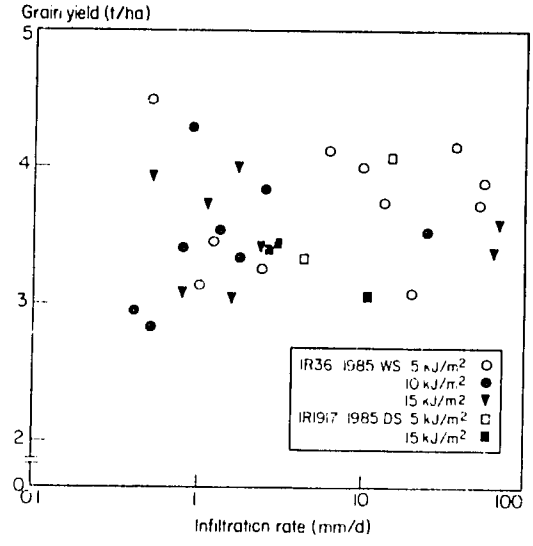
10 kJ/m^2; it decreased no further when energy increased to 15 kJ/m^2. For the FRT, which was tested only at 15 kJ/m^2, and at each of the energy levels applied by P+H, infiltration was 1 mm/d.

The amount of precultivation water applied affected subsequent infiltration only for the SRT at energy input of 5 kJ/m^2. At this input, seasonal averages of infiltration were 8 ± 2 mm/d for cultivation at field capacity and 4 ± 1 mm/d for cultivation with standing water. On most plots, infiltration decreased initially (Fig. 5), probably because soil pores became blocked as a result of soil swelling, clay migration, root penetration, or microbial activity.

Infiltration was strongly influenced by regional hydrology and the local water table. At all levels of cultivation energy, infiltration was faster in areas nearer to a deep drain that lowered the water table. Subsurface hydrology was probably the reason why seepage-plus-percolation, as measured by an inclined scale, was much higher than infiltration as determined by a double-ring infiltrometer. For plots least affected by the deep drain, the ratio of seepage-plus-percolation to infiltration ranged from 18 to 80. The high value for these ratios may indicate that there was preferentially high percolation down unpuddled soil beneath the bunds. Preliminary measurements showed infiltration into soil beneath recently removed bunds to be 100 ± 30 times faster than into puddled soil alongside the bunds.



5. Change in rate of infiltration of water into a puddled Vertic Tropaquept rice soil (measurement by double ring infiltrometer with inner ring extending to 25-cm depth). IRRI, 1985.



6. Relation of rice grain yield to seasonal average infiltration rate and to cultivation energy input. IRRI, 1985.

Grain yield of IR36 was similar at the different inputs of puddling water and energy. Yield was independent of infiltration (Fig. 6) over the range 0.5-80 mm/d — and for all treatments soil was kept saturated throughout the season, and seepage-plus-percolation much exceeded infiltration and ensured sufficient throughput of water to remove toxins and prevent excessive reduction.

Large savings of puddling water and energy can thus be made with no penalty of lost rice yield. Micromorphological measurements can give usable information about the abundance of pores that facilitate transmission of water and penetration of roots. The rate of downward soil migration is related to water percolation rate, and the ratio of seepage-plus-percolation to infiltration is affected by depth to water table. Unpuddled soil beneath bunds may constitute a channel for excessive loss of water from flooded ricefields.

TILLAGE EFFECTS ON SOIL PHYSICAL PROPERTIES AND LOWLAND RICE YIELD

Agronomy Department

Ongoing tillage research for lowland rice had an additional treatment in 1985 dry season (DS): dry seeded rice (DSR) with zero tillage. Other treatments were zero tillage, minimum tillage (one dry

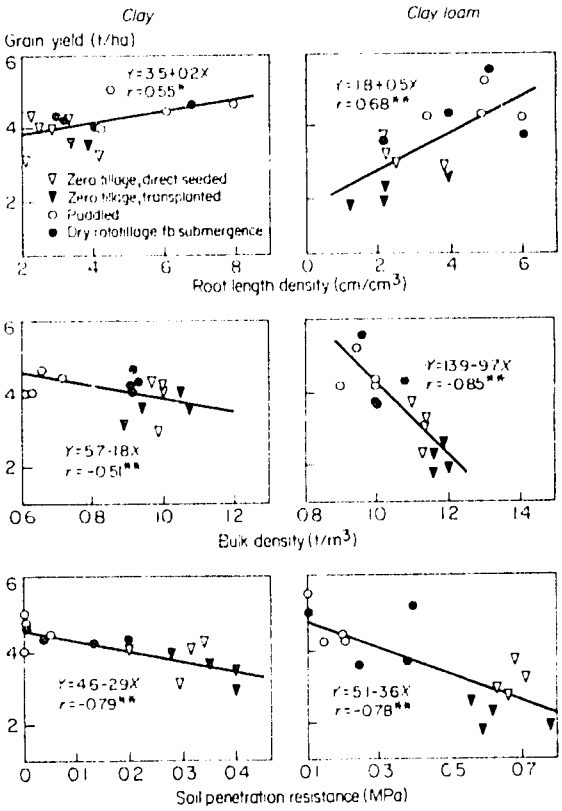
Table 9. Effect of tillage on soil bulk density (0-10 cm), crop water requirement, weed growth, and grain yield of IR36 in 2 lowland rice soils, IRRI, 1985 DS.

Tillage treatment[a]	Bulk density (t/m³)		Water requirement (mm/d)		Weeds (t/ha)		Grain yield (t/ha)	
	Clay	Clay loam	Clay	Clay loam	Clay	Clay loam	Clay	Clay loam
Zero tillage, DSR	0.99	1.14	37	786	4.8	4.3	3.9	3.1
Zero tillage, TPR	0.99	1.17	35	1002	4.0	3.8	3.5	2.6
Minimum tillage, TPR	0.92	1.01	35	527	2.9	2.7	4.3	4.3
Puddling, TPR	0.66	0.96	30	328	1.2	0.7	4.5	4.5
LSD (.05)	0.13**	0.08**	4*	475*	1.8*	2.3*	0.6*	0.9*

[a]DSR = dry seeded rice, TPR = transplanted rice.

rototilling plus submergence), and puddling, all for transplanted rice (TPR).

Two locations on the IRRI farm were chosen: one with clay soil dominated by X-ray-amorphous alumino-silicates and montmorillonite-like clay minerals, and the other with clay loam soil dominated by X-ray-amorphous alumino-silicates and halloysite-like clay minerals.



7. Relation between rice grain yield and root-length density, bulk density, and soil-penetration resistance (0-10 cm). IRRI, 1985 DS.

In the clay loam soil, bulk density with minimum tillage was similar to that with puddling, but was significantly lower than with zero tillage. In the clay soil, minimum tillage produced bulk density similar to that with zero tillage (Table 9).

Crop and soil properties in puddled and zero-tilled plots differed more widely in the clay loam than in the clay soil (Fig. 7). Root-length density in the top 10 cm was positively correlated with grain yield, and bulk density and soil strength as measured by soil penetration resistance were negatively correlated with grain yield.

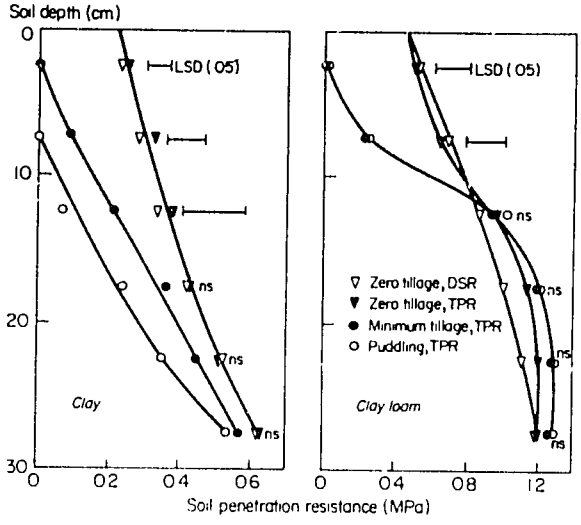
Minimum tillage and puddling significantly reduced soil penetration resistance in the top 15-cm layer (Fig. 8), crop water requirement (except in clay), and weed growth (Table 9). Soil temperature within the top 20 cm was lower in puddled than in zero-tilled plots (Table 10). These reductions were associated with significant increases in grain yield in the puddled and minimum-tilled plots, which had similar yields (Fig. 7, Table 9).

Root-length densities of DSR and TPR with zero tillage did not significantly differ, showing that root injury to seedlings at transplanting does not affect root-length density any more than the hard root medium does.

PERCOLATION RATES IN LOWLAND RICE SOIL

Agronomy Department

Percolation. Greenhouse studies were continued in 1985 DS and wet season (WS). Percolation rates in three soils did not affect grain yield in DS. In WS,



8. Tillage effects on the penetration resistance of 2 submerged rice soils. IRRI, 1985 DS. DSR = dry seeded rice, TPR = transplanted rice.

Table 10. Tillage effects on soil temperature (0-20 cm) in 2 lowland rice soils. IRRI, 1985 DS.

Treatment	Temperature[a] (°C)			
	Clay		Clay loam	
	Minimum	Maximum	Minimum	Maximum
Zero tillage	27.8 ± 0.9	29.6 ± 1.0	28.9 ± 2.0	32.4 ± 4.5
Puddling	26.0 ± 0.7	28.1 ± 0.9	27.2 ± 2.1	29.3 ± 2.6
Air	23.3 ± 0.9	31.5 ± 1.2	23.2 ± 0.9	32.5 ± 1.4

[a]Averaged from transplanting to harvest.

however, high percolation increased grain yield (because of high weight per panicle) only in the silty clay loam soil, which had a 10.3% native organic matter (OM) content.

The amount of exchangeable K and Ca and the Fe content in the three soils significantly increased after two seasons of percolation studies (Table 11). Organic C notably decreased in soils with 5 and 10% OM.

Percolation-organic matter interaction. A silty clay loam with very low native OM content (1.2%) was used to determine the interactive effect of percolation rate and OM amendments on rice yield and nutrient concentrations. Percolation rates were 0, 15, and 30 mm/d, and OM levels were equivalent to 0, 5, 10, and 20 t rice straw/ha, incorporated in the top 15 cm of soil 1 d before transplanting 5 seedlings/pot.

In DS and WS, tillering in pots that received 20 t OM/ha was significantly less than in pots with no added OM (Table 12). Unfilled spikelet percentage was lower with 20 t OM/ha than with 0 or 5 t OM/ha. In WS, tillering was decreased in plots without percolation because of the accumulation of organic acids (Fig. 9).

In DS, an OM level of 20 t/ha and intermediate percolation rate of 15 mm/d gave the highest yield of 41 g/hill (Fig. 10). OM and percolation rate did not significantly affect yield in WS.

An increase in OM level also increased Fe and Mn concentration in the soil solution (Fig. 11, 12).

Table 11. Nutrient status of 3 soils after percolation experiments in 2 seasons. IRRI greenhouse, 1985.

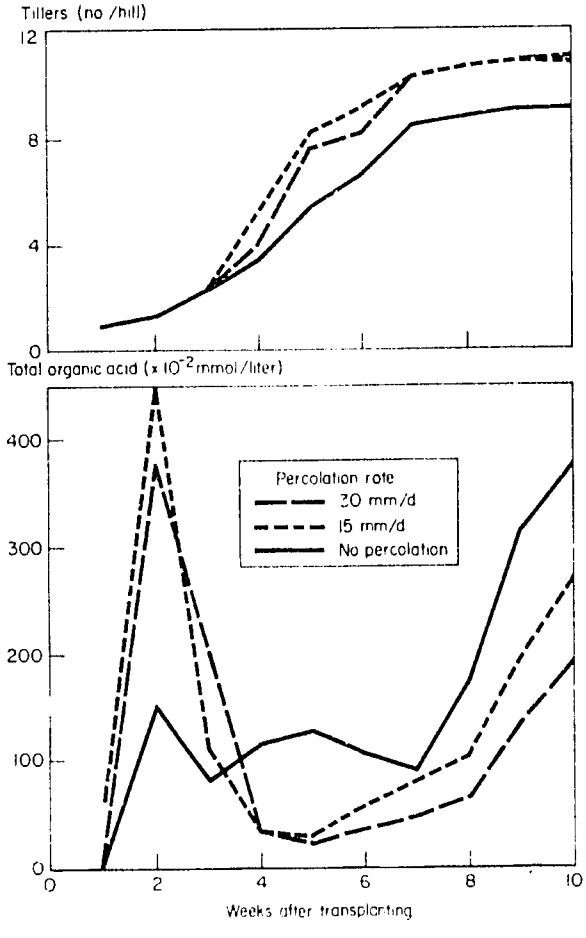
Season	Total N (%)	Olsen's P (ppm)	Exchangeable cations (meq/100 g)			Fe (%)	Mn (%)	Organic C (%)
			K	Ca	Mg			
			Silty clay loam (OM[a] ≅ 10%)					
1984 WS	0.5	7.6	0.17	21	9.3	4.7	0.053	7.2
1985 WS	0.5	8.1	0.28	30	11.4	5.0	0.052	6.7
LSD (.05)	ns	ns	0.02**	7*	0.9**	0.2**	ns	0.2**
			Silty clay (OM ≅ 5%)					
1984 WS	0.3	10.3	0.24	17	9.4	6.2	0.066	3.3
1985 DS	0.2	12.2	0.30	26	11.6	6.4	0.066	3.1
LSD (.05)	ns	0.8**	0.04**	1**	0.4**	0.2*	ns	0.1**
			Silty clay loam (OM ≅ 1%)					
1984 WS	0.1	5.2	0.26	34	7.3	4.4	0.105	0.9
1985 DS	0.1	6.1	0.28	52	7.1	4.5	0.091	0.9
LSD (.05)	ns	0.7**	0.02*	2**	ns	0.1*	0.004**	ns

[a]OM = organic matter.

Table 12. Yield and yield components for rice straw and percolation rate experiment. IRRI greenhouse, 1985.

Treatment	Dry season					Wet season				
	Tillers (no./pot)	Grain yield (g/pot)	Straw yield (g/pot)	Grain to straw ratio	Unfilled spikelets (%)	Tillers (no./pot)	Grain yield (g/pot)	Straw yield (g/pot)	Grain to straw ratio	Unfilled spikelets (%)
Rice straw added[a] (t/ha)										
0	115	164	140	1.2	16	65	120	83	1.4	23
5	103	154	116	1.3	14	62	122	80	1.5	17
10	103	161	118	1.4	13	61	126	79	1.6	13
20	101	184	129	1.4	12	51	115	75	1.5	11
LSD (.05)	13	18	15	0.1	2	8	ns	ns	0.1	4
Percolation rate[b] (mm/d)										
0	114	169	29	1.3	16	57	114	76	1.5	17
15	105	175	128	1.4	12	62	126	83	1.5	16
30	97	153	119	1.3	13	61	121	79	1.5	15
LSD (.05)	11	16	ns	ns	2	ns	ns	ns	ns	ns

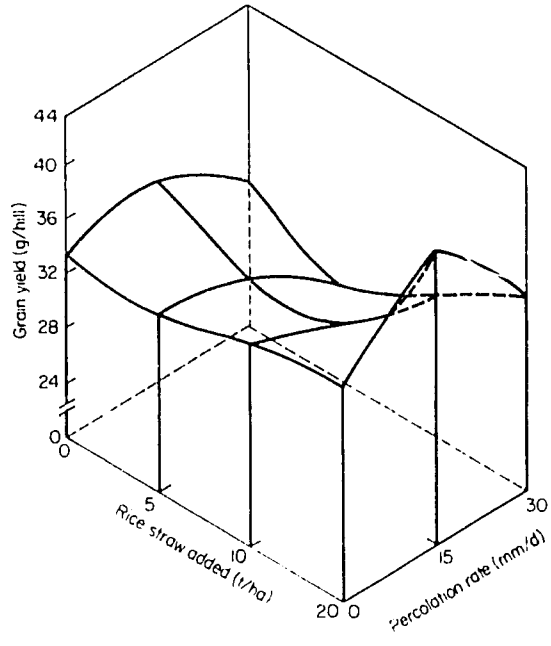
[a]Av over all percolation rates. [b]Av over all added rice straw levels.



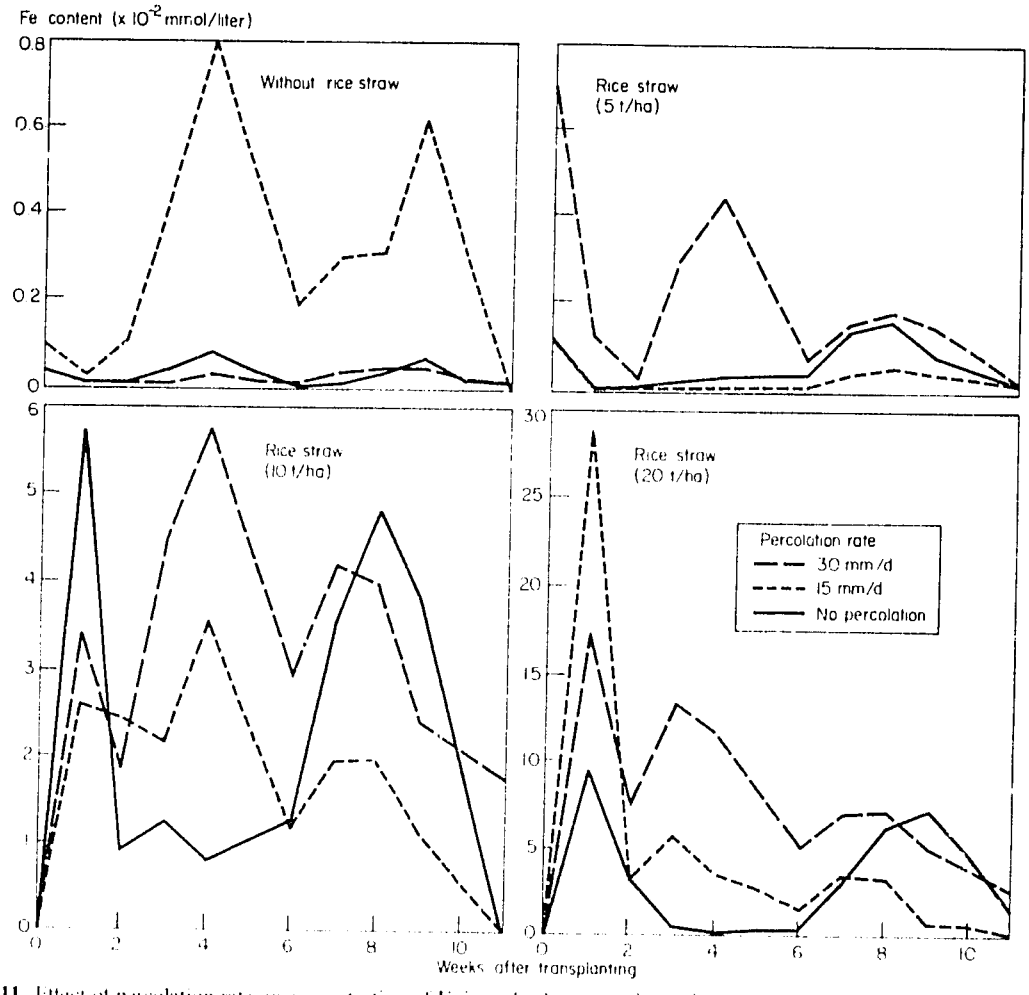
9. Effect of percolation rate on tillering of IR36 and organic acid content in soil solution in pots receiving 20 t rice straw/ha. IRRI greenhouse, 1985-WS.

Percolation, however, did not affect Mn concentration.

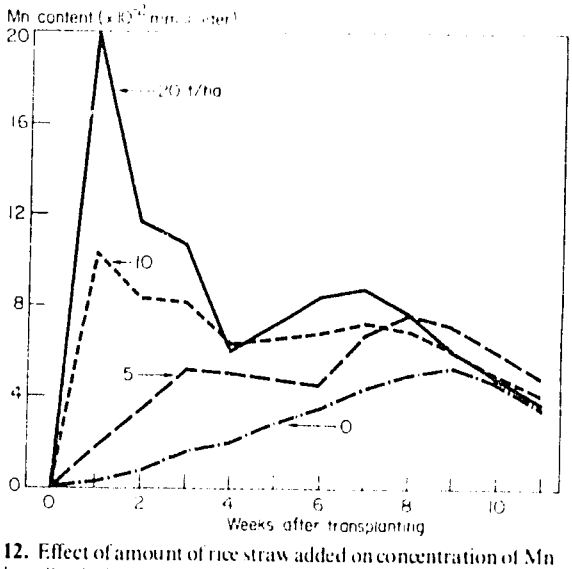
Increased yields because of higher percolation in soils with high OM levels were probably due to organic acids leached from the root zone (Table 13). However, the beneficial effects of leaching on soils with high OM were at times counteracted by



10. Effect of amount of rice straw added and percolation rate on IR36 grain yield. IRRI greenhouse, 1985 DS.



11. Effect of percolation rate on concentration of Fe in soil solution receiving rice straw. IRRI greenhouse, 1985 WS.



12. Effect of amount of rice straw added on concentration of Mn in soil solution. IRRI greenhouse, 1985 WS.

high leaching losses of plant nutrients such as Fe and Mn.

The effects of percolation rate on soils with different OM (native and applied) will vary with changes in nutrient concentration in the percolating water.

RESPONSE TO TILLAGE OF MUNGBEAN AFTER LOWLAND RICE

Agronomy Department

Mungbean was grown in 1985 DS after rainfed lowland rice in 1984 WS to investigate the effects of tillage on physical properties of two soils of different texture and water table depth, on root and shoot growth, and on grain yield. Trials were conducted at IRRI on Maahas clay (Andaqueptic

Table 13. Leached organic acids and nutrient losses for 11 wk of rice straw and percolation experiment. IRRI greenhouse, 1985 WS.

Percolation rate (mm/d)		Organic acids leached	Nutrient losses (kg/ha)		
Intended	Actual	(t/ha)	NH_4^+-N	Fe	Mn
		Without rice straw			
15	14 ± 2	0.7 d	8 a	2.2 ab	6 a
30	29 ± 4	1.6 ab	10 a	0.4 a	2 a
		With 5 t/ha rice straw			
15	14 ± 2	0.9 cd	10 a	1.7 ab	8 a
30	28 ± 3	1.6 ab	39 b	27.5 abc	38 bc
		With 10 t/ha rice straw			
15	14 ± 2	0.9 cd	10 a	11.8 ab	28 ab
30	29 ± 4	1.5 ab	34 b	41.8 c	67 d
		With 20 t/ha rice straw			
15	14 ± 2	1.3 bc	11 a	29.7 bc	57 cd
30	29 ± 4	1.9 a	24 ab	109.7 d	111 e

Haplaquoll) and in a farmer's field in Bulacan on Sibul sandy loam (Aeric Tropaquept). Minimum tillage (two 7- to 10-cm deep rototillings) was compared with zero and conventional tillage (one 15-cm-deep moldboard plowing followed by 2 rototillings). Table 14 shows some chemical properties of the soils.

Tillage soil moisture was 0.49 kg/kg at IRRI and 0.19 kg/kg in Bulacan. At 4 wk after planting at both sites, bulk density was higher and aeration porosity correspondingly lower in zero-tillage plots than in either minimum or conventional-tillage plots (Table 15).

Table 14. Some chemical properties of IRRI and Bulacan, Philippines, soils (0-30 cm), 1985.

Soil property	Clay loam (IRRI)	Sandy loam (Bulacan)
pH (1:1, wt/vol H_2O)	6.5	4.9
Organic C (g/kg)	17.0	5.6
Total N (g/kg)	1.4	0.8
Available Olsen P (mg/kg)	21	6
Exchangeable K (mmol/kg)	12	2
CEC (mmol/kg)	340	58

Soil strength of the Maahas clay progressively increased with depth from 0.3 MPa at the surface to about 4.0 MPa at 60-cm depth. Bulacan had an exceptionally high soil strength of 6 MPa even within the top 20 cm. Matric suction was not affected by tillage at either location. At IRRI, matric suction was less than 13 kPa; in Bulacan, it ranged from 20 to 90 kPa within the first 4 wk after planting and to 900 kPa at crop harvest (Fig. 13).

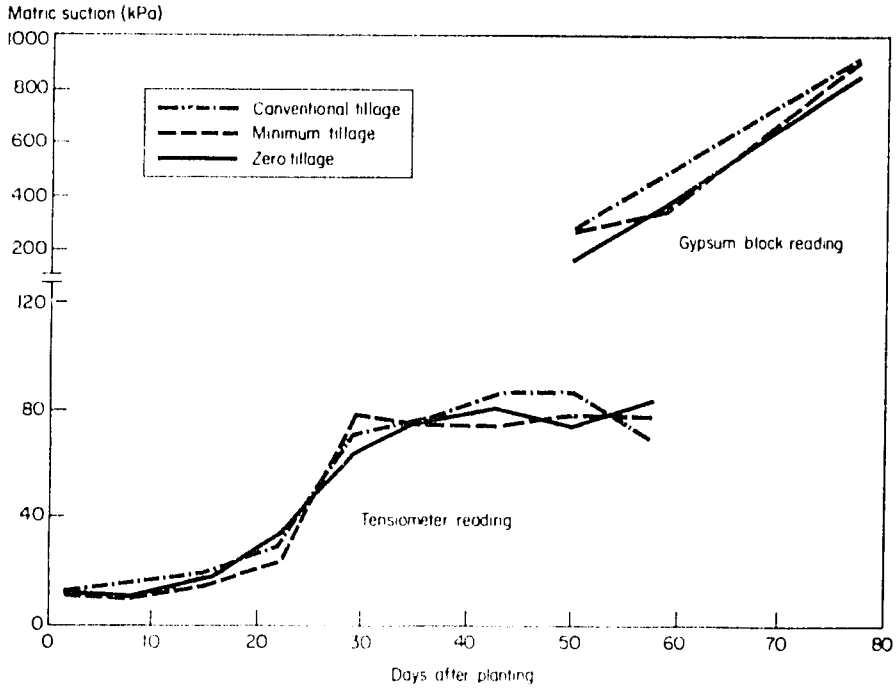
Maximum and minimum soil temperatures averaged 25.8 ± 0.8 and 24.8 ± 0.9 °C at IRRI, and 28.6 ± 1.0 and 26.7 ± 0.9 °C in Bulacan.

Tillage significantly increased plant height, root length, and grain and straw yield, irrespective of water table depth (Table 16). Minimum tillage was as effective as conventional tillage at both sites and

Table 15. Tillage effects on bulk density and aeration porosity in mungbean plots, IRRI and Bulacan, Philippines, 1985 DS.

Treatment[a]	IRRI		Bulacan	
	Bulk density (t/m^3)	Aeration porosity (%, vol/vol)	Bulk density (t/m^3)	Aeration porosity (%, vol/vol)
Zero tillage	1.00	20	1.47	27
Minimum tillage	0.90	30	1.38	43
Conventional tillage	0.91	30	1.36	44
LSD (.05)	0.04	6	0.04	5

[a]At field moisture content of 0-10 cm soil layer, 4 wk after planting.



13. Tillage effects on matric suction at 30-cm depth in sandy loam, Bulacan, Philippines, 1985 DS.

Table 16. Tillage effects on yield, plant height, and root length of mungbean after rainfed lowland rice, IRRI and Bulacan, Philippines, 1985 DS.

Treatment	IRRI[a]				Bulacan[b]			
	Plant height (m)	Grain yield (t/ha)	Straw yield (t/ha)	Root length per plant (m)	Plant height (m)	Grain yield (t/ha)	Straw yield (t/ha)	Root length per plant (m)
Zero tillage	0.56	0.83	1.63	6.1	0.20	0.12	0.21	3.3
Minimum tillage	0.61	0.96	2.44	9.6	0.23	0.16	0.28	4.8
Conventional tillage	0.62	1.04	2.73	10.0	0.24	0.17	0.34	5.4
LSD (.05)	0.04	0.09	0.35	3.3	0.03	0.02	0.07	1.1

[a]Water table ≈ 0.25 m. [b]Water table >2.0 m.

thus was efficient in time and energy input. But in Bulacan where the water table was >2 m deep, mungbean grain yields suffered from severe drought stress.

DEEP CULTIVATION OF PUDDLED AND UPLAND SOILS FOR RAINFED MUNGBEAN

Soil Chemistry/Physics and Agricultural Engineering Departments

In 1984 DS, a mungbean grain yield of 2.1 t/ha was attained without irrigation or fertilizer on a previously puddled soil when that soil's compacted layer was disrupted by strip cultivation to 35-cm depth by a narrow tine (Annual report for 1984). A yield of 1.9 t/ha resulted from moldboard plowing and harrowing, and also from strip cultivation using a wider tine. For all tillage methods, yield declined by about 0.4 t/ha when planting delay (measured from date of field draining) increased from 4 to 6 d.

The high yields derived in part from precision seeding that resulted in uniform crop stands, which effectively intercepted solar radiance. Soil physical

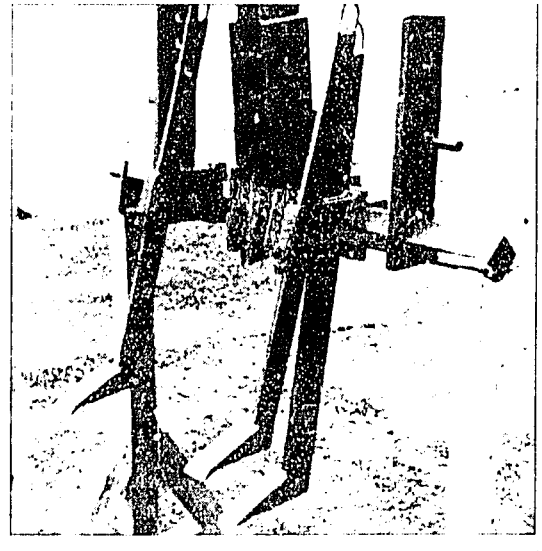
Table 17. Soil physical properties on field F11, IRRI, 1985 DS.

Depth (cm)	Organic C (%)	Bulk density (t/m³)	Clay (%)	Silt (%)	Sand (%)	Texture
0-10	1.5	1.01	40	42	18	Silty clay loam
10-20	1.2	0.99	39	43	18	Silty clay loam
20-30	0.8	0.97	39	42	19	Silty clay loam
30-40	0.5	0.93	36	38	26	Clay loam
40-50	0.4	0.91	47	36	17	Clay

structure also influenced yield: individual plot yields correlated with depth of root-exploitable soil above a horizon of high soil strength.

Using CES 1d-21 mungbean as the test crop, two new forms of deep strip tillage and conventional plowing and harrowing were evaluated. The cultivations were done soon after draining standing water and harvesting lowland rice. The soil was a Vertic Tropaquept with slightly more organic C and higher density (Table 17) than the 1984 soil, with more clay and correspondingly less sand below 40 cm. The water table was maintained below 1.5-m depth by pipe drains installed at 2.5 m. Strip tillages to 35-cm depth were carried out using a deep winged tine (Fig. 14) and a deep narrow tine with two shallow leading tines (Fig. 15). The draft force for pulling the tines (Table 18) was increased by 3.3 ± 0.3 kN when the wing was used, and by

14. Deep winged tine, IRRI, 1985.



15. Deep narrow tine with 2 shallow leading tines, IRRI, 1985.

Table 18. Draft force and specific resistance for various configurations of experimental tines working to 35-cm depth through a Vertic Tropaquept clay loam with and without rice stubble and at moisture content about 0.8 × liquid limit, IRRI, 1985 DS.[a]

	Tine alone		Tine + shallow tines		Tine + wing		Tine + wing + shallow tines	
	Draft (kN)	Resistance (kN/m²)	Draft (kN)	Resistance (kN/m²)	Draft (kN)	Resistance (kN/m²)	Draft (kN)	Resistance (kN/m²)
No stubble	5.4	450	5.6	–	8.8	650	8.8	–
With stubble	–		6.2	160	–	–	–	–

SE: draft = ± 0.2 kN, specific resistance = ± 50%

[a] – = not measured.

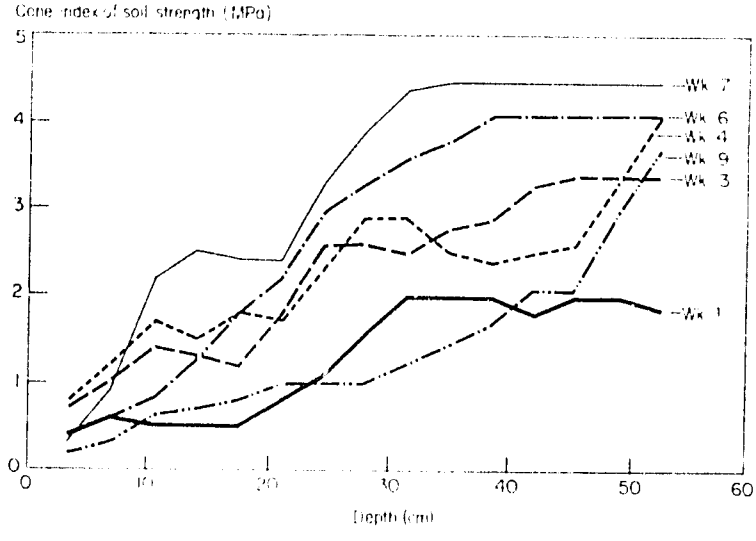
Table 19. Effect of cultivation method on dry bulk density ρ (t/m^3) and on fractional total porosity ϵ at various depths in silty clay loam,[a] IRRI, 1985 DS.

Depth (cm)	Uncultivated soil		Plowed and harrowed		Strip-tilled by winged tine		Strip-tilled by deep + shallow tines	
	ρ	ϵ	ρ	ϵ	ρ	ϵ	ρ	ϵ
0-10	1.01	0.59	0.98	0.60	0.94	0.62	0.95	0.61
10-20	0.99	0.60	1.01	0.59	0.93	0.62	0.97	0.61
20-30	0.97	0.61	1.02	0.58	0.87	0.65	0.87	0.65
30-40	0.93	0.62	0.98	0.60	0.88	0.64	0.88	0.64
40-50	0.91	0.63	0.91	0.63	0.88	0.64	0.89	0.64

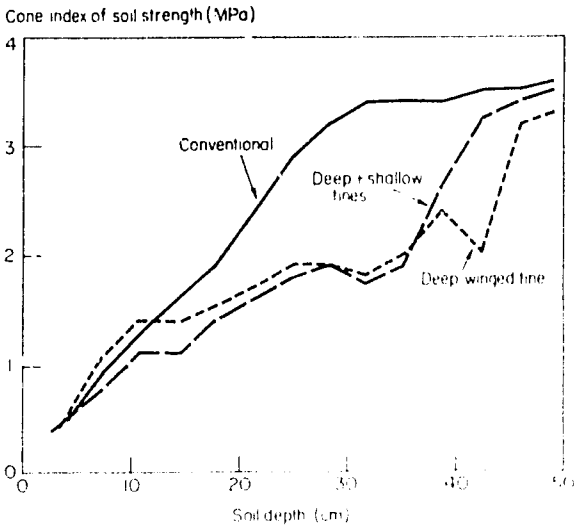
[a]Means of 3 replications at each of 5 sampling dates, and assuming 2.45 t/m^3 particle density.

0.6 ± 0.3 kN when rice stubble was present. The shallow tines, whose purpose was to disturb additional cross-sectional area of soil, did so without requiring extra draft, and decreased specific resistance to soil disturbance from 450 ± 200 to 160 ± 80 kN m^{-2} because they were positioned to exploit the 45° soil-cleavage planes. Both draft and specific resistance were highest with the winged tine. Tillage decreased bulk density by an average of 0.07 ± 0.04 t m^{-3} over the 0-30 cm layer (Table 19); identical decreases with different deep tines were achieved in 1984. Conventional tillage may have compacted the soil slightly between 10 and 30 cm.

Soil shear strength and frictional properties were also changed by soil disturbance and restructuring. Strength increased steadily at all depths as soil dried, and then decreased rapidly between 7 and 9 wk after seeding (WAS) in response to rewetting by 83 mm rainfall (Fig. 16). The two soils tilled by the deep tines were weaker than the plowed soil by about 1.5 MPa in the 25-40 cm soil layer (Fig. 17). Additional measurements of soil strength and friction were made by shear vane; representative data (Fig. 18) show for the 0-20 cm depth seasonal progression in soil-water content θ and in the Mohr-Coulomb parameters of cohesion C and internal friction angle tan ϕ. Both C and tan ϕ generally were least on strip-tilled soil, and were possibly higher on conventionally tilled soil than on untilled soil between crop rows. This may indicate that during harrowing, the fairly moist soil



16. Seasonal progression of cone index of soil resistance to penetration at various depths beneath rows of mungbean plants in a conventionally tilled plot, IRRI, 1985 DS. (Between wk 7 and wk 9, 83 mm rain fell.)



17. Effect of tillage on seasonal average of cone index of resistance to penetration at various depths in previously puddled soil (measured along tilled rows). IRRI, 1985 DS.

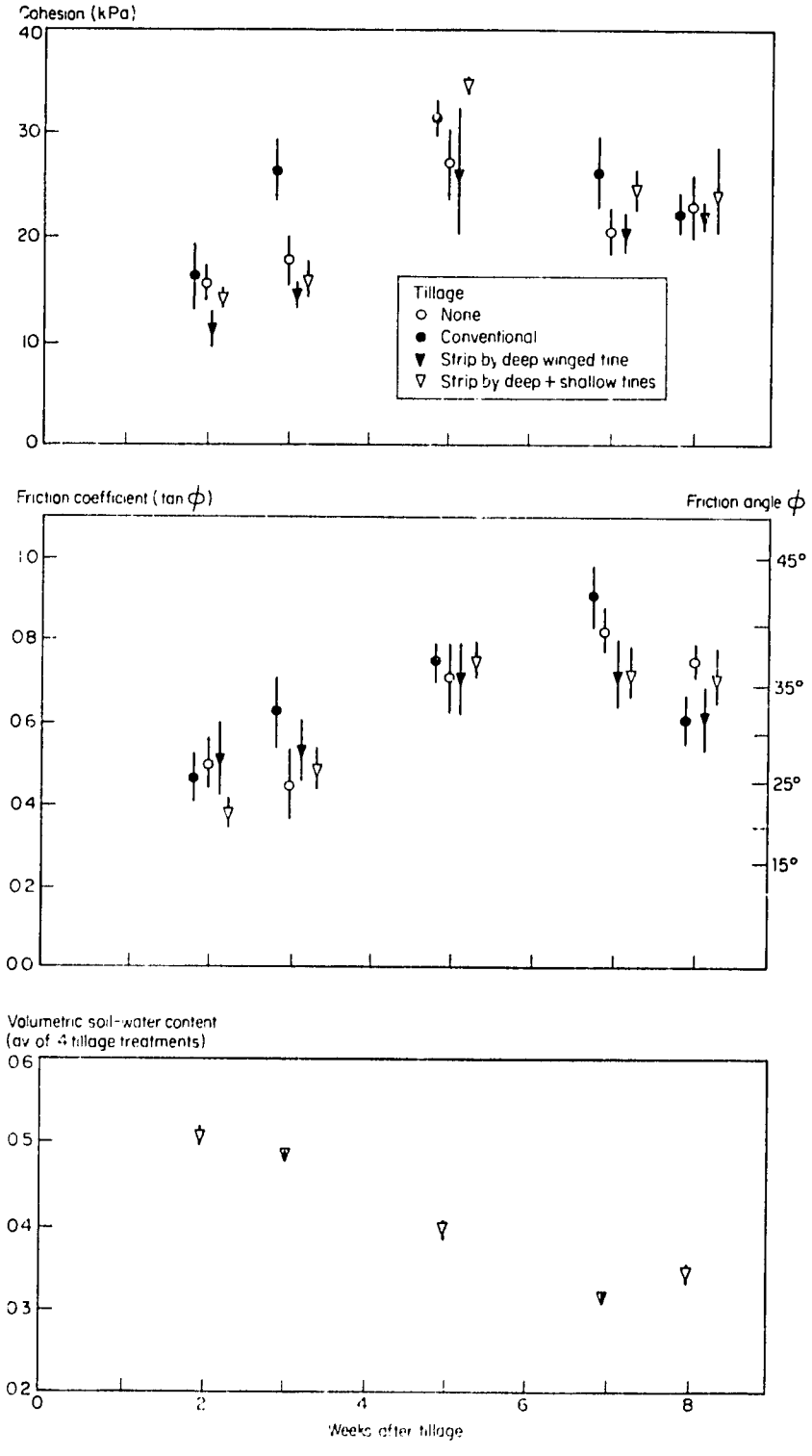
in the top 20 cm may have repacked to higher density (Table 19) and strength. The influence of water content θ on C and tan ϕ is seen in Figure 19. These 1985 data are consistent with those for an adjacent field of similar surface soil texture in 1984. However, tan ϕ at a particular θ was predictably higher for the soil with 23% sand in 0-20 cm (1984) than for that with 18% sand (1985). The more precise data and the larger range of water content sampled in 1985 indicate that C had an expected curvilinear dependence on θ; 1984 data were sufficient only to determine an average value for C, but did in fact conform to the quadratic relation expressed for 1985 results in Figure 19. The revised equations for the soil-water dependence of cohesion and friction coefficient will be used in future studies of root-soil interaction.

For both strip tillage treatments, spacing between tilled strips, and hence between rows of plants, was 0.4 m, as it was also between rows on the conventionally tilled plots. Plot size was 16.0 × 6.4 m, and the 6 replications for each treatment were arranged as two Latin squares. Unintentionally and unavoidably, preceding rice was harvested and irrigation discontinued 50 d earlier on the first square. This difference had significant consequences. Both squares were reflooded briefly and simultaneously to equalize their moisture contents, and blocks within the squares were cultivated and seeded in random sequence during a period of 1 to 5 d following the draining of floodwater. Seeding by hand was uniform both in depth (5 cm) and in within-row spacing (4 cm).

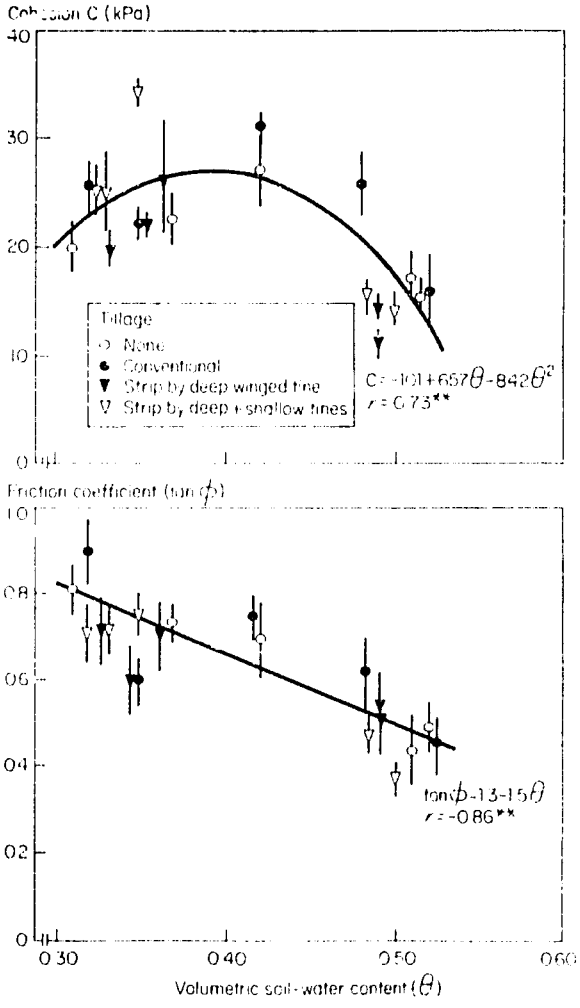
Grain yield of mungbean (Table 20) was highest on plots cultivated by the deep winged tine, both for plots planted sooner (3-d delay) and later (5 d). However, the yield advantage of this treatment (0.09 ± 0.07 t ha) had only slight statistical significance and insufficient practical significance to justify the required high draft force (Table 18). The increase in planting delay (from 3 to 5 d) resulted in additional grain yield of 0.08 ± 0.07 t ha; but in 1984 DS, an increase in delay from 4 to 6 d was associated with a grain yield decline of 0.37 ± 0.07 t ha. This contrast in behavior may have been caused by differences in the oxidation status of the two soils, which in other respects were very similar. Data in Table 21 support this suggestion: for the Latin square where rice in 1985 was harvested 70 d before mungbean planting, mungbean yield was 0.12 ± 0.07 t ha higher than on the square with later rice harvest. In 1984 DS, when the soil had more than 1 yr for possible reoxidation, average yield was higher than in 1985 by 0.46 ± 0.11 t ha. There were similar though less conclusive effects on total dry matter and fresh fodder yields (Table 21).

In both 1984 and 1985, yields were high compared with the Southeast Asian average of about 0.6 t ha, and were achieved without fertilizer or irrigation. In each year, crop-water uptake totaled about 75% of the potential transpiration of 230 mm (in 1984) and 260 mm (in 1985). The water required for these uptakes came from water stored in the soil, at planting, after the 1- to 5-d draining of profiles deliberately saturated to simulate end-of-rice-season conditions. Growing season rainfall was small in each year, and 1984, with less rainfall (33 mm) but also with lower evaporative demand gave higher yield than the wetter (47 mm) 1985.

Yields in 1984 exceeded those in 1985 for causes other than reduced soil conditions. Crops in 1985 suffered more insect pressure, especially from leaffolders, and were harvested for both grain and



18. Cohesion, friction coefficient, and volumetric soil-water content for the 0-20 cm layer at various weeks after different tillage treatments. (For unconfined soil and normal stresses of 0-50 kPa.) IRRI, 1985 DS.



19. Relation of cohesion and friction coefficient to volumetric soil-water content and to tillage for the 0-20 cm layer. (For unconfined soil and normal stresses of 0-50 kPa.) IRRI, 1985 DS.

Table 20. Effect of tillage and 3- and 5-d delay between field draining and seed planting on grain yield of CES 1d-21 mungbean. IRRI, 1985 DS.

Tillage	Grain yield[a] (t/ha)		
	3 d	5 d	Mean
Conventional	1.25	1.32	1.28
Strip by deep winged tine	1.38[b]	1.36	1.37
Strip by deep + shallow tines	1.18[b]	1.36	1.27
SE	0.04	0.11	0.06
Mean	1.27	1.35	
SE	0.03	0.06	

[a]From 2 primings. [b]Excluding 1 replication each for which yields were improbably low because of shallower depth of fertile soil.

fodder earlier than in 1984 because of the earlier onset of WS rains. The mechanism for the yield response to earlier rice harvest and soil reoxidation in 1985 has not been established, although some hypotheses have been rejected. Crop emergence was very high for all tillage treatments (Table 22) and did not differ between early and late planted plots, or between longer and shorter reoxidation regimes. Fe-Mn interactions, which can be affected by reduced soil conditions, were assessed through Fe to Mn concentration ratios in plant tissues at 29, 46, and 58 d after seeding (DAS). Differences in Fe:Mn, as between longer and shorter reoxidations in 1985, were greatest at 46 DAS, but ratios at that plant age did not correlate with mungbean yield, even though they exceeded the upper limit of the 1.5-2.5 range considered optimal for growth of some legumes. Fe:Mn in 1984 also exceeded 2.5, and the higher yields in that year were not the result of more favorable Fe-Mn interactions. Notwithstanding this uncertainty as to the mechanism of the influence of soil-oxidation status on growth of legumes, the effect may have important implications for screening and breeding of cultivars for reduced soil conditions, and such screening may need to be additional to that currently undertaken for waterlogging tolerance.

The decrease of soil strength caused by tillage (Fig. 17, 18) had observable effects on crop rooting. Excavations by the pinboard technique showed that roots in strip-tilled plots proliferated in the fractured soil zone. In these pinboard samplings, the excavated soil slabs were 40 cm wide and 10 cm thick, with depth varying according to plant age at sampling; pins were arranged on a 5- × 5-cm grid, and roots contained in each 5- × 5- × 10-cm-thick soil element were weighed. Root-mass density at depths below 10 cm was higher on deep-tilled than on conventionally tilled soil (Fig. 20), and density of roots within slabs oriented along the plant rows (and hence along the tilled strips) was higher than in slabs oriented across the plant rows — a consequence of there being 25 plants/m along rows and only 2.5 plants/m perpendicular to rows. However, when root-mass density was normalized according to the number of plants included within the 10-cm-thick slab, values were larger for across-row than for along-row sampling, indicating an

Table 21. Yield of grain from 2 primings, total dry matter, and fresh fodder of DS CES 1d-21 mungbean (av over 3 tillage treatments and all planting delays) as affected by duration of possible reoxidation of the previously submerged rice soil. Fields F13 and 11, IRRI, 1984 and 1985 DS.

Variable	1984	1985		
	Rice plots harvested much earlier	Rice plots harvested sooner	Rice plots harvested later	SED
Days of possible reoxidation (d)	406	70	20	
Mungbean grain yield (t/ha)	1.77 ± 0.09	1.37[a]	1.25[a]	0.07
Total dry matter yield (t/ha)	5.2 ± 0.2	3.0[a]	3.2[a]	0.3
Fresh fodder yield (t/ha)	10.3 ± 0.4	7.3[a]	7.1[a]	0.6

[a]Excluding 1 replication each for which yields were improbably low because of shallower depth of fertile soil.

Table 22. Percentage emergence of CES 1d-21 mungbean as affected by tillage, delay between field draining and seed planting, and duration of possible reoxidation of the previously submerged rice soil. IRRI, 1985 DS.

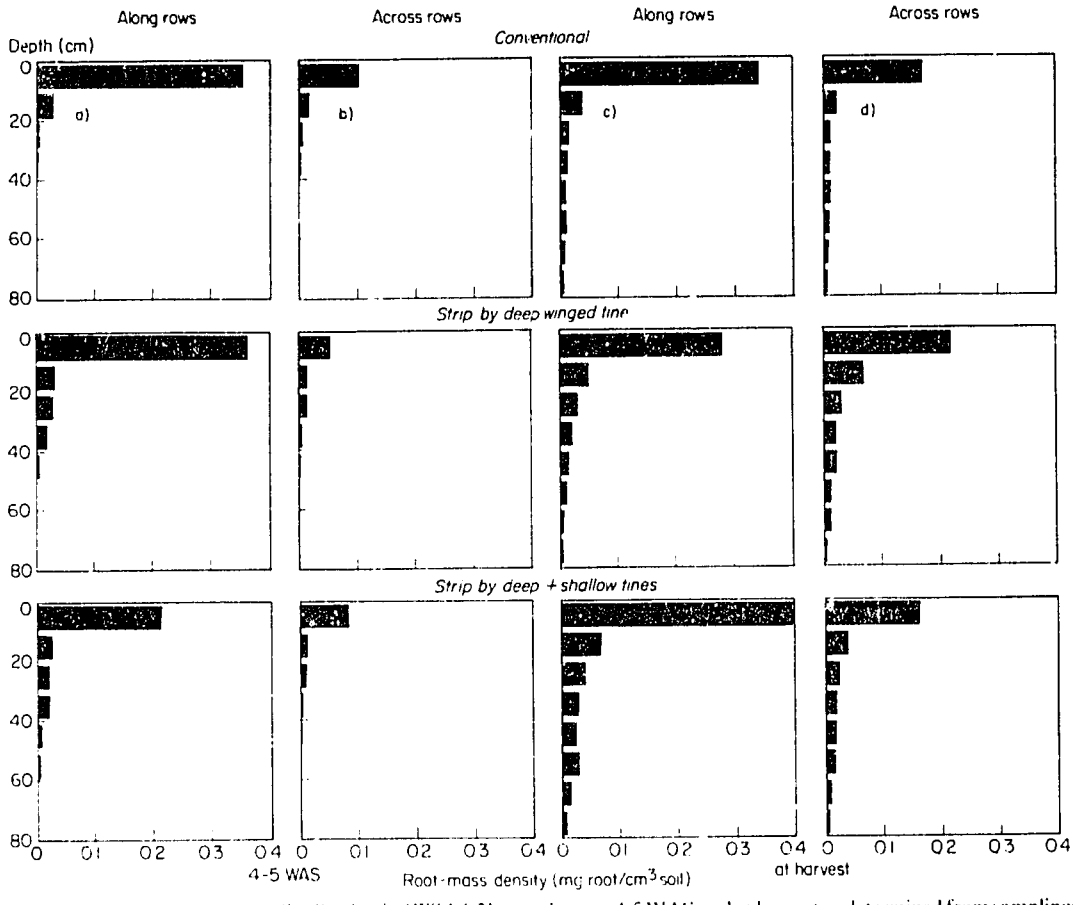
Tillage	Emergence (%)				
	Planting delay		Reoxidation		Combined
	3 d	5 d	70 d	20 d	
Conventional	86	87	91	83	87
Strip by deep winged tine	92	94	91	94	93
Strip by deep + shallow tines	88	90	89	88	89
SE	3	3	3	3	2
Mean	89	90	90	88	89
SE	2	2	2	2	1

effect of interplant competition. Dry root mass in the 10-90 cm layer at harvest was calculated to be equivalent to 0.2 t/ha for deep-tilled and 0.1 t/ha for conventionally tilled plots. The corresponding totals for all roots (including those in 0-10 cm, where thick primary roots contribute most of the mass) were 0.4 and 0.3 t/ha. These values may be compared with the aboveground total dry matter at harvest of 3.2 and 3.0 t/ha (Table 21, 1985 data), although the root-mass totals must be considered as lower-limit estimates for whole-season root production, because much root material would have died or been respired during the season.

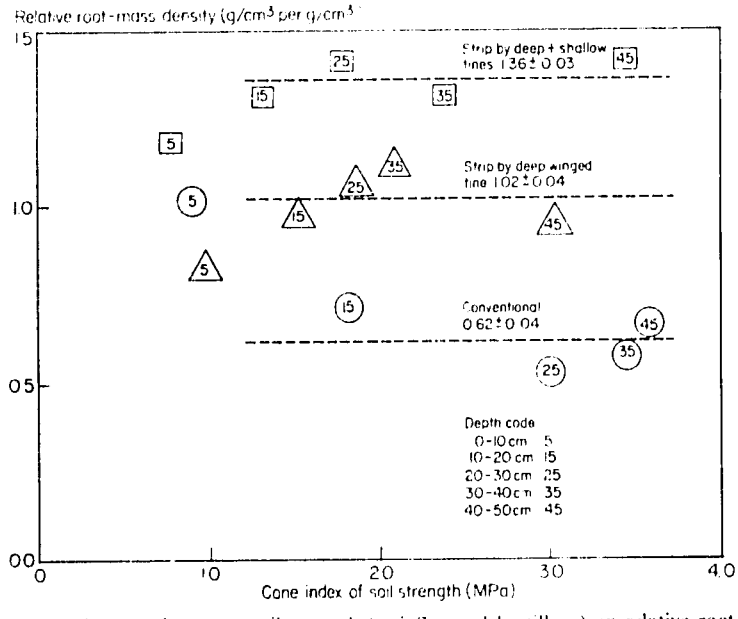
Deep tillage, by fissuring soil as far as 15 cm from the tine shank and tip, promoted indirect as well as direct effects of soil strength on crop rooting. At any specific value of soil-strength index there was relatively much more rooting in deep-tilled than in conventionally tilled soil (Fig. 21). Even though the three tillage treatments may exhibit identical values for cone index of bulk soil strength, the deep-tilled soils include additional fissures and planes of weakness that allow greater proliferation of roots.

Root-length density (Fig. 22) was monitored more frequently than root mass, using cylindrical soil-core samples. Although soil volumes sampled were necessarily much smaller than for pinboard excavations, data were sufficiently precise to indicate that during 0-6 WAS roots penetrated more quickly to depth in soil cultivated by the deep winged tine than in conventionally tilled soil. As in 1984, roots eventually penetrated to 90 cm in all tillage treatments.

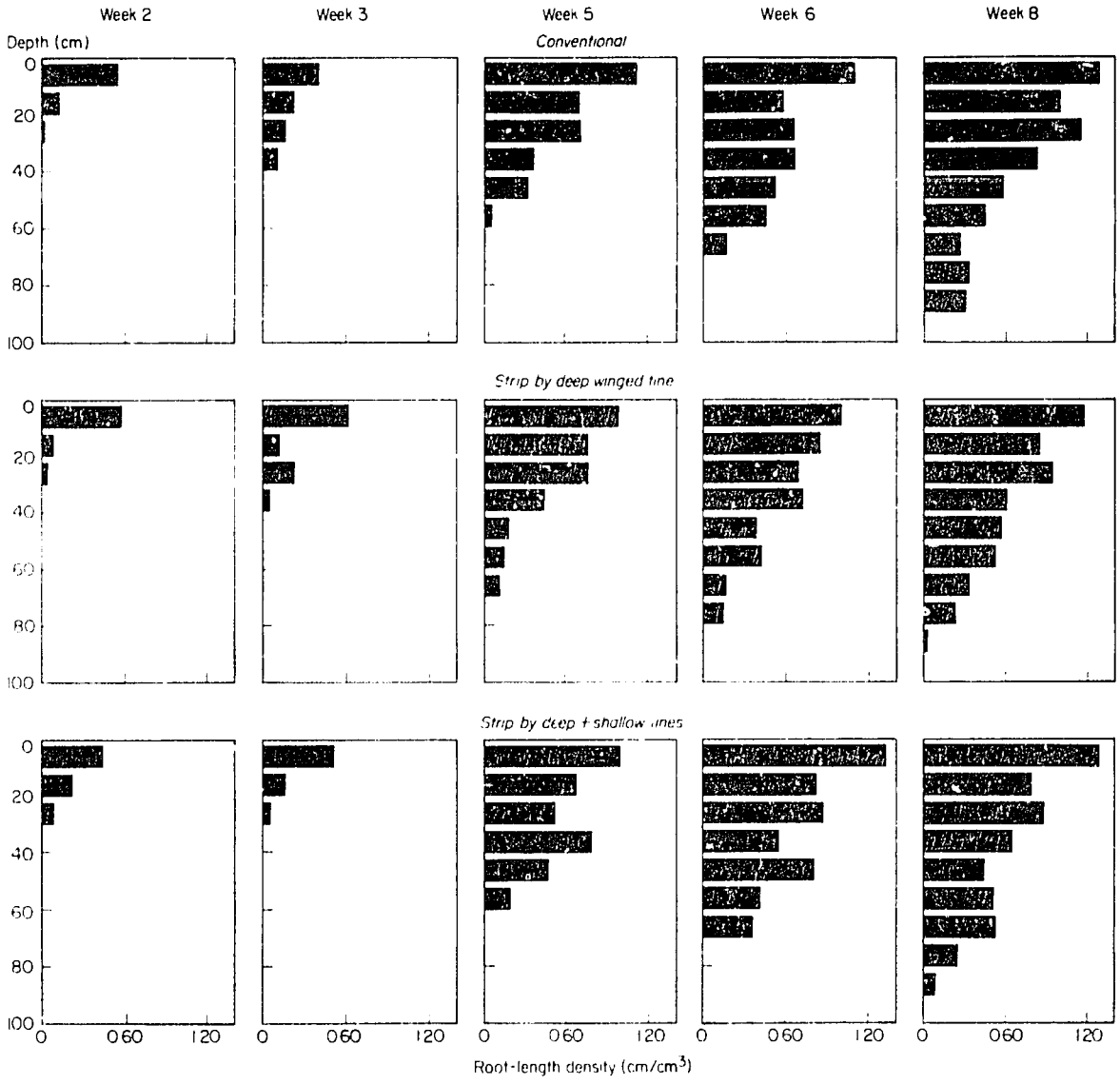
The greater mass and earlier penetration of roots on the deep-winged-tine plots may have resulted in slightly higher grain yield (Table 20). That deeper rooting and consequent exploitation of a greater



20. Effect of tillage on root-mass distribution in CES 1d-21 mungbean at 4-5 WAS and at harvest as determined from samplings using pinboards oriented along and across the crop rows. IRRI, 1985 DS.



21. Effect of seasonal average soil strength (as influenced by tillage) on relative root-mass density in various soil-depth layers. IRRI, 1985 DS.

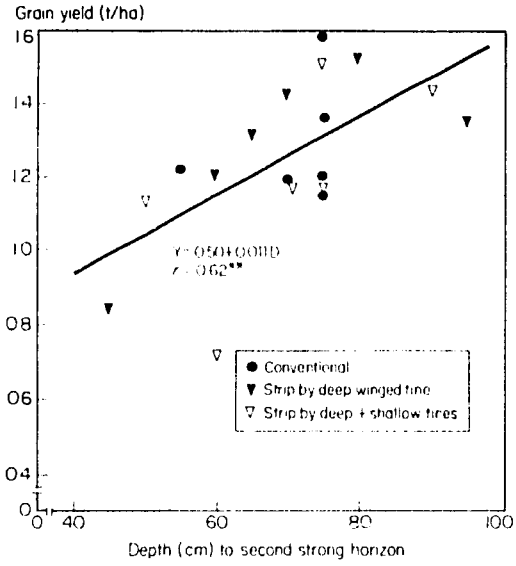


22. Effect of tillage on root-length distribution in CES 1d-2I mungbean during 2-8 WAS, IRRI, 1985 DS.

depth of soil should give higher grain yield is indicated in Figure 23, where grain yield on each of the experiment's 18 plots is related to the plot's depth of exploitable soil above a layer of differing structure and higher strength. (As in 1984, there were two high-strength layers in the top meter of soil in each plot, and Figure 23 relates to the deeper of them.) For each additional 9 cm of exploitable soil depth, one might expect 100 ± 20 kg more grain/ha. The mechanism for the yield increase is probably the increase in soil-water storage capacity contributed by the additional soil depth; this hypothesis is supported by the observed correlation between seasonal water use SWU (in mm) and depth D (cm) of exploitable soil:

$$\text{SWU mm} = 122 + 0.78\ \text{D/cm} \qquad (r = 0.52^{**}, n = 18)$$

This equation, in addition to its significance of correlation, is also physically tenable because the soil's water characteristics were such that a 9-cm soil increment would contribute 11 ± 2 mm of additional water storage. This addition, in relation to an average seasonal water use of 180 ± 30 mm at



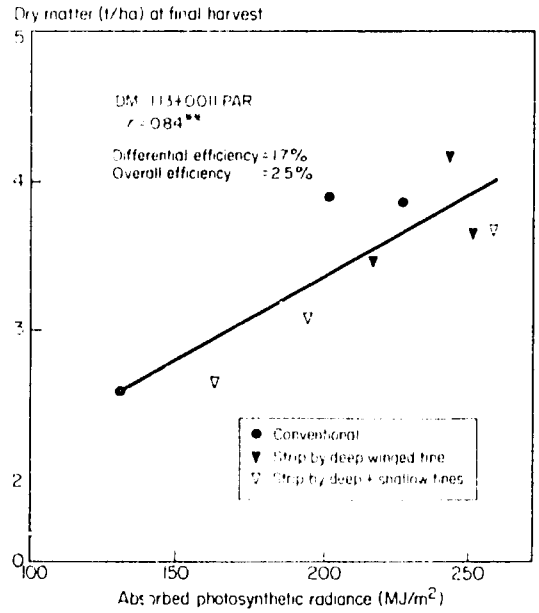
23. Relation of grain yield (Y) of CES 1d-21 mungbean to depth to the second strong soil horizon (D), with data distinguished according to tillage treatment. IRRI, 1985 DS.

a D of 70 cm and an average yield of 1.3 t/ha (Table 20), would generate an extra 80 ± 20 kg grain/ha, in conformity with the 100 ± 10 kg/ha derived from Figure 23.

Deep rooting and enhanced water uptake should affect mungbean growth and grain yield mainly through influences on whole-crop photosynthesis. Seasonal totals of photosynthetically active radiance (PAR) actually intercepted by the crops were measured for three replications each of the three tillage treatments. Final yields of total dry matter (Fig. 24) and of grain yield for those nine plots each correlated strongly with intercepted PAR. On the average, crops on the deep-tilled plots absorbed slightly more radiance than crops on the plowed plots, although there were no significant differences in leaf area index or plant height. The slope of the Figure 24 regression line implies a 1.7% differential thermodynamic efficiency of use of the additional absorbed PAR, but because of the large intercept (1.13 t/ha), the overall efficiency was much higher, averaging 2.5%; within the growing season, the highest efficiency (4.2%) was recorded between 31 and 38 DAS.

Although plants on conventionally tilled plots rooted less quickly to depth than those on deep-tilled plots, they made more rapid initial uptake of nutrients (Table 23), perhaps because the nutrients in the surface soil were made more accessible by plowing and harrowing. There were fewer weeds on conventionally tilled plots. For mungbean production it may be advantageous to combine deep and conventional tillage.

A different tillage strategy for mungbean following rice in puddled soil is to relay-plant the legume in rows between and parallel to rice during the latter part of the ~10-d period between field draining and rice harvest. Reaping, threshing, and drying of rice may then continue without concern or effort for the mungbean. But if to encourage deep rooting of the latter it is necessary to disrupt the compact soil layer by deep tillage, then such tillage can be accomplished through the growing legume crop, as close as 7 cm from the lines of plants, and up to 32 d after sowing the legume, with acceptably low losses of plants. For particular rice-legume sequences, legume row spacing, persisting rice stubble, and through-the-crop tillage operations may require that the preceding rice be planted with nonuniform spacing between rows. Trials of irrigated WS IR58 planted at row spacings of (20, 30, 20, 30, 20) (20, 30, 20, 30, 20) cm, with plantings along rows at 17-cm intervals, showed that tiller



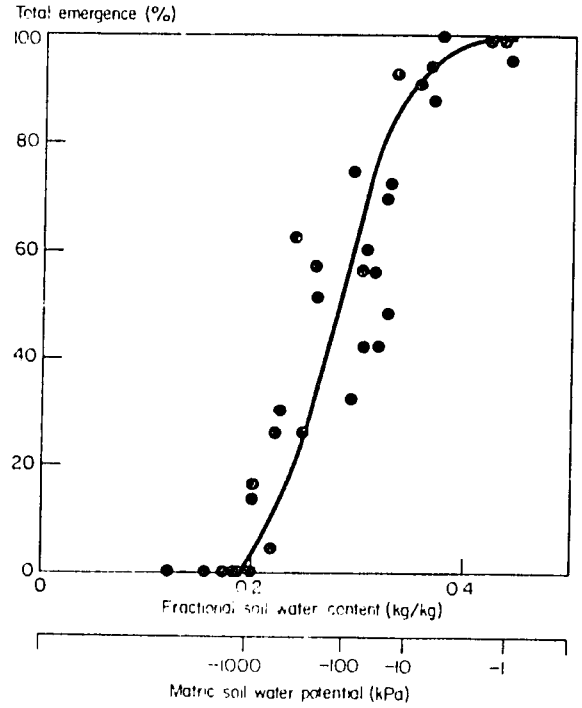
24. Relation of final harvest dry matter (DM) of CES 1d-21 mungbean to season's total of absorbed photosynthetically active radiation (PAR), with data distinguished according to tillage treatment. IRRI, 1985 DS.

Table 23. Effects of conventional and of deep strip tillage on nutrient uptake and weed production in CES 1d-21 mungbean in DS. IRRI, 1985.

Period (DAS)	Rate (mg/m² d) of uptake						Weed dry mass (t/ha)	
	Nitrogen		Phosphorus		Potassium			
	Conventional	Deep	Conventional	Deep	Conventional	Deep	Conventional	Deep
0-28	86	64	10	8	89	53		
28-47	184	189	17	18	153	195		
47-57	50	80	11	13	120	130		
0-29							0.51 ± 0.08	0.71 ± 0.13

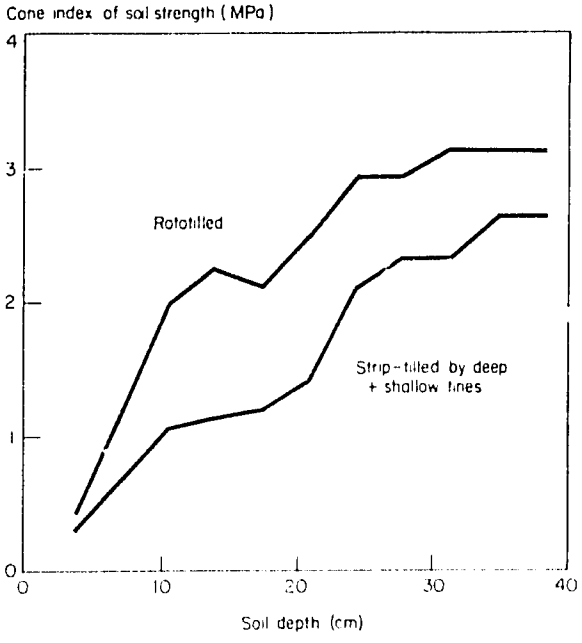
number, leaf area, and rice grain yield were no less than with equal-row spacing. For mungbean relay-planted between rice rows into moist soil at 2 d or more after preharvest field draining, emergence was acceptably high at 75 ± 5%, and relay-planting 4 d before rice harvest gave uniform populations of mungbean plants that suffered little damage during ensuing rice harvest.

For mungbean grown after rice in upland or lowland rainfed cropping systems, seeds and seedlings run risks of soil being too wet, too dry, or too hot for germination. Growth-chamber experiments undertaken as part of the IRRI/International Institute of Tropical Agriculture Collaborative Program have studied the interactive effects of soil temperature and water content on legume emergence from sieved crumbs of IRRI upland soil (soil-water retention characteristics are shown in the section on Climatic environment and rice). Figure 25 shows for 30 °C the effect of soil water-content and potential on the emergence percentage of CES 1d-21 mungbean. Similar curves were obtained at 25 and 35 °C. At 45 °C, there was no emergence either for CES 1d-21 or IPB 79-17-79 mungbean, or for SJ2 or UPL SY2 soybean. For CES 1d-21 between 25 and 35 °C, the potential corresponding to 50% emergence decreased (i.e., became more negative) as temperature increased: −60 kPa at 25 °C, −100 kPa at 30° C, and −150 kPa at 35 °C. At higher temperature the biochemical processes of germination progressed more rapidly, and drier soil was able to supply the necessary water. Associated field studies in collaboration with the University of Reading, England, showed that when puddled soil at about 30 °C dried from saturation, soil at 4-cm depth dried to −100 kPa potential within 2 d in cultivated soil and within 5 d in uncultivated soil.



25. Effect of soil water content and potential on percentage emergence of dry seeded CES 1d-21 mungbean from beds of 2-mm crumbs of IRRI upland soil. Growth chamber at 30° C, 50% relative humidity. IRRI, 1985.

Effects on IPB 79-17-79 of seedbed drying and deep strip tillage were studied with University of Reading colleagues in 1985 DS at a nonpuddled upland site. Uniform fertility across the site was achieved by a preceding WS upland rice crop that was uprooted prematurely on 14 Dec 1984. Strip tillage to 35-cm depth by deep + shallow tines, and surface tillage comprising 3 rototillings to 10-cm depth were compared in factorial combination with prompt (19 Dec) and delayed (26 Dec) plantings that took deliberate advantage of contrasting natural levels of seedbed dryness.



26. Effect of tillage on seasonal average of cone index of resistance to penetration at various depths in upland soil. IRRI, 1984-85 DS.

Deep tillage effects on strength of upland soil were similar to those on lowland soil: the seasonal average for cone index of soil resistance to penetration (Fig. 26) was about 1 MPa less in 10-40 cm depth on deep-tilled soil. There were corresponding effects on cohesion and friction coefficient.

The dominant soil-physical effect in 1984-85 DS, however, was seedbed drying. The 1984 monsoon ended so abruptly that prompt planting was made into soil of only 0.27 kg water content kg⁻¹ much drier than intended. Rates of mungbean emergence were correspondingly low at 65%, compared with a germination rate of 83% in water. For the delayed planting, seedbed soil dried to 0.22 kg kg, and emergence was only 4%. These rates of field emergence are consistent with the growth-chamber findings (Fig. 25).

Both early- and late-planted crops were harvested on 26 Feb 1985. By that date, early-planted crops had received 25 mm rainfall and late-planted crops 14 mm. The consequent soil drying resulted in high soil strength for each planting, and in the difference (Fig. 26) in strength between tillage treatments. Thus, there were more roots in strip-tilled than in rototilled soil, for both 0-10 and 10-30 cm depth (Table 24, for 36 DAS and for early plantings only). Compared with that on lowland soil (Fig. 22, week 5), root-length density in upland soil was of similar magnitude in 0-10 cm, but considerably less in 10-30 cm.

It was not possible to determine whether the extra roots in strip-tilled soil promoted an increase in grain yield. The effect of planting delay (Table 25) was larger: mean grain yield declined from 0.24 to 0.04 t/ha. Moreover, there was high variability in yields within one planting, as shown by the ranges. The yield variations were associated mainly with variations in the number of pods per m^2. Yield was not increased significantly by deep strip tillage.

Growth, yield, and yield components also varied considerably within some individual plots. For regions of good and poor growth within such plots, intensive measurements were made of soil physical and chemical variables. Table 26 shows that some small part of the within-plot variability might have been caused by variations in soil strength: the depth at which the cone index of soil resistance to penetration first attained values of 1 MPa or 2 MPa was slightly less in regions of poor than of good growth, although the difference could have caused only slight effect on growth. Chemically, shoots from good and poor growth areas differed

Table 24. Effect of tillage on root-length density at 36 DAS for IPB 79-17-79 mungbean early planted on an upland clay loam Typic Tropudalf, IRRI, 1984-85 DS.

Depth (cm)	Root-length density (cm root/cm^3 soil)	
	Deep strip-tilled	Rototilled
0-10	0.78 ± 0.12	0.64 ± 0.06
10-30	0.21 ± 0.03	0.16 ± 0.03

Table 25. Effects of tillage and planting delay on grain yield of IPB 79-17-79 mungbean grown on an upland clay loam Typic Tropudalf, IRRI, 1984-85 DS.

Item	Grain yield (t/ha) for planting on	
	19 Dec	26 Dec
Mean	0.24	0.04
Range	0 - 1.5	0 - 0.8
With rototillage	0.23	
With strip tillage	0.25	

Table 26. Depth for regions of good and poor mungbean growth at which cone index of soil resistance to penetration first attained values of 1 MPa and 2 MPa in early-planted, rototilled plots. IRRI, 1984-85 DS.

Cone index of soil resistance to penetration	Depth (cm)		SED
	Poor growth	Good growth	
1.0 MPa	6.5	7.1	0.5
2.0 MPa	8.6	10.2	0.7

most in their Fe and Mn concentrations and ratios (Table 27). At 28 DAS, shoots from poor growth regions had twice as much Fe but less Mn than shoots from good growth areas. Fe:Mn was correspondingly much higher for poor than for good growth areas. Even for good areas, Fe:Mn at 28 DAS was appreciably higher than in lowland mungbean at 46 DAS or than the 2.5 at which legume growth is impaired.

Above the soil, differences in interception of solar radiance can be both a cause and a consequence of variations in plant growth. Calculations indicate that between 29 and 43 DAS, the 25% of plants that grew best intercepted about 30% of incident PAR, but the poorest 25% intercepted only 5%. The PAR was measured on four plots only, and incremental dry matter harvests were taken for the same plots. Thermodynamic efficiency for converting absorbed PAR, measured during 28-54 DAS, was 3.2%, somewhat lower than was found for mungbean on lowland soil with less severe water stress.

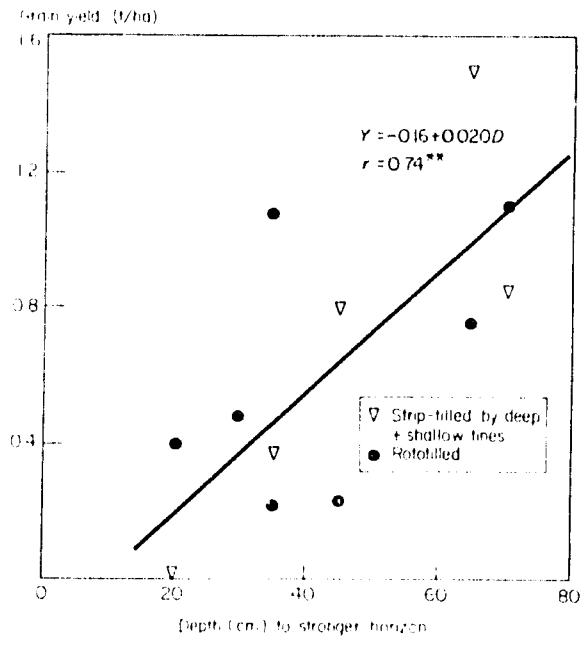
The large range of yields between plots (Table 25) can be explained in part in physical terms. For plots with adequate plant emergence, Figure 27 shows the relation of grain yield to depth of soil above a layer of higher mechanical strength. There is strong similarity with Figure 23, although the slope of Figure 27 is larger, and there is a threshold soil depth below which yield is predicted to be zero. The threshold is only 8 cm, and there is no threshold for the lowland soil, because the strong horizons only impede but do not prevent deep rooting. Differences between the correlation equations arise also because the soil profile at planting was much drier for the upland than for the lowland experiment.

Deep strip tillage lessened soil strength and encouraged quicker rooting to depth of mungbean in both upland and lowland soil, but additional experiments need to determine whether greater production can be achieved through a combination of conventional and strip tillage, and whether strip tillage technology can be developed to give adequate soil disturbance using draft and power appropriate to small farmers. In upland and lowland soils, mungbean yield correlated with depth of readily exploitable soil. In early DS, seed-zone soil dried within 5 d to a water potential low

Table 27. Fe and Mn concentrations in mungbean shoots from regions of good and poor growth on an upland clay loam (Typic Tropudalf) at 28 and 54 DAS: early-planted, rototilled plots. IRRI, 1984-85 DS.

Element	Sampling time (DAS)	Poor growth	Good growth
Fe (ppm)	28	1200	660
Mn (ppm)	28	125	180
Fe (ppm)	54		230
Mn (ppm)	54		100
Fe:Mn[a]	28	9.6	3.6
Fe:Mn	54		2.3

[a]Ratio for optimal growth is 1.5-2.5.



27. Relation of grain yield (Y) of IPB 79-17-79 mungbean in upland soil to depth to the stronger soil horizon (D), with data distinguished according to tillage treatment. IRRI, 1984-85 DS.

enough to cause serious loss of mungbean emergence. In lowland fields, relay-planting of legumes after field draining and before rice harvest avoided this drying and achieved high emergence; relay-planting in lines parallel to rice rows allowed subsequent deep tillage through the growing legumes. Reduced soil conditions continuing after rice harvest possibly reduced growth and yield of the succeeding legumes; the effect may be of sufficient magnitude to merit screening and breeding of cultivars tolerant of such reduced conditions.

Climatic environment and rice

Multiple Cropping, Training and Technology Transfer, Soil Chemistry/Physics, Agronomy, and Plant Breeding Departments and International Rice Testing Program

PERFORMANCE OF THE GUNN-BELLANI SOLAR RADIATION INTEGRATOR **306**
Effect of location on calibration **306**
Effect of water table and ground cover **307**
Effect of temperature, rainfall, and season **307**
EFFECT OF WEATHER ON RICE YIELDS IN THE IRRI CONTINUOUS RICE PRODUCTION SYSTEM **308**
RESPONSE OF RICE TO WEATHER VARIABLES **311**
AGROHYDROLOGY OF UPLAND RICE **313**

PERFORMANCE OF THE GUNN-BELLANI SOLAR RADIATION INTEGRATOR

Multiple Cropping Department

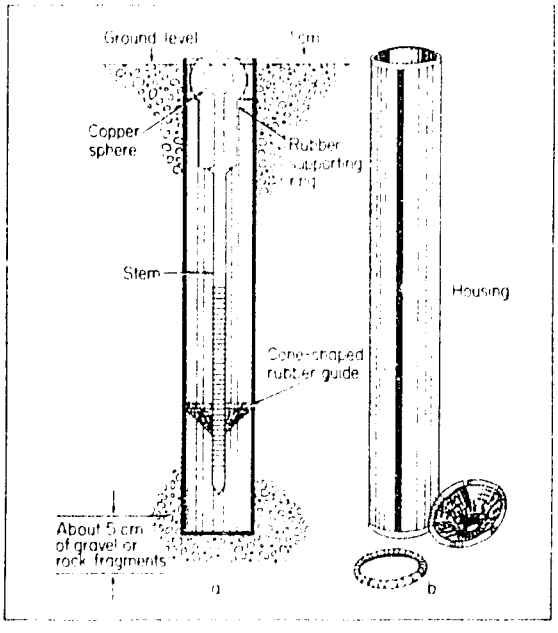
Data on solar radiation are available for only a few agricultural research stations and field research locations in the developing world. Most radiation instruments are electronic, costly, delicate, and difficult to service, so the number of hours of sunshine or estimates of cloud cover are often used to approximate solar radiation.

We tested the usefulness and reliability of the Gunn-Bellani solar radiation integrator (GBSRI) for lowland research sites in the humid tropics. The GBSRI has advantages over the electronically operated Kipp-Zonen, RIMCO, and Licor radiometers in that it is lightweight and mobile, it does not require electric power or batteries so that difficulties in maintaining millivoltmeter installations are eliminated; it is inexpensive, simple to operate and maintain, sturdy, and durable; and it produces results showing a very high degree of correlation with the more expensive Kipp-Zonen or RIMCO radiometers.

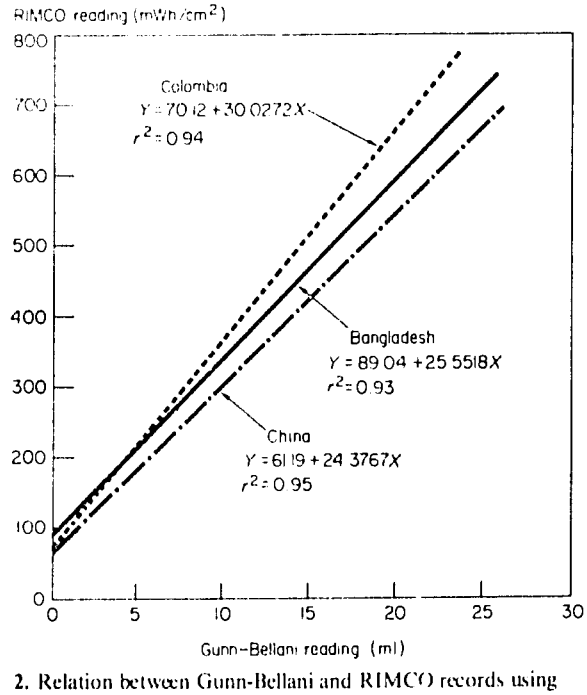
The GBSRI (Fig. 1) houses a black copper sphere containing liquid (water or alcohol) and connected to a glass tube in 0.1 ml graduations that collects distilled liquid. The copper sphere is enveloped by a glass dome. The air pressure within the copper sphere and the glass dome is reduced to 1 mm Hg to balance the onset of nonradiative distillation. The housing (Fig. 1b) is composed of a metal cylinder, rubber funnel guide, and rubber supporting ring. The cylinder is blackened to eliminate reflection of incident radiation and is wide enough (12.7 mm) to prevent instrument contact with the soil. The housing is buried so that only about 10 mm of its rim is above the grassed ground area (Fig. 1a).

When radiation falls on the glass dome, the black copper sphere absorbs and converts it into heat that causes distillation of the liquid into the graduated glass tube condenser. The amount of liquid in milliliters collected in the condenser is proportional to the total incident solar radiation.

Effect of location on calibration. Using 2 yr of daily data, the readings of the GBSRI and the RIMCO solar radiation integrator showed a very high coefficient of determination (r^2) (Fig. 2). The high r^2 values for Colombia, Bangladesh, and China were similar at all 23 sites in the International Rice Weather Studies, suggesting that the GBSRI is an acceptable substitute for the RIMCO.



1. Gunn-Bellani solar radiation integrator.



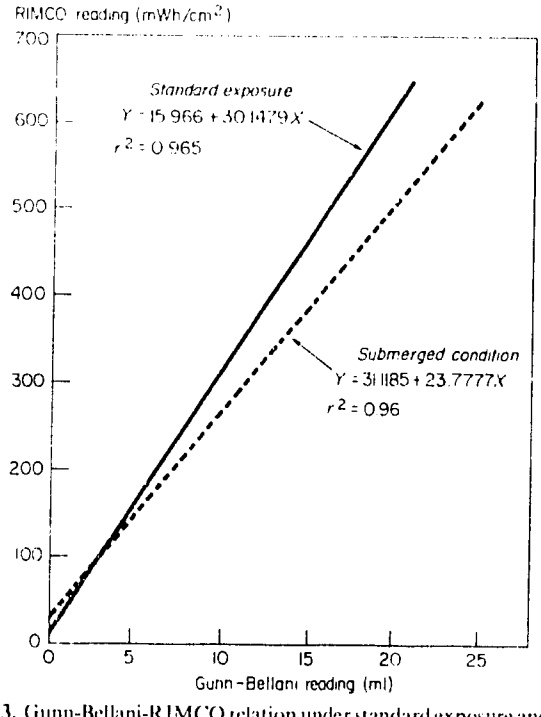
2. Relation between Gunn-Bellani and RIMCO records using 2-yr of daily data from Palmyra, Colombia; Joydebpur, Bangladesh; and Nanjing, China, 1983-84.

The t-test comparing regression coefficients showed significant differences among sites. The regression coefficient for Palmyra, Colombia (30.03), was significantly higher than that for Joydebpur, Bangladesh (25.16), and Nanjing, China (24.38). For the GBSRI to measure solar radiation accurately, it must be calibrated at the site where it is installed.

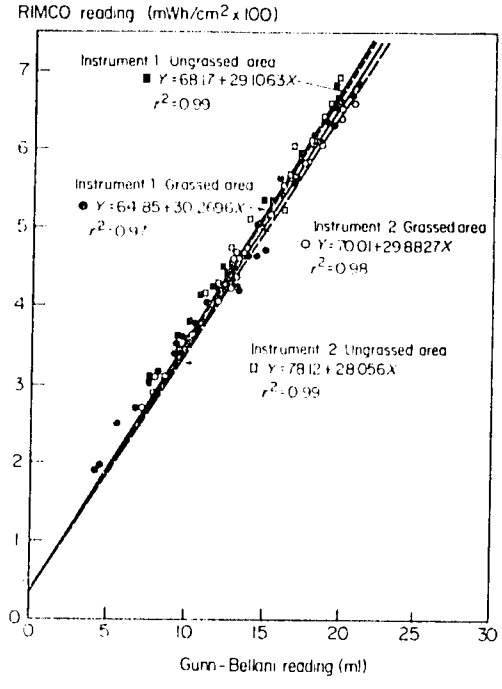
Effect of water table and ground cover. A high water table submerged the stem of the GBSRI and raised the readings by 23%. The regression coefficients of the daily values under the two exposures were significantly different (Fig. 3). A GBSRI calibrated under standard exposures should not be installed in places where the water table is at or near the ground surface.

Placing the instrument in an earth mound 50 cm above ground level produced no major difference in readings. When the water table approaches the surface, the GBSRI may be elevated; however, it should be recalibrated.

Two precalibrated GBSRIs were lifted 25 cm above ground level, one being provided with a 5-mm hole at about ground level. Compared with a standard setup, mean solar radiation values were



3. Gunn-Bellani-RIMCO relation under standard exposure and under submerged condition. IRRI, 1985.

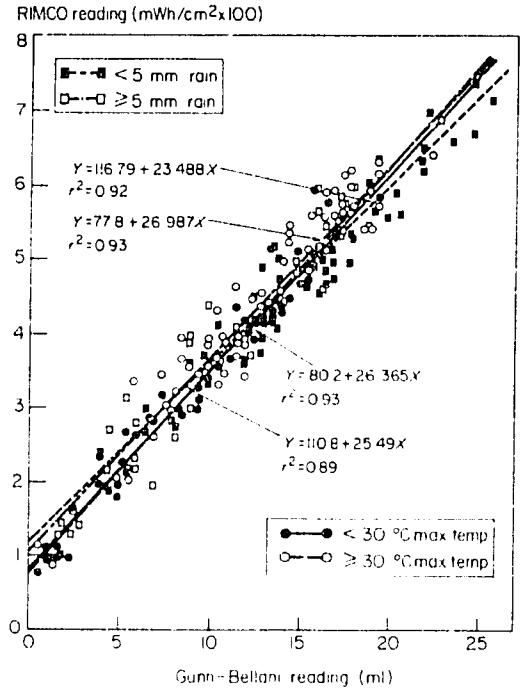


4. Calibration of two GBSRIs under standard exposure (grassed surrounding area) and their behavior on ungrassed area. IRRI, 1985.

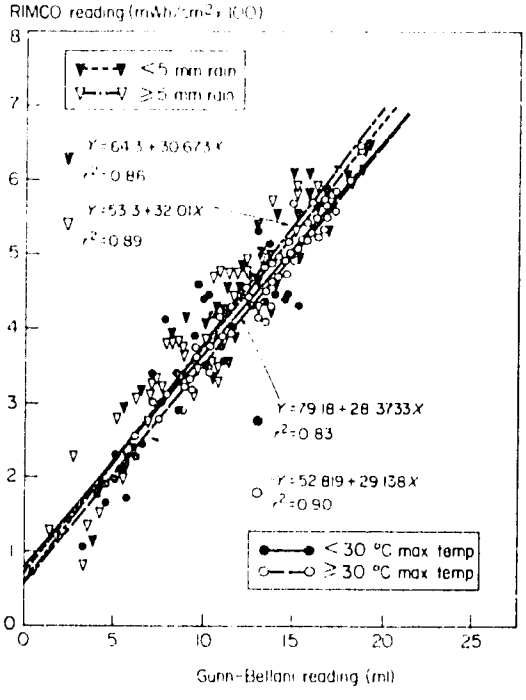
not increased or were slightly increased (6%) by the 25-cm elevation within limits of random experimental variation. Therefore, where grass is not yet available and heavy rainfall is possible, the GBSRI may be elevated 25 cm from ground level to avoid soil particles on the glass dome and to prevent the instrument from floating out of its housing during heavy rains.

The regression coefficients (Fig. 4) were nearly identical among GBSRIs installed in grass cover and those installed in bare ground surroundings, implying that use is possible in a long dry season when it is not possible to irrigate the surrounding grass.

Effect of temperature, rainfall, and season. Figures 5 and 6 show GBSRI and RIMCO regression curves with data sets selected to include daily values contrasting in maximum temperature and rainfall amount for two sites. Regression coefficients among data sets within a site did not significantly differ, implying that the calibration curve for the GBSRI as related to the RIMCO solarimeter is not sensitive to extremes of other meteorological factors.



5. Gunn-Bellani-RIMCO relation under high (≥30°C, ≥5 mm) and low (<30°C, <5 mm) values of temperature and rainfall. Joydebpur, Bangladesh, 1983-84.



6. Gunn-Bellani-RIMCO relation under high (≥30°C, ≥5 mm) and low (<30°C, <5 mm) values of temperature and rainfall. Cuttack, Orissa, India, 1983-84.

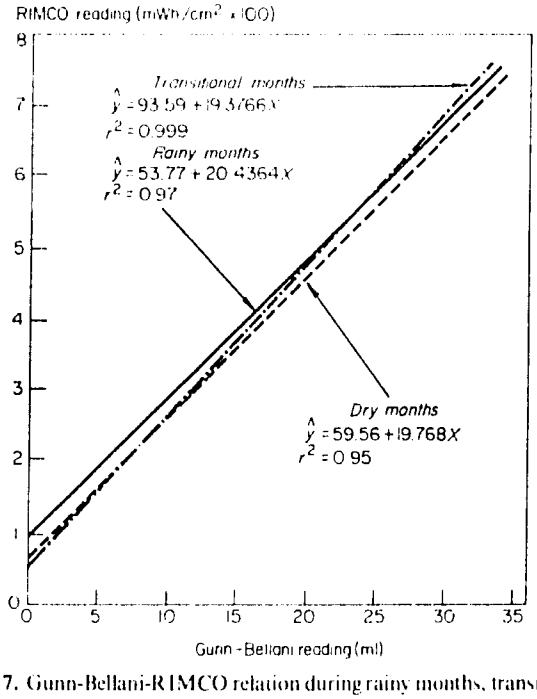
Data on the effect of season on the relation between GBSRI and RIMCO readings were separated according to rainy months, transition months, and dry months (Fig. 7). There were no significant differences, suggesting that calibration may be done during a shorter period of 2-3 mo at any time of the year without significant bias.

Although the manufacturer has included a calibration equation for the GBSRI, calibration does in fact differ significantly from site to site. Therefore, each instrument should be calibrated on site with a standard thermopile solarimeter.

EFFECT OF WEATHER ON RICE YIELDS IN THE IRRI CONTINUOUS RICE PRODUCTION SYSTEM

Multiple Cropping and Training and Technology Transfer Departments

The IRRI continuous rice production system (CRPS) or rice garden had weekly harvests from October 1977 to 1984. The same variety (IR36) and a high level of management practices were used throughout. Six-year (1978-83) weekly grain yield data were regressed against the daily average real-time solar radiation (SR) and air temperature during the 30-d period before each weekly harvest.



7. Gunn-Bellani-RIMCO relation during rainy months, transitional months, and dry months. IRRI, 1983-84.

Table 1. Results of stepwise multiple linear regression in establishing the derived equation using 1977-83 rice garden weekly yield data as dependent variable and data on solar radiation and temperature as independent variables. IRRI, 1985. n = 286.

Step	a	b	SE	F value	r^2
1	−1.1164	0.6415TRANGE	0.0399	258.79	0.477**
2	−1.1279	0.0027SR	0.0011		
		0.5235TRANGE	0.0634	134.34	0.487**
3	−3.4144	0.0023SR	0.0011		
		0.0995TMIN	0.0538		
		0.5416TRANGE	0.0639	91.469	0.493**
4	−49.9977	4.2544TMIN	2.0252		
		0.6530TRANGE	0.0397		
		$-0.0925TMIN^2$	0.0453	91.539	0.493**

To examine the dependence of yield on weather, 2 sets of data were used: 1) 6-yr weekly data consisting of 286 observations, and 2) average data for 6 yr consisting of 52 observations (weeks). To determine the predictive ability of the equations derived here and of the model of Seshu and Cady, we compared the estimated yields for 1984 based on the model equations derived from the 1977-83 period and the actual yield data for 1984.

In stepwise multiple linear regression (MLR) of the 6-yr weekly data, diurnal temperature range (TRANGE) was observed to be the most important variable related to yield, followed by minimum temperature (TMIN) and its square ($TMIN^2$) (Table 1). The derived equation is

$$Y = -49.9977 + \underset{(0.0397)}{0.6530}\,TRANGE + \underset{(2.0252)}{4.2544}\,TMIN - \underset{(0.0453)}{0.0925}\,TMIN^2 \quad (1)$$

where Y is yield in t/ha and TRANGE and TMIN are in °C. When the average weekly data over the 6 yr were regressed by stepwise MLR, only TRANGE was identified as a significant source of variation (Table 2). The established yield-weather relation using average data is

$$Y = -1.588 + \underset{(0.0290)}{0.6939}\,TRANGE \qquad r^2 = 0.92^{**} \quad (2)$$

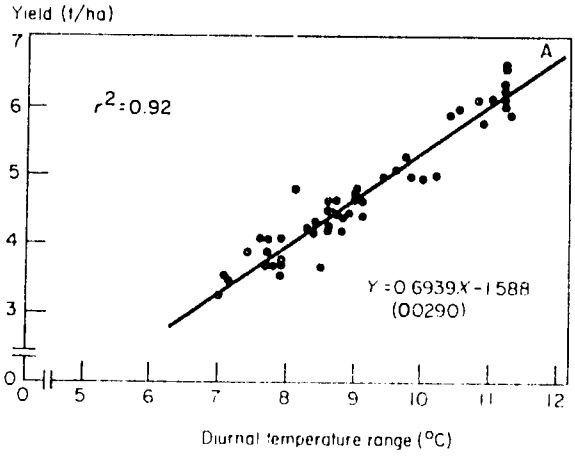
where Y is yield in t/ha (Fig. 8).

The average data of 52 observations showed that SR is highly correlated with TRANGE (Fig. 9). With SR as the dependent variable, the equation developed is

$$SR = -102.827 + \underset{(1.1412)}{55.524}\,TRANGE \qquad r^2 = 0.98^{**} \quad (3)$$

Table 2. Results of stepwise MLR to establish the derived equation using 6-yr average (1977-83) weekly data. IRRI, 1985. n = 52.

Step	a	b	SE	r^2
1	−1.5880	0.6939TRANGE	0.0290	0.92**
Variables not in equation:		F to enter		
	SR	1.576		
	TMAX	1.047		
	TMIN	1.133		
	TNIGH	1.257		
	$TMIN^2$	1.053		

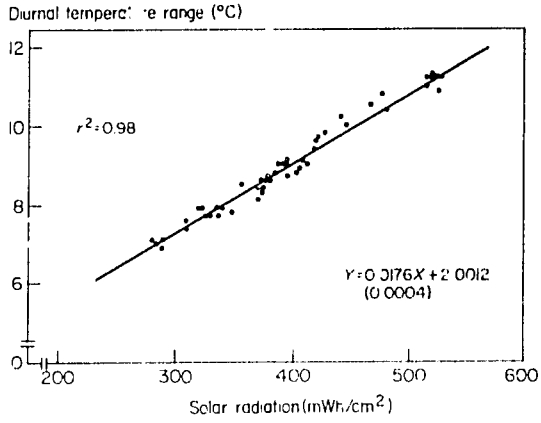


8. Relation between rice yield in the Continuous Rice Production System and mean diurnal temperature range or mean daily solar radiation. IRRI, 1977-83.

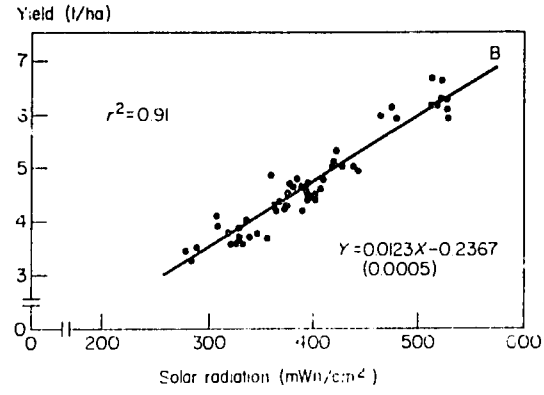
and with TRANGE as the dependent variable, the equation is

$$Y_{TRANGE} = 2.0012 + \underset{(0.0004)}{0.0176}\,SR \qquad r^2 = 0.98^{**} \quad (4)$$

where SR = solar radiation in mWh/cm² per d.



9. Relation between temperature range and solar radiation using average weekly data. IRRI, 1977-83.



10. Relation between rice yield in the Continuous Rice Production System and solar radiation using average weekly data. IRRI, 1977-83.

Dropping TRANGE from the average data set and rerunning the stepwise MLR, the equation for grain yield (Fig. 10) becomes

$$Y = -0.2367 + \underset{(0.0005)}{0.0123}\,SR \qquad r^2 = 0.915^{**} \qquad (5)$$

Weekly averages of the 6-yr data on CRPS grain yield, SR, and diurnal temperature range in Figure 11 show their distribution throughout the year. The curves of TRANGE and SR clearly paralleled the trend of yield response.

A model, using results from sites in the International Rice Testing Program (IRTP), was recently developed by Seshu and Cady to predict grain yield as a function of SR and temperature. The model is of the form

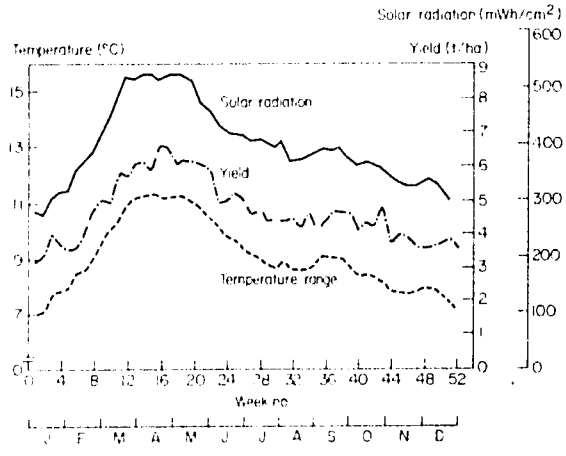
$$Y = 36.8 + \underset{(0.000923)}{0.00462}\,RAD - \underset{(0.348)}{2.73}\,MINT + \underset{(0.00762)}{0.0516}\,MINT^2 \qquad (6)$$

where Y is predicted yield in t/ha, RAD is SR in mWh/cm^2 MINT is minimum temperature in °C, and MINT^2 is the square of MINT. When the same model was applied to the CRPS data set, the relation estimated was

$$Y = -30.3234 + \underset{(0.0006)}{0.010}\,SR + \underset{(1.8494)}{2.75}\,TMIN - \underset{(0.0413)}{0.061}\,TMIN^2 \qquad (7)$$

The predictions estimated by equations 1, 2, 6, and 7 were compared with the actual yields of the 1984 CRPS (Table 3). The 1984 data were not included in the data set used to derive the parameters for these models and were thus independent.

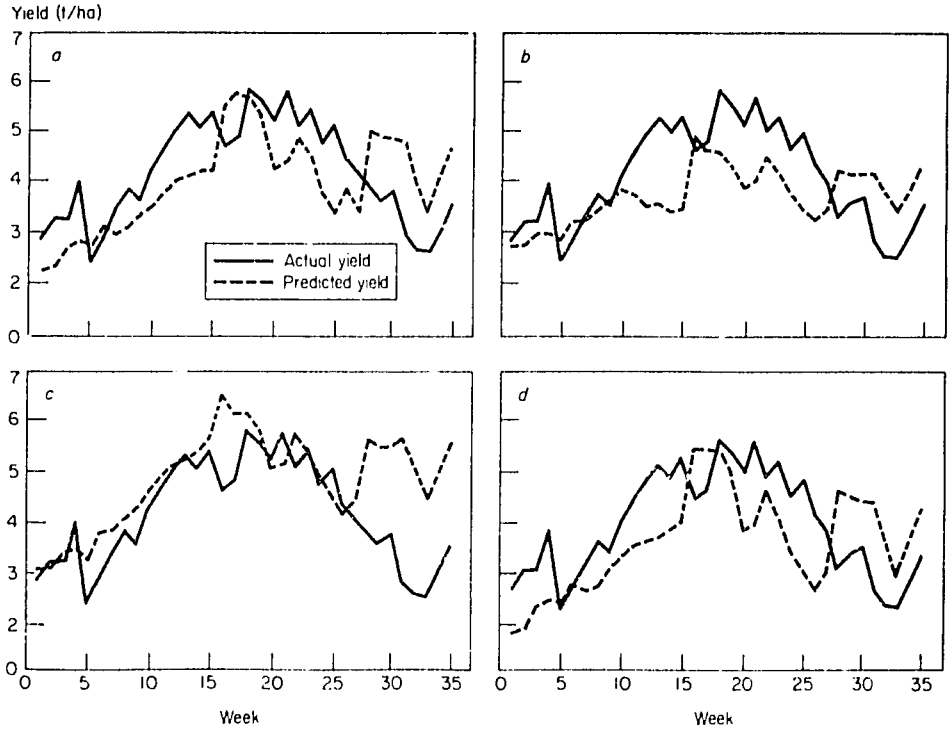
Equation 7 overestimated the actual yield throughout the test period (Fig. 12), resulting in an overestimate of 670 kg/ha compared with the 1984 actual yield. Equation 6 (Seshu-Cady) underestimated actual CRPS yield (Fig. 12) during April to June (high SR periods). This model is known to be more sensitive to minimum temperature than to SR fluctuation. The newly derived model using pooled CRPS data (equation 1) was most sensitive in predicting rice yield of IR36 during 1984 at IRRI.



11. Average weekly distribution of rice yield and weather variables — solar radiation and temperature range. IRRI, 1978-83.

Table 3. Comparison between 1984 actual weekly yields of the IRRI rice garden and estimates from 4 equations employing weather parameters. IRRI, 1985.

Equation (no.)	Mean (t/ha)	Difference (t/ha)	SE of difference	*t*-test probability
1984 actual weekly yield	4.14	0		
IRTP model (Seshu and Cady) (6)	3.77	0.37	0.2016	0.0358
Pooled equation (1)	3.95	0.19	0.2403	0.2183
Average equation (2)	3.80	0.34	0.2450	0.0819
SR substituted TRANGE equation (7)	4.81	0.67	0.2358	0.0030



12. 1984 actual rice garden yield compared with yields predicted by a) pooled data equation, b) Seshu-Cady equation, c) SR-TMin-TMin^2 equation, and d) average data equation. IRRI, 1985.

RESPONSE OF RICE TO WEATHER VARIABLES

International Rice Testing Program

Rice-weather relationships under irrigated conditions were studied during 1983-85 at 22 IRTP sites in 16 countries in Asia, Africa, and Latin America. The test sites, located at latitudes between 6° S and 37° N, represented a wide range of 2 major weather factors: SR and temperature. To minimize the interference of biological stresses, the nine early maturing test varieties with tolerance for major diseases and insects were carefully selected on the basis of their multilocation performance in IRTP trials. Trials with a uniform set of entries were conducted at sites at different latitudes. The test sites generally did not have soil problems; because they were fully irrigated, drought was not a factor. Thus, yield variability could be broadly related to the major weather factors.

The test locations can be grouped into four categories based on the annual fluctuation of the monthly minimum temperature (Table 4).

Table 4. Test sites of rice weather studies grouped according to seasonal temperature fluctuation. IRRI, 1985.

Site	Temperature (°C/d)		Radiation (mWh/cm² per d)	Latitude	Altitude (m)
	Minimum	Maximum			
Group 1: Highly seasonal (minimum temperature fluctuation more than 10°C or lowest minimum temperature less than 10°C)					
Suweon, Korea	−10.1 - +21.8	1.0 - 29.2	190-485	37°16'N	37
Milyang, Korea	− 6.8 - +22.0	5.7 - 30.0	145-360	35°29'N	12
Nanjing, China	− 1.1 - +24.4	6.9 - 32.5	295-585	32°03'N	9
Kapurthala, India	5.2 - 25.7	18.6 - 39.2	350-700	30°56'N	247
Sakha, Egypt	6.0 - 19.0	19.3 - 34.0	290-725	31°05'N	20
Dokri, Pakistan	8.3 - 27.9	22.1 - 43.7	350-640	27°50'N	30
Parwanipur, Nepal	9.0- 25.4	23.2 - 36.7	415-675	27°04'N	115
Group 2: Moderately seasonal (minimum temperature fluctuation 8-15°C)					
Joydebpur, Bangladesh	11.4 - 26.2	25.1 - 32.8	395-610	23°54'N	8
Yezin, Burma	12.7 - 26.0	26.6 - 38.2	425-635	21°57'N	74
Sanpatong, Thailand	13.2 - 23.2	28.3 - 36.0	460-630	18°45'N	312
Hyderabad, India	13.2 - 26.1	27.7 - 38.6	355-650	17°25'N	545
Pingtung, China	13.6 - 24.8	24.6 - 32.5	330-440	22°40'N	24
Cuttack, India	14.3 - 26.3	27.6 - 39.2	350-520	20°30'N	23
Group 3: Weekly seasonal (minimum temperature fluctuation 3-8°C)					
Coimbatore, India	18.4 - 22.3	28.9 - 35.3	445-620	11°02'N	431
Los Baños, Philippines	21.2 - 24.2	28.0 - 32.6	350-635	14°10'N	21
Pattambi, India	22.2 - 26.5	30.3 - 33.5	390-645	10°48'N	25
Paranthan, Sri Lanka	23.3 - 27.1	28.1 - 31.9	450-650	8°59'N	4
Group 4: Nonseasonal (minimum temperature fluctuation less than 3°C)					
Ibadan, Nigeria	22.0 - 23.7	27.3 - 33.8	450-545	7°34'N	200
Sukamandi, Indonesia	21.8 - 23.8	29.0 - 31.6	460-530	6°15'S	7
Muara, Indonesia	21.0 - 21.9	28.4 - 31.0	315-440	6°35'S	240
Palmira, Colombia	17.5 - 18.4	28.6 - 30.7	450-520	3°31'N	1,006
Ahero, Kenya	13.1 - 15.1	28.5 - 31.4	630-720	0°09'S	1,200

Based on data from 39 trials conducted at 19 sites, and considering that the estimates should be reasonable in subject matter knowledge and meaningful in associated standard errors, prediction equations to relate the varietal yield response to weather variables were formulated for each of the 9 test entries (Table 5). The weather variables are three preflowering factors — radiation sum, day temperature, and day-night temperature difference — and two postflowering factors — radiation sum and night temperature. The overall prediction equation estimated from compositing individual entry data is as follows:

$$Y = \underset{(0.047)}{4.800} + \underset{(0.07181)}{0.5743}(DNB-3.1) - \underset{(0.03142)}{0.1492}(TDB-28.1) \quad (8)$$

$$+ \underset{(0.008813)}{0.06384}(RSB-30.446) + \underset{(0.01793)}{0.1665}(RSC-13.964)$$

$$- \underset{(0.02192)}{0.1327}(TNC-24.0)$$

where

DNB = day-night temperature difference before flowering, with an average of 3.1;

TDB = day temperature before flowering (°C), with an average of 28.1;

RSB = radiation sum before flowering, with an average of 30.446 (RSB variable in the equation is the measured RSB multiplied by 0.001);

RSC = radiation sum after flowering, with an average of 13.964 (RSC variable in the equation is the measured RSC multiplied by 0.001); and

TNC = night temperature after flowering (°C), with an average of 24.0.

The values in parentheses are standard errors, and 4.8 t/ha was the average yield of the 9 entries.

From equation 8, isoquant (lines or curves of equal yield) plots may be constructed (Fig. 13). The isoquants are straight lines, since all components of

Table 5. Estimated coefficients for prediction equations with 3 preflowering explanatory variables – day temperature (TDB), day-night temperature difference (DNB), and accumulated radiation (RSB) – and 2 postflowering explanatory variables – night temperature (TNC) and accumulated radiation (RSC).[a] IRRI, 1985.

Variety	Intercept	TDB (°C)	DNB (°C)	RSB (1,000 mWh/cm²)	TNC (°C)	RSC (1,000 mWh/cm²)	Mean	Standard deviation	r^2
BG35-2	3.66 (2.44)	−0.11 (0.085)	0.54 (0.20)	0.088 (0.026)	−0.077 (0.052)	0.10 (0.055)	4.5	0.76	0.75
BG367-4	5.95 (2.98)	−0.073 (0.098)	0.76 (0.23)	−0.0014 (0.032)	−0.17 (0.073)	0.20 (0.056)	4.9	0.94	0.64
MRC603-303	5.73 (2.71)	−0.21 (0.092)	0.57 (0.23)	0.067 (0.028)	−0.069 (0.059)	0.18 (0.065)	4.6	0.88	0.71
IR13429-196-1	3.76 (3.23)	−0.061 (0.11)	0.48 (0.24)	0.074 (0.032)	−0.14 (0.073)	0.18 (0.063)	4.9	0.98	0.67
IR36	5.24 (2.42)	−0.16 (0.080)	0.49 (0.18)	0.068 (0.025)	−0.098 (0.053)	0.22 (0.056)	5.0	0.76	0.77
IR50	9.91 (3.18)	−0.19 (0.10)	0.56 (0.25)	0.064 (0.036)	−0.22 (0.096)	0.15 (0.060)	4.9	1.01	0.68
IR9729-67-3	9.98	−0.22	0.30	0.094	−0.20	0.16	4.5	1.05	0.68
IR9828-91-2-3	5.04 (2.43)	−0.17 (0.081)	0.51 (0.19)	0.077 (0.026)	−0.076 (0.053)	0.19 (0.049)	5.0	0.76	0.76
Taichung sen yu 285	7.40 (2.98)	−0.12 (0.10)	0.88 (0.23)	0.060 (0.028)	−0.24 (0.063)	0.13 (0.063)	4.9	0.90	0.77
Mean	6.12 (0.93)	−0.15 (0.031)	0.57 (0.072)	0.064 (0.0088)	−0.13 (0.022)	0.17 (0.018)	4.8	0.89	0.68

[a]The values in parentheses are standard errors.

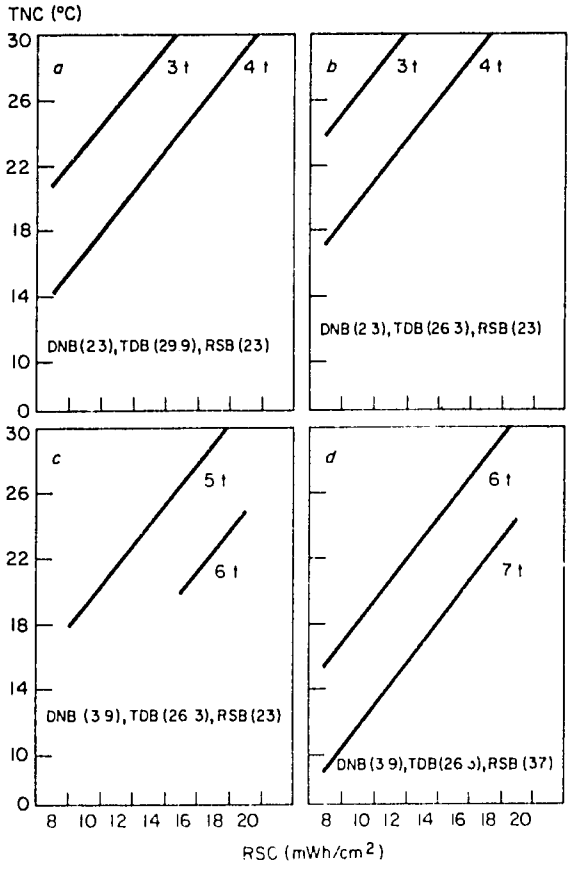
the prediction equation are linear terms. Ripening period variables are used for the axes of the plots, while the preflowering variables are held constant.

AGROHYDROLOGY OF UPLAND RICE

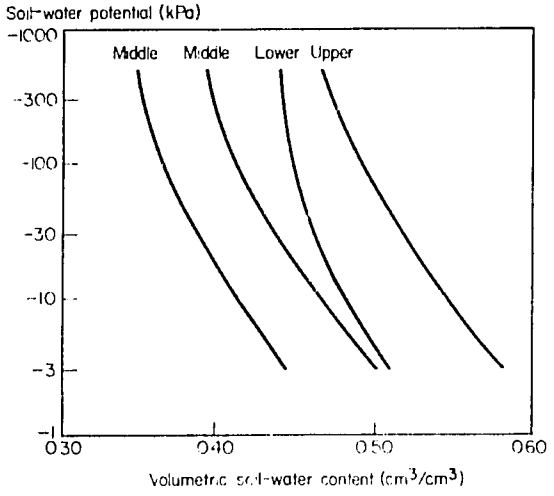
Soil Chemistry/Physics, Agronomy, and Plant Breeding Departments

For upland rice on a gently sloping hill toposequence with shallow water table, growth and yield may depend on position up the hill. Position may affect seedbed temperature, moisture, and soil strength — and hence rice germination and emergence — and may influence groundwater and nutrient uptake, intensity of soil erosion, weed growth, and aboveground physical, micrometeorological conditions that favor fungal disease development. Whether any or all of these effects occur in a particular year, and at what magnitude, is determined by the total rainfall and its distribution before and during the rice-growing season. In 1984 WS research, a low rainfall dispersed among many rain days resulted in a groundwater too deep to affect rice growth appreciably, but persistent topsoil wetness promoted severe weed competition.

In 1985 WS, in a collaborative project with the University of Reading, England, rice was grown in eight 81- × 10-m strips oriented along a 1.5% incline on a 100- × 100-m field. Each strip had 9 sections averaging 0.13-m higher elevation than the one below it. Two pairs of the eight strips were crossed at right angles by a series of vertical wooden barriers (terraces) to restrict aboveground downslope flow of soil and nutrients during intense rain. Within each strip-pair there were thus nine sets of two sections having the same elevation. In each set, one section was chosen randomly to be planted with the lowland variety IR36, the other with upland UPLRi5. Soil and crop variables, and the incidence of weeds, insects, and diseases were monitored regularly in the 72 sections. Meteorological variables, including shortwave SR, were monitored at a nearby observatory. Absorbed photosynthetically active radiance (PAR) was



13. Isoquant (equal yield) lines expressed as functions of 2 postflowering weather variables: night temperature (TNC) and accumulated radiation (RSC). Three preflowering variables day temperature (TDB) in °C, day-night temperature difference (DNB) in °C, and accumulated radiation (RSB) in 1,000 mWh/cm² are held constant at different levels (a, b, c, d). IRRI, 1985.



14. Soil-water retention characteristics for the 20- to 30-cm soil layer at 4 sites at different elevations in 1 field. IRRI, 1985.

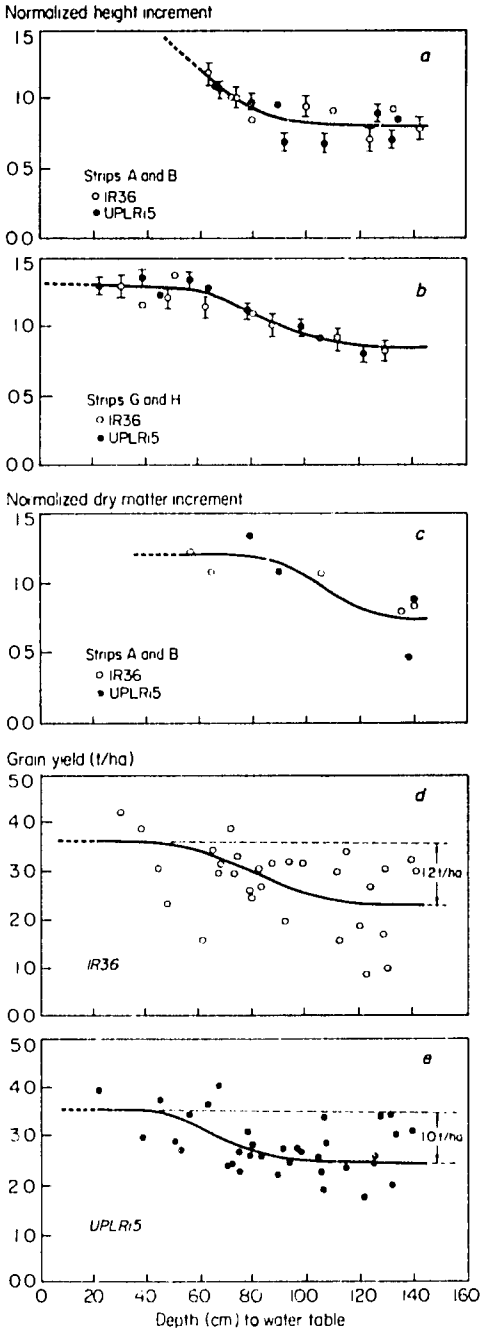
measured in 6 sections and persistence of rice-leaf wetness in 20 sections.

The fine, mixed, isohyperthermic Typic Hapludoll comprised silty clay loam overlying clay over sandy clay loam. Its topsoil had 1.4% organic C, pH 6.5, and 25 meq CEC/100 g. Soil-water retention characteristics for the 20-30 cm soil layer (Fig. 14) show changes across the field that were both statistically and practically significant.

The 1985 WS had abnormally high total rainfall: during the period of this experiment (20 Jun-31 Oct), 1616 mm of rain fell. There was nonetheless a month-long dry spell (29 Jul-31 Aug) that realized only 64 mm of rain from 10 rain days. During this spell, soil in the 0-20 cm layer dried to −0.10 MPa (appreciably drier than the −0.03 MPa at which many rice varieties suffer water stress), and average water table depth was 1.4 m at the highest elevations and 0.3 m for the lowest. The latter depths were uncontrollably shallow because of intrusion of irrigation water from an adjacent flooded ricefield. Rates of recession of the water table ranged from 0.3 to 13 cm/d; rates at higher elevations were, on the average, twice as fast as at lower elevations, where recession was sufficiently slow to allow rice to take up substantial quantities of groundwater.

For the month-long dry spell, variations in average water table depth along the slope were associated with changes in increments of plant height (Fig. 15). For each of the rice varieties, these increments may be presented as ratios to their corresponding varietal mean. Data for the two varieties and for any pair of contiguous strips then conform to one common trend line, as do ratios for increments of plant mass, although the latter have fewer data points and lower precision.

The effects of the dry spell were manifest also at final harvest, as represented by the dependence of the grain yield of both UPLRi5 and IR36 on the dry-spell mean water table depth (Fig. 15). For both varieties, the effect of groundwater on grain yield was minimal for water table depth below 120 ± 20 cm, increased as depth decreased to 40 ± 10 cm, and was constant for depths shallower than 40 cm. Averaged over the 2 varieties, the magnitude of



15. Effect on growth of upland rice of depth to water table during a 4-wk dry period. a,b) Height increments for UPLRi5 and IR36 (normalized as ratio to varietal average increment) in relation to mean water table depth, each during 40-68 DAS and for 2 pairs of contiguous strips. c) Normalized dry matter increments for UPLRi5 and IR36 in relation to mean water table depth, each during 47-61 DAS and for Strips A and B. d,e) Rice grain yield for UPLRi5 and IR36 in relation to mean water table depth during 40-68 DAS.

the yield response to groundwater was 1.1 ± 0.5 t/ha, which is consistent with a prediction of 0.7 ± 0.5 t/ha made in terms of the season's pattern of rice transpiration and the measured water-holding characteristics of the 40-120 cm soil layer. The equivalence of the measured and predicted yield responses led to the conclusion that the response resulted from groundwater uptake and not from variations either in weed competition (weeds were random) or in uptake of major nutrients. Concentrations of major nutrients in both soil and crop were essentially uniform across the site. There was, however, some random variation in the interactions of some minor nutrients, particularly in Fe:Mn in plant tissues, which is sensitive to submerged or reduced soil conditions. Analyses of plant tissues at 29 d after seeding (DAS) showed variations in Fe:Mn across the site, although not in systematic relation to either the depth or duration of submergence. The analysis also revealed varietal differences: the mean value for Fe:Mn for IR36 (2.5 ± 0.2) was significantly higher than for UPLRi5 (1.9 ± 0.2). Moreover, the mean value for IR36 was equal to the upper limit of 2.5 at which rice growth can be affected, and for 60% of the sections Fe:Mn was above this limit (range 1.8-3.7). For UPLRi5, 20% of the sections had Fe:Mn below the lower limit of 1.5 (range 1.1-3.2). However, the effects on rice yield of these micronutrient imbalances were too small to be detected within the precision of the field experiment.

Average grain yields (Table 6) for the 2 varieties were identical. Leaf areas also were equal, but these dry-spell values at 57 DAS were low in comparison with the corresponding measurement for IR36 in 1984. The mature plant height showed the expected difference between varieties. Plant height was probably the factor that caused less weed growth (monitored only from 85 DAS to harvest) with UPLRi5 than with IR36.

The photosynthetic efficiency with which the yields were produced was determined from measurements of the seasonal progressions of plant mass increment and of total and absorbed PAR. The measurements allowed examination of differences in efficiency between varieties, growth stage, and toposequence position. IR36 showed higher efficiency than UPLRi5 (Fig. 16), which is

Table 6. Grain yield, leaf area index, plant height, and weed mass in upland rice toposequence experiments. IRRI, 1984 and 1985.

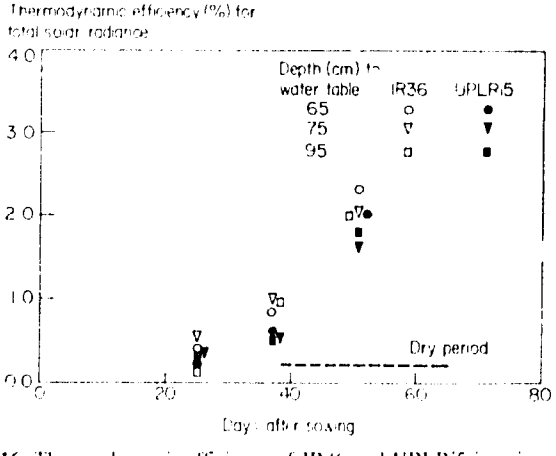
Variable	1984	1985	
	IR36	IR36	UPLRi5
Mean yield (t/ha)	2.4 ± 0.2	2.9 ± 0.1	2.9 ± 0.1
Leaf area index at 57 DAS[a]	6.8 ± 0.5	3.3 ± 0.2	3.5 ± 0.2
Plant height (cm) at 85 DAS	79 ± 1	66 ± 1	110 ± 2
Weed dry mass (g/m²) for 85 DAS to harvest	–	14 ± 1	8 ± 1

[a]1985 dry period = 38-66 DAS.

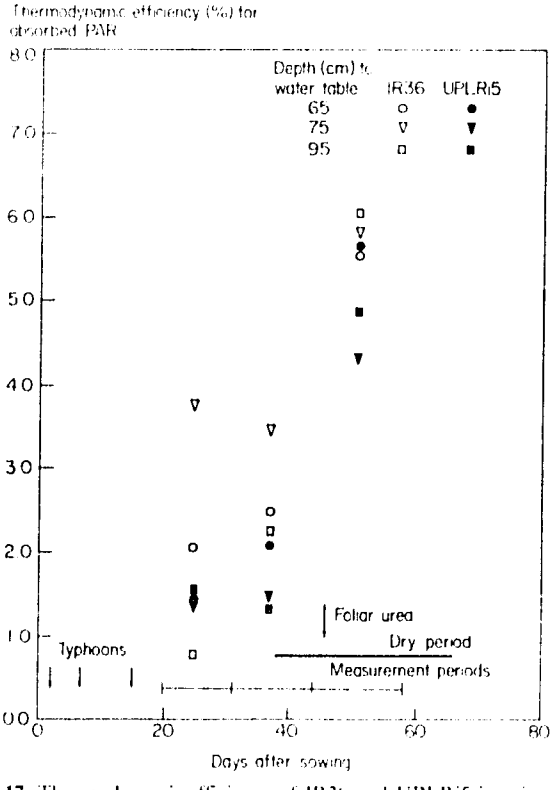
consistent with IR36 producing an equal yield in fewer days. For both varieties, efficiency increased with time — a manifestation of progressive increase in leaf area — and at 50 DAS attained values of 2%. When thermodynamic efficiency is calculated in relation to absorbed PAR (Fig. 17), the effect of leaf-area development is effectively removed, and any influence of water table depth should be manifest. In fact, water table depth had no effect. But photosynthetic efficiency during the 4-wk dry spell was twice as high as in the preceding measurement periods; possibly, lack of N after three major typhoons in the earlier periods depressed efficiency, which in the later dry period was higher because of an application of foliar urea.

In preparation for these toposequence rice experiments, the ratio of PAR to total SR was determined from measurements made without any crop during high-radiance conditions at Los Baños in May 1985. The ratio of 0.55 ± 0.02 was higher than would be expected in temperate latitudes but was consistent with the few data that have been recorded in the tropics.

The terrace boards arrested the flow of rainwater and retained water on the soil surface upslope of the boards. This water infiltrated the soil; consequently, during the dry spell 15 ± 5 mm more water was stored in the 0-50 cm soil layer on terraced than on unterraced strips (Table 7). This additional water was associated with possible plant



16. Thermodynamic efficiency of IR36 and UPLRi5 in using total solar radiation as affected by plant age and mean depth to water table during the dry period, 29 Jul-26 Aug 1985.



17. Thermodynamic efficiency of IR36 and UPLRi5 in using absorbed PAR as affected by plant age and mean depth to water table during the dry period, 29 Jul-26 Aug 1985.

Table 7. Effects of terracing on soil-water content and rice growth. IRRI, 1985.

Variable	Algebraic difference (terraced – unterraced)
Available stored soil water (mm)	+ 15 ± 5
Plant height increment (cm) during 38-66 DAS	
IR36	+ 0.7 ± 2.7
UPLRi5	+ 4.4 ± 5.9
Plant mass increment (g/m²) during 33-59 DAS	
IR36	+126 ± 60
UPLRi5	– 37 ± 60
Grain yield (t/ha)	
IR36	– 0.08 ± 0.26
UPLRi5	+ 0.12 ± 0.18

height and plant mass increases, although there was no increase in grain yield.

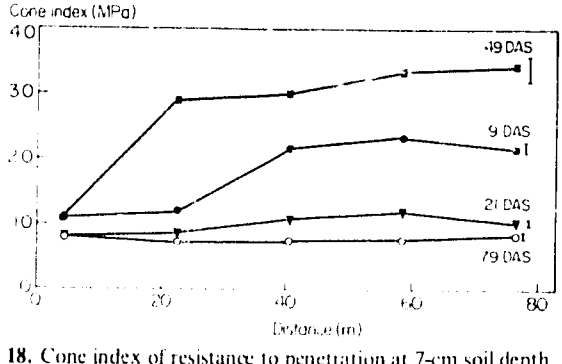
Soil moisture had a direct influence on soil strength, as shown by cone penetrometer measurements at 7-cm depth at various positions along one of the toposequence strips (Fig. 18). The data for 9, 21, 49, and 79 DAS show irregular changes in strength corresponding to changes in soil moisture that in turn resulted from rainy and dry periods. For any one measurement day, variations in strength along the slope correspond to differences in drying of the surface soil. A cone index value of 3 MPa indicates that the bulk soil has become too strong for penetration by roots of almost any crop species.

Soil strength measurements were also made by shear-vane apparatus and fitted to a Mohr-Coulomb model to give estimates of soil cohesion and soil friction. From the latter, shear strength (or soil breaking strength) for the August dry period was predicted for the 20-40 cm subsoil layer and for sections at the upper and lower elevations on the toposequence. The results showed no difference between upper (38 ± 2 kPa) and lower (43 ± 3 kPa) elevations, but soils having these shear strengths may well be too strong for rice roots to penetrate. Where subsoil strength is high, disrupting the strong layer by deep tillage may encourage deeper rooting and higher yields.

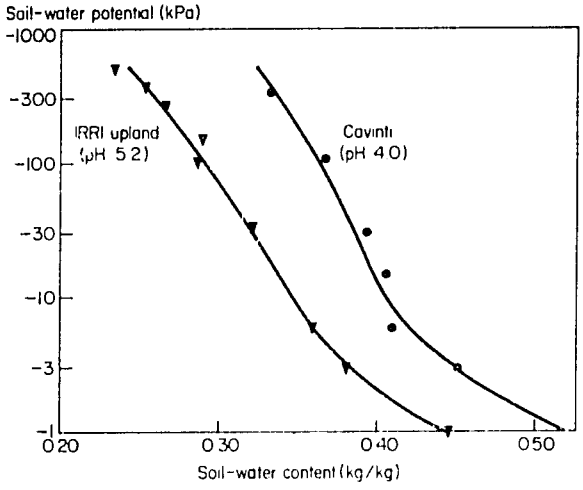
Rooting depths of IR36 and UPLRi5 were similar throughout the growing season. Root depth of each variety was maximal (57 ± 8 cm) toward the end of the August dry period and somewhat less (50 ± 5 cm) at harvest.

Soil-water content and potential, and seedbed temperature and soil structure, also affect upland rice through their influence on seed germination. Temperatures at 1400 h in the toposequence seedbed were as high as 36 °C at a depth of 5 cm and 38 °C at 2 cm. These high temperatures prevailed even in wet soil of high heat capacity during 0-7 DAS; temperatures close to 40 °C can, if maintained, reduce rice germination.

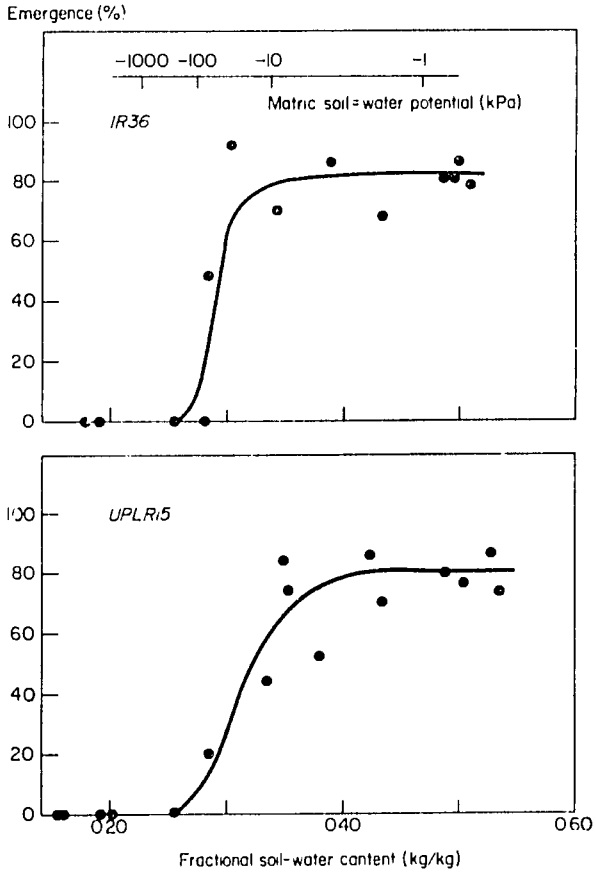
To support the toposequence program, the interactive effects of soil water, temperature, and pH on germination of four rice varieties were measured under controlled environmental conditions. The measurements were made in sieved 2-mm crumbs of 2 upland rice soils: one (pH 5.2) from a field adjacent to the toposequence site and one (pH 4.0) from IRRI's upland rice breeding site at Cavinti, Laguna, Philippines. Their respective water-retention characteristics are shown in Figure 19. Temperature regimes were imposed in 5-K increments from 30 to 45 °C for varieties IR36, UPLRi5, N22 (small-seeded, from India), and IRAT13 (large-seeded, from Africa). IR36 and UPLRi5 each had more than 70% emergence from IRRI soil crumbs at the high temperature of 35 °C provided that the water content exceeded 0.35 kg/kg (Fig. 20). Results for N22 and IRAT13 are as yet available only for Cavinti soil. The larger seeds of IRAT13 were better able to germinate in these soil crumbs than were the smaller N22 seeds, and at these high temperatures (probably because of fungal attacks), soil wetter than 0.65 kg/kg may have promoted less emergence than did drier soil (Fig. 21). At 40 °C emergence was negligible.



18. Cone index of resistance to penetration at 7-cm soil depth at various distances along a toposequence slope and at various days after sowing (DAS). IRRI, 1985 WS.

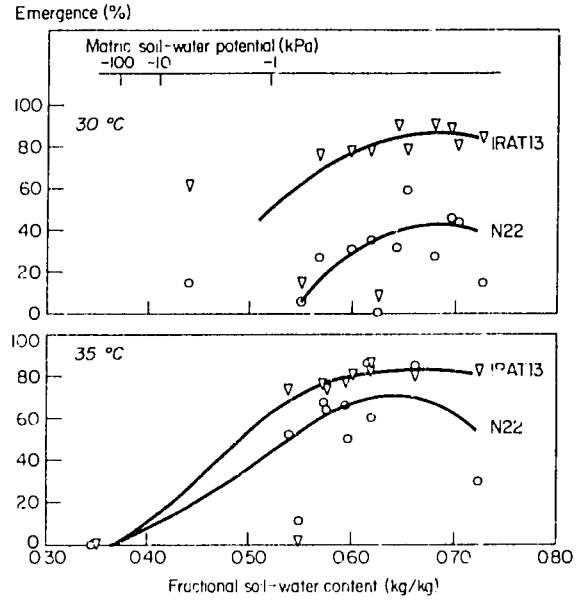


19. Soil-water characteristics for 2-mm sieved crumbs of 2 upland rice soils.

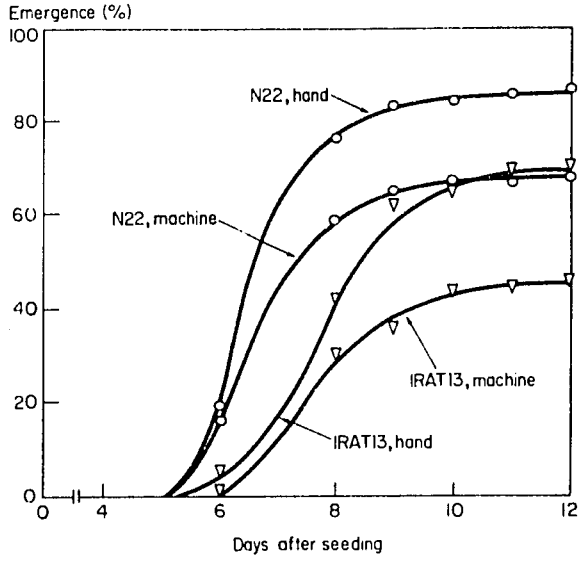


20. Effect of soil-water content and potential on emergence of dry seeded rice (IR36 and UPLRi5) from beds of 2-mm crumbs of IRRI soil (growth chamber at 35 °C, 50% RH). 1985.

These findings are relevant to the adaptation to upland rice seeding of the prototype dryland seeder described in the section on Machinery Development and Testing. Field trials in the Typic



21. Effect of soil temperature, and soil-water content and potential on emergence of dry seeded rice (N22 and IRAT13) from beds of 2-mm crumbs of Cavinti soil (growth chamber at 30 and 35 °C, 50% RH). 1985.



22. Comparison of emergence of seeds of 2 upland rices planted by hand and by a Massey University prototype seeder into soil at 0.34 volumetric soil-water content. IRRI, 1985.

Hapludoll showed that planting by hand or by machine into dry silty clay loam topsoil (0.34 volumetric moisture content) resulted in emergence rates of more than 40% (Fig. 22). Such rates are high enough for upland rice production. The data also show that, in contrast to the findings for the Cavinti soil crumbs (Fig. 21), the smaller seeds of N22 emerged more quickly and more numerously in the IRRI field soil than did IRAT13. For both varieties, rates of emergence were less for machine planting than for hand planting; nonetheless, this shortcoming is offset by the machine's ability to plant large areas quickly.

In 1975, 1983, and 1985, rice yield showed a dependence on toposequence position and water table depth. Common features of the hydrologies of the wet season of those years suggest that such dependence may be expected when rainless periods cause the 0-20 cm soil layer to dry to −0.1 MPa soil-water potential after rains that raise the water table to within 0.8 m of the soil surface. Moreover, on two different fields with different soils and draining to different creeks, rates of groundwater recession may be slow enough to allow upland rice to take up groundwater and to show a grain yield benefit of 1 t/ha. This gain may justifiably be ascribed to hydrological causes. However, effects may in part be mediated chemically, as by N, Ca, Fe, Mn, or biologically, as through weeds and rice blast. And in some years, seedbed temperature may approach 40 °C and hence inhibit germination of some upland rice varieties.

Constraints on rice yields

Agricultural Economics, Multiple Cropping, and Agronomy Departments

SOCIOECONOMIC CONSTRAINTS 322
Budget analysis of management experiments 322
Farmer and researcher technology 322
Profitability of soil nutrients 322
Forms and application methods of urea 323
Seeding rates and weeding in wet seeded rice 323
Upland rice 324
Efficiency in rice production in Punjab, Pakistan 324
Economic efficiency 324
Farm-specific economic efficiency 325
Determinants of loss of profit 326
Fertilizer use in less favorable environments 327
Benefits of fertilizer use 327
Fertilizer adoption 328
MANAGEMENT CONSTRAINTS 328
Wet seeding in less favorable environments 328
Productivity of wet seeded and transplanted rice 328
Adoption of WSR 329
Production constraints in upland rice 330
Farmers' production system 330
Varietal performance 330
Yield constraints on direct seeded rice 334
Irrigated sites in dry season 334
Rainfed sites in wet season 338
Irrigated sites in wet season 339
Yield constraints on transplanted rice 339
Irrigated sites in dry season 339
Rainfed sites in wet season 340
Irrigated sites in wet season 340
Yield constraints on upland rice 341
Performance of management packages 343
Response to N and P 344

SOCIOECONOMIC CONSTRAINTS

Agricultural Economics Department

Budget analysis of management experiments. The Agronomy Department's management experiments were budget analyzed on a regional basis to evaluate the comparative profitability of the researchers' practices and those used by farmers.

Farmer and researcher technology. Budget analysis of fertilizer, insect, and weed control experiments showed that the added cost of the researchers' package over the farmers' practices was $129-200/ha. Despite generally higher yields, the researchers' technology was not more profitable than the farmers'. We therefore examined the profitability of each component of the researchers' technology (Table 1).

In dry season (DS), the researchers' fertilizer management was more profitable than the farmers' in Camarines Sur and Nueva Ecija, but not in Bulacan. The profitability and benefit-cost ratio (B:C) of changing to the researchers' fertilizer management was most attractive in Nueva Ecija, the "rice bowl" of the Philippines. In wet season (WS), the researchers' fertilizer practices were more profitable than the farmers' on rainfed but not on irrigated rice in Camarines Sur, and uniformly profitable across water regimes and establishment methods in Nueva Ecija.

The researchers' insect control strategy — other than in Camarines Sur in DS — was too costly to generate higher return than the farmers' practices.

In DS, the researcher's weed control was profitable in Nueva Ecija but not in Bulacan or Camarines Sur. In WS it was marginally profitable in rainfed but not in irrigated environments in Camarines Sur; and more profitable with wet seeded rice (WSR) than with transplanted rice (TPR) in Nueva Ecija.

Profitability of soil nutrients. It was profitable to apply as much as 87 kg N/ha in Camarines Sur and Nueva Ecija in DS but not in Bulacan (Table 2). In WS, 60 kg N/ha was marginally profitable in Camarines Sur and quite profitable in Nueva Ecija. The application of 30 kg P/ha was not profitable at any site in DS, although it was for rainfed WSR in Camarines Sur in WS. There was no response to K.

Table 1. Economic performance of high levels of 3 inputs and farmers' current practices.[a] Philippines, 1985.

Location, water regime, crop establishment[b]	Sites (no.)	Package profit ($/ha)	Fertilizer[c]		Insect control[e]		Weed control[f]	
			Profit[d] ($/ha)	B:C	Profit[d] ($/ha)	B:C	Profit[d] ($/ha)	B:C
			Dry season					
Bulacan								
Irrigated WSR	6	−194	−35	0.2	−187	neg	−49	neg
Camarines Sur								
Irrigated WSR	14	−104	43	1.6	23	3.4	−132	0.1
Nueva Ecija								
Irrigated WSR	12	24	70	13.9	−70	0.5	90	1.6
			Wet season					
Camarines Sur								
Rainfed WSR	6	− 31	55	2.5	−115	−0.1	5	1.4
Rainfed TPR	3	− 12	127	4.6	−126	0.1	19	1.6
Irrigated WSR	1	−116	−21	0.4	−122	neg	−13	neg
Irrigated TPR	3	−203	−44	neg	−145	neg	−13	0.6
Nueva Ecija								
Rainfed WSR	1	57	132	12.5	−53	0.6	86	8.3
Rainfed TPR	10	−43	58	4.5	−76	0.4	9	1.4
Irrigated WSR	1	−41	93	8.6	−157	neg	46	4.9
Irrigated TPR	4	9	112	9.6	−84	0.3	−12	0.5

[a]neg = negligible, B:C = benefit-cost ratio. [b]WSR = wet seeded rice, TPR = transplanted rice. [c]Researchers' fertilizer was 87-30-30 kg NPK/ha in DS and 60-30-30 kg in WS. [d]At rough rice price of $162/t. [e]Researchers' insect control cost $138/ha in DS and $139/ha in WS. [f]Researchers' weed control cost $10/ha in DS and $15/ha in WS.

Table 2. Profitability of N, P, and Zn application in farmers' fields.[a] Philippines, 1985.

Location, water regime, crop establishment	Benefit-cost ratio		
	N	P	Zn
Dry season			
Bulacan			
Irrigated WSR	neg	neg	n.i.
Camarines Sur			
Irrigated WSR	5.6	1.0	n.i.
Nueva Ecija			
Irrigated WSR	6.4	1.1	n.i.
Wet season			
Camarines Sur			
Rainfed WSR	1.1	3.3	neg
Rainfed TPR	1.8	1.3	2.0
Irrigated WSR	2.2	0.9	neg
Irrigated TPR	1.6	1.0	neg
Nueva Ecija			
Rainfed WSR	1.9	neg	8.0
Rainfed TPR	2.2	0.7	1.4
Irrigated WSR	3.0	0.1	neg
Irrigated TPR	2.2	neg	neg

[a]neg = negligible, n.i. = not included.

Zn application was profitable in rainfed TPR in Camarines Sur and in rainfed WSR in Nueva Ecija, but not at other sites.

Forms and application methods of urea. In DS, deep placed urea supergranules (USG) and the researchers' split gave higher net benefits than the farmers' practice at both 29 and 58 kg N/ha across sites in Camarines Sur and Nueva Ecija. On the average, however, USG was not superior to the researchers' split.

In WS the researchers' split was as good as USG deep point placed by hand or by machine (plunger-auger or press wedge) at both 29 and 58 kg N/ha (Table 3). In Camarines Sur, the farmers' split and the researchers' split were equally profitable, while in Nueva Ecija the researchers' split was superior to the farmers'.

Seeding rates and weeding in wet seeded rice. There were no large differences in net benefit among seeding rates in experiments conducted in

Table 3. Profitability of various N forms and methods of application compared with farmers' practices.[a] Philippines, 1985 WS.

Location, water regime, crop establishment	Net benefit ($/ha)							
	No N	PU FS[b]	PU RS[c]	PU TD[d]	USG DPH[e]	PU PA[f]	USG PW[g]	87 kg N/ha as PU RS
29 kg N/ha								
Camarines Sur								
Rainfed WSR	145	195	181	169	157	180	161	227
Rainfed TPR	200	238	311	257	269	275	257	354
Irrigated WSR	301	371	298	290	377	347	342	413
Irrigated TPR	251	311	-	317	336	311	308	352
Nueva Ecija								
Rainfed WSR	232	301	363	54	229	289	278	293
Rainfed TPR	270	316	365	348	365	355	331	389
Irrigated WSR	287	313	407	390	364	347	359	376
Irrigated TPR	242	280	307	268	298	293	275	306
58 kg N/ha								
Camarines Sur								
Rainfed WSR	n.i.	192	195	212	190	n.i.	n.i.	n.i.
Rainfed TPR	n.i.	275	337	313	297	n.i.	n.i.	n.i.
Irrigated WSR	n.i.	456	384	360	411	n.i.	n.i.	n.i.
Irrigated TPR	n.i.	351	378	361	339	n.i.	n.i.	n.i.
Nueva Ecija								
Rainfed WSR	n.i.	331	346	331	231	n.i.	n.i.	n.i.
Rainfed TPR	n.i.	339	384	383	385	n.i.	n.i.	n.i.
Irrigated WSR	n.i.	410	453	386	376	n.i.	n.i.	n.i.
Irrigated TPR	n.i.	294	302	298	304	n.i.	n.i.	n.i.

[a]Unless otherwise specified, N rates were 29 and 58 kg/ha at high weed and insect control. PU = prilled urea, USG = urea supergranules, n.i. = not included. [b]FS = farmers' split. [c]RS = researchers' split = 2/3 basal, broadcast and incorporated (BBI) and 1/3 at 5-7 d before panicle initiation (DBPI). [d]TD = topdressing entire amount at 5-7 DBPI. [e]DPH = deep point placement by hand at 10-12 cm soil depth at 3 d before seeding (DBS) or 2-4 d after transplanting (DT). [f]PA = plunger-auger machine placement at 3 DBS or 2-4 DT. [g]PW = press wedge machine placement at 3 DBS or 2-4 DT.

Bulacan, Camarines Sur, and Nueva Ecija (Table 4). In Camarines Sur and Nueva Ecija, the benefits of WSR were higher at the researchers' level of weed control, but in Bulacan the farmers' level gave higher benefits.

Upland rice. Over 10 constraints experiments established by the Agronomy Department on upland rice in Batangas, the researchers' varieties IR43 and UPLRi5 were higher yielding and more profitable than the farmers' variety, although they had lower market prices. The researchers' fertilizer practices were not more profitable than the farmers'. The chemical method of weed control was more profitable than the researchers' simulation of farmers' (mechanical) methods of weeding. None of the researchers' management packages or researchers' simulations of farmers' practices were profitable because of low yields caused by drought.

IR43 exhibited higher N response than UPLRi5 or Kinandang Patong, with returns higher under the researchers' level of weed control (Table 5). It was profitable, given a 2:1 B:C on variable inputs, to apply N to IR43 only under high weed control. The application of P was not profitable at this site.

Efficiency in rice production in Punjab, Pakistan. A scenario in world cereal production, including rice, is one of declining output prices but increasing real input prices. This places stress on examining the extent and causes of economic inefficiency in rice production. As part of this concern, we examined the level of profit inefficiency in Basmati rice production in Punjab, Pakistan.

Economic efficiency. Loss of profit of individual firms was estimated with respect to best-practice techniques. To achieve this, a "composed error" stochastic profit function was estimated:

$$S_j = f(P_{ij}, Z_{kj}, D_{tj}) \exp \epsilon_j \qquad (1)$$

where

S_j = normalized profit of the j-th farm defined as gross revenue less variable cost, divided by farm-specific rice price;

P_{ij} = the price of the i-th variable input faced by the j-th farm divided by rice price;

Z_{kj} = level of the k-th fixed factor of the j-th farm;

D_{tj} = dummy variables for soil conditions of the j-th farm;

ϵ_j = an error term; and

j = 1,...,n is the number of farms in the sample.

The error term ϵ_j is made up of two independent components:

$$\epsilon = v - u_j \qquad (2)$$

where $v_j = N(0, \sigma^2_v)$ is a two-sided error term representing the usual random effects found in any system, and $u_j \geq 0$ is a one-sided error term representing profit inefficiency. u_j measures profit inefficiency in the sense that it measures profit shortfall (S_j) from its maximum possible value ($\hat{S}_j$) given by the stochastic frontier. Equation 1, given the error structure defined by equation 2, was estimated using maximum likelihood techniques. Farm-specific estimates of profit inefficiency were derived following the procedures of Jondrow and others.

One hundred and twenty farmers in Gujranwala District were interviewed for information on their

Table 4. Net benefits of various seeding rates and weed control on WSR.[a] Philippines, 1985 DS.

Seeding rate (kg/ha)	Net benefits ($)		
	Bulacan	Camarines Sur	Nueva Ecija
	Farmers' weed control		
100	375	403	587
150	396	409	571
200	403	388	595
	Researchers' weed control		
100	371	429	630
150	378	425	815
200	391	411	628

[a]Av of N applications.

Table 5. Profitability of N application on upland rice. Batangas, Philippines, 1985 WS.

Variety	40 kg N/ha		80 kg N/ha		120 kg N/ha	
	Profit ($/ha)	B:C	Profit ($/ha)	B:C	Profit ($/ha)	B:C
	Farmers' weed control					
Kinandang Patong	4	1.0	16	1.1	15	1.1
IR43	76	1.5	113	1.6	142	1.7
UPLRi5	19	1.1	96	1.7	61	1.3
	Researchers' weed control					
Kinandang Patong	30	1.2	75	1.5	43	1.3
IR43	146	2.1	221	2.5	210	2.3
UPLRi5	80	1.6	132	1.9	123	1.8

Table 6. Ordinary least squares and maximum likelihood estimates of profit function for Basmati rice production in Gujranwala District, Punjab, Pakistan, 1982 crop.

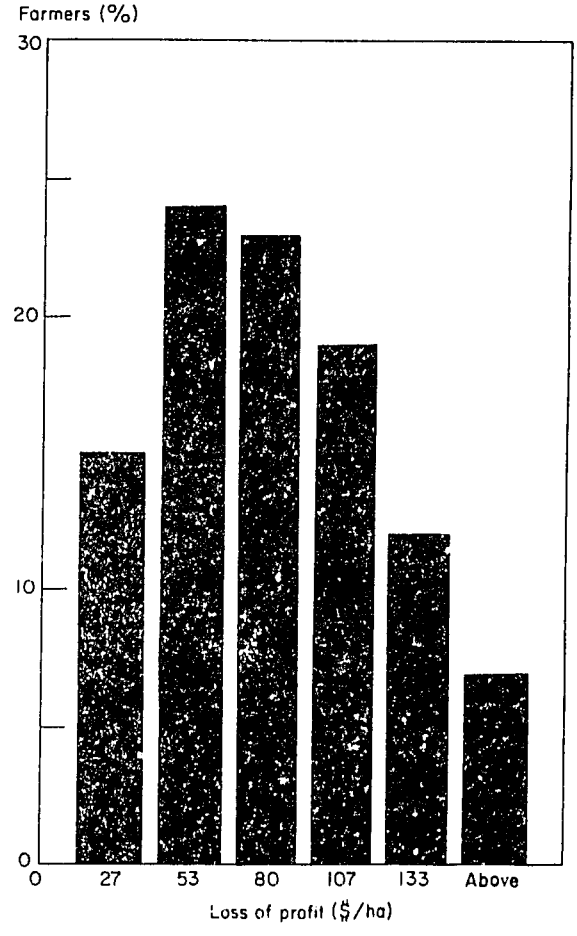
Parameter	Ordinary least squares		Maximum likelihood estimates	
	Coefficient	SE	Coefficient	SE
ln fertilizer price	−0.132	0.048	−0.135	0.038
ln wage rate	− .071	0.021	−0.048	0.017
ln compost	0.011	0.008	0.013	0.006
ln irrigation	0.499	0.087	0.419	0.069
ln family labor	0.047	0.021	0.053	0.021
D_1 saline soils	1.266	0.319	1.226	0.248
ln fertilizer · ln irrigation	0.009	0.006	0.0091	0.005
ln fertilizer · soils	0.071	0.028	0.066	0.024
ln compost · soils	−0.009	0.007	0.011	0.006
ln irrigation · soils	−0.214	0.070	−0.210	0.050
Intercept	4.480	0.417	5.197	0.344
R^2	0.491			
Log-likelihood function	−235.100		−172.054	
σ	0.578	–	0.488	0.035
λ	--		3.523	0.926
σ_u^2	–		0.221	–
σ_v^2	–		0.018	–

Basmati rice production. The mean Basmati rice yield was 1.8 t unhusked rice/ha (range of 0.6-3 t/ha). Thus, there was a gap of more than 1 t/ha between the average and the highest yielding farms, indicating opportunities to increase Basmati yields with current technology.

The ordinary least squares (OLS) and maximum likelihood estimates (MLE) of equation 1 are presented in Table 6 (the OLS estimates are used as starting values for the MLE estimation). The variance ratio parameter λ' (σ_u^2/σ^2) is statistically greater than zero and comparatively large (0.9), given the (0,1) interval within which λ' lies. By inference, variation in actual profit from maximum profit between farms arose mainly from differences in farmer practices, as opposed to random variability.

Farm-specific economic efficiency. The mean economic inefficiency over the sample was 28%. The frequency distribution of farm-specific economic inefficiencies is graphed in Figure 1. Farmers exhibited a wide range of economic inefficiency; the largest inefficiency was 86% less than maximum profit, while the smallest was 5% less than maximum profit. Nearly half (46%) the sampled farmers showed a loss of profit of 25% or less.

Farm-specific economic inefficiency was translated into loss of profit, the product of estimated frontier profit and firm-specific economic inefficiency (Table 7). The mean loss of profit was



1. Loss of profit due to inefficiency. IRRI, 1985.

Table 7. Frequency distribution of loss of profit in Basmati rice production in Gujranwala District, Pakistan, 1982.

Range of loss of profit		Sample farmers (%)
$/ha	Max profit (%)	
0-21	0-12	15
21-51	12-21	24
51-81	21-33	23
81-101	33-44	19
101-131	44-56	12
> 131	>56	7

$74/ha, which represents a 38% loss of profit from the mean frontier profit of $194/ha. The largest farm-specific loss of profit was $209/ha. Fifteen percent of the farmers had a loss of profit of less than $21/ha, 47% were in the range of $21-80/ha, and 38% were losing more than $80/ha. Therefore, there is clear opportunity to improve the economic efficiency of most Basmati rice producers in Gujranwala District.

Economic inefficiency is the sum of technical and price inefficiency. Of the total economic inefficiency of 28%, price inefficiency accounted for 5% on the average and technical inefficiency 23%. Therefore, technical inefficiency is the main source of loss of profit in Basmati rice production.

Determinants of loss of profit. The OLS estimates of the relation between loss of profit and farm-household characteristics are listed in Table 8. Socioeconomic factors accounted for nearly two-thirds of the explained variability in loss of profit. Farm households with more education (measured by proxy as the number of years of schooling of household members associated with farming) exhibited significantly less loss of profit than those with less education. Education was the most important determinant of between-household levels of loss of profit due to economic inefficiency. Farmers who also worked as laborers on other farms showed higher loss of profit than those who hired out less or did not hire out their own labor. This variable was significantly related to tenure: tenants spent more time working as agricultural laborers and, therefore, as a group appeared to be less economically efficient than owner-operators.

Factors associated with the farmers' resource base had a small impact on loss of profit due to economic inefficiency. Biological constraints contributed 27% to the explained variability in loss of profit between farms. Water stress (measured as the number of days after four that a field was without standing water) resulted in a loss of profit of $1.20/ha per day for each day's water stress. Late rice crop establishment (after late June) also resulted in loss of profit. Each day's delay after the optimal date was estimated to reduce profits by $0.40/ha because rice yields decline when the crop matures into the cool, winter season. The late

Table 8. Determinants of loss of profit due to economic inefficiency in Basmati rice production. Gujranwala District, Pakistan, 1982.

Parameter	Estimated coefficient	SE	Contribution to R^2
Socioeconomic			
Education	−37.565	4.341	35
Off-farm employment	182.194	116.197	7
Off-farm agricultural labor	37.774	12.094	15
Credit nonavailability	217.893	101.023	8
Resource base			
Farm size	21.223	16.732	6
Tubewell ownership	−11.657	101.479	1
Tractor ownership	20.311	100.020	1
Biological			
Water stress	17.820	6.098	12
Late crop establishment	5.745	4.083	6
Late fertilizer application	12.618	6.340	9
Intercept	1153.102	147.089	–
R^2	0.469		
F-ratio (n_1 = 10, n_2 = 181)	16.000		
SE of profit loss	525.745		

Table 9. Input use of sample farmers. Camarines Sur, Philippines, 1981-84.

Input	Average value		
	Fertilizer user	Nonuser	*t*-value
Users/nonusers (n = 476) (%)	18	82	
N (kg/ha)	22	–	–
P (kg/ha)	5	–	–
K (kg/ha)	5	–	–
Animal (h/ha)	136	157	1.41ns
Machine (h/ha)	35	27	-1.96*
Total labor (labor days/ha)	70	69	0.12ns
Hired labor (labor days/ha)	42	32	-2.96**
Family labor (labor days/ha)	28	37	3.33**
Pesticides ($/ha)	6.3	3.2	
Insecticides ($/ha)	3.7	2.0	-9.23**
Herbicides ($/ha)	2.6	1.2	-8.19**

application of fertilizer (recommendation was for split application at 25 and 40 d after transplanting) resulted in a loss of profit of $0.87/ha per day for each day's delay.

Fertilizer use in less favorable environments. Widespread adoption of modern varieties (MVs) and crop intensification have occurred in shallow rainfed environments in the Philippines. In many regions like Bicol, for example — where about 85% of the rainfed area is planted to MVs — yields are less than 1.5 t/ha or 60% of the yield of irrigated rices in the same region. One reason for these low yields is the low level of fertilizer adoption and low fertilizer use rates among users.

Table 10. Rice yields of fertilizer users and nonusers by tenure. Camarines Sur, Philippines, 1981-84.

Fertilizer adoption	Rice yield (t/ha)		
	Owner	Tenant	Difference
User	2.6	2.4	0.2ns
Nonuser	2.1	1.9	0.2ns
Difference	0.5*	0.5*	

Benefits of fertilizer use. The mean N rate among rice farmers who applied fertilizer in Bicol was 22 kg/ha (Table 9). Prilled urea was the dominant form. Total labor use was similar between fertilizer users and nonusers. However, users hired more labor and spent nearly twice as much on pesticides.

The mean rice yield was 2.1 t/ha. Among owner-cultivators and tenants, those who applied fertilizer reported significantly higher mean yields than those who did not (Table 10).

Fertilizer users, whether they were owners or tenants, had higher gross incomes than nonusers (Table 11). The cost of current inputs (seed,

Table 11. Yield and income gain of fertilizer users and nonusers by tenure. Camarines Sur, Philippines, 1981-84.

Item	Owner-cultivator		Tenant-cultivator	
	Fertilizer user	Nonuser	Fertilizer user	Nonuser
Revenue				
Gross yield (t/ha)	2.6	2.1	2.4	1.9
Net yield (t/ha)[a]	2.3	1.9	1.4	1.0
Gross value ($/ha)	144.8	118.3	87.5	62.5
Costs ($/ha)				
Current inputs	10.3	2.6	11.1	2.1
Labor	14.1	4.8	17.1	8.9
Power	12.4	12.2	10.7	11.6
Cash costs	36.8	19.6	38.9	22.6
Gross margin ($/ha)	108.0	98.7	48.6	39.9

[a]Net of harvesters' and threshers' shares, and in the case of tenants, owners' shares.

Table 12. Tobit regression coefficients for determinants of adoption and quantity of fertilizer use in rainfed rice.[a] Camarines Sur, Philippines, 1981-84.

Variable and definition	Coefficient	SE	Asymptotic[b] t-values
Constant	- 3.66245	17.09370	-0.21426
Crop establishment method (1 = wet seeded rice)	-21.74606	8.13366	-2.67359**
Landscape position (1 = plateau and bottomlands)	- 0.10936	7.90118	-0.01384
Variety (1 = medium duration variety)	16.64636	10.14868	1.64025+
Tenure status (1 = tenant)	-11.65747	7.13260	-1.63439+
Farm size (ha)	5.28873	2.36726	2.23411*
Education (yr)	1.81478	1.35142	1.34286
Off-farm income ($/yr)	0.00043	0.00102	0.42492
Distance from input source (km)	- 7.08258	1.49884	-4.72537**
σ	49.42166	4.66098	10.60327**

[a]Dependent variable = fertilizer use in kg/ha. n = 476. Log of likelihood ratio statistic = 24.94 at d.f. 8. Correct prediction of users and nonusers = 82.56%. [b]Significant at the 1% (**), 5% (*), and 10% (+) levels.

fertilizer, and pesticide) was substantially higher among users than nonusers, as was that of hired as opposed to family labor (Table 9). As a result, cash costs among users were significantly higher. However, the gains from fertilizer use exceeded the added costs. On the average, farmers who applied fertilizer had higher gross margins, irrespective of tenure, than those who did not.

Fertilizer adoption. The significance of personal, socioeconomic, and biophysical determinants of fertilizer adoption was derived via a tobit regression analysis (Table 12). Factors positively and significantly associated with fertilizer adoption were the planting of early to medium duration MVs (such as IR36 and IR42) and farm size. Factors negatively and significantly associated with fertilizer adoption use were method of crop establishment, tenure status, and distance from farm to input supply point. Distance from the farm to the supply point had the largest impact on fertilizer adoption. This instrument variable reflected a complex of factors such as farm location, difficulty of access to fertilizer delivery, effective fertilizer price, and possibly ease of access to extension services.

MANAGEMENT CONSTRAINTS

Agricultural Economics, Multiple Cropping, and Agronomy Departments

Wet seeding in less favorable environments (*Agricultural Economics*). WSR has spread rapidly in Southeast Asia. This practice, while best adapted to ricelands with good water control, has also been widely adopted in less favorable environments.

We evaluated the adoption of WSR in Bicol, one of the Philippines' largest areas of shallow rainfed rice. Environmental conditions in Bicol are unfavorable. Rice yields are 15% below the national average and 36% below that of Central Luzon, the highest yielding region in the Philippines.

Productivity of wet seeded and transplanted rice. Landscape position was the principal determinant of establishment method, with WSR more common on the plateau and TPR more prevalent on bottomland (Table 13). WSR was also more common in the second season, but this difference was significant only on the plain. The dominant cropping patterns were WSR - WSR on the plateau, TPR - WSR on the plain, and TPR - TPR on flood-prone bottomland.

Table 13. Percentage of farmers adopting WSR by landscape. Camarines Sur, Philippines, 1981-84.

Season	Farmers[a] (%)			x^2
	Plateau	Plain	Bottomland	
First crop	63 (111)	22 (79)	15 (55)	49.4**
Second crop	73 (100)	60 (82)	23 (49)	31.8**
x^2	1.9ns	21.7**	0.6ns	

[a]Numbers in parentheses = sample size.

Total labor input was significantly higher for TPR than for WSR (Table 14). The major difference in labor use was for crop establishment. The important reduction in labor use with WSR was for hired labor, which was half the level of labor for TPR. Most of this reduction was for transplanting, mainly a task for landless laborers. Thus, WSR significantly reduced per-crop demand for hired labor, often drawn from among the poorest households in a community.

About 19 d/ha of animal power were used on the average for land preparation for both TPR and WSR (Table 14). A larger percentage of TPR farmers applied fertilizer, and at higher rates, than did WSR farmers. The trend was similar in herbicide and insecticide use. WSR adopters broadcast significantly higher rates of seed than did TPR growers. WSR farmers, by inference, may face more severe cash constraints than TPR farmers because, while herbicides are purchased in the market, seed tends to be a noncash input drawn from household stocks.

TPR outyielded WSR farms by 0.3-0.6 t/ha on the plateau and plain, but significantly so only on the plateau (Table 15). In bottomlands, mean WSR yields were 0.6 t/ha higher (but not significantly so) in the first season, while TPR yields were significantly higher in the second season.

Table 14. Input use of sample farms, Camarines Sur, Philippines, 1981-84.

Input	Average value		Difference
	WSR adopter	TPR adopter	
Labor, total (d/ha)	54	84	29*
Crop establishment (d/ha)	2	22	20*
Labor source			
Family (d/ha)	22	45	23*
Hired (d/ha)	32	39	7*
Animal (d/ha)	18	20	2ns
Machine (d/ha)	3	4	1ns
Fertilizer users (%)	15	27	12
N level (kg/ha)	17	24	7*
Insecticide users (%)	67	88	21*
Level ($/ha)	2	3	1*
Herbicide users (%)	66	78	12*
Level ($/ha)	1	2	1*
Seed used (kg/ha)	135	104	-31*

Table 15. Rice yields of WSR adopters and nonadopters, Camarines Sur, Philippines, 1981-84.

Item	Rice yield (t/ha)		
	Plateau	Plain	Bottomland
First crop			
WSR adopter	1.5	2.6	3.0
TPR adopter	2.1	2.9	2.4
Difference	0.6*	0.3ns	0.6ns
Second crop			
WSR adopter	1.7	1.9	1.8
TPR adopter	2.1	2.4	2.5
Difference	0.4*	0.5ns	0.7*

The gross value of production for TPR was significantly higher than for WSR on the plateau but not so on the plain or bottomland. Cash costs were significantly higher for TPR across all landscape positions. The savings in cash costs with WSR were due mainly to lower payments to hired labor for crop establishment. TPR yields tended to be higher than WSR yields on the average, but so were costs; therefore, the difference in gross margin between crop establishment methods within landscape position was small ($18/ha or less). However, the rate of return on cash costs was consistently higher for WSR than for TPR.

Adoption of WSR. Factors associated with WSR adoption were analyzed via a multivariate logit model. In addition to landscape and season, varietal duration was a determining factor. Farmers were less likely to establish the shortest duration varieties by wet seeding. Those with access to production credits were more likely to transplant their rice. However, the choice of establishment technique was independent of tenure or farm size.

WSR is a cost-reducing technique that has helped buffer Filipino farmers from declining economic incentives to produce rice. It seems to have been adopted equally by Bicol rainfed rice farmers regardless of tenure or farm size. The technique has possibly helped sustain rainfed rice hectarage in Bicol — particularly on the plain and higher portions of the landscape. For labor displaced from agriculture, off-farm employment opportunities are limited in Bicol. Therefore, the income situation of both poor rice farmers and landless laborers could have worsened without WSR technology.

Production constraints in upland rice (*Multiple Cropping and Agricultural Economics*). IRRI and Philippine scientists have identified improved upland rices that outyield farmers' varieties in research-managed trials, yet acceptance of these cultivars has been modest.

In some areas, as in Mindanao, blast (Bl) is a major constraint to improved variety (IV) adoption. Yet in Batangas, a favorable upland area where Bl is not a problem, and where farmers use advanced management practices (e.g., 40-80 kg N/ha and effective weed control), IVs have not been widely adopted. We seek to understand the factors responsible for this nonadoption of improved upland varieties in favorable conditions before turning to an examination of these issues in more difficult upland areas.

Farmers' production system. To quantify the performance of upland IVs under farmer conditions, we examined the production practices of 60 farmers from 3 municipalities in Batangas: Cuenca, Malvar, and Santo Tomas.

Fertilizer use and mean yield were similar in Cuenca and Malvar, and yields were higher than in Santo Tomas (Table 16); therefore, the first two sites were combined for the following analysis. Farmers in Cuenca and Malvar, on the average, planted 1-2 ha of upland rice by the end of April; those in Santo Tomas planted a similar area by mid-May. The dominant second crop was white maize. Gross farmers' yields over the first 2 sites averaged 1.7 t/ha; in Santo Tomas, which suffered severe drought stress, the mean yield was 1 t/ha less.

Input use and net returns are listed in Table 17. Cuenca-Malvar farmers were divided into two groups: those who used tractors (in combination with bullocks) for the first plowing, and those who used bullocks alone. Tractor users averaged significantly higher yields than nonusers. The largest single production cost was for land preparation and mechanical weeding (>$100/ha), followed by hand weeding (>$60/ha) and fertilizer ($35-46/ha).

Due to severe drought in 1985, rice yields were low. The one group of farmers who covered full costs (cash costs plus opportunity cost on their own resources) were the tractor users in Cuenca-Malvar (Table 17). On a cash cost basis (i.e., assigning zero opportunity cost to owned resources), however, net returns were positive, although small, in Santo Tomas.

Through multiple regression analysis, we examined factors associated with between-farm differences in yield. One significant factor was N rate. However, inadequate specification of drought stress (the dominant determinant of yield in 1985) prevented the estimation of satisfactory statistical relationships. We will apply simulation analysis to approximate soil moisture regimes.

Varietal performance. The performance of 6 IVs or MVs was evaluated against that of local variety Kinandang Patong and the farmers' own variety under farm conditions by superimposing the varietal trials in 14 farmers' fields in Cuenca (5 trials), Malvar (4), and Santo Tomas (5). Planting was simultaneous with farmers' sowing time. Each farmer applied his usual farm practices, such as the rate and timing of fertilizer, *lithao-kalmot* cultivation and weed control operations, hand weeding frequency, and pest control.

Analysis of variance of each experiment showed that data from sites should not be pooled and summarized as a single analysis of variance. Therefore, the comparative performance of the IVs and MVs, using Kinandang Patong as the uniform

Table 16. Mean yields, N fertilizer use, and planting dates of upland rice in Batangas, Philippines, 1985.

Municipality	Sample size (no.)	Rice area (ha)	Yield (t/ha)	N rate (kg/ha)	Planting date	Weeding labor (d/ha)
Cuenca	20	1.1	1.6 a	66 a	25 Apr	41 a
Malvar	20	1.9	1.8 a	73 a	30 Apr	21 b
Santo Tomas	20	1.3	0.7 b	55 a	11 May	31 ab
Mean			1.4	65		31

Table 17. Costs and returns of upland rice production. Batangas, Philippines, 1985 WS.

Item	Cuenca-Malvar		Santo Tomas
	Tractor (n = 23)	Bullock (n = 17)	Bullock (n = 20)
Value of output			
Yield (t/ha)	1946	1378	685
Harvester and threshers' share (kg/ha)	487	344	171
Net yield (kg/ha)	1459	1032	514
Net value ($/ha)	292	206	103
Input cost ($/ha)			
Labor: family	58	65	66
hired	21	6	0
exchange	16	25	9
Tractor: hired	26	0	0
Bullock: owned	61	121	102
hired	2	0	1
exchange	2	2	24
Seed	18	17	19
Fertilizer	48	45	35
Total cash cost ($/ha)	97	51	36
Opportunity cost[a] ($/ha)	4	2	2
Total full cost ($/ha)	101	53	38
Gross margin ($/ha)	252	281	256
Cash cost basis	191	154	65
Full cost basis	40	-75	-153

[a]4% interest for 5 mo.

local check across sites, is given in Table 18. The mean yield over sites was 1.3 t/ha, with a range of 0.5-2.2 t/ha. The IVs and MVs, other than at 3 of 14 locations, were lower in yield or not significantly different from the local checks. Over the 14 sites, the mean yield of the local varieties (1.6 t/ha) was significantly higher than the yield of the IVs as a group (1.2 t/ha), which in turn was higher than the yield of the MVs as a group (0.9 t/ha).

Table 18. Comparative yield performance of upland rice and farmers' varieties. Batangas, Philippines, 1985 WS.

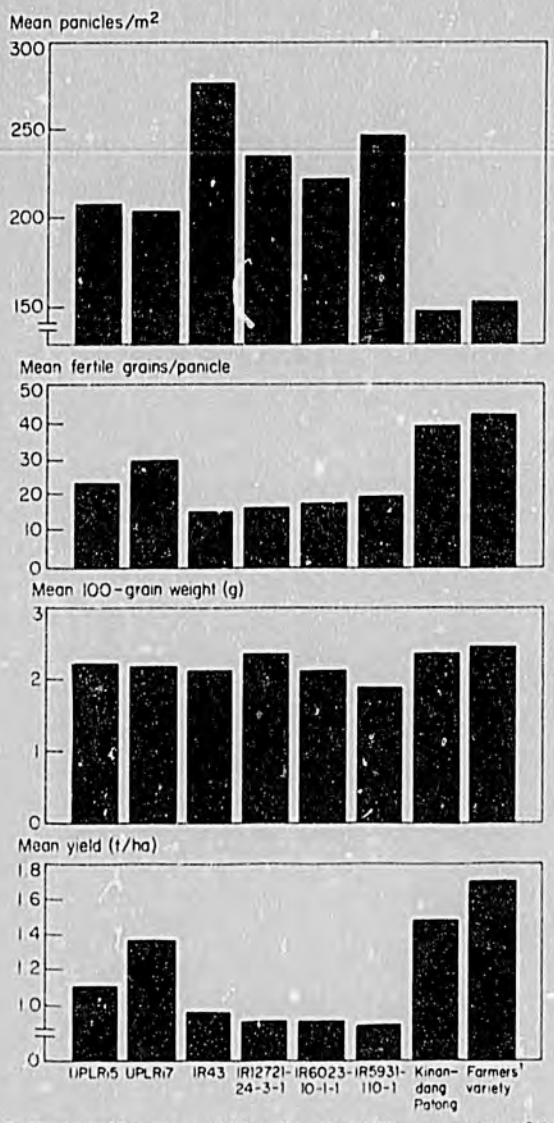
Variety	Sites (no.) where yield compared with check[a] is			Yield[b] (t/ha)
	Lower	Same	Higher	
Improved varieties				
UPLRi5	4	8	2	1.1
UPLRi7	3	11	0	1.3
Modern varieties				
IR43	7	4	3	1.0
IR12721-24-3-1[c]	5	5	0	0.9
IR6023-10-1-1	7	6	1	0.9
IR5931-110-1	5	9	0	0.9
Local checks				
Farmers' variety	0	12	2	1.7
Kinandang Patong	0	14	0	1.5

[a]Means differed significantly from farmers' variety within trials at 14 sites, by DMRT. [b]Mean yield over 14 sites. [c]10 of 14 sites.

Although the IVs and MVs had more (204-266) panicles/m^2 than did the local varieties (150-153), no general yield component advantage resulted because drought caused very high sterility in those entries (Fig. 2). The number of fertile grains per panicle was highly correlated with yield among the IVs and MVs and significantly correlated among the local checks (Table 19). Grain weight was significantly correlated with yield on UPLRi7 and the farmers' variety. Both varieties flowered shortly before a drought period but were subsequently affected by drought stress during the grain filling period.

Soil laboratory tests showed a high fertility level at all sites (Table 20). Effects of the individual chemical properties on yield were not significant because of the overriding influence of drought.

The trial sites were classified into three micro-landforms (Fig. 3). Most upland rice farms in Batangas are plains. An infilled depression was



2. Comparative mean yield and mean yield components of 8 upland rice cultivars across 14 sites. Farmer-managed trials, Batangas, Philippines, 1985 WS.

assumed to have a more favorable hydrological condition than a slope base or a plain, particularly during periods of limited rainfall. The yield from infilled depressions (2.2 t/ha) was relatively higher than from slope bases (1.4 t/ha) and plains (1.0 t/ha) (Table 21). Further verification of microlandform effects under a wider range of rainfall and topographic conditions is needed.

Daily data on soil moisture tension (SMT) were gathered from the 14 sites throughout the growing season using ceramic cup tensiometers placed at 10- and 20-cm depths. Prolonged drought, associated with high average SMT readings, occurred in late May and June (crop establishment) and late July through August (Fig. 4). Several SMT indices were calculated and regressed on the yield of the UPLRi5 check variety (Table 22).

The SMT index T50-30 (mean SMT during the period from 50 to 30 d before harvest) was most consistently highly related to grain yield, suggesting that soil moisture status during flowering was most directly related to yield performance. This parameter alone explained over 95% of yield variation over the 14 trials (Fig. 5).

A soil water balance model was used to estimate daily crop evapotranspiration and the soil water status for upland rice. The model determined daily water use for upland rice crops seeded in April and germinating with the first significant rainfall over a period of 72 yr (1913-85). The probability of drought stress occurrence on each day during the growing season was calculated from long-term simulation data (Fig. 6). When the readily available (100 cb) soil water in the 30-cm root zone was less than 50%, a condition of severe stress was assumed.

The probability of severe or extreme stress

Table 19. Correlation coefficients for yield components and flowering date in relation to grain yield in 8 rice varieties. Batangas, Philippines, 1985.

Variety	Yield component			Flowering date
	Panicles/m²	Fertile grains/panicle	100-grain weight	
UPLRi5	0.65*	0.93**	0.09	0.02ns
UPLRi7	0.11	0.87**	0.66*	-0.91**
IR43	0.65*	0.85**	0.83	-0.05ns
IR12721-24-3-1	0.28	0.97**	0.15	0.60*
IR6023-10-1-1	0.44	0.85**	0.11	-0.16ns
IR5931-110-1	0.60*	0.97**	0.12	-0.80**
Kinandang Patong	0.34	0.74*	0.53	-0.75**
Farmers' variety	0.31	0.76*	0.72*	0.26ns

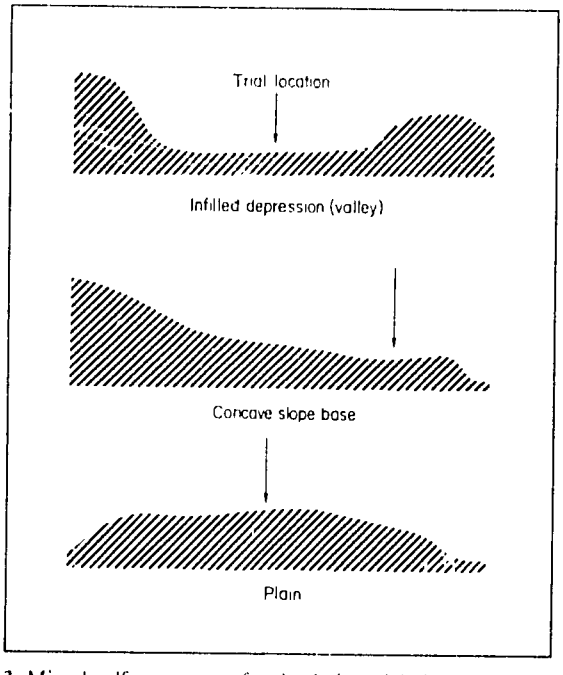
Table 20. Summary of physical and chemical data on upland rice trial sites. Batangas, Philippines, 1985 WS.

Location and site no.	Landform[a]	Surface soil texture (0-20 cm)	pH	CEC (meq/100 g)	N (%)	Olsen's available P (ppm)	Exchangeable K (meq/100 g)
Cuenca							
1	V	Loam	5.5	23.6	0.097	16	2.78
2	P	Loam	5.5	22.4	0.085	8.8	1.43
3	S	Clay	5.3	29.4	0.093	6.3	9.72
4	S	Clay loam	5.1	25.9	0.105	16	1.48
5	S	Loam	5.6	20.4	0.088	12	0.96
Malvar							
6	S	Clay loam	5.7	21.6	0.092	20	0.91
7	P	Clay loam	5.2	21.7	0.098	19	1.54
8	S	Clay loam	5.1	22.0	0.104	31	0.96
9	S	Clay loam	5.5	23.0	0.098	16	1.08
Santo Tomas							
10	S	Loam	5.1	21.7	0.118	25	1.25
11	P	Clay loam	5.2	23.5	0.099	29	1.32
12	S	Clay loam	5.4	21.0	0.090	19	0.96
13	S	Loam	5.6	18.9	0.096	23	0.79
14	S	Clay loam	5.6	23.9	0.107	21	1.02

[a]V = infilled depression (valley), P = plain, S = slope base.

reaches a peak during the last 15 d of August. The flowering period of varieties with 130-d maturity (including most elite improved lines) tends to coincide with this maximum risk period. The prevalent local varieties flower before mid-August.

Drought periods as severe as those observed during August-September occur fairly frequently in Batangas, about 1 in 3-5 yr (Fig. 7). The superior performance of the local varieties compared to that of MVs during this season suggests that two

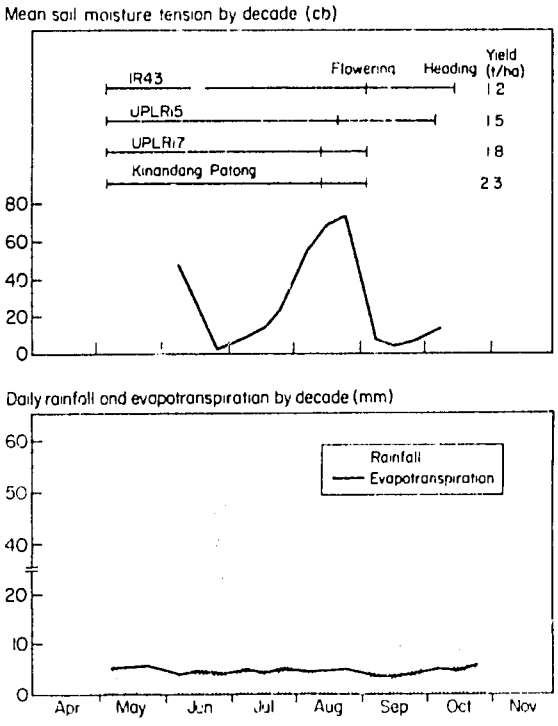


3. Microlandform types of upland rice trial sites. Batangas, Philippines, 1985 WS.

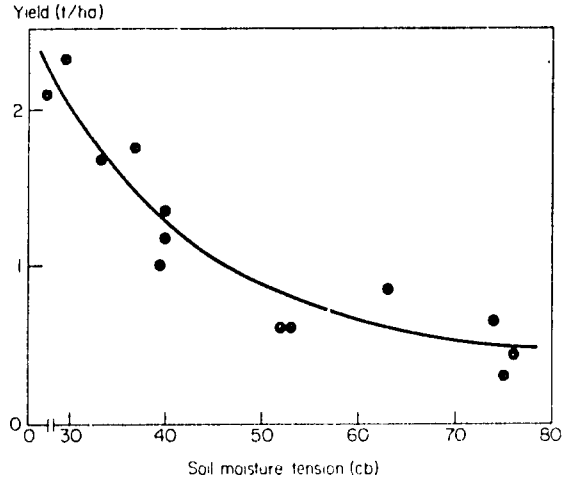
Table 21. Landform type, site distribution, yield, and landform description. Batangas, Philippines, upland rice trials, 1985 WS.

Landform type	Sites (no.)	Mean yield[a] (t/ha)	Remarks
Infilled valley	1	2.2	Remains relatively favorable at the onset of drought because of interflow from surroundings
Slope base	3	1.4 (1.0-1.9)	Temporarily receives runoff and interflow from one elevated side; relatively more favorable moisture condition than in the plain in short periods of drought
Plain	10	1.0 (0.5-1.6)	Depends primarily on direct rainfall; favorable only under uniform rainfall distribution

[a]Range in parentheses.



4. Growing season rainfall, potential evapotranspiration, and soil moisture tension at 10-cm depth. Cuenca, Batangas, Philippines, 1985.



5. UPLRi5 mean yield as related to SMT at 10-cm depth between 50 and 30 d before harvest at 3 sites. Batangas, Philippines, 1985.

matters require more attention in varietal development: 1) the instability of yield in drought years may be a significant constraint to the adoption of currently available MVs, and 2) grain yield of most varieties was higher when flowering occurred earlier (Table 19). MVs that mature no later than local varieties should be considered. Earlier flowering may be required to escape the period in late August when the probability of a dry spell is highest.

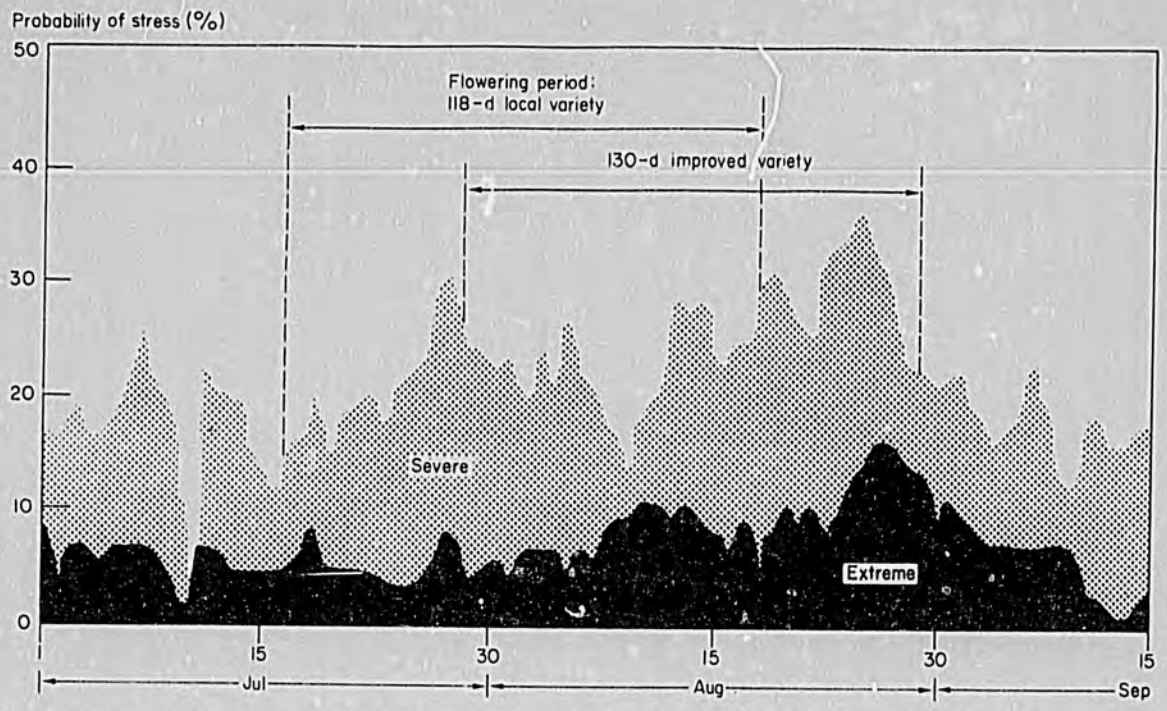
Yield constraints on direct seeded rice (*Agronomy*). *Irrigated sites in dry season.* The yield gap between farmers' and researchers' inputs, and the relative contributions of fertilizer, weed control, and insect control to the yield gap were measured on 12 farms in Nueva Ecija, 6 in Bulacan, and 13 in Camarines Sur, Philippines. Also measured were yield responses to applied N, P, and K, including various forms of N and their application methods.

Soil analyses of test sites are summarized in Table 23. The soil texture of the Nueva Ecija sites varied from loam to clay. Soil pH of the area was ideal for lowland rice, but all sites were deficient in N and Zn. Ten sites were deficient in P and seven in K. The sites in Bulacan were fairly light textured, varying from sandy loam to silty clay loam. Five

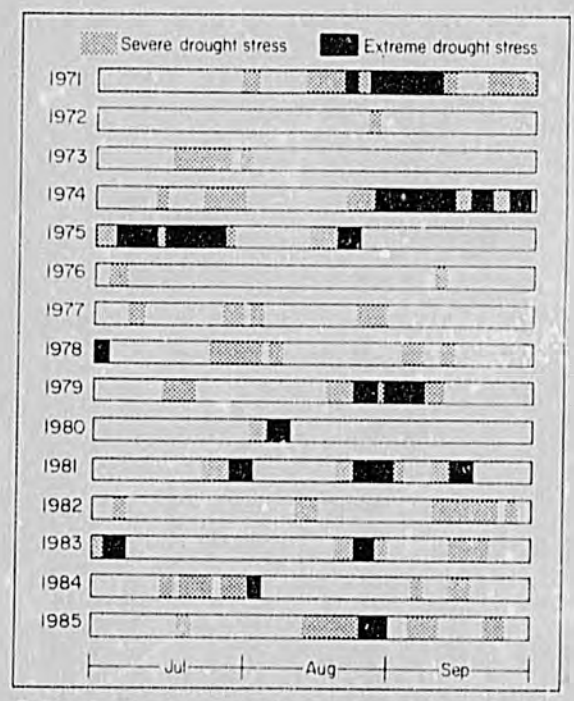
Table 22. Relation between soil moisture tension (SMT) at different growth periods and grain yield of UPLRi5. Farmers' fields, Batangas, Philippines, 1985 WS.

Data set	a	b	SMT index[a]	r^2
Cuenca (5 trials)	3.70	−0.059*	T50-30	0.998
Malvar (4 trials)	3.02	−0.032^{ns}	T50-30	0.840
Santo Tomas (5 trials)	3.37	−0.031*	T60-40	0.940
All (14 trials)	3.388	−0.054*	T50-30	0.980
		−0.022*	T60-40	
		−0.055*	T10	

[a]T50-30 = mean SMT between 50 and 30 d before harvest (DBH), T60-40 = mean SMT between 60 and 40 d DBH, T10 = mean SMT at 10-cm soil depth for entire growing season.



6. Probability of severe or extreme drought stress occurring during the reproductive period of upland rice crop, based on a water balance for Batangas, Philippines, 1913-85. Severe = root zone available water less than 50%, extreme = available water less than 25%.



7. Severe and extreme drought stress estimated by soil water balance for upland rice at mid- to late-growing season using 1971-85 daily weather data from Ambulong, Batangas, Philippines.

were strongly acidic, three N deficient, and two P deficient. P and Zn deficiencies characterized the clay-textured sites in Camarines Sur. The area was generally rich in soil N, but the soil pH of nine sites was below the optimum range, with four sites exhibiting a strongly acidic reaction.

Farmers' N rates in Nueva Ecija averaged 103 kg/ha, higher than the researchers' rate and the rates applied by cooperating farmers in Bulacan and Camarines Sur. Farmers used herbicides to control weeds, and foliar insecticides to control insects. Table 24 summarizes input levels used in the three study areas.

Yields with farmers' inputs from the 31 experimental sites averaged 4.4 t/ha, lower by 1.0 t/ha than the yield obtained with researchers' inputs. Improved fertilizer application accounted for 50% of the yield gap, while improved weed control and insect control each contributed 25%. Among the three factors studied, poor weed control was the major yield constraint of direct seeded rice in Nueva Ecija. In Bulacan and Camarines Sur, low level or inefficient management of fertilizer was the major constraint.

Table 23. Soil characteristics of experimental sites in 3 Philippine provinces, 1985 DS.

Soil property	Range	Mean	Critical limit	Sites (no.) below critical limit
		Nueva Ecija (12 sites)		
pH	5.6 -6.8	6.3	5.5-6.5[a]	4[b]
Organic C (%)	0.8 -1.8	1.2	2.0	12
Total N (%)	0.07-0.14	0.10	0.20	12
Olsen P (mg/kg)	2-6	4	5	10
Exchangeable K (meq/100 g)	0.08-0.2	0.14	0.2	7
Available Zn	0.1 -0.8	0.3	1.0	12
		Bulacan (6 sites)		
pH	4.7 -5.7	5.0	5.5-6.5[a]	5[b]
Organic C (%)	0.8 -2.5	1.6	2.0	4
Total N (%)	0.07-0.19	0.14	0.20	3
Olsen P (mg/kg)	2-5	4	6	2
Exchangeable K (meq/100 g)	0.13-0.44	0.2	0.2	1
Available Zn	0.4 -2.0	1.1	1.0	3
		Camarines Sur (13 sites)		
pH	4.7 -5.9	5.2	5.5-6.5[a]	9[b]
Organic C (%)	1.8 -2.9	2.2	2.0	3
Total N (%)	0.15-0.25	0.18	0.20	0
Olsen P (mg/kg)	1-5	3	5	12
Exchangeable K (meq/100 g)	0.10-0.36	0.2	0.2	4
Available Zn	0.1 -1.1	0.4	1.0	12

[a]Optimum range. [b]Outside optimum range.

Table 24. Input levels in yield constraints experiments on direct seeded, irrigated rice farms in 3 areas in the Philippines, 1985 DS.

Input level	Sites (no.)	Fertilizer (kg/ha)			Weed control[a]		Insect control[b]	
		N	P	K	M	C	F	G
				Nueva Ecija				
Farmers'	12	103	11	7	0.1	1.2	1.5	0
Researchers'	12	87	13	25	0.6	1.0	3.9	2.0
				Bulacan				
Farmers'	6	65	2	3	0	1.2	1.8	0
Researchers'	6	87	13	25	0	2.0	3.0	2.0
				Camarines Sur				
Farmers'	13	52	9	0	0.2	1.0	1.9	0
Researchers'	13	87	13	25	1.0	1.0	3.0	2

[a]Av no. of mechanical (M) weedings by hand and chemical (C) applications. [b]Av no. of foliar (F) sprays (monocrotophos, gusathion, etc.) and granular (G) applications (carbofuran, diazinon, etc.) to floodwater.

In Nueva Ecija, yields from 87-13-25 kg NPK/ha averaged 6.2 t/ha, similar to those from NK and NP (Table 25). Yields without fertilizer and with PK were comparable and significantly lower than that with NPK, indicating that N was limiting. Responses to 13 kg P/ha and 25 kg K/ha were not significant despite the low contents of these nutrients in the majority of the test soils. The critical levels of 0.2 meq K/100 g for K deficiency and 5 mg P/kg for P deficiency may be too high for irrigated rice. All tests soils were Zn deficient, but the crop showed no deficiency symptoms. Perhaps the test varieties were Zn-efficient.

In Bulacan, statistical analyses of individual farms showed no yield response to P or K. However, three of six sites showed a significant

Table 25. Yield responses to N, P, and K on direct seeded irrigated rice farms in 3 study areas in the Philippines, 1985 DS.

Province	Sites (no.)	Yield[a] (t/ha)				
		No fertilizer	PK	NK	NP	NPK
Nueva Ecija	12	4.1 b	4.2 b	6.0 a	5.9 a	6.2 a
Bulacan	6	3.1	3.0	4.3	3.9	4.3
Camarines Sur	13	3.3 b	3.5 b	5.0 a	5.0 a	5.2 a

[a]In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. DMRT for Bulacan is not shown because of farm-to-farm variability. Fertilizer levels: 87 kg N/ha, 13 kg P/ha, and 25 kg K/ha.

response to N. On the average, NPK application yielded 4.3 t/ha, higher by 1.3 t/ha than the yield obtained from PK treatment.

In Camarines Sur, yield levels were lower, but responses to fertilizer applications were similar to those in Nueva Ecija. There was no direct correlation between soil test values and grain yield response to added nutrients. All sites responded significantly to N despite adequate soil N in the area. Response to 13 kg P/ha was not significant even though 12 of 13 sites were P deficient. Similarly, the crop showed no Zn deficiency symptoms even without Zn application.

Drought stress caused low yields on most farms in Bulacan and Camarines Sur. Drought was not observed in Nueva Ecija.

Results of trials on the effect of N source and method of application in the study areas are summarized in Table 26. In Nueva Ecija, the researchers' split-applied prilled urea (PU) (58 kg N/ha) performed better than the farmers' split at 2 of 12 sites. However, the average yield increase of 0.3 t/ha from researchers' split over farmers' at all sites was not significant at both the farmers' and high cultural practices. Yields from deep point placed USG were comparable to those from other application methods.

In Bulacan, the yields of farmers' and researchers' split application of PU under farmers' cultural practices were similar. At high cultural practices, however, the farmers' split produced 4.5 t/ha, while the researchers' split produced 3.9 t/ha. Deep point placed USG produced low yields because of drought stress.

In Camarines Sur, the farmers' split-applied PU yielded lower by 0.3 t/ha than the researchers' split, regardless of cultural practices. At high cultural practices, deep point-placed USG produced 5.0 t/ha, comparable to yields obtained from other application methods.

A separate experiment involving three seeding rates, two weed control levels, and four N levels was conducted on six farms in Nueva Ecija, four in Bulacan, and six in Camarines Sur. Results from the three study areas followed the same pattern. Generally, yield differences among seeding rates

Table 26. Effect of source and method of N application on grain yield of direct seeded, irrigated rice at farmers' (FCP) and high (HCP) levels of cultural practices in 3 study areas in the Philippines, 1985 DS.

N source[a]	Application method	N applied (kg/ha)	Grain yield (t/ha)					
			Nueva Ecija (12 sites)		Bulacan[b] (6 sites)		Camarines Sur (13 sites)	
			FCP	HCP	FCP	HCP	FCP	HCP
–		0	3.6 c	4.2 c	2.7	3.3	3.3 c	3.5 d
PU	Farmers' split[c]	58	5.0 ab	5.5 b	3.5	4.5	4.2 b	4.4 bc
PU	Researchers' split[d]	58	5.3 a	5.8 ab	3.4	3.9	4.5 ab	4.7 b
USG	Deep point placement[e]	58	4.9 ab	5.7 b	3.0	3.9	4.7 a	5.0 ab
SCU	Broadcast and incorporated[f]	58	4.8 b	5.6 b	3.5	4.3	4.8 a	5.0 ab
PU	Researchers' split[d]	87		6.2 a	–	4.3		5.2 a

[a]PU = prilled urea, USG = urea supergranules, SCU = sulfur-coated urea. [b]DMRT for Bulacan is not shown because of farm-to-farm variability. [c]15 d after seeding (DAS) and past panicle initiation (PI) in Nueva Ecija, 17 and 35 DAS in Bulacan, and 15 and 35 DAS in Camarines Sur. [d]Three equal split applications; broadcast and incorporated (B&I) without standing water, at 20-30 DAS, and 5-7 d before panicle initiation (DBPI). [e]Done by inserting USG by hand at 10-12 cm soil depth 3 d before seeding (DBS). [f]As SCU B&I 3 DBS.

(100, 150, and 200 kg/ha) were not significant, regardless of weed management and N level. Optimum yield was obtained at 80 kg N/ha. Results from Nueva Ecija and Camarines Sur also showed that the researchers' weed control (granular butachlor at 1.0 kg ai/ha applied 3 d before seeding) was slightly better than the farmers' method. In Bulacan, farmers' weed control was as efficient as the researchers' method.

Rainfed sites in wet season. The yield gap in WS was determined from eight rainfed, drought-prone farms — two in Nueva Ecija and six in Camarines Sur. Farmers' fertilizer and weed control levels were higher in Nueva Ecija. Yields were generally low at both locations. In Nueva Ecija, a strong typhoon hit the trials at the late reproductive stage. In Camarines Sur, water shortage occurred right after seeding through 30-54 d; average rainfall during that period was only 1.6 mm/d. Across sites, yields with farmers' inputs averaged 2.4 t/ha, lower by 1.3 t/ha than with researchers' inputs. Of the yield gap, the high level of fertilizer accounted for 58%, improved weed control 25%, and improved insect control 17%.

The drought-tolerant lines IR14753-49-2, IR19431-72-2, and IR13146-45-2-3 were tested on drought-prone farms. Farmers in Nueva Ecija grew C1000 and an unknown IR line. In Camarines Sur, most farmers grew IR56. In both areas, the test rices produced generally lower yields than the farmers' varieties. Typhoon damage, rats, and birds contributed to yield losses on test rices, which matured later than the farmers' varieties.

Response of direct seeded, rainfed rice to fertilizer application was determined from one farm in Nueva Ecija and eight in Camarines Sur. In Nueva Ecija, application of 60-13-25 kg NPK/ha produced 3.7 t/ha, comparable to the yields without added P, K, or PK. Yield response to NPK was not significant because of severe lodging due to a typhoon at ripening. Zn (4.5 kg/ha) application also showed no significant response.

In Camarines Sur, NPK treatment produced 2.9 t/ha, comparable to the yield without added K. Without added P, grain yield was significantly lower, indicating that P was limiting. Zn application showed no significant response. Grain yields were generally low because of drought stress at all sites.

On two rainfed farms in Nueva Ecija, response to various methods of applying PU and USG was significant (Table 27). At 29 kg N/ha, deep-placed USG, either by hand or by machine, and PU placed by machine were generally inferior to researchers' split-applied PU. No further yield increase was observed at 58 kg N/ha regardless of N source and application method. The researchers' split outyielded the farmers' split by 0.5 t/ha at 29 kg N/ha

Table 27. Effect of source and method of N application on grain yield of direct seeded rice on rainfed and irrigated farms at high level of cultural practices in 2 study areas in the Philippines, 1985 WS.

N source	Application method	N applied (kg/ha)	Grain yield (t/ha)			
			Rainfed		Irrigated	
			Nueva Ecija (2 sites)	Camarines Sur (5 sites)	Nueva Ecija (1 site)	Camarines Sur (1 site)
–	–	0	3.3 d	2.6 g	3.7 e	3.8 d
PU	Farmers' split[a]	29	3.9 abc	3.1 bcd	4.0 bc	4.4 bc
PU	Researchers' split[b]	29	4.4 a	2.9 def	4.7 ab	3.8 d
PU	Topdressing[c]	29	4.1 ab	2.9 def	4.6 ab	3.8 d
USG	Deep point placement[d]	29	3.8 bc	2.9 def	4.5 abc	4.6 bc
PU	Plunger auger[e]	29	3.8 bc	3.0 def	4.3 bc	4.2 cd
USG	Press wedge[e]	29	3.8 bc	2.8 f	4.4 abc	4.2 cd
PU	Farmers' split[a]	58	4.2 ab	3.1 bcd	4.8 ab	5.2 a
PU	Researchers' split[b]	58	4.4 a	3.1 bcd	5.2 a	4.6 bc
PU	Topdressing[f]	58	4.2 ab	3.3 bc	4.7 ab	4.4 bc
USG	Deep point placement[d]	58	3.6 cd	3.3 bc	4.7 ab	5.0 ab
PU	Researchers' split[b]	87	4.0 abc	3.5 a	4.7 ab	4.9 ab

[a]Commonly used timing of N application by farmers in the study areas during WS: 15 DAS and past PI in Nueva Ecija, 15 and 35 DAS in Camarines Sur. [b]2/3 B&I without standing water (saturated condition) and 1/3 at 5-7 DBPI. [c]Entire amount of N at 5-7 DBPI. [d]10-12 cm soil depth, hand-placed at 3 DBS. [e]Machine placement 3 DBS. [f]1/2 at 20 DAS and 1/2 at 5-7 DBPI.

and by 0.2 t/ha at 58 kg N/ha, but these differences were not significant. Results may not be conclusive because of a typhoon.

On 5 rainfed farms in Camarines Sur, yields from hand point placed USG were comparable to those from other methods of N application, both at 29 and 58 kg N/ha. Yield response at 87 kg N/ha as researchers' split-applied PU was significant. Drought stress caused low yields, and yield differences could not be attributed to treatment effects.

Irrigated sites in wet season. In irrigated areas, the yield gap was determined from one trial each in Nueva Ecija and Camarines Sur. The cooperating farmer in Nueva Ecija applied 73 kg N/ha, higher than the researchers' N rate and that of the farmer in Camarines Sur. Both farmers controlled weeds primarily by herbicides, and insects by foliar insecticides. Combining data, farmers' yields averaged 4.6 t/ha, and researchers' yields 5.2 t/ha. Improved fertilizer application accounted for 67% of the 0.6 t/ha yield gap; the rest was from improved weed control.

Yield performances of IR62 and IR64 were compared with those of farmers' varieties. In Nueva Ecija, the farmer's variety IR60 significantly outyielded IR62 (4.9 vs 4.2 t/ha). In Camarines Sur, the farmer's variety BPI Ri4 also outyielded the test variety IR64 (5.4 vs 4.9 t/ha), but the yield difference was not significant.

On the farm in Nueva Ecija, response to N was not significant except when it was applied together with either K or PK. Zn application gave no further yield increase. Soil analysis of the test site showed deficiency in both N and K. Results from the farm in Camarines Sur were similar to those observed in Nueva Ecija.

In Nueva Ecija, the researchers' split-applied PU yielded highest; however, the yield was not significantly different from that with the other application methods (Table 27). The trial was also hit by a typhoon at ripening. On the farm in Camarines Sur, deep point placed USG at 29 kg N/ha performed better than the researchers' split-applied and topdressed PU. The farmers' split also performed better than the researchers' split and topdressed PU at both low and high N levels. Intermittent irrigation after topdressing the last dose of N at 5-7 d before panicle initiation considerably reduced the yields of researchers' split and topdressed PU.

Yield constraints on transplanted rice (*Agronomy*). *Irrigated sites in dry season.* On 8 farms in Nueva Ecija, yields from researchers' split-applied PU were comparable to those from point placed USG and topdressed PU at both 29 and 58 kg N/ha (Table 28). The farmers' method was inferior to the researchers' method only at 29 kg N/ha, but deep point placed USG was superior to the farmers' method at both N rates. Generally, response to N was significant.

Results from 6 farms in Camarines Sur showed that deep point placed USG was as efficient as researchers' split-applied PU regardless of N level,

Table 28. Effect of source and method of N application on grain yield of transplanted rice at high level of cultural practices in 2 study areas in the Philippines, 1985 DS.

N source	Application method	N applied (kg/ha)	Grain yield (t/ha)	
			Nueva Ecija (8 sites)	Camarines Sur (6 sites)
–	–	0	4.4 f	3.8 e
PU	Farmers' split[a]	29	4.9 e	4.3 d
PU	Researchers' split[b]	29	5.1 cd	4.7 c
PU	Topdressing[c]	29	5.0 de	4.2 d
USG	Deep point placement[d]	29	5.3 abc	4.6 c
PU	Farmers' split[a]	58	5.2 bc	4.8 c
PU	Researchers' split[b]	58	5.4 ab	5.2 b
PU	Topdressing[e]	58	5.3 abc	4.6 c
USG	Deep point placement[d]	58	5.4 ab	5.4 b
PU	Researchers' split[b]	87	5.4 ab	5.8 a

[a]15 DT and past PI in Nueva Ecija, 15 and 35 DT in Camarines Sur. [b]2/3 B&I without standing water (saturated condition) and 1/3 at 5-7 DBPI. [c]Entire amount at 5-7 DBPI. [d]10-12 cm soil depth, hand-placed at 2-4 DT. [e]1/2 at 20 DT and 1/2 at 5-7 DBPI.

as in Nueva Ecija. Both treatments were superior to farmers' split and topdressed PU. Highest yield (5.8 t/ha) was obtained at 87 kg N/ha using researchers' split-applied PU.

Rainfed sites in wet season. The yield gap between farmers' and researchers' inputs was determined from 10 drought-prone and 3 flood-prone farms in Nueva Ecija, and from 3 drought-prone farms in Camarines Sur. All test farms in Nueva Ecija were N deficient, while the farms in Camarines Sur were deficient in P and Zn. The farmers in Nueva Ecija applied higher levels of inputs than the farmers in Camarines Sur. Yields with farmers' inputs at the drought-prone sites in the 2 study areas ranged from 1.3 to 5.3 t/ha, averaging 3.9 t/ha. Researchers' yields ranged from 3.1 to 6.0 t/ha, averaging 5.0 t/ha. Fertilizer contribution to the yield gap of 1.1 t/ha was high, accounting for 47% in each area. Improved weed control contributed 33% and insect control 20%.

In the flood-prone area in Nueva Ecija, farmers' inputs produced an average yield of 4.0 t/ha, lower by 0.5 t/ha than that with researchers' inputs. Improved insect control contributed 80% to the yield gap, and fertilizer accounted for the remainder. Leaffolder and whorl maggot infested two of the three trials in this area.

In Nueva Ecija, the dominant farmers' varieties were BPI Ri10, IR36, and IR58 in the drought-prone area and IR42 in the flood-prone area. The farmers' varieties significantly outyielded the test rices in drought-prone and flood-prone areas (Table 29). The farmers' varieties in Camarines Sur also outyielded the test rices, but the average yield difference was not significant.

Response to fertilizer combinations was measured on 12 farms in Nueva Ecija and 6 in Camarines Sur. In Nueva Ecija, fertilizer response was significant on only eight farms because lodging was severe on four farms. Drought stress affected the trials in Camarines Sur.

Methods of applying PU and USG were evaluated on 11 farms in Nueva Ecija and on 6 in Camarines Sur. In both study areas, neither hand point placement of USG (29 kg N/ha) nor deep placement of USG and PU by machines performed better than the researchers' split application of PU. Compared with the farmers' method, the researchers' split gave an additional yield of at least 0.3 t/ha in Nueva Ecija and 0.5 t/ha in Camarines Sur, regardless of N rate.

Irrigated sites in wet season. In Nueva Ecija, the fertilizer levels of the 4 cooperating farmers averaged 40-10-7 kg NPK/ha. The two farmers' N rate in Camarines Sur was higher than the researchers'. Farmers' yields in Nueva Ecija averaged 3.6 t/ha, lower by 1.2 t/ha than the researchers' yield. The yield gap was due mainly to the effects of fertilizer (67%) and improved insect control (25%). In Camarines Sur, the farmers' average yield of 4.6 t/ha was lower by 0.4 t/ha than the researchers'; fertilizer accounted for 57% of the gap and weed control 43%.

Three of the Nueva Ecija farmers grew IR62. One Camarines Sur farmer grew an unknown variety, and the other used IR64. The test variety

Table 29. Yields of farmers' TPR varieties and test varieties in rainfed and irrigated farms in 2 areas in the Philippines, 1985 WS.

Province	Landscape position	Sites (no.)	Yield (t/ha)		
			Farmers' variety[a]	Test variety[b]	Difference
		Rainfed			
Nueva Ecija	Drought-prone	8	5.3	4.3	−1.0*
Nueva Ecija	Flood-prone	3	4.5	2.8	−1.7*
Camarines Sur	Drought-prone	3	4.1	3.4	−0.7^{ns}
		Irrigated			
Nueva Ecija		4	4.8	5.5	0.7^{ns}
Camarines Sur		2	5.0	5.4	0.4^{ns}

[a]In Nueva Ecija, dominant farmers' varieties were BPI Ri10, IR36, and IR58 on rainfed drought-prone farms, IR42 on rainfed flood-prone farms, and IR62 on irrigated farms. In Camarines Sur, farmers' varieties were IR36, IR56, and an unknown BPI variety on rainfed farms, and IR64 and an unknown variety on irrigated farms. [b]Test varieties on rainfed farms were IR14753-49-2, IR10781-75-3-2-2, and IR13146-45-2-3 for drought-prone, and IR28905-10-1-3, IR26721-135-2-6-1-3, and IR21567-9-2-2-3-1 for flood-prone farms in Nueva Ecija; and IR14753-49-2 and IR19431-72-2 in Camarines Sur. On irrigated farms, the test variety was IR64 in both areas.

(IR64) outyielded the farmers' variety by an average of 0.7 t/ha in Nueva Ecija and by 0.4 t/ha in Camarines Sur (Table 29), but the differences were not significant. However, the yields did not differ significantly.

Results from three trials in Nueva Ecija showed that NK, NP, and NPK applications produced similar yields. N alone yielded 4.1 t/ha; the yield without fertilizer was only 3.2 t/ha. In 2 trials in Camarines Sur, application of N alone gave 4.9 t/ha, while NP and NPK produced similar yields of 5.3 t/ha. Zn application did not increase yield in either area, even though most of the test sites were Zn deficient.

In four trials in Nueva Ecija, yields from various methods of applying PU and USG were low and comparable, regardless of N rate. Severe lodging during ripening at three sites caused substantial yield losses. In five trials in Camarines Sur, yields from various methods of N application were similar to those in Nueva Ecija because of drought stress.

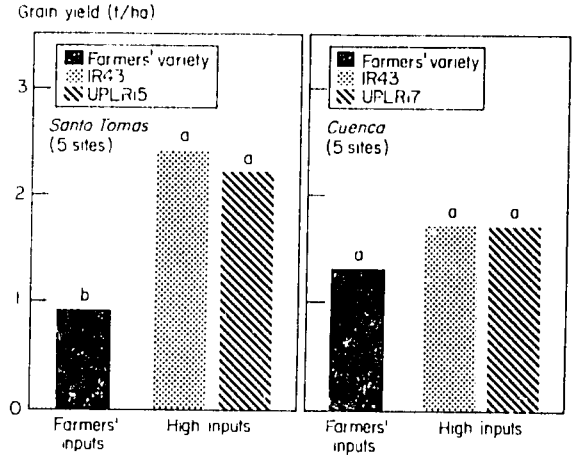
Yield constraints on upland rice (*Agronomy*). WS experiments on five Santo Tomas and five Cuenca farms in Batangas determined the magnitude of the yield gap between farmers' and high inputs and the effects of variety, fertilizer, and weed control and their interactions on grain yield in upland rice. Another experiment on the same farms evaluated five input management packages of fertilizer, weed control, and insect control on farmers' and modern varieties. A separate experiment evaluated the yield response of three varieties to N and P with farmers' and improved weed control methods.

Santo Tomas soils had pH 4.2-5.0, and Cuenca soils pH 4.8-5.4 (Table 30). In most soil characters, Cuenca soils had higher values than Santo Tomas soils.

Santo Tomas farmers' fertilizer rates averaged 83-5-2 kg NPK/ha. Mechanical weed control was done twice with the use of animal-drawn farm implements and twice by hand. Four of five farmers planted traditional upland varieties.

In Cuenca, farmers' fertilizer rates averaged 58 kg N/ha; no farmer applied P or K. Mechanical weed control was done twice with the use of animal-drawn farm implements and once by hand. One of five farmers used herbicide. All farmers planted the traditional upland variety Kinandang Patong.

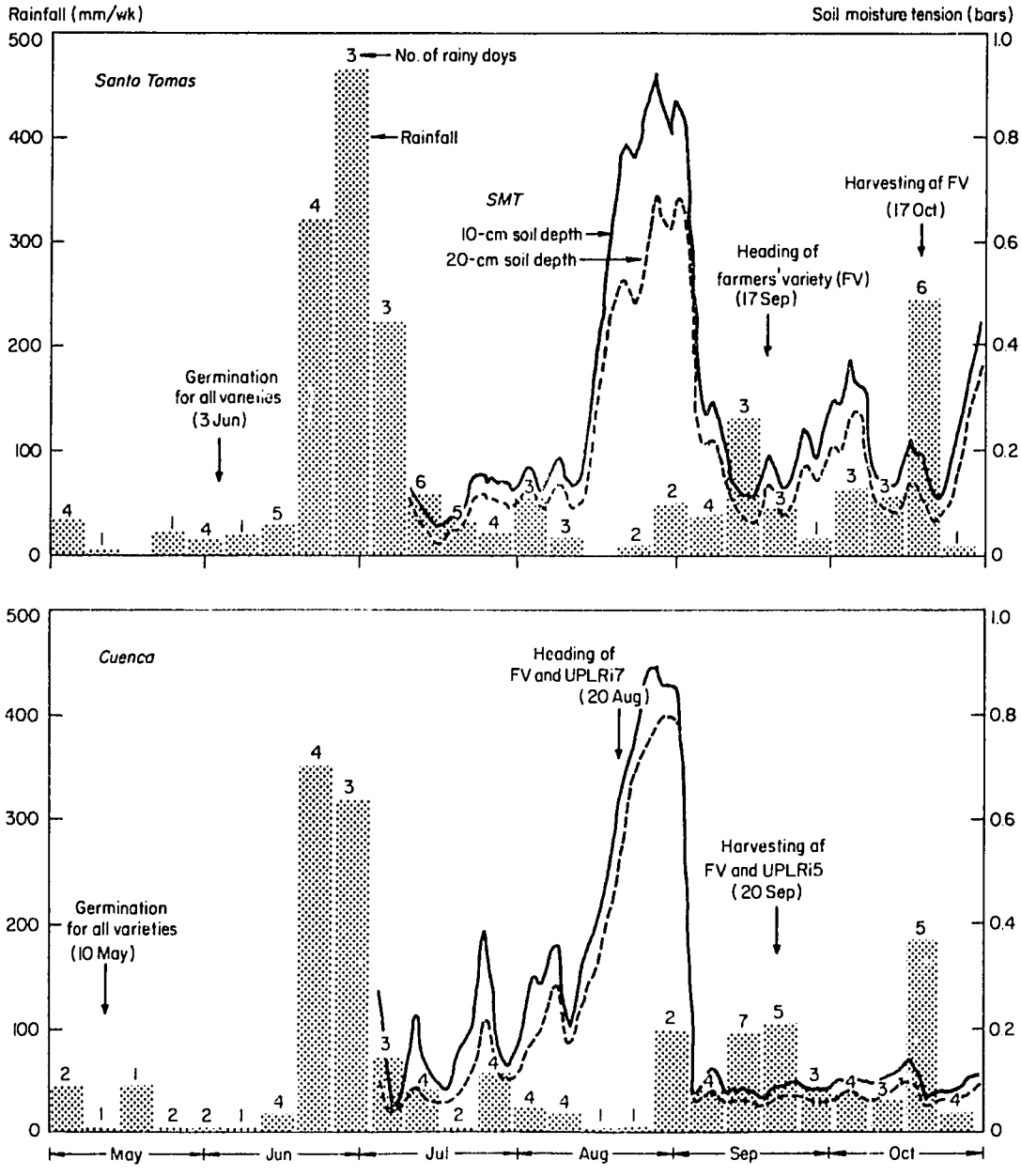
Yields with farmers' inputs averaged 0.9 t/ha in Santo Tomas and 1.3 t/ha in Cuenca (Fig. 8). High inputs significantly increased yields in Santo



8. Average yields of upland rice with farmers' and high inputs. Batangas, Philippines, 1985 WS. Farmers' varieties were Kinandang Patong, Kalibo, and B733C-167-3-2 in Santo Tomas and Kinandang Patong in Cuenca.

Table 30. Properties of 5 Santo Tomas and 5 Cuenca soils where yield constraints experiments in upland rice were conducted. Batangas, Philippines, 1985 WS.

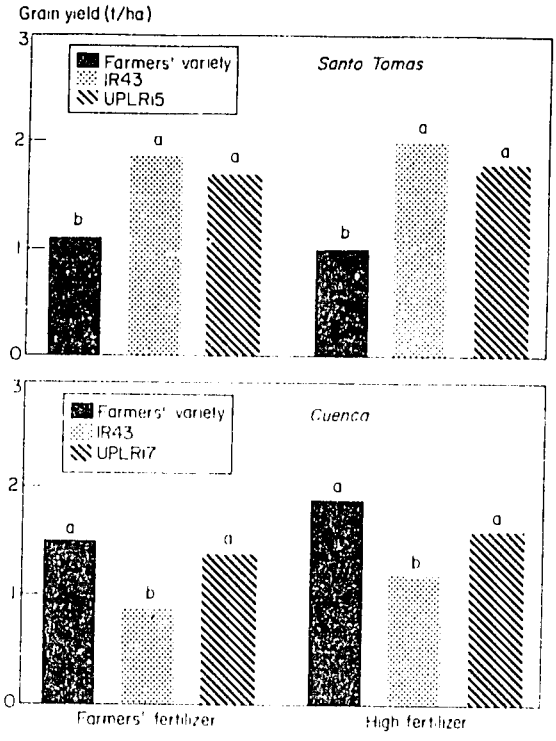
Soil property	Range		Mean	
	Santo Tomas	Cuenca	Santo Tomas	Cuenca
pH	4.2 -5.0	4.8 -5.4	4.7	5.1
Organic C (%)	0.8 -1.0	0.9 -1.4	0.9	1.0
Total N (%)	0.09-0.11	0.09-0.12	0.10	0.10
Exchangeable K (meq/100 g)	0.58-1.50	1.14-1.47	1.00	1.30
Mg	4.7 -5.7	5.4 -6.6	4.9	5.8
Ca	13-16	18-23	14	20
CEC (meq/100 g)	20-27	25-30	22	28
Olsen P (mg/kg)	9-25	3-11	20	8



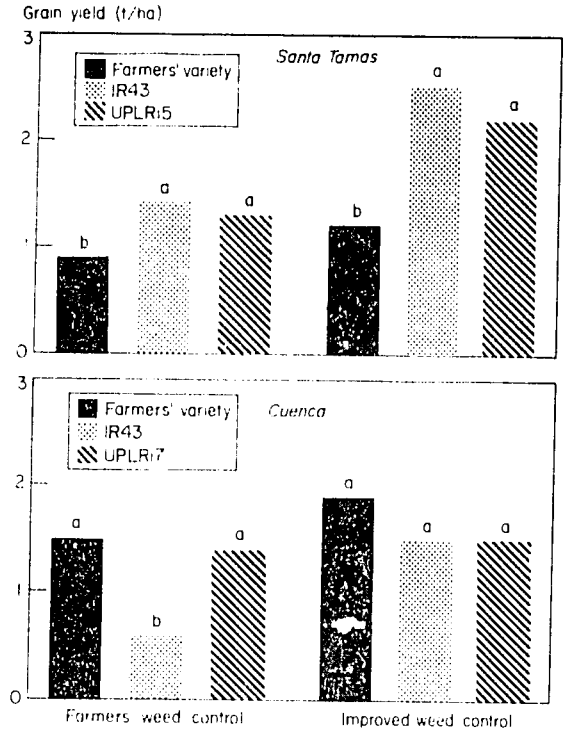
9. Total weekly rainfall and daily (3-point moving) SMT at constraints experiment sites, Batangas, Philippines, 1985 WS.

Tomas despite 92 cb SMT at the late vegetative stage, but not in Cuenca, where SMT reached 89 cb at the reproductive stage, resulting in empty spikelets (Fig. 9). High fertilizer did not increase grain yields because of high farmers' rate in Santo Tomas and moisture stress in Cuenca. Under farmers' and high fertilizer, MVs significantly outyielded farmers' varieties in Santo Tomas (Fig. 10). In Cuenca, moisture stress resulted in lower grain yields of MVs, particularly IR43.

Improved weed control increased yields over farmers' weed control. MVs significantly outyielded farmers' varieties under both weed control methods in Santo Tomas (Fig. 11). With farmers'



10. Effect of farmers' and high fertilizer on upland rice grain yields with farmers' and modern (IR43, UPLRi5, and UPLRi7) varieties. Batangas, Philippines, 1985 WS. Farmers' varieties were Kinandang Patong, Kalibo, and B733C-167-3-2 in Santo Tomas and Kinandang Patong in Cuenca. Av of 2 weed control levels.



11. Effect of farmers' and improved weed control on upland rice grain yields with farmers' and modern (IR43, UPLRi5, and UPLRi7) varieties. Batangas, Philippines, 1985 WS. Farmers' varieties were Kinandang Patong, Kalibo, and B733C-167-3-2 in Santo Tomas and Kinandang Patong in Cuenca. Av of 2 fertilizer levels.

weed control in Cuenca, IR43 produced significantly lower yield; under improved weed control, farmers' varieties and MVs produced similar yields.

Performance of management packages. Another experiment on the same farms showed that no farmers at either location applied insecticides (Table 31). Treatment M_5 gave the highest

Table 31. Farmers' level of inputs and 4 input management packages for upland rice experiments. Batangas, Philippines, 1985 WS.

Location	Sites (no.)	Package level[a]	Fertilizer (kg/ha)			Weed control[b]			Insect control[c]	
			N	P	K	C	M	HW	F	G
Santo Tomas	5	M_1	83	5	2	0	2	1.6	0	0
Cuenca	5	M_1	58	0	0	0.2	1.6	1.2	0	0
Both	10	M_2	20	4	8	0	1	0	1	0
		M_3	40	9	17	0	1	1	2	0
		M_4	60	13	25	1	1	0	3	0
		M_5	80	17	33	1	1	2	4	0

[a]M_1 = farmers' inputs, M_2 = maximization of input efficiency (minimum inputs), M_3 = agronomic optimum with greatest economic return (from agronomist's point of view), M_4 = high yield (may be still profitable), M_5 = maximum yield (flexible practices as needed to duplicate experiment station practices) with no economic consideration. [b]Number of chemical (C), mechanical (M), and hand weedings (HW). [c]Number of foliar (F) and granular (G) applications.

Table 32. Average yields of upland rice with farmers' and modern (IR43, UPLRi5, and UPLRi7) varieties at 5 input management packages in farmers' fields. Batangas, Philippines, 1985 WS.

Package level[a]	Grain yield[b] (t/ha)							
	Santo Tomas (5 sites)				Cuenca (5 sites)			
	Farmers' variety	IR43	UPLRi5	Av	Farmers' variety	IR43	UPLRi7	Av
M_1	0.7	1.3	1.0	1.0	1.5 b	0.4 b	0.8 c	0.9
M_2	0.1	0.1	0.2	0.7	0.2 c	0.1 b	0.2 d	0.2
M_3	0.5	1.1	1.0	0.9	1.5 b	0.2 b	1.2 b	1.0
M_4	0.5	0.7	0.4	0.5	0.5 c	0.1 b	0.6 c	0.4
M_5	1.3	2.5	2.0	1.9	2.4 a	1.1 a	1.8 a	1.8

[a]See footnote to Table 31. [b]DMRT for Santo Tomas is not shown because of farm-to-farm variability. Farmers' varieties were Kalibo, Kinandang Patong, and B733C-167-3-2 in Santo Tomas and Kinandang Patong in Cuenca.

Table 33. Grain yields of upland rice with farmers' and modern (IR43, UPLRi5, and UPLRi7) varieties with 3 N levels.[a] Batangas, Philippines, 1985 WS.

Location	Sites (no.)	Variety	Grain yield (t/ha)			
			40 N	80 N	120 N	Av
Santo Tomas	4	Farmers'[b]	1.1	1.5	1.5	1.4
		IR43	2.1	2.7	2.9	2.6
		UPLRi5[c]	2.3	2.9	3.1	2.8
		UPLRi7[d]	1.1	1.6	1.3	1.3
		Av	1.7	2.2	2.2	
Cuenca	1	Farmers'[b]	1.9	2.4	2.0	2.1
		IR43	1.5	2.0	2.2	1.9
		UPLRi7	1.0	1.1	1.2	1.1
		Av	1.5	1.8	1.8	

[a]Av of 2 weed control levels. [b]Farmers' varieties were Kalibo, UPLRi5, and Kinandang Patong in Santo Tomas and Kinandang Patong in Cuenca. [c]UPLRi5 was planted at 2 sites. [d]UPLRi7 was planted at the 2 other sites.

average grain yield; M_1 and M_3 produced comparable average yields (Table 32). M_2 and M_4 produced low yields because of ineffective weed control.

Response to N and P. A separate experiment on 4 farms in Santo Tomas and 1 farm in Cuenca showed that grain yield with 40 kg N/ha averaged 1.7 and 1.5 t/ha, respectively (Table 33). At 80 kg N/ha, yields averaged 2.2 and 1.8 t/ha, respectively. No increase in yield was obtained with 120 kg N/ha. Application of 40 kg P/ha did not increase grain yield, indicating the test sites were not P deficient.

Consequences of new technology

Agricultural Economics Department

TECHNICAL CHANGE, POLICY, AND EQUITY IN THE INDONESIAN RICE ECONOMY, 1969-83 **346**
The model **346**
Data and estimation procedures **349**
Distribution between producers and consumers **349**
DETERMINANTS OF FERTILIZER USE IN ASIA **350**
The model **350**
Patterns across countries **350**
Regression results **351**
RICE PRODUCTION STABILITY **352**
Changes in rice production **352**
Sources of production changes **352**
Sources of changes in production variability **353**
ENERGY AND RICE PRODUCTION **354**
IMPACT OF MECHANICAL REAPING **356**
IMPACT OF AXIAL-FLOW THRESHER **357**

Indonesia achieved self-sufficiency in rice in the mid-1980s as a result of remarkable production gains over the previous 15 yr. From 1955 to 1967, rice production grew by 1.8%/yr, a rate below that of population growth (Table 1); production increased by 4.7% annually from 1969 to 1983, but imports remained high, averaging 1-2 million t throughout the 1970s. The high growth rates of population (2.3%) and gross domestic product per capita (5.1%) and the relatively high income elasticity of demand for rice (0.35) increased rice consumption per capita from 90 kg in the 1960s to more than 140 kg by 1983. As growth of production accelerated, imports declined to an annual average of 300,000 t by 1980 and ceased altogether in 1985.

Growth in rice production since 1969 has been primarily from intensified use of land. While the average yield stagnated at 2 t/ha in the 1950s and 1960s, it grew at 2.9%/yr from 1969 to 1977 and more rapidly at 5.6% in recent years. Yield increases accounted for nearly 80% of growth in production from 1969 to 1983 as average yields doubled to almost 4 t/ha by 1983. Crop area continued to expand after 1969, initially at 0.5%/yr. Although the rate of crop area expansion (1.4%) after 1977 was equal to that from 1955 to 1967, its contribution to production growth was only 20% compared with 73% in the early period.

Adoption of modern varieties (MVs), increased use of fertilizer, and improvements in irrigation caused yield growth and expansion of the crop area (Fig. 1). Separating the impact of each of these factors is difficult because they are highly complementary. MVs raise profitability of both irrigation and fertilizer, while greater availability and lower cost of irrigation and fertilizer induce higher rates of MV adoption. Progress in yield from 1969 to 1976 was achieved primarily through the BIMAS extension credit program, which introduced MVs nationwide in 1969. Adoption of MVs reached 33% of the planted area by 1974, but serious outbreaks of brown planthopper (BPH) slowed down adoption rates by the mid-1970s. After 1977, dramatic increases in fertilizer use per hectare and irrigation investments accelerated the growth rate of yields and production. With the release of IR36, which is early maturing and resistant to BPH biotype 2, MV adoption gained further momentum.

Table 1. Growth rates of production, area, and rice yield in Indonesia, 1955-82.[a]

Period	Growth rate (%)		
	Production	Area	Yield
1955-67	1.84	1.34 (73)	0.50 (27)
1969-77	3.79	0.86 (23)	2.93 (77)
1977-83	7.02	1.42 (20)	5.60 (80)

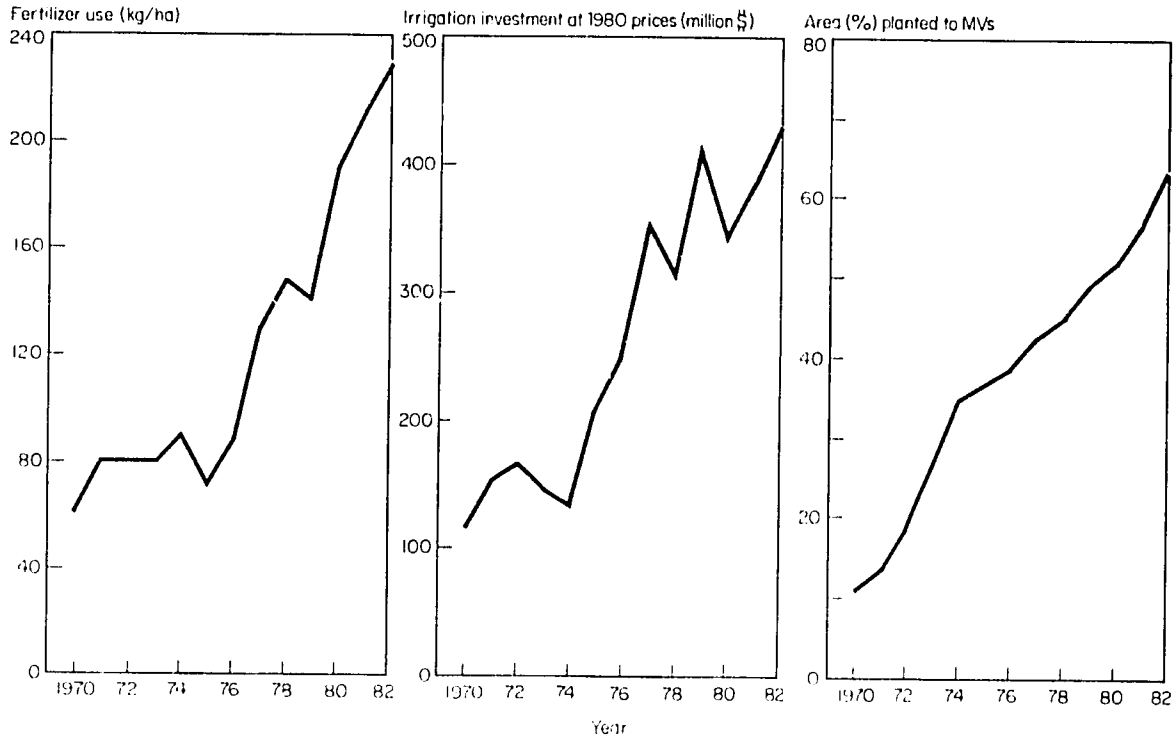
[a]Percentages of production gain attributable to area and yield increases are given in parentheses.

This section analyzes the distributional implications of the modern rice technology for consumers and producers. Attention is drawn to the role of government policies on rice and fertilizer price and irrigation investments, as these have affected not only rice productivity but also the distributional implications of technical change.

The model. The method is based on the supply-demand framework closely following the Hayami and Herdt analysis. This model, which considers the semicommercial orientation of rice farming but assumes a closed economy, is extended to analyze the case of an open economy with government intervention in the product market.

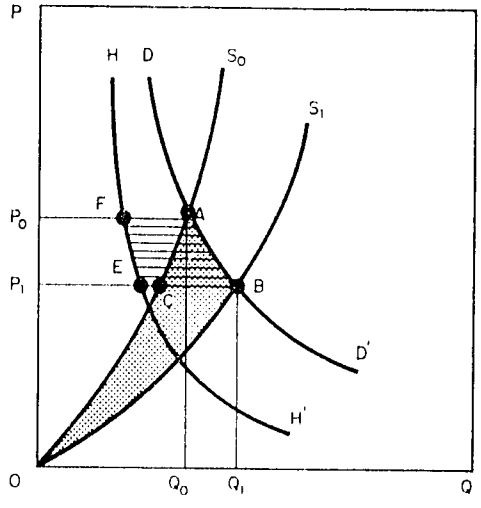
Increases in productivity through adoption of MVs and irrigation investment (i.e., technical change) or through lower input prices reduce the unit cost of output and hence shift the supply function of a commodity rightward (Fig. 2). Assuming perfect competition, the distribution of the benefits from the supply shift between producers and consumers depends on the price elasticities of demand and supply for the commodity, the degree of commercialization of farming, and government trade and pricing policies.

In a closed economy, the producer faces the domestic demand curve (DD'), which is typically inelastic for rice (Fig. 2). A rightward shift in the supply curve from OS_0 to OS_1 as a result of technical change or lower input prices will reduce output price (OP_0 to OP_1) at a more rapid rate than the increase in quantity demanded (OQ_0 to OQ_1) unless government policy fixes the price level.



1. Trends in fertilizer use, irrigation investment, and proportion of area planted to modern varieties (MVs), 1970-82.

Consumers' welfare increases through the consumption of a larger quantity (OQ_1) at a lower price (OP_1). If rice producers are fully commercialized (i.e., they sell all of their output), their income from rice decreases by ($P_0P_1CA - OBC$), and hence consumers become the major beneficiaries of technical change by a welfare gain of (P_0P_1BA). But, in a semicommercial economy where a major proportion of output is consumed directly by rice-producing households (as represented by demand curve HH'), the net benefit to rice producers may be positive, as some of the consumer surplus (P_0P_1EF) is received by producers. Net consumer surplus (henceforth referred to as the consumer surplus) is represented by FEBA.



2. Impact of technical change in a closed economy.

In Indonesia, rice is internationally traded, and hence producers' price depends on the world price and government trade and domestic marketing policy. In a country that is a small trader in the world market, an increase in domestic production that will either substitute for imports or increase exports will not change world prices. When domestic prices do not change with technical change, all benefits accrue to producers in direct proportion to their sales. Domestic prices may decline with technical change if the country initially restricts imports or if it shifts from an importing to an exporting situation as domestic competition shifts the benefits of the trade and natural pro-

tection from producers to consumers in terms of lower prices.

Over the period under study, rice has been an import competing crop and the central focus of government agricultural policy. The changing trends and sources of productivity growth reflect the changing structure of government policy with respect to the balance between the two often conflicting objectives of rice self-sufficiency and low stable prices to consumers.

Rice price policy essentially insulated the domestic rice economy from the turbulent world rice market, as the real price of rice remained about constant between 1969 and 1983. The policy shifted from implicitly taxing producers 20-30% from 1969 to 1976, when world prices were unprecedentedly high, to slightly subsidizing the farm price (5-10%) as world prices declined in the early 1980s.

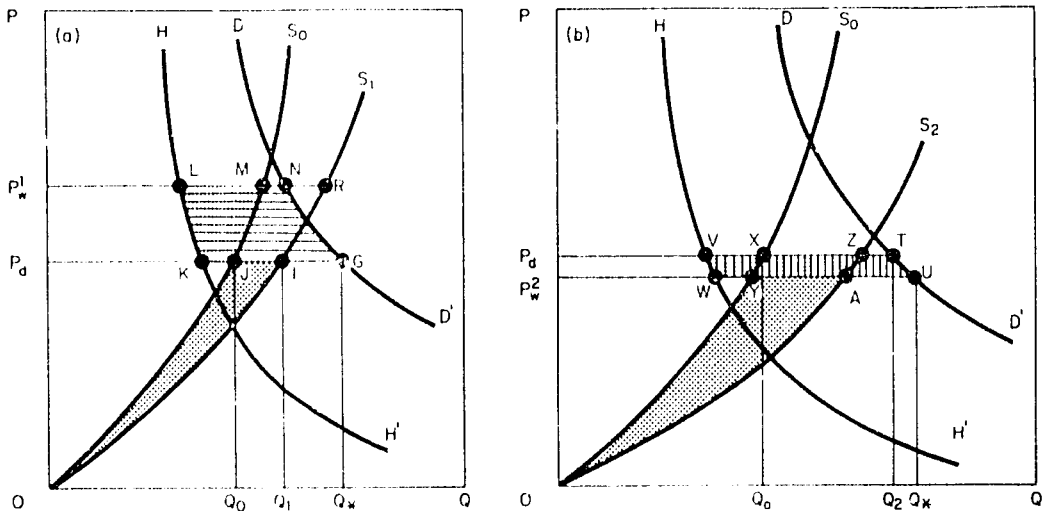
Input subsidies were also provided, and these have been more substantial since 1977. Subsidies on fertilizer reduced the N to paddy price ratio from an average of 3.0 between 1969 and 1976 to 1.5 in recent years. The domestic price of urea was 36% below the world price from 1979 to 1983.

Annual irrigation investments in 1980 prices have averaged $367 million (Rp 627 = US$1 in 1980) since 1977, more than double the investment levels in 1970-76. Government policy noticeably switched from heavily protecting consumers in 1969-76 to heavily assisting rice farmers.

Figure 3 illustrates conceptually the effect of the new technology and of rice pricing policy on producers' and consumers' welfare in those two subperiods.

In the initial period (Fig. 3a), given the supply function before technical change OS_0 and the demand function DD', domestic price P_d is kept much lower than world price P_w by the policy of importing a larger amount JG than the free trade import level MN. Under a semicommercial situation, consumers gain by LKGN, of which LKJM is an income transfer from producers to consumers. A rightward shift in the supply function to OS_1 increases producers' surplus by JOI. There is no increase in consumer surplus, as neither price to producers nor that to consumers changes. The extent to which the net gain JOI due to technical change will offset the producers' loss from pricing policy (LKJM) is an empirical question. By lowering imports, however, the new technology shifts at least part of the government cost of subsidizing consumers to producers. Although price per se does not change as supply shifts under this scenario, the potential producers' gain from technical change is lowered by MJIR because of price policy.

In the later period (Fig. 3b), a higher rate of technical change is depicted, and therefore net benefit to producers is greater. Furthermore, the domestic price is slightly above the world price as the government maintains the real price of rice



3. Impact of technical change and government policy in an open economy.

constant despite a sharp decrease in the world price. Price policy therefore provides producers protection equal to VWAZ, of which XYAZ is also due to technical change. Without the price protection, technical change increases producers' surplus by YOA. Total gain to producers amounts to VWYOAZ. Empirically, VWYX is considered producers' net benefit from price policy; XOZ is producers' gain from technical change. Price policy reduces consumers' surplus by VWUT. Technical change does not directly affect consumer surplus, as rice continues to be import-competing.

Data and estimation procedures. To quantify the changes in producer and consumer surplus due to the new technology and to price policy, the following supply and demand functions were econometrically estimated based on pooled time-series, cross-section data of 23 provinces from 1969 to 1983.

$$Q_s = f(P_r, P_m, P_f, R, IR, MV, Ds)$$
$$Q_d = f(PR, PM, I, N)$$

where Q_s is rice net production, P_r the deflated floor price of rice, P_m the deflated rural price of maize, P_f the deflated rural price of fertilizer, R the annual rainfall, IR the deflated expenditure on irrigation, MV the net proportion of area under MVs, Ds a provincial dummy variable, Q_d the production plus net entry of rice, PR the deflated retail price of rice, PM the deflated retail rice of maize, I the deflated income per capita, and N the population. The equations are specified in log-linear form, and the data were obtained from the Central Bureau of Statistics, Department of Public Works, BULOG, and Department of Communications.

Distribution between producers and consumers. Tables 2 and 3 summarize the changes in consumer and producer surpluses resulting from supply shifts as estimated for each year from 1969 to 1983. Three factors account for the supply shifts: technical change through adoption of MVs, irrigation investments, and fertilizer price subsidy. Two subperiods are distinguished to infer the differential impact of the supply shifts and rice price policies over time.

In the hypothetical case of a closed economy, consumers were the main beneficiaries of supply shifts (Table 2). Considering only the effect of MVs, fully commercialized producers selling all their output at lower prices would have lost $126 million at 1983 prices (Rp 909.30 = US$1) annually in 1969-76 and $273 million annually in 1977-83. In the semicommercial case, which is more relevant to Indonesia, 33% of the annual total social benefit, amounting to $258 million yearly for 1969-76, accrued to producers and over 67% to consumers. After 1976, as the average level of total benefit almost tripled, producers' surplus increased, but consumers still gained relatively more than producers.

In an open economy (Table 3), price policy in 1969-76 clearly provided substantial annual subsidies to consumers worth $817 million at 1983 prices, while producers suffered an annual net loss of $594 million. The producers' benefit from MVs, irrigation investments, and fertilizer price subsidy

Table 2. Average annual changes in consumers' and producers' surplus due to modern varieties, assuming a closed economy.

Item	Change[a] (million $)		Ratio (2/1)
	1969-76 (1)	1977-83 (2)	
Commercial			
Consumers' surplus	384	1006	2.6
Producers' surplus	126	273	2.2
Semicommercial			
Consumers' surplus	173	553	3.2
Producers' surplus	85	180	2.1

[a]At 1983 prices.

Table 3. Average annual changes in consumers' and producers' surplus due to supply shift and price policy in an open economy and with government intervention in semicommercial economy.

Item	Change[a] (million $)	
	1969-76 (1)	1977-83 (2)
Effect of price policy		
Consumers' surplus	817	−214
Producers' surplus	−594	118
Effect of supply shift		
Producers' surplus	415	1336
Modern varieties	143	558
Irrigation investment	19	105
Fertilizer price subsidy	253	673

[a]At 1983 prices.

($415 million) was not sufficient to offset their implicit losses due to price policy during this period. After 1977, producers benefited both from price policy, which held the real domestic price constant as the world price declined, and from a more rapid rate of technical change. While the level of consumers' surplus did not actually change from the previous period, consumers' potential gain from lower world prices ($118 million/yr) was passed on to producers to protect their income. The total supply shift in recent years increased producers' surplus by $1,336 million, representing a fourfold increase from the previous period. The contributions of MVs and irrigation are better viewed as a combined effect because of their strong complementarity. However, the fertilizer price subsidy accounted for about half of the shift of the supply function over the whole period.

DETERMINANTS OF FERTILIZER USE IN ASIA

Increased fertilizer use has accounted for at least a third of the growth in rice yields in South and Southeast Asia since the mid-1960s. Asia registered the highest regional growth rate (10.5%) of fertilizer consumption during the period, almost twice the 5.9% global rate. This section analyzes the factors affecting fertilizer demand in the Asian rice sector in order to address two related questions. First, why have per-hectare application levels remained low in many South and Southeast Asian countries despite the speed with which fertilizer consumption has increased within a relatively short period of time? By the early 1980s, an average of only 30-40 kg of fertilizer nutrients was applied per hectare of cultivated land in South and Southeast Asia — a level less than one-tenth that in East Asia. The rapid diffusion of fertilizer-responsive rice varieties since the 1960s and the sharp increase in fertilizer prices with the two oil price shocks in 1973 and 1981 have had opposing impacts on fertilizer consumption.

The second question is: How have changes in the price of fertilizer relative to that of rice and changes in production technology or fertilizer response functions affected fertilizer demand in Asia?

The model. Demand for fertilizer in rice production is a function of its own price relative to that of rice, the price of substitute inputs, and the factors affecting productivity of fertilizer such as MVs and irrigation. A demand model with the following specification has been estimated in log-linear form.

$$F/ha = f(P_f/P_r, S, MV, IRR, T_i)$$

where

F/ha = fertilizer use on rice in kg NPK/ha,
P_f/P_r = ratio of price of urea N to price of paddy,
S = measure of land density (rice crop area in ha per capita),
MV = percent of rice area planted to MVs,
IRR = percent of rice area irrigated, and
T_i = time.

This demand model was estimated using pooled cross-section, time-series macro data of Asian rice-growing countries for 1960-82. S is included as a proxy variable for price of land, while the time variable is to account for the learning time required in the diffusion process of any new technology.

Patterns across countries. Table 4 shows the average levels of fertilizer use and the values of the variables affecting fertilizer demand among Asian countries from 1980 to 1982. The relative price of fertilizer to rice was negatively correlated with fertilizer use. In Thailand, where fertilizer use was among the lowest, the price of fertilizer was about 400% of paddy price. In Japan, Taiwan, and the Republic of Korea, where fertilizer application exceeded 200 kg/ha, fertilizer price was only about 70% of paddy price. These countries have historically had well developed irrigation systems and have been using fertilizer-responsive varieties since the 1930s, because land is extremely scarce.

The low application of fertilizer in Bangladesh, Burma, and Thailand is consistent with the relatively low proportion of irrigated area and adoption of MVs. The 50% MV adoption in Burma was achieved only in recent years with the launching of a strong production program. Thailand and Burma continue to be competitive in the world rice market mainly because of relatively abundant land resources. Although Bangladesh has a relatively high rice area per capita, it has perhaps the harshest environment for agriculture.

Fertilizer use per hectare in the Philippines, India, and Pakistan ranged from 30 to 70 kg NPK/ha and their fertilizer to rice price ratios from 3.0 to 3.8. Pakistan and India had low rice area per capita, but wheat was also an important staple.

Table 4. Patterns of fertilizer use on rice, fertilizer to paddy price ratio, rice crop area per capita, adoption of MVs, and percent irrigated area across Asian rice economies, 1980-82.

Country	NPK (kg/ha)	Fertilizer: paddy price	Rice area (ha) per capita	MV (%)	Irrigation (%)
Bangladesh	13	2.17	0.12	23	13[a]
Thailand	21	4.27	0.19	12	28[a]
Burma	22	1.81	0.13	51	18[a]
Philippines	32	3.81	0.07	81	50
India	53	3.63[a]	0.06	47	43[c]
Pakistan	69	3.02	0.02	44	100
Malaysia	87	1.31	0.05	44[b]	76[a]
Sri Lanka	96	2.14[a]	0.05	88	62[a]
Indonesia	112	1.33	0.06	71	78
Korea, Republic of	244	0.72	0.03	100	100
Taiwan, China	276	0.96[b]	0.04	100	100
Japan	356	0.71[b]	0.02	100	100

[a]Based on 1981. [b]Based on 1980. [c]Based on 1978.

Despite its highest rate of MV adoption, the Philippines had the lowest fertilizer application in this group because of the unfavorable price ratio. Rice areas in Pakistan were all irrigated, and with a fertilizer to rice price ratio of 3.0, fertilizer use was nearly 70 kg/ha. India also had one of the most unfavorable price ratios in Asia, but in the northern and southern regions, where the proportion of irrigated area and adoption of MVs ranged from 80 to 100%, fertilizer use was 60-70 kg NPK/ha. In eastern India, however, where the environment is not suited to the new fertilizer-responsive rice varieties, fertilizer application was relatively low.

Malaysia, Sri Lanka, and Indonesia had the highest rate of fertilizer application per hectare among South and Southeast Asian countries and relatively small rice areas per capita. Substantial fertilizer price subsidies resulted in low fertilizer to rice price ratios. The proportion of irrigated area and adoption of MVs were relatively high.

Regression results. The regression results of the fertilizer demand model are presented in Table 5. The R^2's from equations 2 to 5 are remarkably high, even without the inclusion of the time variable. Except for the fertilizer price when specified separately from rice price, all the t values are statistically significant. All the coefficients have the expected signs.

The substantial increase in the R^2's from 0.16 to 0.71 as the percent of MVs and irrigated area are added, and their high t values demonstrate the

Table 5. Factors affecting fertilizer use (kg NPK/ha) in the rice sector of 12 Asian countries, 1960-81.[a]

Factor	1	2	3	4	5
Price ratio	−0.989 (−6.299)	−0.284 (−2.826)	−0.211 (−2.004)	−0.189 (−1.804)	–
Price N		–	–	–	−0.0274 (−0.341)
Price paddy		–	–	–	0.3377 (4.361)
Percentage of MV		0.010 (13.130)	0.010 (12.846)	0.010 (11.682)	0.0077 (10.522)
Percentage of irrigated area		0.009 (8.817)	0.004 (1.729)	0.004 (1.609)	0.0066 (7.533)
Rice area per capita		–	−0.550 (−2.105)	−0.606 (2.333)	
Time		–	–	0.010 (2.268)	
Intercept	0.055	0.005	0.002	0.027	0.005
R^2	0.158	0.708	0.712	0.718	0.798

[a]Figures in parentheses are t-values.

relative importance of shifts in fertilizer response functions in explaining the differences in fertilizer use over time and across countries in Asia. The estimate of price elasticity (specified as ratio of price of fertilizer to that of paddy) remains statistically significant in each equation. As expected, demand is more price elastic in the long run (-1.0) than in the short run (-0.2), when farmers operate on a fixed fertilizer response curve. The separate specification of price (equation 5) indicates that fertilizer demand is more price elastic with respect to changes in rice price than with changes in N price. Indeed the t value for the price of N was not statistically significant.

The negative and significant coefficient of the measure of land constraint (rice area per capita) implies that as land becomes more scarce, fertilizer demand per hectare increases. While time is a significant variable, it did not substantially raise the R^2 nor affect the coefficient of the other variables. An equation estimated with dummy variables for country did not add to the explanatory power. Intercountry differences in omitted variables either are not so important or are highly correlated with the included variables.

RICE PRODUCTION STABILITY

It is unclear whether modern technology has increased or decreased rice production variability. Therefore, in collaboration with the International Food Policy Research Institute (IFPRI), we initiated studies on the impact of modern rice technology on production stability. Here we report our initial study of rice production stability in the Philippines. The decomposition analysis developed by IFPRI was used; stability in Philippine rice production in the period preceding the advent of MVs is compared with that in the period following their release.

Changes in rice production. Philippine rice production increased by 3.2 million t/yr (93%) from the first to the second period (Table 6). Most of this increase was due to a 56% increase in mean yield as opposed to an area effect. The CVs of average production, area, and yield were less in the second than in the first period. Variances were not significantly higher in the second period. Therefore, there is no strong evidence that modern rice technology has led to increased rice production instability in the Philippines.

Mindanao recorded the greatest absolute increase in total rice production (Table 7), where area increased by over 60% and yield by over 50%. The second largest increase was in Central Luzon, the "rice bowl" of the Philippines, where substantial increase in mean yield was associated with a small increase in mean area. The smallest absolute gain in total production occurred in Ilocos.

In Central Luzon the relative variability, as measured by the coefficient of variation, increased in the second period. This region has the highest rate of MV adoption and irrigated area (both in absolute and relative terms) in the Philippines. It is also one of the most typhoon-prone regions of the country, and dry season irrigation in recent years (eg., 1982, 1983) was substantially reduced due to inadequate water supply. Thus, while MV yields have increased with improved agronomic practices (e.g., with irrigation and increased fertilizer use), potential losses are larger if typhoons occur or when there is failure in the input delivery system.

Sources of production changes. The changes in average production between periods reported in

Table 6. Changes in the mean values and variability in rice production, area, and yield in the periods before (1948-68) and after (1969-83) MV adoption in the Philippines.

Item	Mean values			Coefficient of variation			F-ratio[a]
	Pre-MV	Post-MV	Change (%)	Pre-MV	Post-MV	Change (%)	
Average production (million t/yr)	3.4	6.6	93	6.7	6.4	−55	3.39^{ns}
Average area harvested (million t)	2.8	3.5	23	5.4	4.0	−26	0.84^{ns}
Average yield (t/ha)	1.2	1.9	56	4.4	4.0	− 9	2.08^{ns}

[a]Calculated as the ratio of variances of mean values to detect whether variances between periods differed significantly one from another.

Table 7. Changes in the mean and variability of rice production by region in the Philippines. First period = 1948-68, second period = 1969-83.

Region	Average production				Coefficient of variation (%)			F-ratio
	Pre-MV (t)	Post-MV (t)	Change		Pre-MV	Post MV	Change	
			t	%				
Ilocos	145,501	281,165	135,664	93.2	18.7	14.7	−21.4	2.32^{ns}
Cagayan	340,814	750,583	309,769	120.2	18.7	13.8	−26.2	2.63^{ns}
Central Luzon	941,333	1,486,168	554,835	57.9	8.9	10.3	15.7	3.34^{ns}
Southern Tagalog	402,270	767,347	365,077	90.7	10.1	7.5	−25.7	2.00^{ns}
Bicol	283,202	596,254	313,052	110.5	13.9	11.6	−16.5	3.04^{ns}
Visayas	741,804	1,236,945	495,141	66.7	16.1	11.8	−26.7	1.48^{ns}
Mindanao	584,195	1,441,389	857,194	46.7	22.2	14.0	−36.9	2.41^{ns}
Philippines	3,410,260	6,565,717	3,156,457	92.5	6.7	6.4	− 4.5	3.39^{ns}

Table 7, E(Q), may be broken down into four sources:

$$E(Q) = \bar{A}_1 \Delta \bar{Y} + \Delta \bar{A} \Delta \bar{Y}_1 + \Delta \bar{A} \Delta \bar{Y} + \Delta Cov(A, Y) \quad (1)$$

where

$\bar{A}_1$ is the mean area in the first period and $\Delta \bar{A}$ is the change in mean area from the first to the second period,

$\bar{Y}_1$ is the mean yield in the first period and $\Delta \bar{Y}$ is the change in mean yield from the first to the second period, and

$\Delta Cov(A, Y)$ is the change in area-yield covariances between periods.

These components of change in average Philippine rice production are listed in Table 8. Nationally, production changes were dominated by changes in mean yield. The area effect was due mainly to intensification as opposed to area expansion. Changes in harvested area varied considerably between regions. The increase in cropping intensity is attributed to irrigation expansion and shorter-duration MVs, coupled with techniques of early crop establishment that allowed two rice crops to be grown in rainfed areas in the wet season, where previously only one was possible.

Sources of changes in production variability. Changes in production variance may be partitioned into two broad components: 1) the sum of production variances within regions, and 2) the sum of interregional production covariances. Notationally,

$$V(Q) = \sum_i V(A_i Y_i) + \sum_i \neq \sum_j Cov(A_i Y_i, A_j Y_j) \quad (2)$$

where

V(Q) is total production variance;

A_i, A_j denote area planted in region i and region j, respectively; and

Y_i, Y_j denote yield in region i and region j, respectively.

Table 8. Components of change in average Philippine rice production, 1948-68 to 1969-83.

Region	Change (%) in				Contribution (%) to change in average production
	Mean yield $\Delta \bar{Y}$	Mean area $\Delta \bar{A}$	Area-yield covariance $\Delta Cov(A, Y)$	Interaction term $\Delta \bar{A} \Delta \bar{Y}$	
Ilocos	54.4	30.6	−0.6	15.6	4.35
Cagayan	37.0	40.2	0.9	19.2	13.14
Central Luzon	84.6	10.8	−0.6	5.2	17.45
Southern Tagalog	62.8	23.6	0.1	13.4	11.70
Bicol	69.0	17.9	−0.6	13.7	10.03
Visayas	89.1	6.6	0.3	3.9	15.87
Mindanao	36.4	41.4	0.3	22.0	27.47
Philippines	60.7	25.5	0.1	13.7	100.0

Each of the two terms in equation 2 can be attributed to a number of sources, which are identified as the columns in Table 9. Nationally, the increase in rice production variance in the Philippines from the first to the second period was equally attributed to increases in production variances within regions and to increased production covariances between regions. Specifically, within-region increases in production variances accounted for 49.7% of the increase in the total production variance between the 2 periods. Two regions, Mindanao (20%) and Central Luzon (14%), accounted for two-thirds of the within-region increases in variance.

About 40% of the change in variance in Philippine rice production was attributed to changes in mean yields within regions (Table 9) and much of this increase came from changes in yields in the Visayas, Mindanao, and Central Luzon. About 15% of the increase in total variance was derived from changes in mean area, largely due to area changes in Mindanao. Another 21% of the increase in variance in total production was due to changes in the variance and covariance of yields. Changes in yield variance within regions accounted for most of this, with changes in yield variance and covariance in Central Luzon dominating this effect. Finally, changes in area-yield covariance accounted for 24% of the increase in total production variance, with most of this change due to changes in interregional covariance.

ENERGY AND RICE PRODUCTION

The cost of energy embodied in purchased inputs has declined steadily since 1982. To examine the quantity and composition of energy used in rice production, a series of energy budgets was constructed for 21 systems ranging from upland slash-and-burn techniques used in Latin America to input-intensive irrigated systems in Asia (Table 10). The concept of the energy efficiency ratio is expressed in the following equation:

$$\text{Efficiency ratio} = O_i / I_i$$

where

O_i = output energy = $\sum_{j=1}^{m} E_j Y_j$

I_i = input energy = $\sum_{k=1}^{m} E_k X_k$ and

E_j = unit energy of output Y_j

E_k = unit energy of input X_k.

Graphing efficiency against yield (Fig. 4) gives an inverse relationship, illustrating the relative superiority of upland and rainfed systems to irrigated systems in the use of input energy.

The energy efficiency criterion is, however, only a partial measure and is misleading as an indicator for the allocation of investment or research resources. The energy efficiency ratio analysis provides no insights into the support capacity of individual systems. The Latin American upland system supports only five individuals per year on each hectare of cultivated land. A single cropped

Table 9. Disaggregation of the components of change in the variance of rice production in the Philippines, 1948-68 to 1969-83.

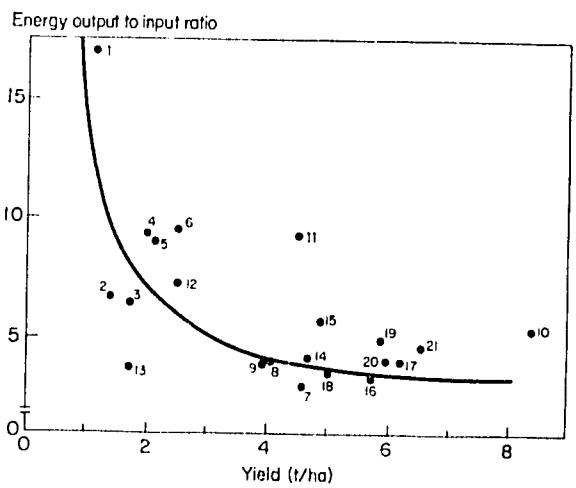
Item	Change (%) in							Row sums
	Mean yield	Mean area	Yield variance and covariance	Area variance and covariance	Area-yield covariance	Interaction term[a]	Residual	
Regional variance								
Ilocos	0.31	0.22	0.22	0.16	-0.20	0.19	-0.09	0.81
Cagayan	3.68	0.95	-0.58	-0.83	2.10	0.68	-0.45	5.55
Central Luzon	7.44	0.07	18.59	-3.05	-5.33	-4.63	0.59	13.68
Southern Luzon	1.54	0.26	0.45	-0.62	0.27	-0.54	0.03	1.39
Bicol	1.12	0.28	2.26	0.08	-0.88	0.23	-0.42	2.67
Visayas	15.83	0.19	3.47	-7.14	2.09	-9.34	0.62	5.72
Mindanao	10.46	12.79	-4.52	2.11	2.21	-2.30	-0.82	19.93
Sum of regional variances	40.41	14.78	19.89	-9.30	0.25	-15.77	-0.53	49.74
Interregional covariance	-1.43	9.30	1.41	1.39	23.99	19.47	-3.88	50.25
Column sum	38.98	24.08	21.30	-7.91	24.25	3.71	-4.41	100.00

[a]Aggregate of the 5 interaction terms identified in the text.

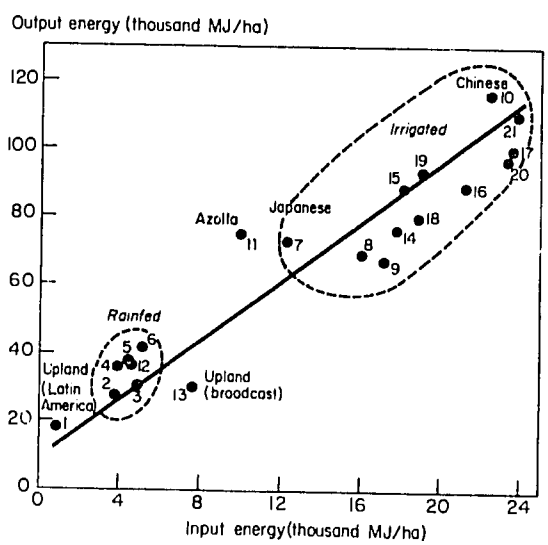
Table 10. Total energy embodied in inputs, and yields for rice production systems. 1985.

No.	System	Energy (MJ)		
		Inputs	Brown rice output[a]	Efficiency ratio
1.	Upland Latin America	1,087	18,995	17.46
2.	Rainfed unfavorable	3,640	23,748	6.52
3.	Rainfed favorable	4,416	28,497	6.45
4.	Rainfed unfavorable	3,991	33,246	8.33
5.	Rainfed favorable	4,343	34,828	8.02
6.	Rainfed favorable	4,899	41,163	8.40
7.	Irrigated, Japan	22,682	72,037	3.18
8.	Irrigated, Laguna	16,179	64,912	4.01
9.	Irrigated rice garden	16,866	63,330	3.75
10.	Irrigated organic, Chinese	22,405	118,560	5.29
11.	Irrigated azolla	9,933	72,828	7.33
12.	Deep water low input	4,528	33,345	7.36
13.	Upland broadcast	7,882	30,079	3.82
14.	Irrigated Philippine dry season (DS)	17,518	74,410	4.25
15.	Irrigated Philippine DS	17,974	88,661	4.93
16.	Irrigated Philippine DS	21,392	90,242	3.89
17.	Irrigated Philippine DS	23,592	98,158	4.16
18.	Irrigated Philippine DS	18,384	79,163	4.31
19.	Irrigated Philippine DS	18,845	93,325	4.96
20.	Irrigated Philippine DS	23,330	94,995	4.07
21.	Irrigated Philippine DS	23,707	107,661	4.54

[a]Brown rice specified as 78% by weight of the yield of paddy rice.



4. Energy efficiency vs yield for 21 rice production systems.



5. Energy efficiency of 21 rice production systems.

irrigated production system in Asia is capable of supporting 20 persons.

The relationship between input energy and yield is shown in Figure 5. The marginal productivity of energy remains relatively constant — moving from low input, low capacity systems to high input, high capacity systems. Across all systems, the incremental output to input energy ratio remains nearly constant at between four and five output units per unit of input energy.

A major limitation in utilizing energy budgets as a guide in resource allocation is the absence of monetary values attached to individual energy components. Farmers' decisions to use inputs

depend on costs and not on the quantities of energy embodied in them. Components of the energy budgets comprising each production system are heterogeneous, being composed largely of human and animal labor in traditional systems and of chemical fertilizers and pesticides in modern systems. In addition, the energy components of individual systems generally have a low degree of substitutability.

As illustrated by the use of azolla in system 11 and the use of organic fertilizers in system 10, there is considerable scope for raising the technical efficiency of high yielding production systems. Innovations to increase fertilizer and water use efficiency, reduce pesticide requirements, and reduce grain losses would improve the energy efficiency ratio. The degree to which such innovations are adopted would, however, be conditioned by economic viability as well as technical efficiency.

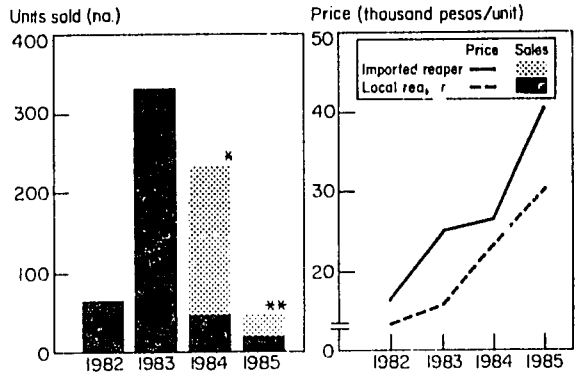
IMPACT OF MECHANICAL REAPING

IRRI collaborated with the Chinese Academy for Agricultural Mechanization Sciences on a 1.0-m power tiller-mounted reaper. In 1982, the reaper was introduced to Philippine farmers. Many local manufacturers produced prototypes, and by 1984 over 400 reapers had been sold by 27 manufacturers, primarily in Bataan Province. Paralleling development of the reaper in the Philippines, a design embodying similar performance specifications was manufactured in Japan and exported to the Philippines. Nearly 200 of these units were sold in 1982-84 (Fig. 6).

Declining rural wages and rice prices combined with inflation and rising interest rates and a fall in the foreign exchange rate effectively halted sales of the reaper in 1984.

In 1984-85, a survey in Bataan evaluated the adoption pattern of the reaper and assessed its impact on production and welfare. Data were obtained from 4 groups comprising 18 reaper owners, 41 nonowner users, 37 nonusers, and 58 landless harvest laborers.

Owners and farmers contracting the services of the machine found that it provided timely, efficient service. Technical limitations included the inability to operate effectively in small, wet or flooded fields — common conditions during the wet season



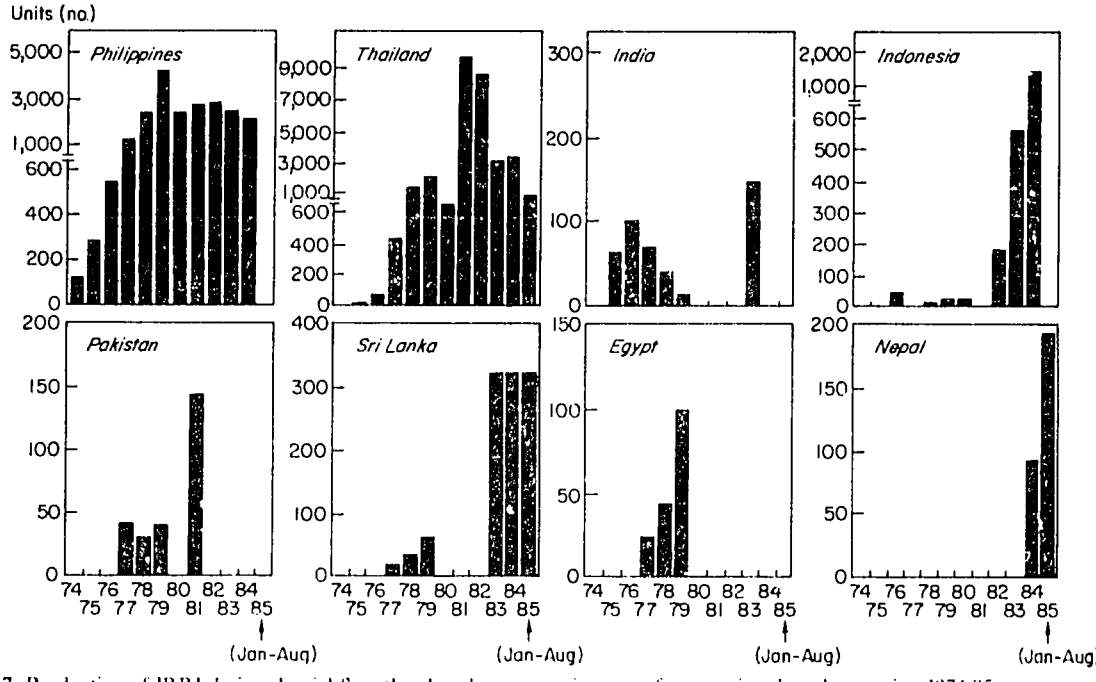
6. Sales and price of imported and local reapers, Bataan and Pampanga, Philippines, 1982-85. * = sales of imported reaper cumulative for 1982-84, ** = approximate sales of imported and local reapers as of Apr 1985.

harvest. Locally built machines experienced frequent breakdowns and extended downtime while awaiting spare parts.

Locally made reapers operated below annual breakeven levels. Owners of these machines performed less contract work than did those with imported models. Imported units purchased before 1985 operated well above the breakeven level. Following devaluation of the Philippine peso in 1985, both locally made and imported units became unprofitable.

The reaper displaced 13-15 labor days/ha and reduced the harvest income of laborers by up to 47%. Harvest payments were redistributed, mainly to machine owners and away from the landless class. While other farm, off-farm, and nonfarm employment opportunities were available to harvest workers, only one-fourth of the working members in respondent households reported sufficient new income to offset losses attributed to introduction of the reaper. In addition, the poorest households were most adversely affected, as harvest wage labor represented a higher proportion of total income for this group. In-migration of harvest workers from other provinces also ceased after adoption of the reaper.

For owners of both imported and locally built reapers, earnings generated by custom hiring of the machines increased total household income less than 10%. Harvesting costs were reduced only moderately. Farmer nonusers benefited indirectly as a result of the low harvest wage and increased competition among harvest laborers for available harvest contracts.

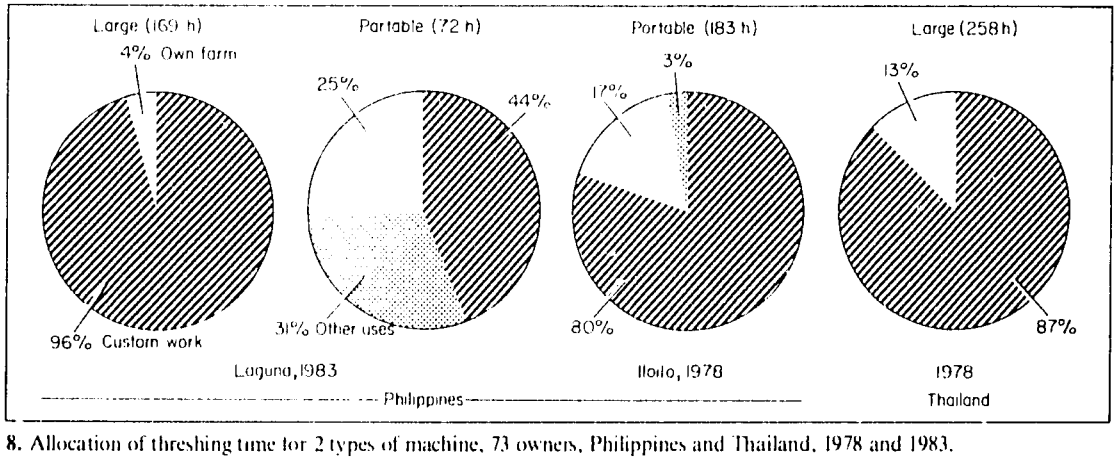


7. Production of IRRI-designed axial-flow threshers by cooperating manufacturers in selected countries, 1974-85.

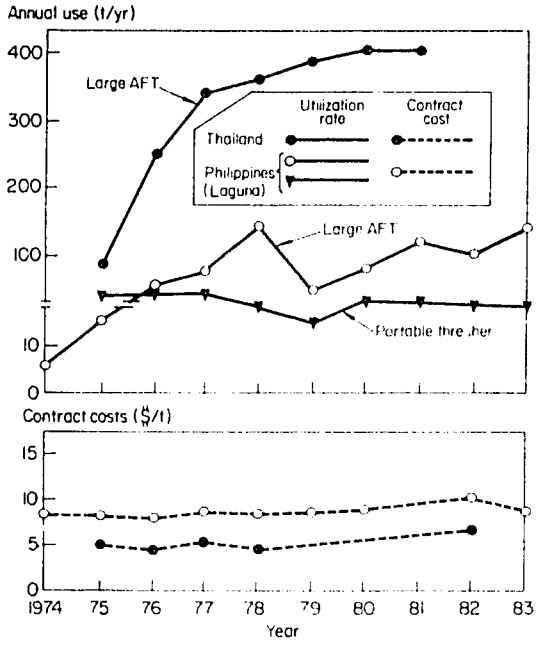
IMPACT OF AXIAL-FLOW THRESHER

Design work on the axial-flow thresher began in 1970, and a finished design was released to Philippine manufacturers in 1974. Statistics on the production and sale of the machine are incomplete. IRRI industrial extension network data summarize the production and sale of threshers by cooperating manufacturers in a number of countries but underestimate the true volume sold, as the design has been freely copied by numerous firms having no formal association with the IRRI program. Figure 7 illustrates the rapid takeoff of the design in the Philippines and, with a lag of about 1 yr, in Thailand. Sales rose steadily in the Philippines and Thailand until 1982, when world economic conditions dampened economic growth and accelerated inflation. Fewer but significant numbers of the machine have been produced in Egypt, Indonesia, Sri Lanka, Nepal, and India.

In both Thailand and the Philippines, ownership of a thresher is not required for using it, as contract rental is a well established practice (Fig. 8). Initially, with few threshers available and no demon-



8. Allocation of threshing time for 2 types of machine, 73 owners, Philippines and Thailand, 1978 and 1983.



9. Annual utilization and contract costs for mechanical axial-flow threshers, Thailand and Philippines, 1974-83. AFT = axial-flow thresher.

strated performance record, annual use levels were low (Fig. 9). In both countries, the increasing stock of threshers began to dampen further increases in use. Competition for threshing contracts also mitigated further increases in contract rates despite the fact that the investment cost of the machine and fuel prices more than doubled since 1975.

To correctly assess the overall costs and benefits of the axial-flow thresher, a detailed summation of all costs associated with development and extension of the design and a measure of the net benefits from use of the machine at the farm level are required. To simplify the analysis of benefits, attention is moved back in the marketing chain to the manufacturer. Since the inception of the thresher program in 1967, statistics have been maintained cataloguing the manufacturers participating in the industrial extension program and the number of machines sold each year. To determine the costs of thresher development and extension, total expenditures for 1967-84 were obtained from accounting records (Table 11).

Table 11. Design, development and extension costs, production, and value of IRRI axial-flow thresher, 1967-84.

Year	Research and development[a] (man-yr)	Funding (thousand $)			Thresher project			Thresher production		
		Core	Project	Total[b]	% share[c]	Cost (thousand $)	Cumulative cost (thousand $)	Number[d]	Value[e] (thousand $)	Cumulative value (thousand $)
1966	7	23	36	59	0	–	–	–	–	–
1967	9	18	87	105	10	10.5	10.5	–	–	–
1968	14	15	123	138	15	20.7	31.2	–	–	–
1969	10	21	88	109	25	27.2	58.4	–	–	–
1970	14	29	105	134	30	40.2	98.6	–	–	–
1971	19	32	173	205	30	61.5	160.1	–	–	–
1972	17	28	235	263	40	105.2	265.3	–	–	–
1973	20	40	214	254	40	101.6	366.9	–	–	–
1974	21	49	274	323	40	129.2	496.1	120	120	120
1975	23	273	81	354	40	141.6	637.7	347	347	467
1976	27	340	330	670	25	167.5	805.2	798	798	1,265
1977	33	432	450	882	20	176.4	981.6	1,875	1,875	3,140
1978	34	486	242	728	15	109.2	1,090.8	4,228	4,228	7,368
1979	35	545	264	809	10	80.9	1,171.7	6,533	6,533	13,901
1980	36	643	268	911	5	45.5	1,217.3	2,952	2,952	16,853
1981	38	675	539	1,214	5	60.7	1,278.0	12,692	12,692	29,545
1982	41	739	543	1,282	5	64.1	1,342.1	12,221	12,221	41,766
1983	35	684	520	1,204	5	60.2	1,402.3	6,501	6,501	48,267
1984	35	630	736	1,366	5	68.3	1,470.6	7,251	7,251	55,518

[a]Total senior and support staff in IRRI small-scale machinery design and development program. [b]Total from both recurring budget commitments and from special projects. [c]Estimates based on semi-annual progress reports of the Agricultural Engineering Department. [d]Estimates based on statistics compiled by the Agricultural Economics Department and the industrial extension program. [e]Each unit has been valued at $1,000.

The values of both expenditures and sales were discounted to reflect their current values. From these figures, an aggregate benefit to cost ratio (B:C) was constructed. Calculations were also made to examine the time profile of returns to thresher development (Table 12). During the first 10 yr, the B:Cs were less than 1. Only in 1975, following intensive extension and widespread fabrication by manufacturers and adoption by farmers, did the design demonstrate an acceptable B:C.

A series of internal rate of return (IRR) calculations was carried out to compare returns to engineering developments with those to other research activities at IRRI. Investment of resources in thresher development produced an IRR of over 50%, which compares favorably with biological research endeavors at IRRI.

An important lesson from this analysis is the need for long-term commitments to effectively develop new engineering inputs. Had the IRRI program been terminated anytime during the first 10 yr, it is doubtful that there would have been a positive return on the resources expended on thresher development. The analysis also reveals the importance of achieving a proper blend of development and technology transfer elements to achieve success. While the transfer component did not become an important factor until 1974, without an intensive commitment to extension, the spread of the axial-flow thresher would have been largely limited to the Philippines.

Table 12. Estimated discounted benefit to cost ratios at alternative discount rates from resource investments in development and extension of IRRI axial-flow thresher.

Period	B:C at discount rate of			
	12%	20%	30%	40%
1967-75	0.6	0.5	0.4	0.3
1976-80	24.8	22.9	20.8	18.4
1981-84	125.0	162.1	165.5	168.9
Overall (1967-84)	20.4	11.9	7.6	4.4
Overall internal rate of return from 1966 to 1984	57.6%			

Cropping systems program

Analysis of the physical and biological environment

Plant Pathology, Entomology, and Agronomy Departments

GUIMBA 362
Diseases 362
Insects 362
Weeds 362
CLAVERIA 363
Diseases 363
Insects 364
Weeds 364

361

We are currently working at sites in Guimba, Nueva Ecija, Philippines, to establish methods to improve income from partially irrigated farms; and in Claveria, Misamis Oriental, to evaluate available technologies for upland rice-based cropping systems on acid soils. Physical characteristics of the sites have been described (Annual report for 1984). Here we describe briefly the sites' biological characteristics.

GUIMBA

Plant Pathology, Entomology, and Agronomy Departments

Diseases (*Plant Pathology*). Although the Guimba site has broad alluvial topography, two landforms, locally called lungog and turod, are distinct. Lungog comprises low-lying areas where water accumulates in wet season (WS) and remains longer in dry season (DS). Turod is the upper stratum where water does not stay for extended periods.

In crop year (CY) 1984-85 in a researcher-managed field, high stem rot (SR) incidence (90% infected hills/plot) in the first rice crop and a slightly lower (78%) level in the second rice crop were observed in lungog. Thirty percent SR infection was observed in other lungog areas in farmers' second rice crop, which was planted 1 mo later than the researcher-managed fields.

In turod, leaf blast (Bl) with an intensity of 95% was observed in farmers' seedbeds of IR54. IR36, IR42, and IR56 had disease intensities of 42%, 34%, and 5%, respectively. In a researcher-managed field planted to IR52, the occurrence of leaf Bl was 71% and sheath blight (ShB) 93%. Neither disease progressed as the crop matured. In turod, the second crop (maize) was healthy.

In CY 1985-86, SR was again prevalent in the first rice crop in lungog, with an incidence of 100% at maturity in some plots of the researcher-managed field. In turod, leaf Bl and ShB were again common and severe in farmers' fields planted to a variety called "IR58" by the farmers (but not IRRI's IR58). At booting, the incidence of Bl was 95% and that of ShB 80%. Neither disease progressed.

The population of vesicular-arbuscular mycorrhizal (VAM) fungi was determined at various stages of the rice-based cropping system by the most probable number method, which is also indicative of the inoculum potential. The number of infective mycorrhizal fungi in the soil was low after a 2-mo fallow, but the population increased during DS cropping. The maize crop caused more than a 16-fold increase: from 170 to 2,800 VAM units/g of air-dried soil. The inoculum potential, however, dipped once more in soil samples taken after the fallow period before the WS rice crop. The population also varied with the cropping pattern: infective VAM units were consistently fewer in the field with two lowland rice crops per year than in the area with one rice crop and an upland crop.

The incidence of ShB in rice was reduced by about 30% with the addition of VAM fungi in soil containing sclerotia of *Rhizoctonia solani*.

Insects (*Entomology*). Farmers ranked stem borers (SB) as their most serious insect pest problem, followed by tungro (RTV) and caseworm (CW). Less important to farmers were rice bugs (RB), defoliators, leaffolders (LF), and whorl maggots (RWM). Pest outbreaks recalled by farmers were caused by hoppers and insect-vectored virtses, particularly in the 1970s and early 1980s. Farmers had trouble diagnosing pest problems when shown actual specimens. The most readily recognized pests were RTV and RB. Few farmers could identify Zn deficiency (which they often confuse with insect infestation), defoliating worms, LF, or brown planthopper (BPH). The most popular cultural control practices were roguing (for RTV), synchronized planting, weeding, use of plant parts to repel insects, draining the field (for CW), and burning rice stubble (for SB). Few farmers could name pests controlled by insect-resistant varieties. Most common natural enemies named were spiders, toads, and birds. Most farmers thought spiders were killed when the crop was sprayed with insecticides.

On hybrid maize planted in December, few insect pests were recorded, and there was no yield loss. The key pest on rice appeared to be yellow stem borer (YSB), causing over 3% whiteheads. An insignificant 0.2 t/ha yield loss was recorded from green semilooper and RWM in the vegetative stage.

Weeds (*Agronomy*). Of 60 farmers interviewed in 1984, 93% stated that weeds were a problem in transplanted rice (TPR). The major effects were yield reduction, competition for nutrients, stunted

growth of rice, and reduced tillering. Most farmers estimated that weeds reduced yields by 26-30%, with a range of 6 to 55%.

All the farmers considered the perennial grass *Paspalum distichum* to be a major weed of TPR, and 95% considered it to be the most difficult to control. One farmer commented that thorough land preparation controlled *P. distichum* while butachlor controlled the annual weeds.

Most farmers plowed their fields once. They usually plowed twice when *P. distichum* was abundant. The number of harrowings ranged from two to seven. Reasons given for increasing the number of harrowings were to bury and decompose weeds, to eliminate *P. distichum*, and to make transplanting easier.

For weed control in TPR, 98% of the respondents used herbicides either alone or in combination with hand weeding. Butachlor was the most common herbicide; it was applied 1-4 d after transplanting (DT), usually at rates lower than those recommended by the manufacturer. Only 6% of the farmers applied it at the recommended rate of 1.0 kg ai/ha. 2,4-D was applied at 15-35 DT; only 3 farmers applied it at the recommended rate. Reasons for not using recommended rates included prior experience in the use of herbicides, inconvenience, toxicity caused by suggested rates, and lack of cash to buy sufficient herbicide. Means for measuring the herbicide to apply included the cap of the herbicide bottle (48%), cover of the sprayer tank (25%), a tablespoon (13%), and a graduated plastic cup (14%).

In 1985, data on weed control practices were collected from six farmers' fields in the turod and lungog portions of the landscape.

Farmers were transplanting weed seedlings along with rice seedlings. The percentage of weed seedlings in the bundles of rice seedlings to be transplanted ranged from 4.5 to 14.2%. The percentage of weed infestation was negatively correlated with the time taken for preparation of the seedling nursery ($Y = 17.828 - 0.814X$, $r = -0.97^*$). Grasses comprised 63% of the weeds transplanted into the fields, and sedges accounted for 35%.

The major weeds in the six fields were *P. distichum*, *Fimbristylis miliacea*, *Monochoria vaginalis*, *Scirpus supinus*, *Echinochloa glabrescens*, and *E. oryzoides*.

Weed seed contamination was observed in the crop seed after threshing. The number of weed seeds ranged from 1,630 to 64,948 per kg of crop seed. Sedges, primarily *S. supinus* and *F. miliacea*, accounted for 96% of the contamination.

CLAVERIA

Plant Pathology, Entomology, and Agronomy Departments

Diseases (*Plant Pathology*). The upland research site is composed of two strata, namely, volcanic plateau and alluvial plain. Although each stratum has slightly distinct physical features, the current cropping pattern including maize, upland rice, and sometimes cowpea is similar in each. During the CY 1984-85 survey, bacterial leaf streak (caused by *Xanthomonas campestris* pv. *oryzicola*), leaf Bl (*Pyricularia oryzae*), and ShB (*Rhizoctonia solani*) were observed. *Rottboellia cochinchinensis* infesting a field planted to a local variety had brown spot (*Helminthosporium* spp.) infection. On maize, which was the dominant crop grown after rice at the site, leaf spot (*Helminthosporium maydis*), leaf blight (*H. turcicum*), and rust (*Puccinia polysora*) were common. Of the 16 maize fields from the 6 villages, 15 had leaf spot, 9 had blight, and 6 had rust. Mosaic was observed in one field, but the incidence was low. The maize plants at the site were stunted and chlorotic because of nutritional deficiency.

In CY 1985-86, cowpea, the first crop, was healthy. Most farmers' fields planted to maize were infected with leaf spot, leaf rust, Physoderma spot, and leaf blight, but the incidence was low. Downy mildew was observed in one field with an incidence of <10%. In Patrocinio, the second crop — UPLRi5 rice — was severely infected with brown spot at later stages. In a researcher-managed field, the incidence of ShB (77%) and neck Bl (100%) were recorded. In Ane-i, many entries in an upland rice variety trial had severe leaf and neck Bl.

Of 60 farmers from 6 barangays, 28 recognized downy mildew of maize by the name *alcojeres*. Fifteen of the 28 stated that the disease was common in the first crop or during the rainy months, and only 5 observed that the infected plants either die, fail to produce ears, or produce undersized ears. Twenty-two of the farmers who recognized downy mildew practiced roguing,

which, they said, would prevent the spread of the disease to healthy plants. Only six of all farmers interviewed observed yellowing of maize plants, which they called *layab*, and four of the six attributed such yellowing to nutrient deficiency in the soil.

No rice diseases were known to the farmers except neck Bl. Only one farmer indicated that this causes darkening of the panicle base, toppling of panicles, and empty grains.

Two farmers reported that they spray their tomato fields with fungicides directed against late blight. All respondents mentioned insect pests in naming the diseases that they recognized.

Insects (*Entomology*). Farmers considered rats, oriental maize borer, seedling maggot, and AW the most important pests. When shown specimens or damaged plants, fewer than 50% of farmers could recognize maize aphids, planthoppers, silk beetles, or thrips, while most could at least partially name the maize borer, seedling maggot, semilooper, and earworm. Resistance to pests and high yield were qualities of maize varieties most mentioned as desirable by the farmers.

Farmers named birds, chickens, and reptiles as natural enemies of insects. Less than 10% mentioned wasps, spiders, crickets, and ants. The commonly mentioned (80%) practice to conserve natural enemies was to avoid hunting birds.

Farmers did not regularly apply insecticides to maize but had done so in the past because of abnormally high infestation. Techniques mentioned included walking backwards while spraying to avoid being contaminated, and not spraying when it looks like rain. Safety practices stated were wearing a mask (77%), taking a bath after spraying (23%), wearing long sleeves and long pants (20%), and spraying downwind (17%).

Weeds (*Agronomy*). A preliminary survey was made of the weeds growing in association with maize in three fields in November 1984. Two fields were heavily infested. In one field, the major weed species was *Borreria laevis*; in the other the major weed species were *Echinochloa colona* and *Digitaria setigera*. In the third field, which was relatively free of weeds, interrow cultivation at 1 mo after planting was used for postplant weed control.

Sixty-seven percent of 60 farmers regarded weeds as the most important pest in their fields. The major effects of weeds were stunted growth of rice, reduced tillering, rat damage, and yield reduction; in maize, weeds were known to cause yield reduction by stunting growth, increasing rat-damage, and causing the production of small ears. Farmers estimated that weeds reduced yields in both crops by 61-65%.

More than 50% of the farmers reported *Digitaria longiflora*, *Rottboellia cochinchinensis*, *Pennisetum polystachyon*, and *B. laevis* as the major weed species in their fields. All said that *R. cochinchinensis* was the most difficult to control.

Most farmers plowed and harrowed their fields twice for maize and four times for rice. Better soil tilth and better weed control were obtained with more thorough land preparation.

The commonly used method of weed control for both crops was interrow cultivation + hand weeding. This was done twice at 2 and 4 wk after emergence (WE) for maize and once, at 4 WE, for rice.

Yield increases of 43-80% over farmers' weed control practices (hand weeding once or interrow cultivation) were obtained in 3 upland ricefields by doing additional weed control (either hand weeding or applying 2,4-D) during the critical period of weed competition. Two fields were still weedy at harvest despite additional weeding. With a higher level of weed control, a further increase in yield might have been obtained in them. Weeds need to be controlled for about 8 WE in upland rice in Claveria to prevent yield loss.

Cropping systems program

Analysis of the social and economic environment

Agricultural Economics Department

AGROECONOMIC PROFILE OF THE UPLAND RICE SITE AT CLAVERIA **366**
Farm-household characteristics **366**
Farm characteristics **366**
Labor and power **366**
Cropping patterns **366**
Purchased inputs **367**
Labor **367**
Varieties and yields **367**
Net benefits **367**

AGROECONOMIC PROFILE OF THE UPLAND RICE SITE AT CLAVERIA

Farm-level agroeconomic data were gathered through a baseline survey of 202 farm operators living in 6 barangays of Claveria during August to October 1984.

Farm-household characteristics. The average farm operator in Claveria was a 44-yr-old male with about 6 yr of formal education and 25 yr of farming. Spouses averaged slightly younger (39 yr) but had a similar level of formal education. The family included 2-3 dependent children at home, with an average of 4 yr of education.

Off-farm income increased with farm size. The main source of agricultural income was hiring out services for land preparation, crop harvesting, and the processing of cash crops such as coffee and cassava. The principal sources of nonagricultural income were trading and employment in the public service.

Farm characteristics. Mean farm size was 3.0 ha, with a range of 0.3 to 19.5 ha. The modal farm was 1.5 ha. Seventy percent of farms were less than 3 ha.

The multiple cropping index over all farms was 1.4; however, it decreased as farm size increased, and it was significantly higher for the first than for the second crop. Therefore, there was substantial opportunity to increase cropping intensity, particularly in the second season.

The dominant forms of tenure were owner-cultivators and tenant-cultivators. Tenant occupancy was more common on small (58%) than on large (29%) farms; owner-cultivators were more prevalent on large (59%) than on small (30%) farms. The most common sharing arrangement on tenanted land was three-fourths of output for the tenant and one-fourth for the landowner after harvester's and thresher's shares of one-sixth of gross yield were deducted.

Labor and power. Farm operators, irrespective of farm size, claimed they worked about 26 d/mo on the farm. Spouses were available for work only 5-6 d/mo, and children between 10 and 20 d/mo. The land area per household worker declined as farm size increased.

More than half of the small farms and a third of the large farms did not own draft cattle. Among owners, the number of draft cattle per farm increased as farm size increased, and the land area per animal increased with increasing farm size.

The total value of livestock per farm averaged $278 and increased as farm size increased. The single largest investment was the work animal, averaging $250-275/head. Most farm households kept pigs (1.3 head/household); few kept goats or chickens.

Both farm resources of labor and power diminished as farm size increased — quite sharply in the range of 1-2 ha.

Cropping patterns. The dominant cropping patterns were maize - maize, rice - maize, maize - fallow, rice - fallow, cassava, and perennial crops such as coffee, cacao, and coconut.

Table 1. Comparison of income per hectare per year and its share among earners by cropping pattern and tenure, Claveria, Misamis Oriental, Philippines, 1984.

Cropping pattern	Owner-cultivators		Tenant-cultivators	
	$/ha	%	$/ha	%
Maize - maize				
Value added[a]	100	100	108	100
Earners				
Landlord	--	--	27	25
Farmer	78	74	57	53
Capital[b]	(28)	(27)	(28)	(26)
Labor	(29)	(28)	(40)	37
Operator surplus	(21)	(20)	(−11)	(−10)
Hired laborer	27	26	24	22
Maize - fallow				
Value added[a]	65	100	65	100
Earners				
Landlord	--	--	16	25
Farmer	52	80	34	52
Capital[b]	(16)	(25)	(15)	(23)
Labor	(29)	(45)	(26)	(40)
Operator surplus	(6)	(10)	(−7)	(−11)
Hired laborer	13	20	15	23
Rice - fallow				
Value added[a]	108	100	108	100
Earners				
Landlord	--	--	27	25
Farmer	70	65	43	40
Capital[b]	(8)	(7)	(8)	(7)
Labor	(30)	(28)	(30)	(28)
Operator surplus	(32)	(30)	(5)	(5)
Hired laborer	38	35	38	35

[a]Output value less current input costs. US$ = 20. [b]Includes return to hired capital. Numbers in parentheses are subtotals.

Maize was the most prevalent crop, being grown on 85% of upper (elevation about 500 m) barangay (district) and 75% of lower (about 400 m) barangay farms. Rice was grown by more lower than upper barangay farmers, while tree crops were more widespread on upper barangay farms. More maize was grown in the first than the second season; upland rice was usually grown as a first crop, particularly in the upper barangays, with root crops as a second season crop, particularly in the lower barangays. The area under fallow was twice as high in the second as in the first season.

Purchased inputs. Few farmers applied fertilizer or insecticides. The use of such inputs was more prevalent in the first than in the second season. The small minority of farmers who did apply fertilizer and herbicides in the wet season reported that they applied them at approximately the recommended level on modern varieties of maize and rice.

Labor. A rice crop required 87 d/ha and a maize crop 40-60 d/ha. The largest allocations of labor in rice production were for harvesting and threshing (24-31 d/ha) and for weeding (32 d/ha). For maize, the most labor inputs were for harvesting and shelling (16-18 d/ha) and land preparation (10-12 d/ha).

Varieties and yields. All but 4% of the farmers who grew rice planted local varieties, of which Speaker and Kayatan were the most common. Local white and yellow maize were the most common varieties, and 30% was modern varieties of yellow hybrid and white (UPCA) maize. The high incidence of high yielding maize varieties is attributed to the Maisagana maize program.

Farmers reported local rice yields of 1.5 t/ha, local maize yields of 1.0 t/ha, and improved maize yields of 1.4 t/ha.

Net benefits. The incomes per hectare generated from the three principal cropping patterns are listed in Table 1. Rice earned a higher profit than maize because of its higher price and yield. For each pattern, an owner-cultivator earned a surplus after cash costs and an imputed cost for the farm families' labor were paid. Tenant-cultivators, however, did not generate an operator's surplus from the maize patterns, and the return to the family's labor was slightly less than the current wage rate.

Farmers generated cash income from selling their limited surplus of food grains — rice and maize — and cash crops, notably coffee, cassava, and vegetables.

Cropping systems program

Pest control in rice-based cropping systems

Agronomy, Entomology, and Plant Pathology Departments

DISEASES 370
Microbial rice straw decomposition and survival of *Rhizoctonia solani* 370
Diseases of upland crops after rice 370
INSECTS 372
Insect control in rice 372
Yield loss in upland rice 372
Upland rice plant density and insect pests 374
Insect pests of cowpea 374
Insect pests of maize 375
WEEDS 375
Partially irrigated rice 375
Upland rice 375
Upland crops after rice 376
Control of *Scirpus maritimus* 377
Echinochloa species 378
Morphological characteristics 378
Response to herbicides 379

DISEASES

Plant Pathology Department

Microbial rice straw decomposition and survival of *Rhizoctonia solani*. Sheath blight (ShB)-infected rice stubble left in the field after rice harvest serves as an inoculum reservoir for succeeding crops. Before it is decomposed, the stubble provides a substrate for the pathogen. Decomposition could be enhanced by cellulose decomposers such as *Trichoderma* spp. Five species of *Trichoderma* were detected in ricefield soil. The effect of straw decomposition was further evaluated in the laboratory and in the greenhouse.

The cellulolysis adequacy index (CAI) of different *Trichoderma* spp. on filter paper, autoclaved straw, and unautoclaved straw was determined by Garrett's method. Regardless of substrate, *T. harzianum* and *T. aureoviride* had the highest CAI and *Rhizoctonia solani* the lowest (Table 1). CAI on filter paper was positively correlated with CAI on autoclaved and unautoclaved rice straw. In the soil, *T. aureoviride* decomposed rice straw faster than any other *Trichoderma* species.

T. harzianum and *T. aureoviride* were more competitive than *R. solani* in colonization of autoclaved rice straw. *R. solani* was more efficient colonizing unautoclaved rice straw. This information thus confirmed that *Trichoderma* spp. is more effective in competition with *R. solani* when the plant tissues are dying than when they are living.

Straw colonization was enhanced when soil moisture condition was high. Decomposition of infected straw increased as soil moisture content increased (Table 2). Similarly, decomposition of ShB-infected straw was faster when the straw was incorporated in the soil than when it was surface applied (Fig. 1). Consequently, the recovery of *R. solani* was reduced and the potential inoculum was suppressed (Fig. 2).

Table 2. Weight loss of ShB-infected straw in soil of different moisture content and with *Trichoderma* spp.[a] IRRI, 1985.

Species	Rice straw weight loss (%) at soil moisture level of					Mean weight loss
	20	40	60	80	100	
T. aureoviride-1	35	41	51	59	70	51
T. aureoviride-2	30	48	50	49	58	47
T. harzianum	20	22	30	39	40	30
T. glaucum	18	30	31	35	40	30
T. pseudokoningii	13	30	34	31	41	30
No *Trichoderma* spp.	0	21	21	18	22	16
Mean	19	32	36	39	45	

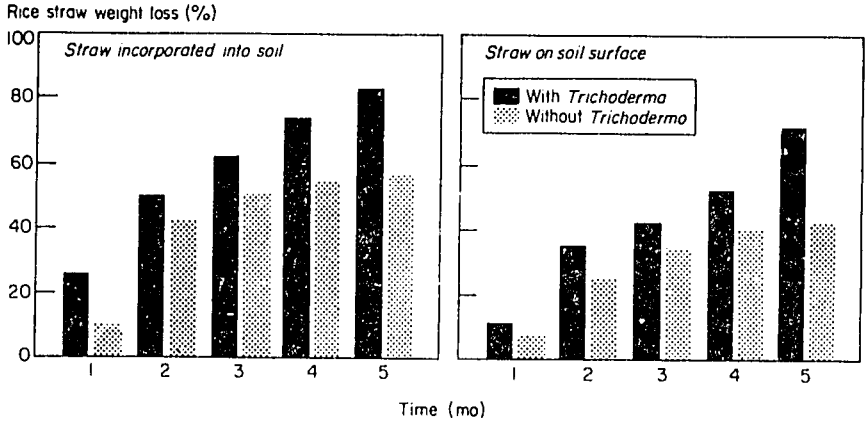
[a]Av of 3 replications.

Diseases of upland crops after rice. Damping-off and other soilborne diseases of legumes planted after upland rice are common. To assess the effect of *Trichoderma* spp. on crop establishment after rice, inocula of *T. aureoviride* and *T. glaucum* were either applied as seed treatment to cowpea, mungbean, soybean, and maize or incorporated into the soil in the 1985 dry season (DS). Damping-off was lowest when *T. aureoviride* was soil-incorporated. The treatment also increased grain yield (Table 3). *T. glaucum* was not as effective as *T. aureoviride*. The increase in *Trichoderma* population as a result of soil incorporation perhaps enhanced straw decomposition and provided protection for the crops by lowering the inoculum potential (Fig. 3).

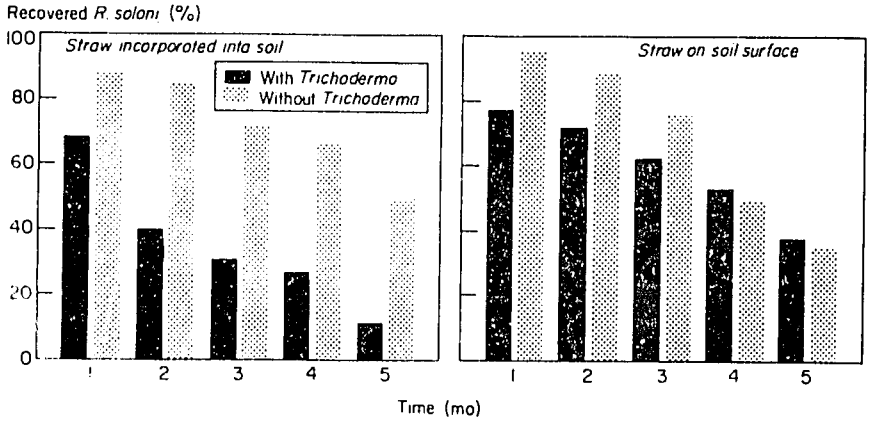
Table 1. Cellulolysis adequacy indices of 4 species of *Trichoderma* and 2 *Rhizoctonia solani* isolates using filter paper and rice straw as substrates. IRRI, 1985.

Species and isolate	Cellulolysis adequacy index[a]		
	Filter paper	Autoclaved rice straw	Unautoclaved rice straw
T. harzianum	2.19 a	1.93 a	1.98 a
T. aureoviride-1	1.40 b	1.20 ab	1.20 b
T. glaucum	0.96 c	0.78 b	0.93 c
T. aureoviride-2	0.77 d	0.80 b	0.71 d
R. solani UR-1	0.65 d	0.60 b	0.76 d
T. pseudokoningii	0.45 e	0.53 b	0.58 e
R. solani LR-1	0.38 e	0.45 b	0.47 f

[a]Means followed by a common letter are not significantly different at the 1% level by DMRT.



1. Weight loss of rice straw as affected by method of placement. IRRI, 1985.

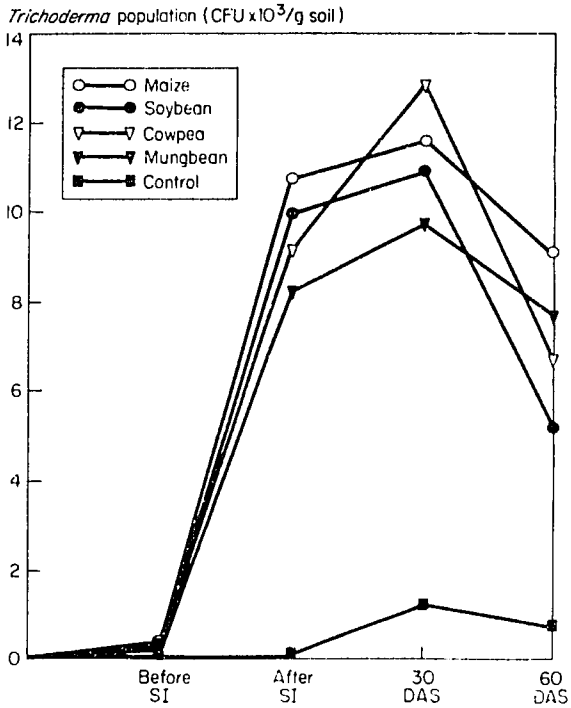


2. Effect of method of straw placement on percentage of recovered *R. solani*. IRRI, 1985.

Table 3. Damping-off incidence and yield of plants as affected by *Trichoderma* treatment.[a] IRRI, 1985.

Crop	Species	Damping-off incidence (%)		Yield (g)	
		Soil incorporation	Seed treatment	Soil incorporation	Seed treatment
Cowpea	*T. aureoviride*	2.21 a	4.44 a	501.00 a	485.95 a
	T. glaucum	7.26 a	2.90 a	413.25 b	410.30 a
	Control	23.50 b	3.64 a	381.65 b	449.63 a
Mungbean	*T. aureoviride*	0.80 a	3.25 a	447.18 a	408.30 a
	T. glaucum	8.70 b	1.78 a	414.83 a	443.28 a
	Control	11.09 b	3.06 a	437.80 a	371.58 a
Soybean	*T. aureoviride*	0.68 a	1.46 a	–	–
	T. glaucum	3.25 ab	1.59 a	–	–
	Control	6.00 b	1.90 a	–	–

[a]In a column and within a crop, means followed by a common letter are not significantly different at the 5% level by DMRT.



3. Inoculum dynamics of *Trichoderma aureoviride* in rhizosphere of different crops after soil incorporation (SI). CFU = colony-forming unit, DAS = d after seeding.

INSECTS

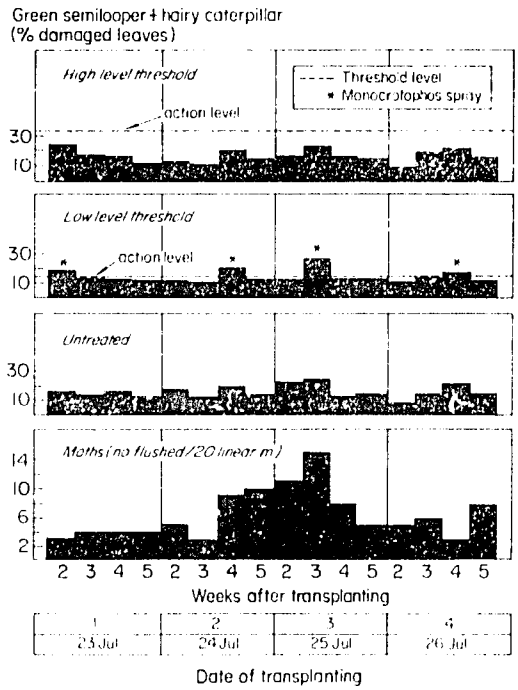
Entomology Department

Insect control in rice. A field trial in Guimba, Nueva Ecija, replicated across four farms, tested methods of chemical insect control on green leafhopper- and brown planthopper (BPH)-resistant IR58. Tungro, a problem in 1983 and 1984, subsided because of the extended DS in 1985. Insect pests caused a 12% yield loss — the difference between complete insect control (3.7 t/ha) and untreated (3.2 t/ha) plots. Yellow stem borer (YSB) caused over 3% whiteheads (Table 4).

All four fields were sprayed in the low value threshold treatment as the action level of 15% damaged leaves was reached (Fig. 4). Spraying 0.4 kg ai monocrotophos EC/ha controlled green semilooper, but yield was not increased. The threshold, therefore, was too low. Whitebacked planthopper (WBPH) populations increased to 75/20 hills during the reproductive stage, still far below the 1/tiller action threshold level. The population soon subsided from natural causes, and control was not necessary. IR58 is resistant to BPH but susceptible to WBPH. WBPH frequently becomes abundant in wet season (WS).

Weekly counts of stem borer (SB) egg masses and moths from 120 hills failed to anticipate the level of whiteheads; therefore, insecticide applications were not made in the threshold plots. Two sprays of chlorpyrifos as prophylactic treatment at 45 d and 55 d after transplanting significantly controlled YSB.

Yield loss in upland rice. Early planted upland rice grown under favorable rainfall conditions in Claveria, Misamis Oriental, yielded 5.1 t/ha in a fully protected treatment (Table 5). The untreated plot yielded 3.1 t/ha — a 40% yield loss attributed to seedling maggot *Atherigona oryzae*; ants *Solenopsis geminata*; white grubs *Leucopholis*, *Anomala*, and *Holotrichia*; root aphid *Tetraneura nigriabdominalis*; SB *Chilo suppressalis*, *Sesamia inferens*, *Scirpophaga incertulas*, and *S. innotata*; leaffolders (LF) *Marasmia patnalis* and *Cnaphalocrocis medinalis*; and rice bugs (RB) *Leptocorisa oratorius* and *L. acuta*.



4. Weekly incidence of green semilooper *Naranga aenescens* and hairy caterpillar *Rivula atimeta* in high- and low-threshold plots, showing when insecticide was applied on irrigated transplanted IR58 rice. Guimba, Nueva Ecija, Philippines, 1985 WS.

Table 4. Development of a chemical insect control recommendation based on the economic threshold level on irrigated transplanted rice IR58.[a] Guimba, Nueva Ecija, Philippines, 1985 wet season.

Damaged leaves (%)		Whitebacked planthopper[d] (no./20 hills)	Stem borer[e]		Yield[f] (t/ha)
Whorl maggot[b] at 21 DT	Green semilooper[c] at 21 DT		Deadhearts at 35 DT (%)	Whiteheads (%)	
Complete protection: vegetative stage – 0.6 kg ai carbosulfan EC/ha before planting (root soak); reproductive stage – 0.75 kg ai Brodan EC/ha at 35, 45, and 55 DT; ripening – 0.75 kg ai monocrotophos EC/ha at milking.					
5.1 a	8.3 a	3 a	0.7 ab	0.2 a	3.7 a
No vegetative protection					
8.3 bcd	14.1 bc	9 ab	0.8 b	0.1 a	3.4 abc
No reproductive protection					
5.0 a	7.9 a	75 c	0.3 ab	3.3 b	2.9 d
No ripening protection					
5.3 ab	8.2 a	6 ab	0.2 ab	0.4 a	3.6 ab
Untreated					
8.4 cd	15.9 c	70 c	0.1 a	2.1 b	3.2 bcd
Economic threshold[g] (high level)					
8.5 cd	16.5 c	62 c	0.6 ab	2.4 b	3.1 cd
Economic threshold[h] (low level)					
10.2 d	15.9 c	61 c	0.1 a	3.1 b	3.3 bcd
Prophylactic: vegetative stage – 0.3 kg ai carbosulfan EC/ha (root soak) before planting; reproductive stage – 0.4 kg ai Brodan EC/ha at 45 and 55 DT.					
6.7 abc	8.5 a	18 bc	0.6 ab	0.3 a	3.4 abc
Farmers' practice[i]					
6.6 abc	12.2 ab	69 c	0.2 ab	4.4 b	3.1 cd

[a]Av of 4 replications. Carbosulfan (Marshal 15 EC), Brodan (20% chlorpyrifos + 11% BPMC), monocrotophos (Azodrin 202 R 30% EC). DT = days after transplanting. [b]*Hydrellia philippina*, 20 hills sampled. [c]*Naranga aenescens* + *Rivula atimeta*, 20 hills sampled. [d]*Sogatella furcifera*, 20 hills sampled. [e]*Scirpophaga incertulas*, 20 hills sampled. [f]20-m^2 yield cut sample. [g]Action threshold for insect pest was not reached. [h]Action threshold for *Naranga aenescens* + *Rivula atimeta* was reached at 35 DT; 0.4 kg ai monocrotophos EC/ha sprayed in all fields. [i]Farmer 1: Seedbed = 0.14 kg ai monocrotophos EC/ha at 10 d after emergence (DE). Sprayed 0.17 kg ai monocrotophos at 20 and 36 DT. Farmer 2: Sprayed 0.05 kg ai cypermethrin EC/ha at 15 and 25 DT. Farmer 3: No insect control. Farmer 4: Seedbed = 0.17 kg ai monocrotophos EC/ha at 10 DE. Sprayed 0.1 kg ai Azocord EC/ha at 21 DT.

The use of γ-BHC was designed to control white grubs and other soil pests. Bendiocarb seed treatment was aimed at ant and seedling maggot control. A 24% yield loss was recorded when γ-BHC G was not used, and without bendiocarb a 9% loss occurred. Unfortunately, γ-BHC granules controlled not only white grubs but also seedling maggot, confounding the yield loss treatment designed to isolate the impact of soil and seedling pests. The high level of seedling maggot control in the complete protection treatment was a result of the combined activity of γ-BHC granules and bendiocarb. Therefore, yield loss from seedling maggot was underestimated, while that of white grub was overestimated.

Reduced plant stand occurred only in the untreated plot and was probably due to both seedling maggot and ants. Both bendiocarb and γ-BHC control ants; only the untreated plot had none of these compounds. Other soil pests encountered were termites *Macrotermes gilvus* and mealybugs. Termites were common in the root system of pulled plants. A nearby plot of wheat seeded at the same time was totally killed by termites. Root-feeding mealybugs were rare.

Weekly sprays of monocrotophos targeted SB, LF, and armyworm (AW). AW, however, was not prevalent in 1985. The 8 weekly applications from 21 to 60 d after emergence did not significantly depress SB deadhearts, whiteheads, or LF-damaged leaves, probably because of the frequent rains. However, a 3% yield loss was recorded from SB and LF. This figure probably underestimated the actual yield loss from these pests.

The highly mobile and long-lived RB congregate on the isolated upland ricefields, presenting a pest

problem not common in the expansive lowlands. Sampling by recording RB numbers per area does not always adequately reflect the level of control. Numbers were lowest in the untreated plot, probably because the plants had fewer panicles and were slower to mature because of seedling maggot injury. Yield loss to RB was estimated at 5% in the treatment without γ-BHC spray.

Benomyl was also sprayed during the ripening stage to prevent grain discoloration from fungi. A 5% yield loss was registered in the treatment without benomyl. Benomyl also controlled Bl, so the estimated yield loss must be due to a combination of Bl and dirty panicles.

Upland rice plant density and insect pests. Upland rice farmers in Claveria normally overseed, in part to compensate for expected insect damage. If the seeds were treated with insecticide, lower seeding rates might be justified.

Plant stand increased linearly with seeding rate. There was no significant yield difference among 4 seeding rates (50, 75, 100, and 125 kg/ha) with or without carbosulfan, except at 100 kg/ha, implying that seeding rates lower than the recommended 100 kg/ha will not reduce yield.

Increasing the seeding rate increased plant stand and density of *Atherigona* deadhearts, implying that denser stands attract proportionately more ovipositing seedling maggots. Lower seeding rates therefore should suffer less damage. Populations of root aphid, SB, white grub, and LF did not show any response to plant density.

Insect pests of cowpea. Insect pests caused a 41% yield loss on early season cowpea. Insecticide treatments recorded almost equal losses at preflowering and postflowering. Preflowering insects — beanfly *Ophiomyia phaseoli* and thrips *Thrips palmi* — reduced plant height by 21%. Plant height and crop growth would have been depressed more if the crop had suffered drought stress. High yields were attained because of constant rain, adequate fertility, and only moderate insect pressure. *Maruca testulalis* was the dominant pod borer, causing a 21% yield loss.

The recommended practice did not control these cowpea pests. Seed treatment with carbosulfan EC against beanfly and thrips and endosulfan EC sprays against *Maruca* were no better than no treatment. Better chemical control technology will be needed, because cowpea insect pests are expected

Table 5. Yield loss of UPLRi5 upland rice from insect and panicle fungal pests. First rice planting,[a] Claveria, Misamis Oriental, Philippines, May-Oct 1985 WS.

Seedling maggot deadhearts (%) at 7 + 14 DE	White grubs[b] (no./2-m row) at 70 DE	Rice bugs[c] (no./25 m²) at 63-109 DE	Grain yield[d] (t/ha)
	Complete insect control[e]		
5.6 a	0.8 a	53 ab	5.1 a
	Omit γ-BHC G soil pest protection		
12.8 b	5.6 b	–	3.9 bcd
	Omit bendiocarb seedling protection		
15.8 b	0.4 a	–	4.6 ab
	Omit monocrotophos vegetative pest protection		
8.6 ab	0.2 a	–	4.7 ab
	Omit monocrotophos vegetative and oxamyl root aphid protection		
12.6 b	1.2 a	56 ab	4.0 bcd
	Omit γ-BHC WP rice bug protection		
12.0 b	0.0 a	74 b	4.5 abc
	Omit benomyl discoloration protection		
11.2 b	0.6 a	–	4.3 abc
	Untreated		
33.2 c	3.0 b	39 a	3.1 d

[a]Av of 5 replications. γ-BHC G, bendiocarb WP, oxamyl EC, monocrotophos EC, γ-BHC WP, benomyl WP. [b]Species of *Leucopholis*, *Anomala*, and *Holotrichia*. [c]*Leptocorisa oratorius* and *L. acuta*. Total of 10 sampling dates. [d]5 X 5 m² crop cut. [e]Seed or seedling stage: 2 kg ai γ-BHC G/ha basal application, seed treatment of 0.6 kg ai bendiocarb/ha; vegetative stage: 0.75 kg ai oxamyl/ha + 0.75 kg ai monocrotophos/ha sprayed at 21, 28, 35, 42, 49, 56, 63, 70 d after emergence; panicle formation stage: 1 kg ai γ-BHC WP/ha + 1 g benomyl/liter solution per ha, 5 sprays twice weekly starting at panicle emergence.

to become progressively worse as more area is planted to cowpea year round.

Insect pests of maize. A field trial compared the insect pests and control practices in traditional and hybrid maize varieties.

The local variety Calimpos and hybrid variety Cargill suffered equal yield losses (33%) from insects. Both varieties received 3 t lime/ha and 28 kg NPK/ha in furrows before planting, but the hybrid received a sidedressing of an additional 35 kg N/ha at hilling up. Yield loss was about equally divided among three growth stages. At the seed or seedling growth stage, numerically higher yield loss occurred due to the seedling maggot *Atherigona oryzae* and possibly ants. The dosage of bendiocarb seed treatment in the complete control treatment was low, and seedling maggot control was less than desired. Maize borer *Ostrinia furnacalis* was the prevalent pest in the pretasseling and posttasseling growth stages. The higher fertility level in the hybrid resulted in higher maize borer infestation, but the yield was 24% more.

The farmers' practice of soaking seed in kerosene caused phytotoxicity and did not improve plant stand or seedling maggot control. Spraying monocrotophos in response to seedling maggot damage thresholds did not improve control. Seed treatments appear to offer the most economical and effective means of control. Rain was not a factor in washing off insecticides during this crop.

WEEDS

Agronomy Department

Partially irrigated rice. A number of experiments were conducted in Guimba, Nueva Ecija, to determine the effect of weed control practice, method of herbicide application, rate and time of herbicide application, and tillage level on weed growth and on yield of transplanted rice (TPR). In all trials except one, no response to weeding was obtained. Weed growth was light in most fields because of good land preparation and good water control. Adjacent farmers' fields that were poorly prepared and in some instances had poor water control were heavily infested with weeds.

In the trial where a response to weeding was obtained, the average weed weight in the untreated check was 103 g/m^2. The major weeds in this experiment were *Echinochloa glabrescens* and *Monochoria vaginalis*. Herbicide application (butachlor at 0.6 kg ai/ha at 3 DT) and 2 hand weedings at 22 and 35 DT resulted in a significant decrease in weed weight and a significant increase in yield in all treatments except one. A significant yield increase was not obtained when butachlor was applied in plots that had been plowed once and harrowed three times with a carabao. With better land preparation (the same amount of land preparation with a hand tractor or increased land preparation with a carabao), significant yield increases were obtained when butachlor was applied.

Land preparation techniques were tested in an attempt to control *Paspalum distichum*, the most problematic weed in TPR. One plowing using an animal-drawn plow plus 3 harrowings with a hand tractor reduced the weight of *P. distichum* compared with other land preparation methods used (7.8 g/m^2 vs 47.0 g/m^2). Control of *P. distichum* resulted in a significant increase in the weight of *E. glabrescens* (418.3 g/m^2 vs 129.8 g/m^2). As a result, this treatment significantly reduced yield compared with the other treatments (0.9 t/ha vs 2.1 t/ha). Thus, the tall annual grass *E. glabrescens* was more competitive than the short perennial grass *P. distichum*.

Upland rice. The major weed species in a maize trial conducted in Claveria in 1985 were *Digitaria setigera* and *Borreria laevis*. Except for interrow cultivation at 15 d after emergence (DE) and interrow cultivation at 15 and 30 DE, all weed control practices significantly reduced weed weight at 45 DE (Table 6). Grain yields from all weeding treatments were significantly higher than those from the unweeded check. The highest yields were obtained with interrow cultivation + hand weeding. Use of a double moldboard plow for interrow cultivation is likely to gain acceptance among farmers because of high yields, relatively low cost, and the resultant high marginal benefit-cost ratio (B:C). The herbicide pendimethalin is unlikely to be used at present because of its cost, even though it saves labor — 46 h/ha compared with an average of 130 h/ha for interrow cultivation + hand weeding.

Weeds, primarily *B. laevis* and *Rottboellia cochinchinensis*, caused significant yield reductions in rice (Table 7). All weed control treatments caused a significant reduction in weed weight

Table 6. Weed weight, grain yield, cost of weed control, and marginal benefit-cost ratio as affected by weed control practice in DMR-2 maize.[a] Claveria, Misamis Oriental, Philippines, 1985 WS.

Treatment[b]	Time of application (DE)	Dry weed weight (g/m^2) at 45 DE	Grain yield (t/ha)	Cost of weed control ($/ha)	Marginal benefit:cost
Modified IRC + HW	15 & 30	7.3 a	3.4 a	13.53	26
Conventional IRC + HW	15 & 30	5.5 a	3.3 a	19.80	18
Pendimethalin (1.32 kg ai/ha) fb HW	PE[c] fb 30	1.4 a	3.2 ab	37.42	9
IRC + HW	15	22.1 ab	3.0 ab	12.71	23
HW	15 & 30	6.1 a	2.9 ab	22.75	12
IRC + hoe weeding	15 & 30	7.3 a	2.5 ab	13.64	16
IRC	15 & 30	36.4 bc	2.3 ab	5.13	37
IRC	15	45.6 bc	2.3 ab	2.56	72
IRC + hoe weeding	15	26.1 ab	2.1 b	8.73	19
No weeding	–	58.4 c	1.1 c	–	–

[a]DE = d after emergence. [b]IRC = interrow cultivation using a single moldboard plow, HW = hand weeding, fb = followed by, modified IRC = interrow cultivation using a double moldboard plow. [c]Preemergence.

Table 7. Weed weight, grain yield, cost of weed control, and marginal benefit-cost ratio as affected by weed control practice in UPLRi5 rice. Claveria, Misamis Oriental, Philippines, 1985 WS.

Treatment	Time of application (DE)	Dry weed weight (g/m^2) at 60 DE	Grain yield (t/ha)	Cost of weed control ($/ha)	Marginal benefit: cost
HW	15, 30, & 45	8.9 a	3.7 a	42.99	11
Hoe weeding	15, 30, & 45	6.7 a	3.5 a	36.01	13
Pendimethalin (1.5 kg ai/ha) fb IRC + HW	PE fb 30	9.1 a	3.1 a	48.82	8
Hoe weeding	15 & 30	30.6 abc	3.0 ab	25.42	16
Pendimethalin (1.5 kg ai/ha) fb HW	PE fb 30	19.2 ab	3.0 ab	44.30	9
IRC + HW	15, 30, & 45	9.8 a	3.0 ab	47.41	8
HW	15 & 30	21.0 ab	2.8 ab	39.38	9
IRC + HW	15 & 30	41.0 bc	2.1 bc	35.35	7
HW	30	32.5 abc	1.7 cd	21.11	10
Hoe weeding	30	54.7 c	1.4 cd	20.02	8
IRC + HW	30	50.9 c	0.9 de	20.95	4
No weeding	–	203.3 d	0.3 e	–	–

except for interrow cultivation + hand weeding at 30 DE, resulting in a significant increase in yield compared with the untreated check. Hand weeding or hoe weeding three times resulted in the highest yields and among the highest marginal B:Cs. The highest B:C was from two hoe weedings. Even though the herbicide treatments gave high yields, the marginal B:Cs, although still very attractive, were lower because of the high cost of herbicide ($37.21/ha).

Upland crops after rice. The effect of time of planting on weed growth and yield of upland crops planted after TPR was studied at IRRI. *Eleusine indica*, *Cleome rutidosperma*, and *Cyperus rotundus* were the dominant weed species regardless of the crop grown and the date of planting. *E. indica* was favored by the high soil moisture content in the 30 Oct planting, while *C. rotundus* preferred the lower soil moisture when planting was 30 Nov or 15 Dec. Weed weight at 45 DE decreased progressively from an average of 213.1 g/m^2 in the 30 Oct planting to 9.1 g/m^2 in the 15 Dec planting, and the number of weed species in the unweeded plots also decreased from 30 to 8. No crop planted on 30 Oct gave any yield because flooding soon after planting killed the germinating

Table 8. Crop yield as affected by time of planting and weed control method.[a] IRRI, 1984-85.

Time of planting	Crop yield (t/ha)		
	No weeding	Weeded once at 15 DE	Weeded twice at 15 & 35 DE
		Mungbean	
30 Oct	0 c	0 c	0 b
15 Nov	1.0 ab	1.4 a	1.5 a
30 Nov	1.5 a	1.3 a	1.2 a
15 Dec	0.6 bc	0.5 b	0.5 b
		Sorghum	
30 Oct	0 c	0 d	0 c
15 Nov	1.2 ab	2.0 a	1.9 a
30 Nov	1.3 a	1.6 b	1.7 a
15 Dec	0.9 b	1.0 c	1.1 b

[a]Within each crop, means in a column followed by the same letter are not significantly different at the 5% level by DMRT. LSD (0.05) to compare yields among weed control methods within planting date = 0.3 for mungbean, 0.4 for sorghum.

crop seeds. The 30 Nov and 15 Dec plantings gave no maize yield because of water shortage. Uncontrolled weed growth did not significantly reduce yield in the 15 Nov planting.

For both mungbean and sorghum, uncontrolled weed growth significantly reduced yield in the 15 Nov planting but not in the later plantings (Table 8). The significant decrease in yield in both crops in the 15 Dec planting was due to water shortage.

Control of *Scirpus maritimus*. In DS cropping pattern trials, the yield of rotary weeded plots in a continuous-TPR pattern was significantly higher than that of the untreated check (Table 9). Many *S. maritimus* escaped the bentazon treatment. The untreated check gave no yield because of high *S. maritimus* and annual sedges.

When maize was intercropped with soybean, the highest yields were obtained with hand weeding. Without weeding, the low yield was due to a mixed population of broadleaf and grassy weeds. Where maize was planted alone, hand weeded and herbicide-treated plots gave similar yields. Because of the buildup of broadleaf weeds, the untreated check gave a low yield.

In continuous TPR during WS, the yield of rotary weeded plots was higher than that of herbicide-treated and unweeded checks (Table 10).

In the upland crop - TPR pattern, yield differences were similar to those in continuous TPR. Yields of the untreated plot were low because of the annual sedge *Fimbristylis miliacea*.

In dry seeded, rainfed, bunded rice following maize, yields were higher with hand weeding only. The butachlor and untreated plots gave low yields because of *Macroptilium lathyroides* and *Ipomoea triloba*. *Cyperus* spp. was present in the plots.

Table 9. Effect of weeding method and cropping pattern on crop yield and population density of weeds. IRRI, 1985 DS.

Cropping pattern and weeding treatment[a]	Yield/ha[a]	Weeds (no./m²)				
		Broadleaf weeds	Grasses	Sedges	*Scirpus maritimus*	*Cyperus rotundus*
Continuous TPR	*Rice (t)*					
Rotary weeding	3.0 a	4	0	21	66	0
Bentazon (2.0 kg ai/ha)	1.7 ab	1	2	0	131	0
No weeding	0 b	4	0	131	436	0
Upland crops - TPR	*Maize (ears) + soybean (kg)*					
Hand weeding	30,500 a + 716 a	6	44	0	0	2
Butachlor (1.5 kg ai/ha)	15,500 b + 654 a	8	9	0	2	0
No weeding	11,500 b + 496 a	13	63	15	12	0
Maize - rainfed bunded DSR[b]	*Maize (ears)*					
Hand weeding	12,000 a	52	17	0	0	4
Butachlor (1.5 kg ai/ha)	14,000 a	76	6	0	0	0
No weeding	3,500 b	116	0	0	7	0

[a]Av of 2 replications. [b]Dry seeded rice.

Table 10. Effect of weeding method and cropping pattern on rice yield and population density of weeds. IRRI, 1985 WS.

Cropping pattern and weeding treatment	Rice yield[a] (t/ha)	Weeds (no./m²)				
		Broadleaf weeds	Grasses	Sedges	*S. maritimus*	*C. rotundus*
Continuous TPR						
Rotary weeding	3.0 a	4	5	143	21	0
Bentazon (2.0 kg ai/ha)	2.2 b	0	12	0	330	0
No weeding	0.03 c	7	5	16	453	0
Upland crop - TPR						
Rotary weeding	3.3 a	2	1	166	17	0
Bentazon (2.0 kg ai/ha)	3.2 a	1	3	104	7	5
No weeding	0.8 b	17	0	597	107	9
Upland crop - rainfed bunded DSR						
Hand weeding	1.6 a	228	6	60	0	0
Butachlor (1.5 kg ai/ha)	0.4 b	180	1	4	1	1
No weeding	0.6 b	129	12	0	0	8

[a]Av of 2 replications.

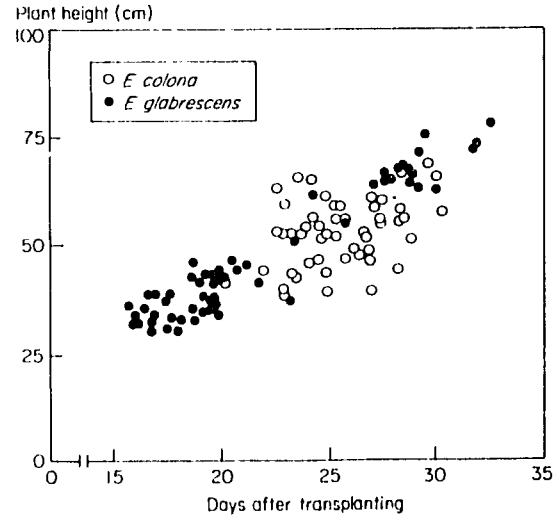
***Echinochloa* species.** *Morphological characteristics.* Seeds of different plants of *Echinochloa colona*, *E. glabrescens*, and *E. crus-galli* ssp. *hispidula* were collected from upland and lowland fields at IRRI, and seeds of *E. oryzoides* were collected from lowland fields in Guimba. The seeds collected from each plant were regarded as a separate strain. There were 37 strains of *E. colona*, 37 of *E. glabrescens*, 21 of *E. crus-galli* ssp. *hispidula*, and 9 of *E. oryzoides*.

After germination in petri dishes, 1-day-old seedlings of each strain were planted in soil in plastic trays in the greenhouse and watered regularly. Ten days later, five seedlings of each strain at the three-leaf stage were transplanted into the field.

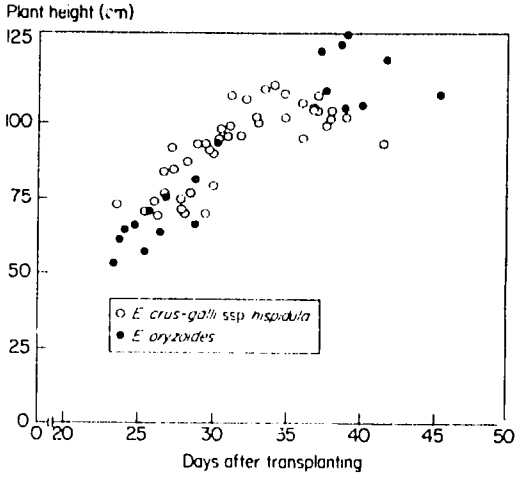
The range of the days to heading of the different strains was 16-33 DT for *E. glabrescens*, 24-42 DT for *E. crus-galli* ssp. *hispidula*, 23-45 DT for *E. oryzoides*, and 20-30 DT for *E. colona* (Fig. 5, 6).

The strains of *E. glabrescens* and *E. oryzoides* could be grouped into early- and late-heading types. Between the early- and late-heading groups of *E. glabrescens*, there was a 10-d difference in mean heading time. Three strains with intermediate time to heading would not fit into these groups. For *E. oryzoides*, there was a 13-d difference in mean heading time between the 2 groups. Although the strains of *E. crus-galli* ssp. *hispidula* had a wide variation in heading time and there were early- and late-heading strains, the variation in heading time was continuous from one strain to the next, and it was not possible to separate them into early and late groups.

There were also differences in some other morphological characters among the *Echinochloa* species and between the early- and late-heading



5. Days to heading and plant height of *Echinochloa colona* and *E. glabrescens* strains. IRRI, 1985.



6. Days to heading and plant height of *Echinochloa crus-galli* ssp. *hispidula* and *E. oryzoides* strains. IRRI, 1985.

groups (Table 11). Culm diameter, the number of elongated internodes, panicle length, leaf length, and leaf width were consistently smaller for the early-heading groups. There were similarities in these characters between the early-heading *E. glabrescens* strains and the *E. colona* strains and between the late-heading *E. glabrescens* strains and the *E. crus-galli* ssp. *hispidula* strains.

Based on the colors of the basal stem, leaf margin, stigma, and anther, two types of *E. colona* could be distinguished: the common (red) type and the green type (Table 12). The other *Echinochloa* species showed no variation within a species. Differences in color of the characters can be used to separate *E. colona* and *E. oryzoides* from *E. glabrescens* and *E. crus-galli* ssp. *hispidula*, but the colors are common for the latter two species even though there are differences in some of the other morphological characters.

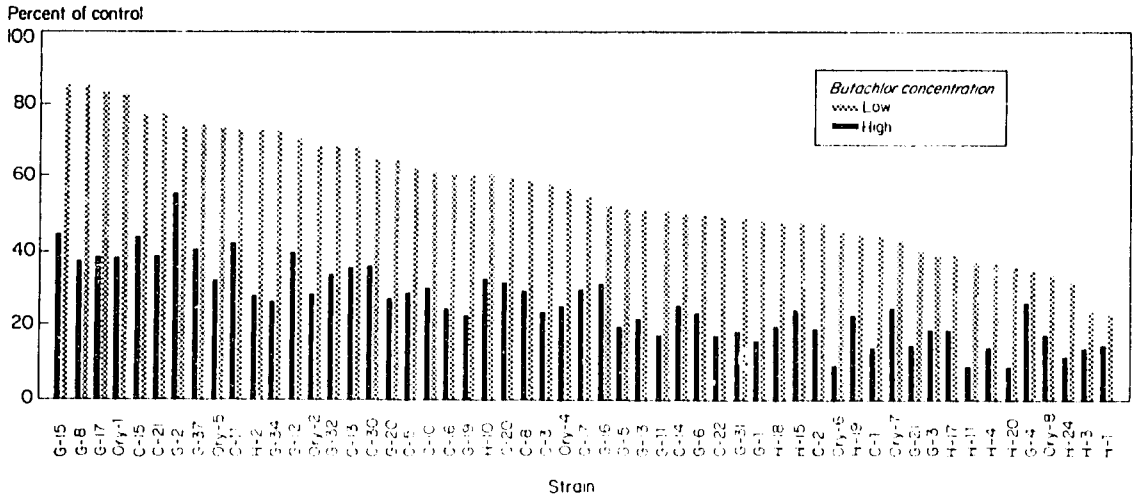
Response to herbicides. Variation among *Echinochloa* species and among strains in their susceptibility to herbicides was observed in a pot (9-cm diameter) trial (Fig. 7). *E. crus-galli* ssp. *hispidula* was more susceptible to a low concentration of butachlor (2 ml of 2.4 ppm vol/vol ai) than *E. glabrescens* and *E. colona*. The herbicide reduced shoot length by more than 50% in 10 of 12

Table 11. Morphological characteristics of *Echinochloa* species. IRRI, 1985.

Species and group	Culm diameter (mm)	Elongated internodes (no.)	Panicle length (mm)	Flag leaf	
				Length (mm)	Width (mm)
E. colona	3-5	4-7	80-150	85-160	7-16
E. glabrescens					
Early	3-5	3-5	80-130	100-150	8-12
Late	6-8	5-7	140-200	150-220	12-17
E. crus-galli ssp. *hispidula*	5-9	4-8	120-180	150-200	10-16
E. oryzoides					
Early	4-6	4-6	100-200	150-190	<10
Late	7-10	6-8	>200	250-290	13-17

Table 12. Color of some morphological characters of *Echinochloa* species. IRRI, 1985.

Species and type	Basal stem	Leaf margin	Stigma	Anther
E. colona				
Common (red)	Brown or red	Red	Red	Purple
Green	Green	White	Whitish pink	Whitish yellow
E. glabrescens	Green or brown	Mostly white	Red	Brown
E. crus-galli ssp. *hispidula*	Green or brown	White or red	Red	Brown
E. oryzoides	Green	White	Pink	Whitish yellow



7. Variation in susceptibility of *Echinochloa* species (G = *E. glabrescens*, C = *E. colona*, H = *E. crus-galli* ssp. *hispidula*, Ory = *E. oryzoides*) to butachlor. IRRI, 1985.

tested strains of *E. crus-galli* ssp. *hispidula*, 4 of 20 in *E. glabrescens*, and 2 of 16 in *E. colona*. There was a positive correlation ($r = 0.824^{**}$) between susceptibilities of the strains to low and high concentrations of butachlor.

Reduction in shoot length was less when thiobencarb was applied. *E. colona* tended to be more susceptible to this herbicide than did the other *Echinochloa* species.

Cropping systems program

Design and evaluation of cropping patterns

Multiple Cropping, Water Management, and Agricultural Economics Departments

PARTIALLY IRRIGATED ENVIRONMENT 382
Agronomic performance 382
1984 wet season rice 382
Transition season — maize in turod 382
Transition season — rice in lungog 383
Late dry season crops 383
1985 wet season rice 384
Assessing economic viability of tested cropping patterns 385
Sensitivity analysis 385
Technical feasibility 386
Management of water in the service area 386
1984 wet season water management 386
1985 dry season water management 388
Improving water use 389
The irrigators' association 392
Production potentials in the service area 392
System adjustment to move toward production potential 392
UPLAND RICE ENVIRONMENT WITH ACID SOILS 393
Cropping pattern testing on acid upland soils in Claveria 393
Fertilizers for upland rice 394
Mungbean in an acid upland environment 394

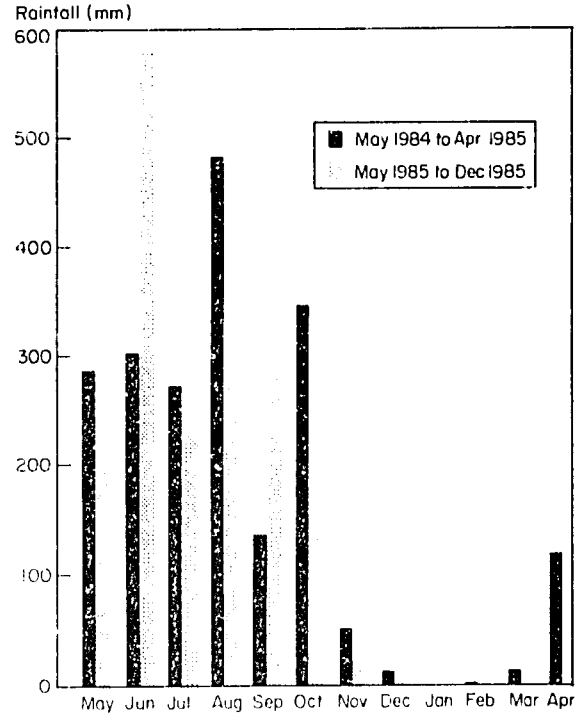
PARTIALLY IRRIGATED ENVIRONMENT

Multiple Cropping, Water Management, and Agricultural Economics Departments

In the Guimba project, 24 farmer-cooperators tested cropping patterns in about 1,000-m^2 fields in the irrigation service area. Originally 96 ha, the service area had decreased to about 60 ha. The research objectives were to develop cropping patterns that farmers could manage with their resources on lungog (low-lying, water accumulating) and turod (upper stratum) land; to produce higher returns to land, to cash inputs, and to labor than in current patterns; and to determine what irrigation management strategies could be used to efficiently distribute limited and costly water in most of the service area.

Agronomic performance. The crop year at the research site is conveniently divided into three seasons: wet season (WS, June to October), transition season (November to January), and late dry season (DS, February to May). The divisions are arbitrary, but the seasons are sufficiently different to affect crop performance. A major difference with respect to field operation and crop adaptation occurs during the transition season. Turod fields drain more quickly than lungog fields, enabling upland crops to be established sooner after rice harvest. During the transition season, the water table is near the surface in lungog. As the water table recedes, these fields also drain, but not as quickly as turod. Because drainage of lungog is slow, a second rice crop following the WS crop would be best for lungog during the transition period. Maize or other upland crops were tested in turod during the transition season. Monthly rainfall during 1984 WS and transition season and all of 1985 is shown in Figure 1.

1984 wet season rice. Grain yields in 24 fields averaged 4.0 t/ha, with no difference between lungog and turod. Research-managed experiments showed no response to P or K in lungog or turod; a 1.4 t/ha response to 30-60 kg N/ha in a turod field, but no detectable response to N in a lungog field; and a 1.1 t/ha response to 10 kg $ZnSO_4$/ha in a lungog field and a 0.3 t/ha response in a turod field. Grain yields were slightly lower (by 0.5 t/ha) than expected because 2 varieties, IR36 and IR42, were affected by tungro (RTV).



1. Monthly rainfall in Guimba, Nueva Ecija, Philippines, May 1984-Dec 1985.

Transition season — maize in turod. The mean yield of maize in 10 cropping pattern test fields in turod was only 2.6 t/ha — well below the 8 t/ha possible from the maize hybrids used. Crop establishment was a major obstacle. On many fields, large clods that formed during primary tillage were not sufficiently reduced in size by secondary tillage with local implements. Consequently, soil-seed contact was poor and emergence was low. Other obstacles were drought, especially in fields far from the pump, and waterlogging in fields close to ditches or adjacent to flooded ricefields. In two of the cropping pattern test fields, farmers reversed earlier decisions to plant maize and kept the fields idle for 3 mo, intending to plant rice in January. Rice yield from one field was 2.9 t/ha, but the other did not get sufficient water for land preparation and transplanting because it was too far from the pump.

Fertilizer trials showed that, although maize responded to N fertilizer, responses were not consistent across fields. The highest mean yield from 6 superimposed trials and 1 researcher-managed trial was 3.5 t/ha. N fertilizer efficiency

averaged 28 kg grain/kg N, which was satisfactory, but mean yield at 50 kg N/ha, the lowest N rate in the trial, was only 2.3 t/ha. Tillage and seed placement studies were implemented in November and December 1985.

Transition season — rice in lungog. Only 4 of the 12 cropping pattern test fields in lungog were transplanted before 30 Nov. The mean yield of the 3 fields where transplanting was between 15 Nov and 15 Dec was only 1.4 t/ha. Three early planted fields were so heavily damaged by insects and rats that they were plowed under. The mean yield of the 6 fields planted between 5 and 11 Jan was 3.7 t/ha. Early planted transition season rice crops were fraught with constraints, but late planted crops used irrigation water inefficiently and left no time for a third crop before WS. Farmer cooperators were aware that yields from early transplanted rice would be low, and they delayed planting until many neighbors were proceeding with field preparations. Those who delayed obtained higher yields, but these yields were below DS potential because water was not sufficient for all fields in the command area during a season when percolation losses and evaporative demand were high. Mean class A pan evaporation for January, February, and March was 5.9 mm/d, compared with 3.5 mm/d from June to September.

The few ricefields that were planted early were isolated and attracted insects and rats; standard control measures were inadequate. Although percolation rates were probably not high, seepage losses were. Notwithstanding relatively frequent irrigation, fields occasionally dried to the point of cracking. Even if insects and rats were controlled and fields were maintained fully flooded, 1 or more of 3 weather factors may have limited yields to less than 4.0 t/ha: during the transition season, solar radiation is relatively low, minimum temperatures are below 18 °C some nights, and winds from the northeast are strong and dry at midday. Low solar radiation from booting to maturity constrains yields; low temperatures hamper panicle exsertion and promote sterility; and strong, dry winds place crops under high transpiration demands. In the 1985 transition season, research was implemented to determine the yield limitations imposed by solar radiation, temperature, strong winds, insects, Zn deficiency, and insect pests.

Late dry season crops. Delayed rice transplanting in lungog left insufficient time for mungbean before WS rains were expected. Therefore, no late DS crops were planted in lungog. Furthermore, even when ricefields were transplanted early and harvested by 28 Feb, they were surrounded by flooded fields until May and were therefore too wet for mungbean.

In turod, mungbean was well adapted to the postmaize period, but peanut was not. Moreover, farmers were reluctant to plant peanut because its labor requirement is high. Of the 12 turod fields, peanut was sown in only 3 and mungbean in 8. The 12th field remained fallow. The mean peanut yield was only 0.74 t/ha, and seed quality was low. Because peanut requires 110-120 d to mature, crops planted in early March after maize harvest were not ready for harvest until June.

Mungbean yields averaged 0.92 t/ha. Major cultural problems were not encountered except that mean planting date was 29 Mar, which is risky if WS rains start early. Some late planted mungbean was exposed to early WS rainfall, which adversely affected grain quality. Mungbean is of interest to farmers in the project area as a late DS crop because it yields well, is relatively easy to establish, does not require fertilizer, competes well with weeds, requires only 70 d, has a good price in the local market, and is not excessively demanding on labor.

Researcher-managed peanut experiments indicated that close hill spacings (20 or 25 cm) with 2 plants/hill was superior to wider spacings and to 1 plant/hill. Mean yield was 1.09 t/ha from 20- and 25-cm spacings with 2 plants/hill and 0.81 t/ha from the 30-cm spacing with 2 plants/hill. Mean yield from all treatments with 1 plant/hill was 0.84 t/ha. Peanut yields were also higher (mean 1.24 t/ha) when seeds were planted by the local method (seed furrow opened with a native plow, seeds dropped by hand, and covered and pressed by bare foot) compared with 0.89 t/ha when planted with an animal-drawn seed fertilizer applicator at 0.30 t/ha with a rolling injection planter.

A researcher-managed experiment on mungbean establishment indicated that satisfactory stand and yield could be obtained from seed broadcast or placed with a seed and fertilizer applicator on fields plowed twice and harrowed

twice, or from seed planted by the local method (field plowed once and harrowed once, seed dropped by hand and covered and pressed by bare foot). Mean mungbean yield from the 3 treatments was 1.0 t/ha. Mean yield from seed placed by a rolling injection planter was 0.29 t/ha. Tillage treatments had no effect on rolling injection planter performance.

1985 wet season rice. The 1984 WS and 1985 WS differed in several ways. Grain yields in 1985 averaged 4.5 t/ha — 0.5 t/ha more than in 1984. In 1985, only IR56 and IR58 were grown, and therefore RTV was not the problem it was in 1984. Populations of stem borer and other insect pests were lower in 1985 than in 1984.

Once 1984 rains started in early April, the weekly rate was nearly uniform over the next 18 wk, averaging approximately 79 mm. In 1985, however, rainfall during the first 9 wk averaged only 42 mm/wk, even though rains started at the same time. Soils presumably remained aerobic longer in 1985 than in 1984. Relatively low early rainfall also contributed to slight but manageable delays in seedbed sowing. Consequently, fields were transplanted later in 1985 than in 1984. In 1985, competition for transplanters delayed transplanting so that seedlings in some fields were beyond optimum age. Nevertheless, yields were relatively high in all cases. Mean yields from IR56 and IR58 differed by less than 0.1 t/ha, but mean yields from turod fields were 0.4 t/ha higher than those from lungog.

Researcher-managed and superimposed experiments in both turod and lungog showed no response to Zn: 20 or 40 kg $ZnSO_4$/ha applied to the seedbed, incorporated before transplanting, or broadcast and incorporated 1 wk after transplanting. Nor did fields exhibit Zn deficiency symptoms in 1985. Mean yield from researcher-managed experiments was 5.0 t/ha in turod and 4.8 t/ha in lungog. The difference in WS onset may explain some of the difference observed in insect pressures and Zn deficiencies between the two years. Researcher-managed and superimposed trials on both terrains showed no evidence of P or K deficiency. Response to N, however, was significant in both terrain positions.

Partial budgeting was used to determine the most profitable level of fertilizer application in a

Table 1. Costs and returns of cropping patterns in the experimental (E) and farmers' (F) fields by land type.[a] Guimba, Nueva Ecija, Philippines, 1984-85.

Cropping pattern[b]	Costs (₱/ha)				Yield (t/ha)			Gross return	Return above variable costs (₱/ha)[c]	Rates of return (₱/₱)				Marginal benefit-cost ratio[h] to replace R-F (F)
	Labor and power	Materials	Irrigation	Total variable	1	2	3			Labor and power[d]	Materials[e]	Irrigation[f]	Total variable[g]	
							Turod							
R-M-MG (E)[i]	316	410[j]	227	953	3.88	2.42	0.92	1641	688	3.18	2.68	4.03	1.72	1.90
R-M-P (E)[i]	394	420	227	1041	3.71	2.99	0.74	1590	549	2.39	2.31	3.42	1.53	1.62
R-R (F)[k]	217	214	192	623	3.44	2.39	–	928	305	2.40	2.43	2.59	1.49	1.66
R-F (F)[k]	93	95	77	265	2.15	–	–	333	68	1.73	1.71	1.88	1.26	
							Lungog[m]							
R-R (E)[l]	305	381	183	869	3.74	1.91[m]	–	898	29	1.06	1.08	1.16	1.03	0.99
R-R (F)[k]	201	218	192	611	2.69	3.21	–	944	333	2.66	2.53	2.73	1.54	1.89
R-F (F)[k]	104	94	77	275	2.19	–	–	309	34	1.33	1.36	1.44	1.12	

[a]$1 = ₱18.74. [b]R = rice, M = maize, MG = mungbean, P = peanut, F = fallow. [c]Gross return – total variable cost. [d](Gross return – material + irrigation cost) ÷ labor and power cost. [e](Gross return – labor and power + irrigation cost) ÷ material cost. [f](Gross return – labor and power + material cost) ÷ irrigation cost. [g]Gross return ÷ total variable cost. [h]Marginal benefit cost ratio = $\frac{\text{gross return of potential pattern – gross return of prevalent pattern}}{\text{total variable cost of potential pattern – total variable cost of prevalent pattern}}$

[i]With IR42 as first crop. [j]An interest rate of 30% for material costs was included. [k]Av of all varieties grown by farmers. [l]With IR36 as first crop and IR36 (5 plots) and IR56 (6 plots) as second crop. [m]Included 3 plots with zero yield due to rat and insect damage.

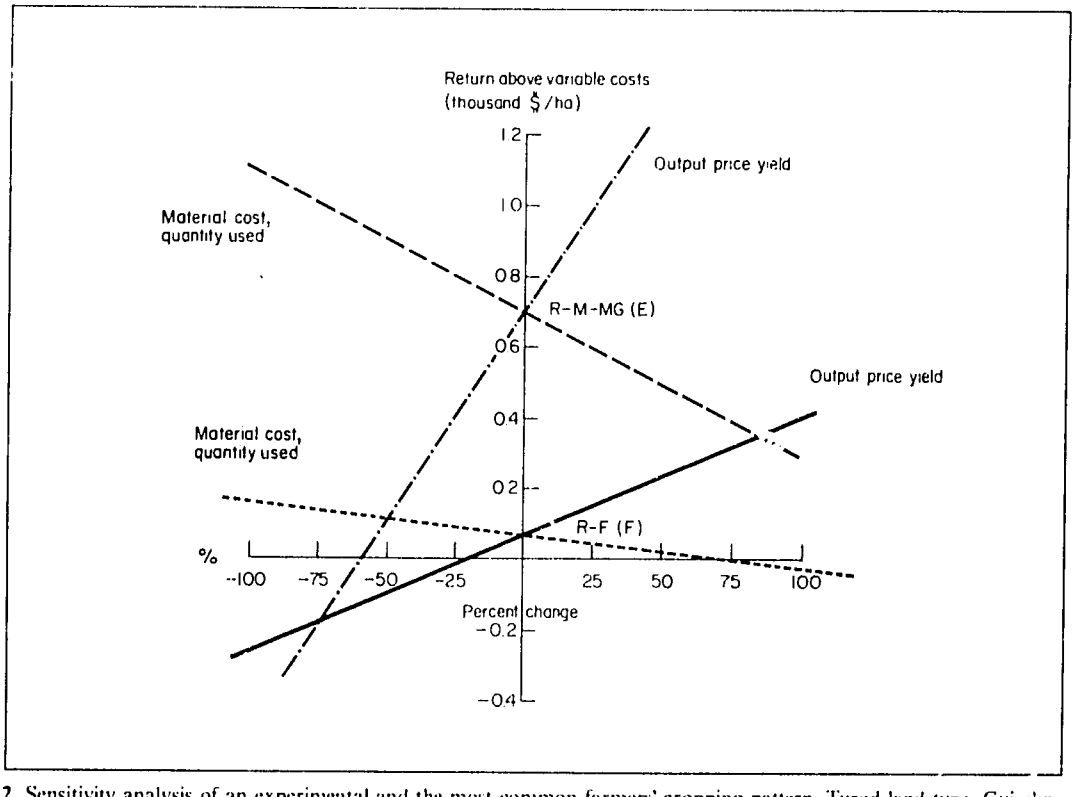
researcher-managed 1985 WS rice experiment in lungog. Yield was maximum at 60-13-24 kg NPK/ha, but net benefit per ha was highest with a rate of 60-0-0.

A comparison of $(NH_4)_2SO_4$ and urea N in lungog showed that efficiencies were not significantly different.

Assessing economic viability of tested cropping patterns. Enterprise budgeting was used to compare the results of the experimental and farmers' cropping patterns (Table 1). The experimental cropping pattern rice - rice (R - R) in lungog generated lower return above variable costs (RAVC) than the farmers' R - R pattern because of the low yield of the second rice crop in the experimental pattern.

In turod, both experimental cropping patterns — rice - maize - mungbean (R - M - MG) and rice - maize - peanut (R - M - P) — generated higher RAVC than the two most common patterns followed by farmers — rice - fallow (R - F) and R - R. R - M - MG also generated higher rates of return to labor and power, material inputs, irrigation costs, and total variable costs than either of the farmers' cropping patterns. The marginal benefit-cost ratio of 1.9 for R - M - MG indicates that, for each $1.00 increase in variable costs above the cost of the farmers' R - F pattern, an increase of $1.90 was returned.

Sensitivity analysis. The variable cost of the most profitable experimental pattern (R - M - MG, $953/ha) was much higher than that of the farmers' patterns of R-R ($623/ha) and R - F ($265). Parametric budgeting was used to assess the degree to which these higher costs might expose the farmer to economic losses resulting from cost increases or from price and yield decreases. Figure 2 compares the most common farmers' cropping pattern in turod (R - F) with the experimental R - M - MG. The experimental pattern required larger percentage of changes in costs, yields, or prices than the farmers' pattern to reduce RAVC to zero. R - F required an increase in variable costs of 75% or a decrease in yield or price of 20% to reduce



2. Sensitivity analysis of an experimental and the most common farmers' cropping pattern. Turod land type, Guimba, Nueva Ecija, Philippines, 1984-85.

Table 2. Effect of changes (%) of input prices or quantities and output prices or yields on return above variable costs. Turod land type, Guimba, Nueva Ecija, Philippines, 1984-85.

Cropping pattern	Change (%)			
	$100 increase		$200 increase	
	Input price or quantity	Output price or yield	Input price or quantity	Output price or yield
Farmer's (R-F)	−105	+30	−210	+60
Experimental (R-M-MG)	−24	+6	−48	+12

RAVC to zero. In contrast, R - M - MG required a 150% increase in costs or a 50% decrease in yield or prices to do so.

A lower percentage of change in costs, yields, or prices was required for R - M - MG than for R - F to raise RAVC an absolute amount (Table 2). RAVC was more sensitive to changes in yields or prices than to changes in costs.

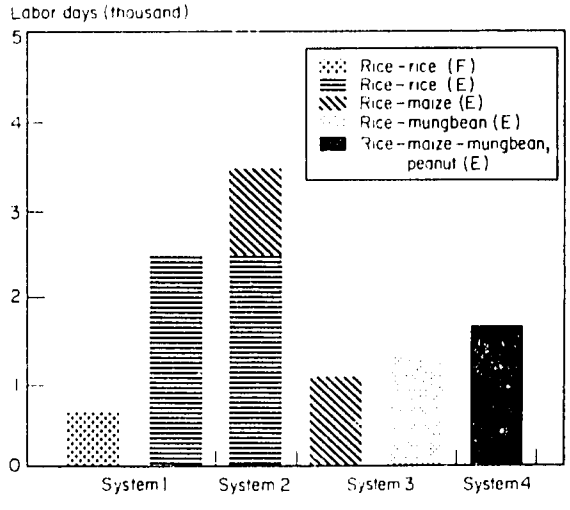
Technical feasibility. Labor, power, credit, marketing, and irrigation were seen as potential constraints to the adoption of R - M - MG on a substantial part of the P-27 tubewell service area, although neither DS upland crop in three-crop sequences required more than 30 labor-d/ha during the 180-d season (Fig. 3). Household labor generally was not sufficient to meet labor requirements during peak periods of land preparation, seeding or transplanting, and harvesting if the whole turod was planted to R - M - MG.

Credit from institutional sources, was not available to farmers, but they made use of informal credit sources, paying an annual interest of about 120%. Marketing of mungbean or maize was not a constraint.

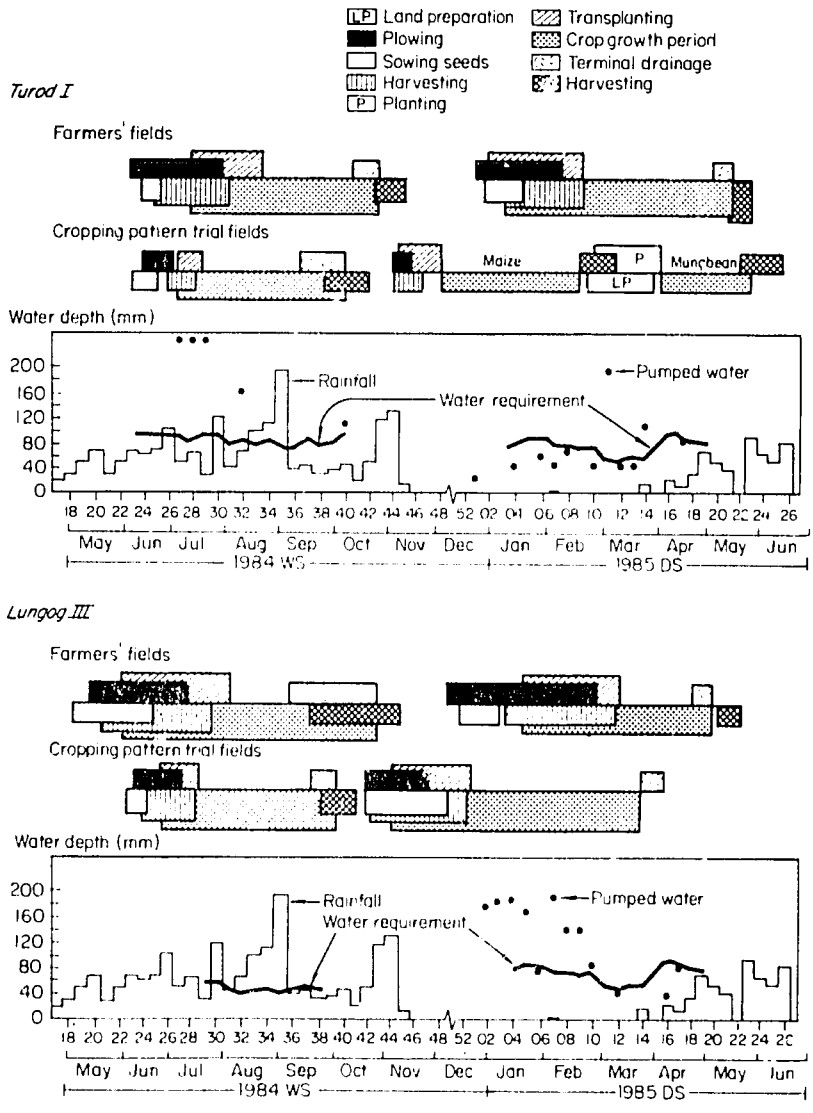
The major technical constraint limiting the cultivation of experimental cropping patterns centered on irrigation and field operations during the transition season.

Management of water in the service area. The continuing increase in electrical power costs has severely jeopardized the economic viability of deep tubewell irrigation systems. The cost of energy is primarily responsible for the current irrigation service fees of 450 kg of rice/ha for WS and 800 kg/ha for DS. With these fees, many farmers within the P-27 service area have chosen not to use water from the deep tubewell, increasing the cost of pumping for the remaining farmers.

1984 wet season water management. During 1984 WS, all farmers in the P-27 service area grew rice. Rainfall provided most crop water requirements, and it was necessary to pump only a few times to provide water when rainfall was inadequate (Fig. 4). Data from 24 sample farms, 12 in lungog and 12 in turod, indicated high variability in water requirement. The average water requirements for WS were 518 mm for land preparation and 694 mm for crop growth. Farmers' actual average water use was 446 mm for land preparation, of which 344 mm was rainfall. The remaining 102 mm was supplied from the pump for 3 wk in July when weekly rainfall averaged less than 60 mm — insufficient to meet all water requirements. The deficit of 72 mm during WS land preparation can be attributed to farmer reluctance to use the



3. Potential total DS employment from using alternative cropping systems (F = farmers', E = experimental) in the P-27 service area, 50% water use efficiency. Guimba, Nueva Ecija, Philippines, 1984-85.



4. Cropping pattern and crop activity schedules in farmers' and experimental cropping patterns, weekly rainfall, pumped water, and crop water requirements. P-27, Guimba, Nueva Ecija, Philippines, 1984 WS and 1985 DS.

pump, thereby reducing the energy bill. Many farmers opted to wait for further rainfall so that they could avoid using pumped water, as was the case in many lungog fields (Fig. 4). The reluctance to use pumped water, together with other technical problems such as unavailability of labor, power, and credit, resulted in 110 d between initial plowing and final transplanting — about twice that of comparable systems in Tarlac and Bulacan.

Water use for WS crop growth averaged 896 mm (Table 3), most of which was rainfall. Only two irrigations were required during crop growth to supplement rainfall: one in early August, another in late September. In both, however, the amount of water applied exceeded the rainfall deficit, leading to lower-than-desired water use efficiency (WUE). For WS as a whole, WUE with the pump in operation was low. Because each farmer could request water on an individual basis, and the canals had to be filled before water could flow into a given field, conveyance loss in the main canal was high; an average of 28% loss was measured over a 325-m section during the season. Farmers who were able to use pumped water on

Table 3. Water requirements of rice and water supplied to farmers' fields for land preparation and crop growth. Guimba, Nueva Ecija, Philippines, 1984 WS and 1985 DS.

Area	1984 wet season		1985 dry season	
	Water requirement (mm)	Water supplied (mm)	Water requirement (mm)	Water supplied (mm)
		Land preparation		
Lungog	492	331	408	320
Turod	557	561	368	402
P-27 service area	518	446	397	353
		Crop growth		
Lungog	628	853	761	1041
Turod	759	939	1036	583
P-27 service area	694	896	871	694

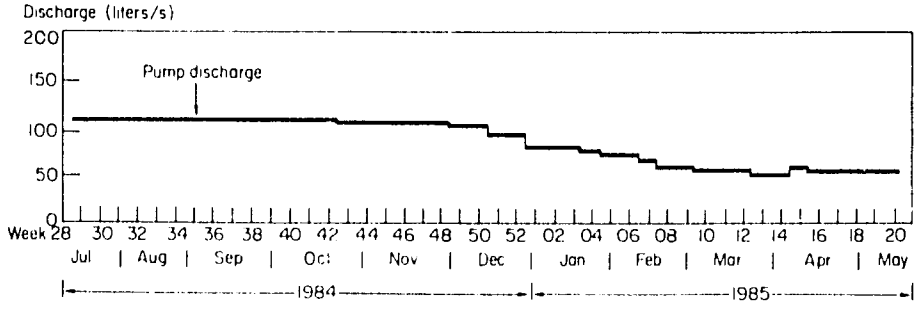
Table 4. Mean crop-cut yields and water productivity in farmers' fields. Guimba, Nueva Ecija, Philippines, 1984 WS and 1985 DS.

Area	1984 wet season		1985 dry season	
	Yield (kg/ha)	Productivity (kg rice/m³ water)	Yield (kg/ha)	Productivity (kg rice/m³ water)
Lungog	3488	0.25	4150	0.40
Turod	2713	0.17	3809	0.39
P-27 service area	3100	0.22	4014	0.42

demand achieved an average 41% WUE in the season. The average water productivity, 0.22 kg rice/m³ of water for WS (Table 4), was comparable to that in gravity systems where the irrigation fee is only 100 kg rice/ha.

1985 dry season water management. Water management activities in 1985 DS were closely monitored because they were most critical in terms of cost saving. Pump discharge during DS showed a much greater decline than expected (Fig. 5). Pump discharge remained static at 112 liters/s throughout WS, but from mid-December onwards it steadily declined to 56 liters/s in mid-March. It remained at this level until the end of DS. WUE thus had to be high to irrigate sufficient land to make energy costs reasonable, particularly as water requirements are considerably higher in DS.

Average water requirements were 397 mm for land preparation and 871 mm for crop growth (Table 3). The low value for land preparation can



5. Pump discharge from P-27, Guimba, Nueva Ecija, Philippines, 1984 WS and 1985 DS.

be attributed to the effects of residual moisture from the WS crop, while the increased value for crop growth reflects higher evapotranspiration during the latter part of DS and higher seepage and percolation due to soil cracking.

In DS, virtually all crop water needs must be met by pumping. During land preparation, average water deliveries were almost adequate to meet requirements. However, lungog areas received only 78% of the requirement, while turod areas received 109% (Table 3).

During crop growth, the water supply became increasingly constrained. In the initial stages, the relative water supply (RWS) was almost always greater than 1.0, indicating that supply exceeded demand. The lungog was better off than the turod (Table 5). However, as DS progressed, evapotranspiration increased and pump discharge declined, causing RWS to fall in all areas. For the entire cropped area, water supply was less than required by about 20%. The failure of the pump in April intensified the stress that had already developed. Yields were higher for DS than WS, presumably because of higher solar radiation and less disease.

Because rainfall was negligible, productive value of water was higher in DS. For both lungog and turod, about 0.42 kg of rice/m^3 of water was obtained, making the system more efficient than gravity irrigation systems but still well below potential. In experiments conducted on a turod farm growing maize, the productive value of water was 1.18 kg of maize/m^3 of water. However, the price of rice exceeded that of maize about 2.5 times; in monetary terms the productive value of water was almost the same for the 2 crops.

Despite the obvious scarcity of water, it was not used much more efficiently during DS. WUE for farmers with access to water on demand averaged 48%, indicating that farmers applied twice as much as required. Following repairs to the main canal, conveyance losses fell from 28% to 26% over the 325-m section in which measurements were made. WUE in the experimental area and on farms that were supplied with water on demand was less than 35%, well below the acceptable level.

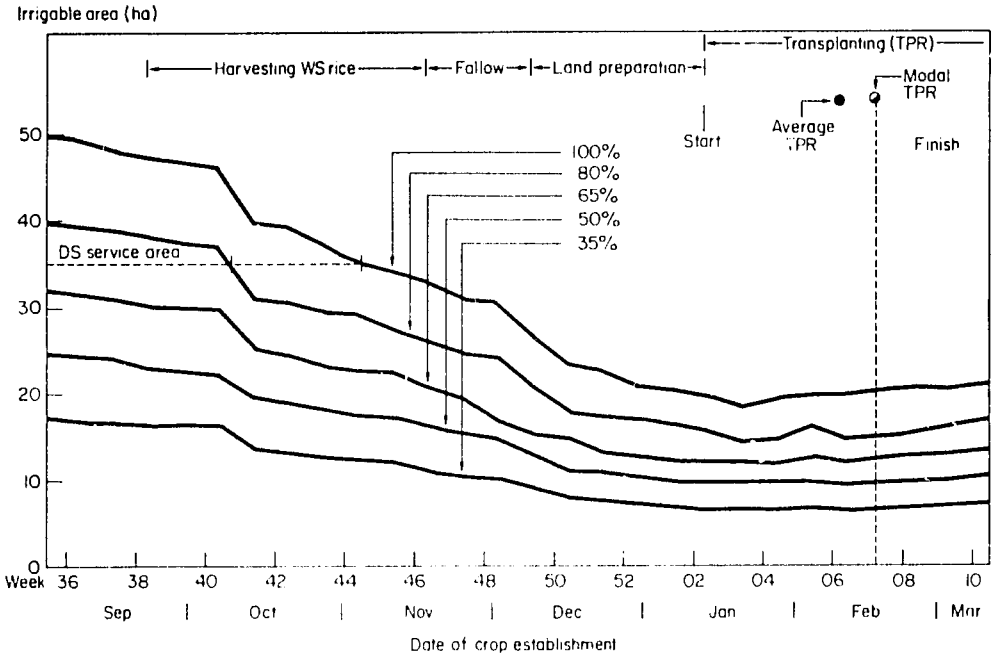
Improving water use. If pumping costs of P-27 are to be reduced, field operations must be coordinated, on-farm WUE raised, and water deliveries coordinated.

- *Timing of operations.* The current cropping calendar causes undue pressure on water resources in DS. Because discharge from the pump is lowest in March, a late start for DS land preparation means that the period of highest crop water requirement coincides with the lowest level of water availability, effectively limiting the area that can be served. The irrigators' association currently aims to irrigate 35 ha in DS. Using measured values of field level water requirements and pump discharge, and assuming no rainfall, it is possible to determine what area can be irrigated at different levels of WUE if no stress is to occur on crops. If the pump is operated for 12 h/d (actual use in 1985 DS was 12.8 h/d), and if WUE is 100%, then the latest planting date for a 35-ha DS area is week 45 (Fig. 6). If an 80% WUE is assumed, then the latest planting date is week 41 (early October). If WUE is lower than 65%, it is not possible to irrigate 35 ha for rice in DS. To plant the DS crop earlier, the

Table 5. Mean weekly relative water supply (RWS). P-27, Guimba, Nueva Ecija, Philippines, 1984 WS and 1985 DS.

Area	Mean RWS[a]			
	1984 wet season		1985 dry season	
	Vegetative period	Reproductive period	Vegetative period	Reproductive period
Lungog	1.61	1.44	1.48	0.91
Turod	1.46	1.12	1.15	0.73
P-27 service area	1.53	1.28	1.35	0.84

[a] $RWS = \frac{\text{irrigation + rainfall}}{\text{water requirements}}$



6. Irrigable areas for crop establishment dates at 5 water use efficiency levels (35-100%), assuming that P-27 operates 12 h/d. Guimba, Nueva Ecija, Philippines, 1985.

WS crop must have been previously harvested, which in turn presumes that the WS crop is transplanted earlier than currently.

The modal date of planting by farmers in 1985 DS was week 7 (mid-February). If WUE is 80%, then it is possible to guarantee only 16 ha of rice, given the declining pump discharge (Table 6). Current WUE of 35% in well watered areas can guarantee only 8 ha of rice, indicating that crop stress is inevitable with larger areas cultivated. Operating the pump for periods longer than 12 h/d would allow

Table 6. DS areas irrigable under 4 water use efficiencies (WUE) for 3 cropping patterns established at different periods, assuming that P-27 operates 12 h/d. Guimba, Nueva Ecija, Philippines, 1985.

Cropping pattern	Establishment period	Dry season irrigable area (ha)			
		WUE 80%	WUE 65%	WUE 50%	WUE 35%
Pattern 1: rice - rice					
Rice (lungog and turod)	1-15 Oct	37.1	30.2	23.2	16.2
	12-25 Feb	15.6	12.8	10.0	6.9
Rice (lungog only)	1-15 Oct	40.2	32.6	25.1	17.6
	12-25 Feb	16.7	13.6	10.4	7.3
Rice (turod only)	1-15 Oct	34.5	28.0	21.6	15.1
	12-25 Feb	14.7	12.0	9.2	6.4
Pattern 2: rice - rice (lungog) and rice - upland crop (turod)[a]	1-15 Oct[b]	(41.3)	(33.6)	(25.9)	(18.2)
Rice (lungog)		30.0	24.4	18.8	13.2
Maize (turod)		30.0	24.4	18.8	13.2
Pattern 3: rice - upland crop	1-15 Nov				
Maize		89.4	67.4	51.8	39.1
Mungbean		100.4	81.6	62.7	43.4

[a]Data in parentheses show effective rice area weighted by farmgate price of $0.06/kg maize and $0.17/kg rice. [b]Establishment period for rice only; upland crops planted on 1-20 Nov.

cultivation of larger areas but would not reduce per hectare pumping costs. There is also a risk that longer pumping hours would make crops more susceptible to drought stress if the pump failed and could not be repaired quickly.

An analysis of the cost of pumping shows the same basic trend (Table 7). If rice is transplanted by the first half of October, then with 12 h/d of pumping and a WUE of 80% the cost to farmers would be $84/ha. Delaying planting to February, but keeping other factors constant, would increase the cost to $200/ha. If planting were in February, then costs would rise to $312/ha at 50% WUE and $453/ha at 35% WUE. The current DS irrigation fee is equivalent to $138/ha, which requires that planting be done in October and that the system be operated at more than 50% WUE.

If farmers switched to crops other than rice, then there would be potential for a large increase in the service area and a reduction in per hectare operating costs. If all farmers were to plant either maize or mungbean in DS, then it would be possible to cultivate the entire service area if planting were early and WUE 80% (Table 6). Pumping costs would be $18-$23/ha. With 50% WUE, it should be possible to grow about 52 ha of maize or 63 ha of mungbean, with pumping costs of only $39/ha for maize and $30/ha for mungbean. But because of waterlogging problems in lungog, it is likely that rice will remain the preferred crop, at least in the transition season and early DS. Thus, a more realistic scenario is to grow upland crops on the lighter turod soils and rice on lungog soils. This would permit 30 ha of each crop area to be cultivated if WUE were 80%, decreasing to 19 ha each if WUE were 50%. The pumping costs would be reduced to $76/ha if WUE were 80%, and $121/ha if WUE were 50%. However, it is essential to maintain an early start in DS; each day of delay in planting after mid-October requires a WUE increase of about 1% or a reduction in area of 0.25 ha if stress on crops is to be avoided.

- *On-farm water use efficiency.* In both WS and DS, WUE on farms where water requirements were fully met averaged 45-50%. Farmers appear to have used irrigation water extravagantly, partly because during periods of water scarcity they may not feel certain that they can get another irrigation before their fields dry out, but more likely because there is no financial incentive to use water efficiently

the irrigation fee is fixed regardless of the actual volume of water used. Because volume is directly related to pumping hours, a variable

Table 7. Energy costs for 3 cropping patterns established at different periods and WUE, assuming that P-27 operates 12 h/d. Guimba, Nueva Ecija, Philippines, 1985.

Cropping pattern	Establishment period	Energy costs[a] ($/ha)			
		WUE 80%	WUE 65%	WUE 50%	WUE 35%
Pattern 1: rice - rice					
Rice (lungog and turod)	1-15 Oct	84	103	135	193
	12-25 Feb	200	244	312	453
Rice (lungog only)	1-15 Oct	78	96	124	178
	12-25 Feb	187	230	300	428
Rice (turod only)	1-15 Oct	91	112	145	207
	12-25 Feb	212	260	340	488
Pattern 2: rice - rice (lungog) and rice - upland crop (turod)	1-15 Oct[b]	76	93	121	172
Pattern 3: rice - upland crop	1-20 Nov				
Maize		23	30	39	52
Mungbean		19	23	30	44

[a]Energy cost/ha computed based on electricity cost of $0.09/kWh. [b]Establishment period for rice only; upland crops planted on 1-20 Nov.

irrigation fee based on time of irrigation is feasible if acceptable to farmers.

- *Main system efficiency.* The low WUE at the farmer level is due largely to high operational losses. The main channel takes a long time to fill before water flows into the fields. Thus, it is inefficient to serve isolated farmers more or less at random. In addition, many farmers deliberately leave turnouts open — each farm having independent access to the main channel — so that they will benefit whenever a farmer further down the channel receives water. At present, the farmer requesting water must close upstream turnouts, most of which no longer have gates.

The irrigators' association. Although many technical matters influence WUE, agronomic, economic, and irrigation management research suggests the potential to increase DS crop production in the P-27 service area. To improve efficiency, the management of the P-27 system must improve. P-27 is managed by an irrigators' association. Examination of the organization, power structures, and functions of the P-27 irrigators' association showed that collection of the seasonal irrigation fee is an important function. This fee and farmers' perceptions of the benefits they receive in return for paying it are important elements in their decision to pay the fee or not.

Production potentials in the service area. Ability to pay the cost of pumping implies that a farmer has used water to generate an economic return.

Using the estimates in Tables 6 and 7, and agronomic and economic data from farm record keeping and cropping pattern monitoring, RAVCs from growing alternative combinations of DS crops were determined for the entire command area. It was assumed that no privately owned shallow tubewells were used and that all irrigation was provided by the P-27 system.

Total RAVC in the command area was higher when upland crops were grown instead of rice. Assuming farmers' rice cultivation practices and a 50% WUE, a total of 10.4 ha could be irrigated, resulting in a $2,500 RAVC (Table 8). Devoting half of the area to rice and half to maize allowed 18.8 ha to be irrigated and increased total RAVC to $4,330. Growing mungbean on the whole area allowed 62.7 ha to be irrigated and resulted in a total RAVC of $19,100. Growing 2 upland crops in sequence increased the irrigated area further to 114.6 ha and total RAVC for the command area to $24,340.

Replacing DS rice with upland crops would allow a much larger part of the command area to be irrigated and would benefit most farmers. Those who would receive the greatest increase in RAVC, up to $1,308/ha, are those presently leaving land fallow. Farmers who planted R - R would increase RAVC by $713/ha by growing R - M - MG. Farmers previously growing only a WS rice crop would also increase their income from household labor working on their own land.

System adjustment to move toward production potential. DS crop production could be increased significantly in the service area and ample income generated to pay pumping fees. Technically, the adjustments necessary to improve water distribution are straightforward: coordination of field operations to achieve greater cropping synchrony, improvements in on-farm WUE, and main system efficiency. However, examination of the irrigators' association suggests that management adjustments necessary to improve water distribution are not so straightforward.

Recognizing that water is distributed across fields and that rice and upland crop requirements are different, the objective should be a continuous service area where virtually all farmers are members and one that is organized for a common goal. In a continuous service area, water distribution could be organized more efficiently by blockwise irrigation; canals could be used optimally because water would not pass nonmembers' fields; more farmers would be interested in keeping the canals and ditches clean to improve WUE; and coordinated timing of field operations would be easier.

However, a continuous service area could not be maintained. Private shallow pumps were installed because farmers could not rely on water delivery from the deep well. Even if water distribution from P-27 were governed by strict rules, water delivery would still be uncertain because of brownouts and technical defects.

The private pumps should not, however, encourage the owner or user to leave the association. The pumps can be integrated into the deep well

Table 8. Potential dry season RAVC from alternative cropping systems, P-27 command area, Guimba, Nueva Ecija, Philippines.

Cropping system[a]	RAVC ($) at WUE of			
	80%	65%	50%	35%
Systems 1: rice - rice (lungog)				
Rice (F)	4,020	3,270	2,500	1,760
Rice (E)	560	450	350	250
System 2: rice - rice (lungog) and rice - maize (turod)				
Rice (E)	420	340	260	130
Maize (E)	6,490	5,280	4,070	2,850
System 3: rice - upland crop				
Maize (E)	19,340	14,580	11,210	8,460
Mungbean (E)	30,590	24,860	19,100	13,320
System 4: rice - upland crop - upland crop				
Maize (E)	19,340	14,580	11,210	8,460
Mungbean (E)[b]	15,290	12,430	9,550	6,610
Peanut (E)[b]	5,980	4,660	3,580	2,480
Total maize - mungbean and peanut	40,610	31,670	24,340	17,550

[a]F = farmers' practice, E = based on data from the experimental patterns tested in cropping pattern trials. [b]Assuming that the total area will be allocated equally to mungbean and peanut in the 3d season.

system to supplement irrigation if P-27 fails. Perhaps private pump owners may be allowed to deduct fuel and other costs incurred in running pumps from their fees (as one of them actually does) in return for an obligation to operate their pumps in times of water scarcity for other members. All the implications must be scrutinized, but the objective should be more contractual relationships that bypass the existing social structure.

UPLAND RICE ENVIRONMENT WITH ACID SOILS

Agricultural Economics and Multiple Cropping Departments

Cropping pattern testing on acid upland soils in Claveria (*Agricultural Economics and Multiple Cropping*). Upland rice, maize, cowpea, and an upland rice + cowpea intercrop were planted by farmers in early WS as first crops in three-crop sequences. Costs and returns are shown in Table 9.

Table 9. Costs and returns of first crops (early WS plantings) in cropping patterns tested in farmers' fields in Misamis Oriental, Philippines, 1985-86.[a]

Cropping pattern[b]	Fields (no.)	Costs ($/ha)			Yield (t/ha)	Gross return ($/ha)	Net return[c] ($/ha)	Rates of return		MBCR to replace M (F)[f]
		Labor and power	Material	Total variable				Labor and power[d] ($/$)	Material[e] ($/$)	
CP (E)[g]	14	64	116	180	1.00	382	202	4.15	2.73	1.93
UR (E)[h]	11	88	124	212	3.95	450	238	3.70	2.92	1.98
M (E)[i]	8	52	127	179	3.23	360	181	4.48	2.43	1.73
UR + CP (E)	5	42	107	149	3.10+ 0.46	526	377	9.98	4.52	4.84
M (F)[j]	15	76	3	79	1.69	187	108	2.42	37.00	

[a]US$1 = ₱20. [b]E = experimental crop, F = farmers' crop, CP = cowpea, UR = upland rice, M = maize. [c]Gross return – total variable cost. [d]Gross return – material cost/labor and power cost. [e]Gross return – labor and power cost/material cost.

[f]Marginal benefit cost ratio (MBCR) = $\frac{\text{gross return of potential pattern} - \text{gross return of prevalent pattern}}{\text{total variable cost of potential pattern} - \text{total variable cost of potential pattern}}$

[g]Based on IT82D-889. [h]Based on UPLRi5. [i]Based on IPB Var 1 or DMR2. [j]Based on farmers' variety.

Table 10. Costs of materials used on experimental (E) and farmers' (F) crops. Cropping pattern trials, first crop, Claveria, Misamis Oriental, Philippines, 1985-86.

Materials	Costs (US$)				
	Cowpea (E)	Upland rice (E)	Maize (E)	Upland rice + cowpea (E)	Maize (F)
Seed	14	14	4	15	3
Fertilizer					
N	4	23	10	0	0
P	30	18	4	29	0
Compound	0	8	49	0	0
Lime	37	38	36	37	0
Insecticide	31	24	24	26	0
Total	116	124	127	107	3

Material costs exceeded $100 for all crops, considerably higher than the $3 value of seed farmers used for a traditional maize crop grown during the same season. Table 10 shows that the major contributions to these high material costs were for lime and insecticides. Concurrent researcher-managed experiments suggested that fertilizer costs for upland rice can be reduced by about 40% without reducing net returns.

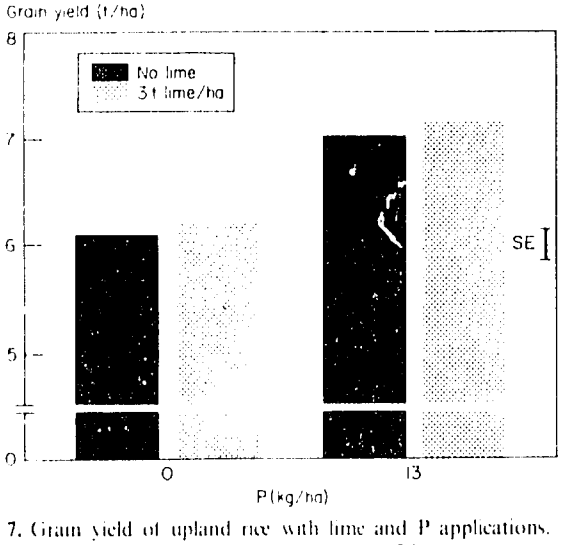
Net returns from the experimental crops were above net returns from the traditional maize crop. Marginal benefit-cost ratios (MBCR) to replace farmers' maize substantially exceeded unity for all experimental crops (Table 9). The highest MBCR was for the upland rice + cowpea intercrop, in which fertilizer costs were low because N fertilizer was not applied.

Fertilizers for upland rice (*Multiple Cropping*). Net benefits from fertilizer were highest with N at 25 kg/ha and with P at 9 kg/ha. Upland rice responded to lime, but the cost of 3 t lime/ha was not offset by the 0.6 t/ha grain yield increase.

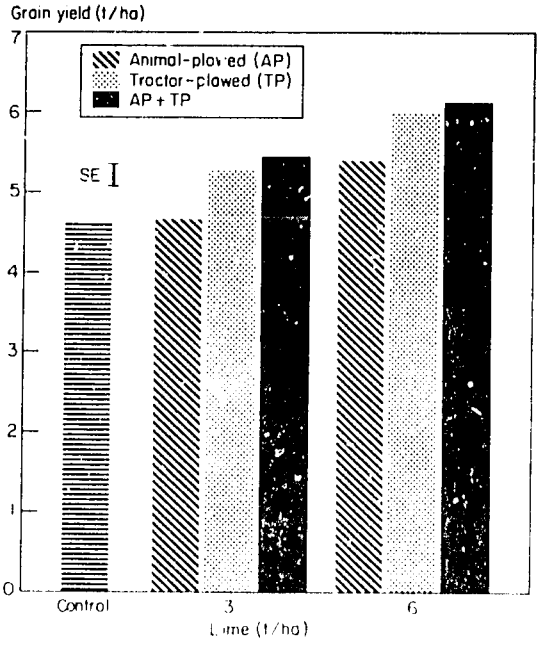
Two experiments were initiated on sequences starting with upland rice in 1985 WS. Upland rice grain yields were exceptionally high even without P or lime (Fig. 7). Response to lime was not significant at 0.1 t/ha. Response to 13 kg P/ha was highly significant at 0.9 t/ha. The crop in this experiment received uniform applications of 50 kg N/ha and 17 kg K/ha.

In the second experiment, lime rate and method of incorporation were the only variables. Lime was broadcast and incorporated (B&I) to 15 cm by an animal-drawn plow; B&I to 30 cm by a tractor-drawn plow; and B&I to 15 cm by an animal-drawn plow, after which the field was replowed to 30 cm by a tractor-drawn plow. Lime rates were 3 and 6 t/ha. Yields from these incorporation methods are shown in Figure 8. Rice benefited from deeper incorporation and the higher lime rate. The effect of lime on soil pH was reflected in a pH increase (Fig. 9). Soil samples for pH determinations were taken from the surface 15 cm, which may explain why pH after application of 6 t lime/ha incorporated by an animal-drawn plow was much higher than with 6 t lime/ha incorporated by a tractor-drawn plow.

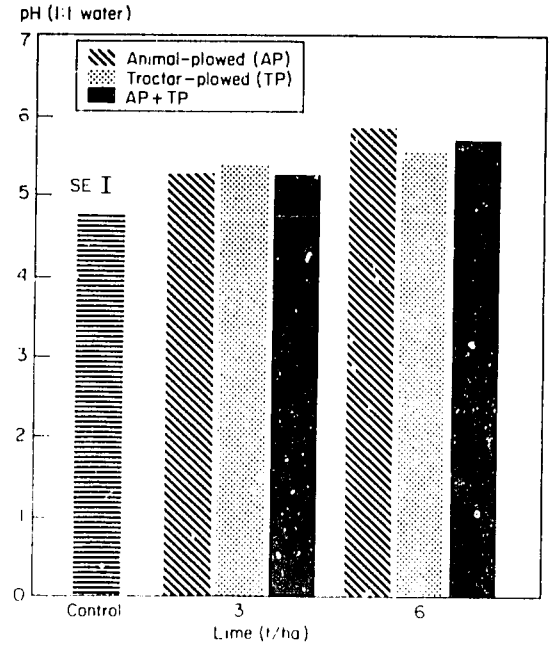
Mungbean in an acid upland environment (*Multiple Cropping*). Mungbean has three possible roles



7. Grain yield of upland rice with lime and P applications, Claveria, Misamis Oriental, Philippines, 1985 WS.



8. Grain yield of UPLRi5 as affected by rate and method of lime incorporation. Claveria, Misamis Oriental, Philippines, 1985 WS.



9. pH changes in the soil as affected by rate and method of lime incorporation. Claveria, Misamis Oriental, Philippines, 1985 WS.

in upland rice-based systems: 1) it can be planted early in WS before rice in areas where WS is long and rains build up gradually; 2) it can be intercropped with rice; and 3) it can be grown on residual soil moisture and late rains after rice. These three roles were to be tested at Claveria. However, researcher-managed experiments showed low mungbean plant growth, nodulation, and grain yields in experiments planted at five locations in early DS. Grain yields from experiments designed to test response to inoculation with *Rhizobium*, lime, and P are given in Table 11. Analysis of variance showed that inoculation response was not significant at any location, P response was significant at some locations, and lime response was significant at all locations. Even though lime and P responses were significant, they were not large.

Because mungbean could be an important crop on these acid soils, research continued during DS. A pot experiment using soil from location 1 in Table 11 showed that responses to chicken manure were pronounced. Yield was 0 g/pot from the control, 1.1 g/pot from 20-17-32 kg NPK/ha + 3 t lime/ha, 1.3 g/pot from 86 kg P/ha, and 5.7 g/pot

Table 11. Yield of mungbean CES ID-21 across 5 locations as affected by P and lime application. Claveria, Misamis Oriental, Philippines, 1984 DS.

Treatment	Yield[a] (kg/ha) at each location				
	1	2	3	4	5
Unfertilized	45	231	91	104	300
13 kg P/ha	57	336	174	216	266
26 kg P/ha	62	357	184	178	313
3 t lime/ha	119	310	240	111	295
13 kg P/ha + lime	203	447	277	185	459
26 kg P/ha + lime	213	524	329	196	467
CV (%)	19	11	20	28	13

[a]Means over 2 inoculation rates and 4 replications.

from 3 t chicken manure/ha. Moreover, mean pH from control pots and chicken manure pots was identical at 4.35 after the experiment. Another pot study showed dramatic response of grain yield and nodulation to chicken manure (Table 12). These treatments, including lime rates, were repeated in a farmer's field with similar results (Fig. 10). Experiments were also conducted at two locations to test response to N, P, K, and lime. Response to P was most pronounced. Mean yield from treat-

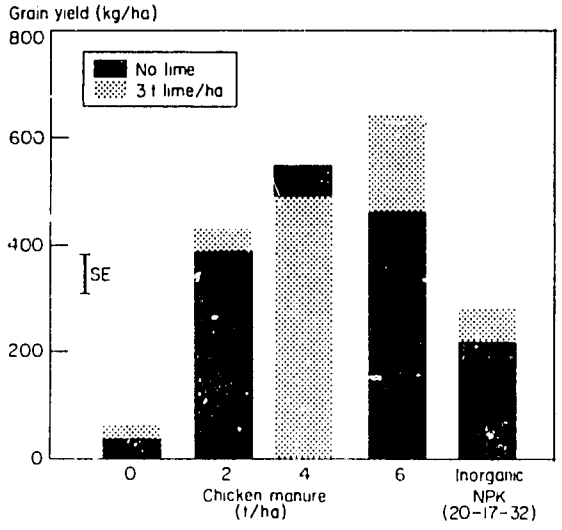
Table 12. Grain yield and nodule count[a] of mungbean as affected by inorganic fertilizer and chicken manure in pot experiment. Claveria, Misamis Oriental, Philippines, 1985 WS.

Treatment	Grain yield (g/pot)	Nodules (no./plant)
Control	2.7	14
20-17-32 kg NPK/ha	3.4	14
2 t chicken manure/ha	7.4	33
4 t chicken manure/ha	10.6	48
6 t chicken manure/ha	13.0	52
CV (%)	20	30

[a]Means over 2 lime rates and 4 replications.

ments without P was 66 kg grain/ha; from treatments with 17 kg P/ha, 168 kg/ha; from treatments with 17 kg P/ha and 3 t lime/ha, 256 kg/ha; and from treatments with 85 kg P/ha and 3 t lime/ha, 458 kg/ha.

In another pot experiment on mungbean, two levels of three factors (with and without *Rhizobium* inoculation, with and without mycorrhizae [*Glomus fasciculatus*], and with and without P) were arranged in all factorial combinations. This experiment was conducted in Los Baños, but with acid soil from Claveria. Inoculation with mycorrhizae increased root colonization. Dry matter yields were determined on 28-day-old plants. The main effects of mycorrhizae and P, but not *Rhizobium*, were significant. Dry matter yield was increased 17% by mycorrhizae and 21% by P. Interactions were not significant.



10. Response of mungbean to chicken manure, lime, and inorganic fertilizers in a farmer's field. Claveria, Misamis Oriental, Philippines, 1985 WS.

Cropping systems program

Selecting and testing varieties for rice-based cropping patterns

Rice Farming Systems Program

VARIETAL TESTING 398
Cowpea 398
Mungbean 398
Soybean 398
Peanut 398
Pigeonpea 399
Chickpea 399
Sorghum 399
Sweet potato 399
CHEMICAL ANALYSIS OF PROMISING UPLAND CROP VARIETIES 399

The most important upland crops grown before and after rice are maize, sorghum, soybean, peanut, mungbean, and cowpea. The Institute of Plant Breeding (IPB) at the University of the Philippines at Los Baños (UPLB) received a grant from the International Development Research Centre to develop varieties of upland crops for rice farming systems. The project involves screening of lines and varieties from the international centers (International Crops Research Institute for the Semi-Arid Tropics [ICRISAT], International Institute of Tropical Agriculture [IITA], and Asian Vegetable Research and Development Center [AVRDC]) and national breeding programs, hybridization of selected promising varieties, and selection. The breeding program concentrates on soybean, peanut, and mungbean. Hybridization, selection, and screening are done at IPB; preliminary yield trials at IPB or Pangasinan State University (PSU); and general yield trials at IPB and PSU and in Iloilo. IITA assigned a senior scientist to IRRI under the IRRI-IITA Grain Legume Project to identify varieties of cowpea and soybean that fit the rice farming systems. For maize and sorghum, we are collaborating with IPB, the Centro Internacional de Mejoramiento de Maiz y Trigo, and ICRISAT. The Thailand Field Crops Research Institute (FCRI) and Indonesian Central Research Institute for Food Crops (CRIFC) intensified their work on breeding for rice farming systems and contributed elite materials to the varietal testing in the Asian Rice Farming Systems Network (ARFSN).

VARIETAL TESTING

The most promising entries from IPB, FCRI, CRIFC, and national programs are submitted to IRRI for seed increase and distribution to countries involved in the ARFSN collaboration on varietal testing of upland crops before and after rice.

Cowpea. Ten early maturing cowpea lines were evaluated before rice. IT82D-891, CES41-6, and IT82D-889 performed well and produced a seed yield of 0.9-1.0 t/ha in 60 d, plus a green fodder yield of 14-16 t/ha.

A sizable area of tropical Asia has acid soil, where cowpea performs much better than mungbean or soybean. The seed yield of cowpea lines in acid upland ranges from 0.9 to 1.5 t/ha, compared with 0.2-0.4 t/ha for mungbean or soybean. One hundred fifty lines of early and medium maturing cowpea were screened, and 20 lines better than the check IT82D-889 were selected for yield performance.

Seven hundred forty-nine accessions of cowpea were screened for beanfly at IRRI and AVRDC; five lines consistently showed resistance: TVu 2181, TVu 3073, TVu 3296, TVu 652, and F-1.

Mungbean. In the observation nursery 255 mungbean entries were evaluated after rice. Twenty lines better than the check were selected for the general yield trial after rice. From the combined results of the UPLB and PSU experiments, five lines were eventually selected for seed increase and inclusion in ARFSN varietal testing: IPB M79-12-168, IPB M79-20-113, IPB M79-17-91, IPB M79-25-106, and IPB M79-25-115.

Soybean. Soybean varietal improvement for rice-based farming systems is done by the IRRI-IITA Grain Legume Project and IPB. At IRRI we screened 1,400 soybean lines for their adaptation after rice; 350 were selected, the most promising of which were Acc. 94, Acc. 2120, TGx 536-02D, SJ-5, and TGx 442-02D. Medium maturing cultivars performed better than early and late maturing types in rainfed lowland conditions.

In another study, 16 improved soybean lines were evaluated during wet season in Davao under upland conditions. Seed yield ranged from 1.41 to 2.42 t/ha. The top yielding cultivars were SJ-5 (2.4 t/ha), TGx 536-02D (2.3 t/ha), and TGx 442-02D (2.3 t/ha).

In the preliminary yield trial, 49 entries involving materials from Asian countries and the International Soybean Program were planted at UPLB and PSU; 20 lines were selected for inclusion in the general yield trial.

Five lines were selected for inclusion in the ARFSN varietal testing: IPB SY 138-28, GC 60068-9, GC 50193-7-6, Acc. 770, and GC 50123-8-6.

Peanut. A total of 609 peanut lines were planted at PSU. Fifteen were selected for further evaluation in the general yield trial after rice.

We evaluated 11 lines from Tainan, China. Bean yield ranged from 0.8 to 2.12 t/ha. UPLB PN-4, one of the check varieties, gave the highest bean (2.12 t/ha) and fodder (17.9 t/ha) yield. However, all entries except NS 8328 outyielded UPL PN-2,

another check variety. The promising varieties were NS 8344 (1.73 t shelled bean/ha), NS 82105 (1.57 t/ha), and NS 8304 (1.54 t/ha). Maturity of these varieties was 100 d, and fodder yield 11-12 t/ha.

Pigeonpea. Fifty-four pigeonpea varieties from ICRISAT and Queensland, Australia, were screened after rice. Grain yield of ICRISAT materials ranged from 0.78 to 3.25 t/ha and fodder yield from 6.50 to 23.8 t/ha. The most promising varieties in terms of grain and fodder production were ICPL 84060, ICP909-E3-5EB, ICP3009-E3-4EB, and ICPL 265. These varieties mature in 120 d. Yield levels of varieties from Australia were low: from 0.8 to 1.56 t/ha for grain and 1.25 to 6.83 t/ha for fodder; QPL 72 and Hunt were the most promising.

Chickpea. We evaluated chickpea under upland conditions in 1984 and 1985; IC78002 was the most promising.

In 1984, we obtained 16 entries from ICRISAT for evaluation. Yield ranged from 0.49 to 1.38 t/ha. All entries were better than IC78002. The most promising were BND-9 and 81220.

Sorghum. Thirty-six early (95-100 d) and medium (110-115 d) maturing sorghum varieties from ICRISAT were screened after rice. Grain yield of early materials ranged from 0.22 to 1.01 t/ha; that of medium maturing varieties ranged from 0.75 to 1.73 t/ha. Goldfinger and Tropic were the outstanding entries in the early group, and M-80200 and SPV 475 topped the medium maturing group.

Sweet potato. We evaluated 11 sweet potato varieties from IPB and the Visayas State College of Agriculture (VISCA) under lowland and upland conditions. The lowland trial was under zero tillage and the upland with tillage. In the lowland trial, the outstanding varieties were CI 693-9 (10.1 t marketable tuber yield/ha), Tinipay (9.4 t/ha), and G145r-4 (8.1 t/ha). Fodder yield ranged from 2.3 to 7.0 t/ha. The highest yielders were G53r-17b (7.0 t/ha), G113-2b (6.1 t/ha), and Tinipay (6.0 t/ha). All varieties were harvested in 110 d.

In the upland, tuber yield ranged from 6 to 14 t/ha. V2-1 from VISCA gave the highest marketable tuber yield (14.1 t/ha), followed by G145r-4 (13.0 t/ha) and G53r-17b (10.2 t/ha). All varieties were harvested in 110 d.

CHEMICAL ANALYSIS OF PROMISING UPLAND CROP VARIETIES

Mungbean Pag-asa 2 had the highest protein content in grain (26.0%) and fodder (16.0%) and the lowest crude fiber content (24.1%), indicating that this variety will be preferred by animals. The other promising dual-purpose varieties were cowpea TVx 3671-14C-01D (23.1% protein in grain and 13.2% in fodder) and bush sitao BS_6 (3.1% protein in fresh pods and 19.2% in fodder). Highest protein content in grain was obtained in soybean 7521-26-2 (46.7%), peanut CES 2-25 (31.7%), sorghum CS116 (9.0%), pigeonpea ICPL-6 (23.1%), and maize variety Early DMR Composite I (11.4%).

Cropping systems program

Agronomic management in rice-based cropping systems

Multiple Cropping and Soil Chemistry/ Physics Departments

GREEN MANURING 402
- Long-term green manure experiment 402
- Evaluation of green manure species 402
- Performance of three *Sesbania* species 403
- *Sesbania rostrata* seed rates 405
- Incorporation vs surface application of green leaf manures 406
- Intersowing *S. rostrata* with rice 407
- Experiments in farmers' fields 408

INTERCROPPED RICE AND GRAIN LEGUMES 408
- Rice and cowpea in replacement series 408
  - Grain yield 409
  - Nitrogen yield 410
- Rice + cowpea vs rice + mungbean 411
- Intercropping and relay cropping in upland rice 412

NITROGEN MANAGEMENT IN RICE-BASED CROPPING SEQUENCES 414

NITROGEN MANAGEMENT FOR SORGHUM 416

TILLAGE FOR LOWLAND RICE - LEGUME SEQUENCE 418

PERFORMANCE OF SORGHUM AND MAIZE VARIETIES IN POSTRICE ENVIRONMENTS VARYING IN WATER AVAILABILITY 419

TEPARY BEAN 420

EFFECT ON SOYBEAN OF SHADING SEQUENCES SIMULATING RELAY CROPPING AND INTERCROPPING 420

FERTILITY MANAGEMENT FOR UPLAND RICE ON ACID SOILS 424
- Cavinti 424
- Claveria 426

401

Our studies on the agronomic management of rice-based cropping systems concentrated on the role of legumes in providing N to other crops in the system. We also continued studies of wheat and sorghum management after rice.

GREEN MANURING

Multiple Cropping Department

Long-term green manure experiment. In 1984 dry season (DS), the residual response from green manure incorporated for wet season (WS) rice was determined after the fourth WS crop. The 1984 DS crop (IR54) received no fertilizer except a uniform application of 40 kg N/ha before the last harrowing. As in previous DS plantings of this experiment, residual effects were not detected. The mean yield was 3.35 t/ha ($SE_{\bar{x}}$ = 0.07).

In 1985 WS, green manure and organic N treatment were applied as in the previous 4 yr, but with minor changes. *Sesbania rostrata* replaced cowpea and mungbean, and a 30 kg N/ha application at panicle initiation (PI) replaced the split application of 80 kg N/ha (1/3 before last harrowing and 2/3 at PI).

Total dry matter yield (TDMY) and N accumulation in the three green manure growth durations are shown in Table 1. N accumulation was most rapid between 25 and 35 d after emergence (DE). TDMY and N yield of IR54 were significantly influenced by green manure age, but the green manure-inorganic N interaction was not significant. N efficiency, utilization, and recovery were examined by regression analysis (Fig. 1). Apparent N recovery and N utilization were similar, regardless of source. The efficiency of inorganic N topdressed at 30 kg/ha was not significantly different from that of an equivalent quantity of green manure, although numerically higher.

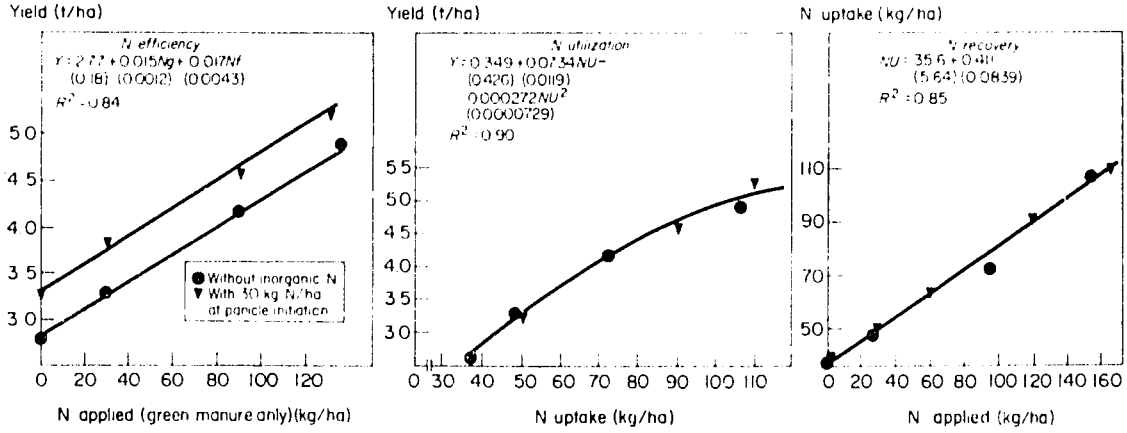
The crop (IR54) to test residual N after the WS crop was transplanted earlier than in previous years, but otherwise the same procedures were followed. As in previous years, no residual response was detected. The mean yield was 2.68 t/ha ($SE_{\bar{x}}$ = 0.05).

Evaluation of green manure species. The 1984 experiment evaluating eight green manure crops for biomass production, N accumulation, and effect on 1984 WS rice yields was continued in 1985 with some modifications. The soil of the experimental field was Maahas silty clay, Andaqueptic Haplaquoll, fine mixed, isohyperthermic. Initial

Table 1. Total dry matter yield (TDMY) and N accumulation by *Sesbania rostrata* at 3 growth stages. IRRI, 1985 WS.

Green manure age[d] (DE)	TDMY (t/ha)	N accumulation (kg/ha)
25	0.7	27
35	3.2	91
45	6.3	135
$SE_{\bar{x}}$	0.17	6.4

[d]DE = d after emergence.



1. Efficiency, utilization, and recovery of N from *Sesbania* green manure incorporated at 3 growth stages, with or without 30 kg N/ha. IRRI, 1985 WS.

soil pH was 6.3; organic C, 1.02%; total N, 0.123%; and available P (Olsen), 15 ppm.

To determine residual effects from the green manures incorporated before the 1984 WS crop, IR54 rice was direct seeded on 15 Dec 1984. Inorganic N at 60 kg/ha (1/2 at sowing + 1/2 38 d after sowing [DAS]) was applied to all treatments. Rice was harvested on 3 Apr 1985 and grain and straw yields were recorded. Differences among treatments were not significant. Grain yield and N uptake were slightly higher after green manure than after inorganic N, regardless of green manure species and inorganic N level.

In 1985 WS, the experiment was repeated on the same field with the following modifications: pigeonpea, unpromising in 1984 WS, was replaced by weed-free fallow; and inorganic N levels on fallowed plots were reduced from 0, 50, 100, and 150 kg N/ha in 1984 to 0, 35, 70, and 105 kg/ha in 1985; on plots in which green manure was incorporated, inorganic N was reduced from 50 kg/ha to 35 kg/ha.

The green manures were sown on 23 Apr 1985 with no fertilizer application. Biomass production and N accumulation at 30, 45, and 60 DE and from weedy fallow after 60 d of growth are reported in Table 2. Differences among species were similar to those observed in 1984. *Sesbania* and *Crotalaria* exhibited rapid early growth, which continued until incorporation at 60 DE. Other green manures started slowly, but growth rates increased with time. *Sesbania* had maximum and indigo minimum biomass and N accumulation at the three crop ages.

The green manures were incorporated into the soil and inorganic N treatments applied before rice (IR54) was transplanted on 2 Jul 1985. Rice responded significantly to inorganic N up to 105 kg/ha (Fig. 2). Rice yield increased significantly irrespective of green manure application, with no significant difference among treatments. Application of 35 kg N/ha on green manure depressed rice yield where *Sesbania* or *Crotalaria* were incorporated but increased yield slightly in other green manure treatments. The most notable response to 35 kg N/ha was in application as a supplement to indigo, which accumulated the least N (58 kg N/ha).

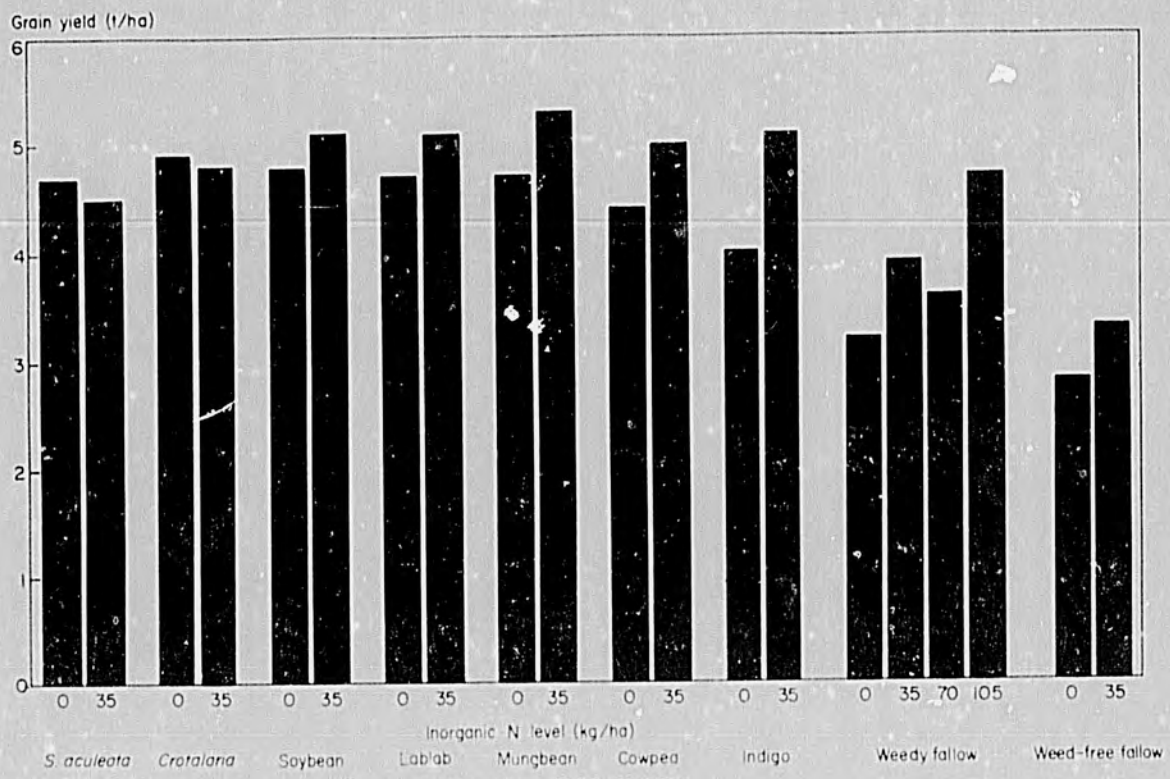
Comparing green manures and inorganic N levels showed that rice yields obtained with green manures alone and those with 105 kg N/ha were comparable. Furthermore, weed-free fallow that received 35 kg N/ha produced as much rice yield as weedy fallow, where weeds accumulated about 25 kg N/ha.

Green manures varied considerably in biomass production and N accumulation, but rice yield did not vary significantly. *Sesbania* and *Crotalaria* accumulated more N in 60 d than required by the crop, indicating a need to determine optimum green manure growth duration for the most productive species, biomass for other green manures, and inorganic N combinations.

Performance of three *Sesbania* species. The green manure potentials of three *Sesbania* species were compared under unflooded and partially flooded conditions. Treatments were applied to the same plots as for the 1984 crop. In 1985, however, *S. sesban* replaced *S. "china type."* Growth durations were 62 and 49 DAS. Water management treatments were applied on 25 Jun to main plots containing eight subplots. The green manures were

Table 2. Weight of green manures and N accumulation at 3 stages. IRRI, 1985.

Green manure	Fresh weight (t/ha)			Dry weight (t/ha)			N accumulation (kg/ha)		
	30 d	45 d	60 d	30 d	45 d	60 d	30 d	45 d	60 d
Sesbania aculeata	27.0	33.1	31.3	3.9	6.7	8.0	81	143	173
Crotalaria juncea	22.1	27.8	31.0	3.1	6.0	7.6	85	120	144
Soybean	7.9	15.3	21.8	0.7	2.6	4.8	19	67	134
Mungbean	16.1	22.3	20.0	2.3	4.5	4.7	54	115	136
Lablab purpureus	8.6	12.7	16.3	1.0	1.9	3.0	35	62	76
Cowpea	9.3	18.1	21.7	0.70	2.4	3.6	21	63	80
Indigo	1.2	5.0	9.8	0.03	0.5	1.7	1	19	58
Weeds			10.5			1.5			21



2. Rice yields from green manures and inorganic N fertilizer. IRRI, 1985 WS.

Table 3. TDMY and N accumulation in 3 *Sesbania* species planted on 2 dates, grown under 2 water regimes, and incorporated on 18 Jul.[a] IRRI, 1985 WS.

Treatment		TDMY (t/ha)		N accumulation (kg/ha)	
Green manure	Planting date	Unflooded	Flooded	Unflooded	Flooded
S. aculeata	18 May	6.7	5.5	171	151
S. aculeata	1 Jun	4.1	3.6	132	128
S. rostrata	18 May	7.2	6.8	219	179
S. rostrata	1 Jun	5.3	3.7	167	111
S. sesban	18 May	4.9	4.7	156	130
S. sesban	1 Jun	3.4	2.9	112	91
SE		0.3		20	

Analysis of variance

Source of variation	*df*	*Mean square*	
		TDMY	*N accumulation*
Growth duration (D)	1	55.1**	23276**
Species (S)	2	12.8**	8813**
D × S	2	0.78*	886
Flooding (F) × D	1	0.124	469
F × S	2	0.378	1340
F × D × S	2	0.960*	260
CV (a) (%)		12	20
CV (b) (%)		9	19

[a]Means of 4 replications.

planted (50 kg seed/ha) on 40-cm row centers on 18 May and 1 Jun 1985. They were incorporated on 18 Jul, and on 24 Jul 22-day-old IR54 seedlings were transplanted in 20-× 20-cm hills. Inorganic N was split-applied (20 kg N/ha at planting and 40 kg N/ha at PI) to one control; another control was unfertilized.

Growth duration and species affected TDMY and N accumulation (Table 3). Minor interactions were observed in green manure TDMY but not in N accumulation. Mean N accumulation was 169 kg/ha by *S. rostrata*, 146 kg/ha by *S. aculeata*, and 122 kg/ha by *S. sesban*. Mean accumulation was 168 kg/ha in the 62-d crop and 124 kg/ha in the 49-d crop.

Grain yield, TDMY, and N uptake responded to inorganic N, green manure growth duration, and green manure species (Table 4). The highest grain yield and N uptake came from incorporation of 62-day-old *S. rostrata* grown without flooding, which accumulated 219 kg N/ha. Grain yield increase was 2.7 t/ha and N uptake increase, 68 kg N/ha. The experiment confirmed 1984 WS results.

***Sesbania rostrata* seed rates.** Five seed rates (20, 30, 40, 50, and 60 kg/ha) were sown by 2 methods (broadcast and row-seeded) on 19 May 1985 on a plowed and rototilled field. Broadcast treatments were seeded before the final rototilling. Row-sown seed was dropped in shallow furrows opened on 25-cm centers. Except for one 20-mm sprinkler irrigation applied immediately after planting, the crop was unirrigated. Early growth and nodulation were inhibited because rainfall was light during the next 2 wk. TDMY was determined at 35, 45, and 55 DE. Herbage was subsampled and analyzed for percentage N. N yield was computed from TDMY and percentage N.

Plants in this experiment did not exhibit typical nodulation (stem or root) for 14-21 DE, and early growth was slow. Seed rate affected N yield of samples taken at 35 and 45 DE but not of those 55 DE. Seeding method affected N yield on all dates

Table 4. Grain yield, N uptake, and TDMY after green manure incorporation.[a] IRRI, 1985 WS.

Treatment		Grain yield (t/ha)		N uptake (kg/ha)		TDMY (t/ha)	
N and green manure	Green manure planting date	Unflooded	Flooded	Unflooded	Flooded	Unflooded	Flooded
Fallow, no N		1.8	2.3	70	54	4.4	5.1
Fallow, 60 kg N/ha		3.5	3.7	72	90	6.6	8.2
S. aculeata	18 May	4.2	3.8	101	86	9.3	8.8
S. aculeata	1 Jun	3.8	3.6	93	85	8.5	7.7
S. rostrata	18 May	4.5	4.0	108	101	9.4	9.3
S. rostrata	1 Jun	3.9	3.6	82	81	7.9	8.4
S. sesban	18 May	3.8	3.8	87	99	8.7	8.7
S. sesban	1 Jun	3.5	3.4	83	79	8.3	8.0
SE		0.14		6.20		0.42	

Analysis of variance

Source of variation	*df*	*Mean square*		
		Grain yield	*N uptake*	*TDMY*
N0 vs N1	1	9.98**	4415**	27.5**
Growth duration (D)	1	1.83**	1584**	9.35**
Species (S)	2	0.500**	301*	0.483**
D × S	2	0.062 ns	161 ns	0.448 ns
Flooding (F) × D	1	0.0276 ns	23 ns	0.000469 ns
F × S	2	0.108 ns	291*	0.820 ns
F × D × S	2	0.0293 ns	264*	0.231 ns
F × (N0 vs GM)	1	0.802**	476*	1.42 ns
Remainder	1	0.117 ns	561**	4.73**
CV (a) (%)		4	16	13
CV (b) (%)		6	10	8

[a]Means of 4 replications.

Table 5. N yield of *S. rostrata* at different seeding rates (SR) and 2 seeding methods (SM) determined at 35, 45, and 55 DE. IRRI, 1985 WS.

Seeding rate (kg/ha)	Nitrogen yield (kg/ha)					
	35 DE		45 DE		55 DE	
	Broadcast	Row-seeded	Broadcast	Row-seeded	Broadcast	Row-seeded
20	17	31	21	41	60	58
30	26	32	30	47	61	52
40	28	38	41	45	60	53
50	45	53	48	50	62	48
60	46	47	50	46	65	55
SE	3.9		4.3		4.8	
SR	**		**		*	
SM	**		**		ns	
SR × SM	ns		ns		ns	

(Table 5), but between 45 and 55 DE, broadcast plants accumulated N at a much faster rate than row-seeded plants. If 55 d are available for green manure growth, broadcasting at 20-30 kg/ha is adequate to accumulate maximum N; if 45 d are available, broadcasting at 50-60 kg/ha is adequate; and if only 35 d are available, row seeding at 50-60 kg/ha is adequate. These suggestions may apply to fields in which early plant development and nodulation are delayed.

Incorporation vs surface application of green leaf manures. Green leaf manure *S. rostrata* at rates of 7, 14, and 21 t fresh weight/ha was surface applied in 1 set of treatments and incorporated in another before transplanting WS rice. *S. rostrata* for this experiment was grown for 43 d in a field about 50 m from the experimental field.

In addition to the green leaf manure treatments, *S. rostrata* was sown directly on two plots in each replication of the test field. Growth in one plot was incorporated on the same day green leaf manure treatments were applied. A control plot (without green manure or green leaf manure) was included in each replication. Quantities of N in the green leaf manure and green manure are shown in Table 6.

Green leaf manure incorporation increased grain, TDMY, and N yield (Table 7). Rice responded to increasing green leaf manure rates. Grain yield from incorporating 21 t/ha was equal to that from in situ treatment. However, TDMY and N yield from the in situ treatment were substantially higher. Regression analysis showed that apparent recovery of surface-applied green leaf manure N was only 18%, but N utilization was the same regardless of application method (Fig. 3). The lower apparent recovery of N in surface application was reflected in lower N efficiency.

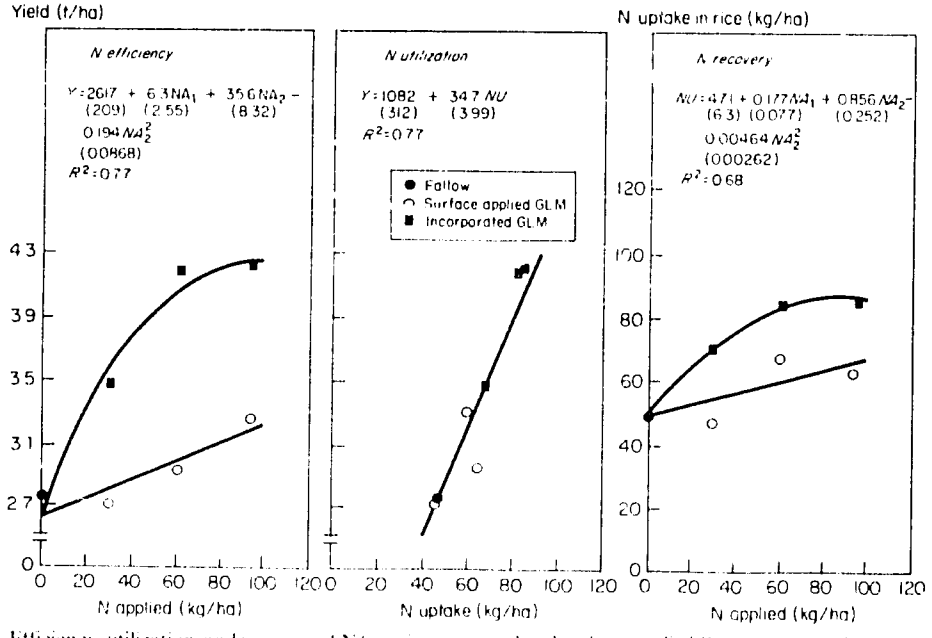
Table 6. Green manure dry matter and N yields from 43-d-old *S. rostrata*. IRRI, 1985 WS.

Treatment	Dry matter yield (t/ha)	N yield (kg/ha)
In situ	4.7	117
Green leaf manure	1.0	32
Green leaf manure	1.9	63
Green leaf manure	2.9	95

Table 7. Grain yield, TDMY, and N yield of transplanted rice with various rates and methods of GLM[a] application. IRRI, 1985 WS.

Treatment[b]	Grain yield (t/ha)	TDMY (t/ha)	N yield (kg/ha)
Fallow, no green manure	2.7	7.0	48
Grown and incorporated, 50 DE	4.2	15.3	159
Grown and removed, 50 DE	3.1	6.4	62
7 t GLM/ha			
On surface	2.7	5.8	48
Incorporated	3.5	9.5	69
14 t GLM/ha			
On surface	3.0	8.3	66
Incorporated	4.2	11.9	84
21 t GLM/ha			
On surface	3.3	8.6	61
Incorporated	4.2	12.6	86
SE	0.2	0.8	7

[a]Green leaf manure. [b]DE = days after *Sesbania* emergence.



3. Efficiency, utilization, and recovery of N from incorporated and surface-applied *S. rostrata* green leaf manure (GLM). IRRI, 1985

Intersowing *S. rostrata* with rice. *S. rostrata* was sown 40 d before rice was transplanted, sown between rice rows at the time rice was transplanted, and sown between rice rows at 20 d after transplanting (DT). Rice that received green manure (grown either before or intercropped with rice) also received 50 kg N/ha as a basal dressing or as a topdressing at PI. For control treatments, rice was grown without green manure and N fertilizer, and without green manure and with 50 kg N/ha (split applied, 50% before transplanting and 50% at PI).

The green manure sown when rice was transplanted — which therefore shared a basal N application with rice — obviously responded to it (Table 8). The green manure sown at 20 DT was affected by flooding during periods of heavy rains after planting and by competition from rice. Only 4 kg N/ha accumulated in the green manure in these treatments.

Grain and N yields of rice are shown in Table 9. The prerice green manure plus 50 kg N/ha increased grain yield by 2.5 t/ha and N yield by 92 kg/ha regardless of the time inorganic N was applied. The 40-d intersown green manure plus 50 kg N/ha (mean of basal and topdressed N treatments) jointly increased grain yield and N yield, but by only 1.3 t/ha and 60 kg/ha. The grain yield increase, however, was 0.7 t/ha more than the response to split-applied 50 kg N/ha without green manure. Grain yield response to topdressed N applied jointly with the green manure sown 20 DT was also 1.3 t/ha. However, N yield increased only 29 kg/ha, suggesting that N in this treatment was used more efficiently to produce grain.

Table 8. Green manure, TDMY and N accumulation with various *S. rostrata* crop establishment and N application methods.[a] IRRI, 1985 WS.

Treatment[b]	TDMY (t/ha)	N accumulation (kg/ha)
Sown before rice incorporated at 40 DE	3.8	115
Intersown with rice and incorporated at 40 DE		
With basal N	3.2	102
With topdressed N	1.9	59
SE	0.3	19

[a]50 kg N/ha, basal and topdressed, was applied to rice.
[b]DE = days after *Sesbania* emergence.

S. rostrata can be intercropped with rice to accumulate N, which in turn will increase rice grain yield. It will compete with rice for basally applied N fertilizer, but the net result may not be completely negative because the N is reincorporated at a later date.

Table 9. Rice grain and N yields with various green manure crop establishment and N application methods.[a] IRRI, 1985 WS.

Treatment[b]	Grain yield (t/ha)	N yield (kg/ha)
Fallow, no N	2.3	38
Fallow, 50 kg N/ha split applied	2.9	45
Green manure sown before rice and incorporated at 40 DE		
With basal N	4.8	128
With topdressed N	4.9	131
Green manure intersown with rice and incorporated at 40 DE		
With basal N	3.5	97
With topdressed N	3.7	99
SE	0.3	13

[a]50 kg N/ha, basal and topdressed, was applied to rice.
[b]DE = days after *Sesbania* emergence.

Experiments in farmers' fields. In 1985 WS, *S. rostrata* was tested in Guimba in farmers' fields to determine response from rice. Incorporation of green manure by power tiller and carabao plow were also compared. Forty-five-day-old *Sesbania* accumulated 75 kg N/ha. Rice grain yield from green manuring alone (3.9 t/ha regardless of method of incorporation) was significantly more than that from 60 kg fertilizer N/ha (3.2 t/ha) and from the control (2.6 t/ha).

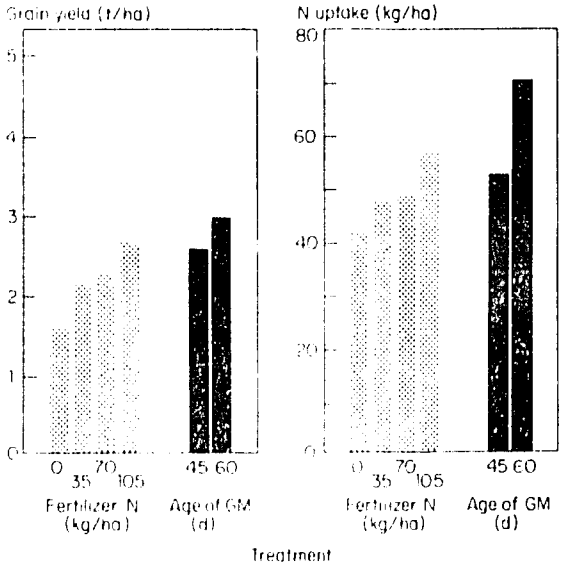
In a small-plot replicated field experiment, *Sesbania* accumulated 58 kg N/ha by 45 DE and 192 kg N/ha by 60 DE. Grain yield (2.8 t/ha) from green manured treatments, regardless of age, was comparable to yield (2.7 t/ha) from 105 kg inorganic N/ha (Fig. 4). Grain yield with green manuring *Sesbania* at 60 DE was significantly more than that at 45 DE. N yield response followed a similar pattern.

INTERCROPPED RICE AND GRAIN LEGUMES

Multiple Cropping Department

Rice and cowpea in replacement series. Upland rice *Oryza sativa*, often intercropped by subsistence farmers in the tropics, is commonly grown without N fertilizer. A recently developed cowpea [*Vigna unguiculata* (L.) Walp] line (IT82D-889) is compatible with upland rice (Annual report for 1984). Four experiments were conducted to determine grain and N yield sensitivity of intercropped rice (UPLRi5) and cowpea (IT82D-889) to crop proportion (rice and cowpea in a series of replacement treatments), organic amendment (containing 75 kg N/ha), and irrigation (42, 150, and 239 mm 20-65 d after planting, full irrigation before and after this interval). Table 10 summarizes the soil chemical characteristics of the experimental fields. Soils in Los Baños are moderately productive Typic Tropudalfs. The soil in Claveria is a Fluventic Oxic Dystropept.

In experiment 1, the 9-row arrangements of a replacement series with rice and cowpea were planted in a farmer's field in Claveria in September 1984. In experiment 2, the crops of the replacement series were planted in subplots at IRRI in December 1984. To create soils with contrasting fertility, dried leucaena [*Leucaena leucocephala* (Lam) de Wit] leaves and chicken manure (equivalent to 37.5 kg N/ha from each source) were incorporated into main plots 1 wk before planting. In experiment 3, five rice to cowpea proportions were grown at three levels of irrigation. Irrigation treatments imposed between 20 and 65 d after planting (DAP) were applied by a line source sprinkler system. Before 20 and after 65 DAP, all plots were irrigated uniformly. The experiment was planted at IRRI in December 1984. Experiment 4 was identical to experiment 1, but planted at IRRI in May 1985.



4. Effect of green manure (GM) on yield and N uptake of rice. IRRI, 1985 WS

Table 10. Chemical properties of soils in fields before experiments. IRRI and Claveria, Misamis Oriental, Philippines, 1984-85.

Experiment no.	pH	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	Exchangeable K (mmol/kg)	CEC (mmol/kg)
1	4.3	0.221	0.021	5	5.9	124
2	5.3	0.095	0.013	18	11.2	283
3	5.2	0.137	0.015	34	13.9	268
4	5.3	0.095	0.013	18	11.2	283

During the season immediately before the experiment, however, an irrigated sorghum crop was grown to remove much of the labile N from the soils.

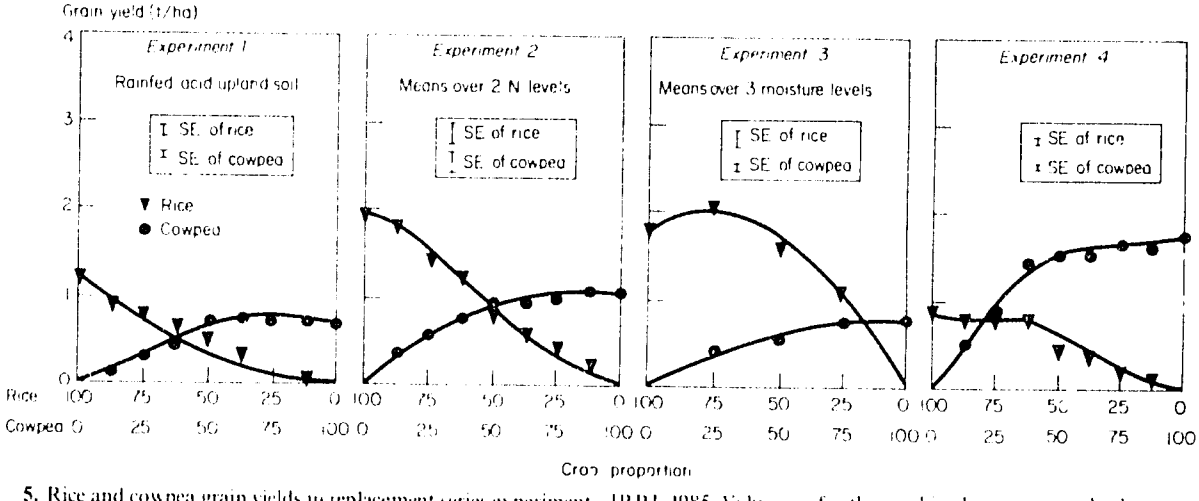
Insect and vertebrate pests on both crops in all experiments were adequately controlled. A preemergence herbicide (butachlor, 1.2 kg ai/ha) was applied to experiments at IRRI. Experiments were hand weeded as needed. Except in the two experiments in which N was an experimental factor, N fertilizer was not applied. On all plots, 13 kg P/ha was broadcast and incorporated before planting. Rice was seeded at 100 kg/ha (adjusted for area proportion). Cowpea was overseeded and thinned to obtain 10-15 plants/row m. Experiments at IRRI were sprinkler irrigated.

Experiments 1 and 4 were arranged in randomized complete blocks. Experiment 2 was arranged in complete blocks of split plots with N fertility in main plots and crop proportion in subplots. Experiment 3 was arranged in strip-strip plots with moisture gradients in strips parallel to the irrigation line and crop proportions in strips perpendicular to the line. In all experiments, treatments were replicated four times, except in experiment 1, where treatments were replicated three times.

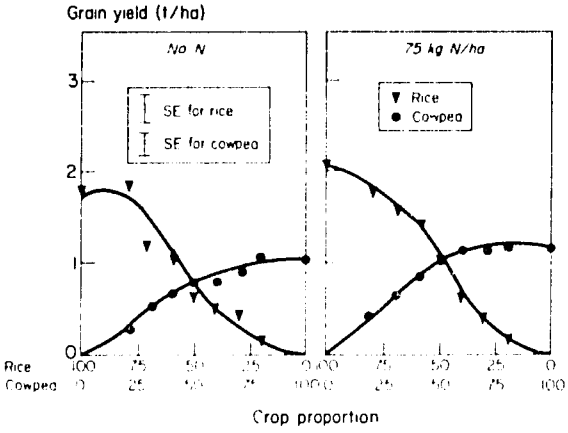
Grain yield. Interactions of crop proportion with N in experiment 2 and with irrigation in experiment 3 were not significant.

In all experiments, as cowpea proportion increased to 50%, cowpea yield increased more than proportionally (Fig. 5). Rice yield responses to increasing rice proportion were not consistent. In experiments 1 and 2, rice yield decreased in an approximate linear trend as cowpea replaced rice. In experiment 3, rice yield increased in response to a 25% replacement by cowpea. In experiment 4, rice yield remained relatively stable as cowpea replaced rice up to 50%, above which yield decreased sharply.

Grain yield responses of both species to organic amendments in experiment 2 were significant (Fig. 6). However, the response of monocropped



5. Rice and cowpea grain yields in replacement series experiments, IRRI, 1985. Values are for the combined area sown to both crop species.



6. Rice and cowpea grain yield response to crop proportion at 2 N levels in experiment 2, IRRI, 1985. N sources were combined chicken and green manures. Values are for the combined area sown to both crop species

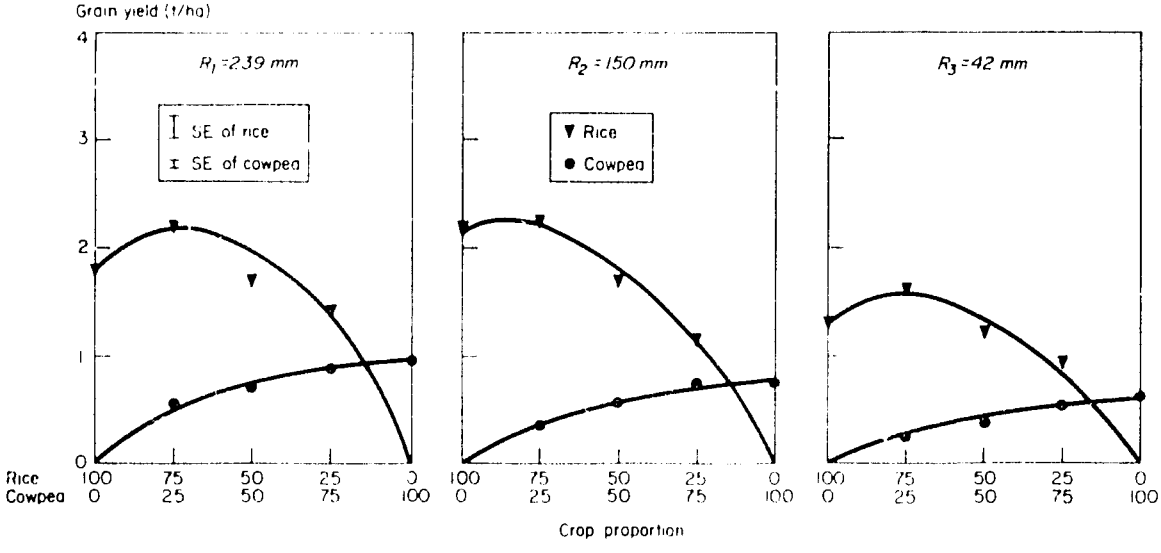
rice to 75 kg N/ha in the organic amendment was only 0.4 t/ha, suggesting that a factor other than N probably limited yields.

The interaction between crop proportion and water application in experiment 3 was not significant (Fig. 7). Mean grain yield responses from the highest water application during the period 20-65 DAP were 0.5 t/ha for rice and 0.3 t/ha for cowpea. Because irrigation treatments could not be randomized, tabular probabilities for the *F*-ratios testing responses to water application are not correct. However, it is reasonable to conclude that crop proportion and irrigation treatment affected the yield of both crops.

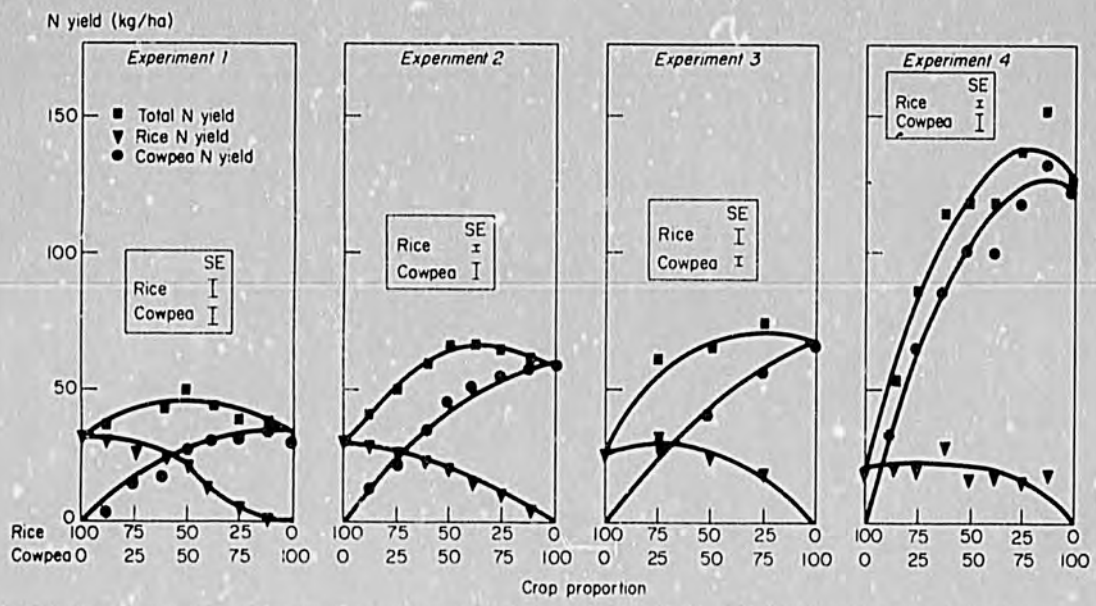
Nitrogen yield. Crop proportion significantly affected N yields of both species (Fig. 8). Interaction between crop proportion and organic amendment in experiment 2 significantly influenced rice N yield, but the interaction between crop proportion and irrigation was not significant in experiment 3.

Organic amendment increased total N yield, and N yield in rice and cowpea individually in experiment 2 (Fig. 9). Rice N yield was also significantly affected by an interaction between crop proportion and organic amendment. The rate of cowpea N yield increase as cowpea proportion increased was significantly greater on amended than on untreated plots.

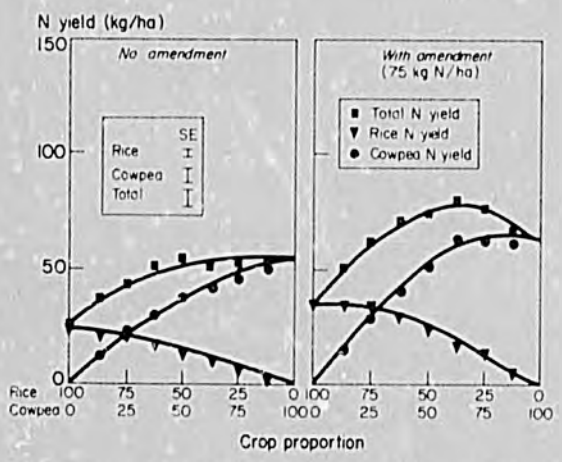
Although organic amendment significantly influenced N yield in experiment 2, both directly or through an interaction with crop proportion, it did not strongly influence rice N yield and only moderately influenced cowpea yield. Apparent recovery of the 75 kg N/ha in the organic amendment was low. Apparent recovery was 10% for the rice monocrop and 22% for the cowpea monocrop. For the 50:50 intercrop, apparent recovery was 28%.



7. Rice and cowpea grain yield responses to crop proportion at 3 irrigation levels (R_1-R_3), IRRI, 1985. Values are for the combined area sown to both crop species.



8. N yields of intercropped rice and cowpea in 4 replacement series experiments. IRRI, 1985. Values are for the combined area sown to both crop species.



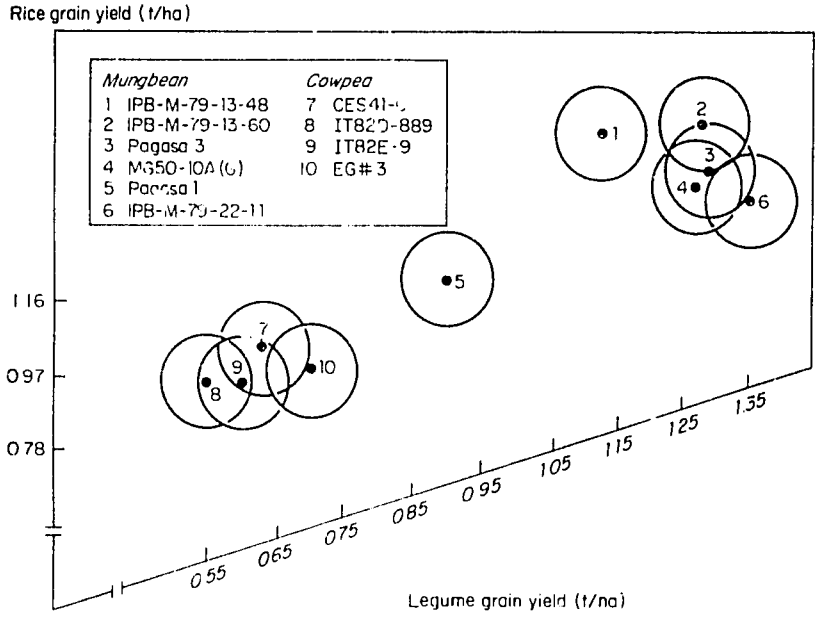
9. N yields of intercropped rice and cowpea with and without organic amendment in experiment 2. IRRI, 1985. Data points (means of 4 replications) are for the combined area sown to both crop species.

Although the benefit from intercropping was large, interaction between water application and crop proportion was not significant for N in individual crops, but was significant for total N. Mean N yield response to the additional 197 mm water applied to level 1 was 8 kg N/ha for rice and 27 kg N/ha for cowpea.

Rice + cowpea vs rice + mungbean. An experiment compared six mungbean and six cowpea lines for intercropping with upland rice. Two rice rows, 20 cm apart, were alternated with a legume row (centered 30 cm from adjacent rice rows) in a well prepared field on 10 Jun 1985. Crops were adequately protected from insects and diseases. They were planted without N fertilizer, but 13 kg P/ha was broadcast and incorporated. The field had received animal and green manures during the previous year to build up soil fertility. Water was applied with a sprinkler irrigation system during dry periods. Therefore, neither fertility nor water was a major constraint.

Cowpea lines IT82E-16 and IT82E-18 grew poorly and were excluded from the analysis. Data from the remaining 10 entries were examined in a bivariate analysis of variance. Yield pairs are shown in a bivariate diagram in which the angle between the axes is a function of the correlation between residual errors from upland rice and the legumes (Fig. 10).

Mungbean entries Pagasa 3, IPB-M-79-13-48, IPB-M-79-13-60, IPB-M-79-22-11, and MG50-10A(G) clustered in the upper right of the diagram; their mean yield was 1.2 t/ha. The four cowpea lines were at the lower left. The corresponding mean upland rice yield was 1.0 t/ha. As monocropped equivalents, these yields would be doubled because each crop occupied 50% of the intercrop.



10. Grain yields from intercropped rice and mungbean or cowpea. Diameters of circles around means are equal to 2 SE $\bar{x}$. IRRI, 1985 WS.

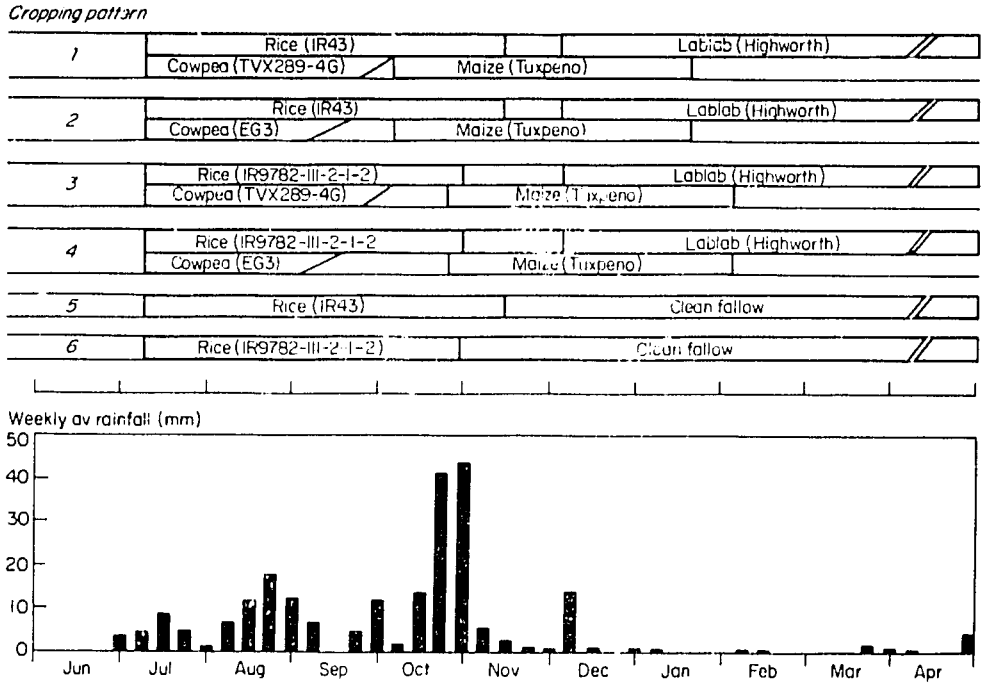
The five mungbean lines not only outyielded the four cowpea lines, but grain yield from rice grown with them was slightly higher. The cowpea lines were aggressive and grew over the rice. Growth duration of these grain legumes appeared to have little influence on rice yield or rice maturity. Rice matured in 128-129 d irrespective of grain legume. No association was detected between grain legume maturity and rice yield.

Intercropping and relay cropping in upland rice. To determine if intercropped rice and cowpea could be followed by maize and a drought-tolerant dual-purpose legume (*Lablab purpureus*), in crop year 1984-85 crops were grown without N fertilizer and irrigation in the sequence in Figure 11. Weekly rainfall is shown below the sequences. To start the experiment, the soil was plowed and harrowed, and rice was planted on 20-cm row centers with 2 rows skipped for intercropped cowpea. One cowpea row replaced two rice rows. When expressed as monocropped equivalents, rice was seeded at 100 kg/ha and cowpea was seeded to obtain 300,000 plants/ha. P at 26 kg/ha was uniformly applied. Weeds were controlled by butachlor and insects by carbofuran and monocrotophos. Maize was planted into rows vacated by cowpea, and lablab was planted into rows vacated by rice (Fig. 11).

As expected, yields of both rices were low without N fertilizer (Table 11). Cowpea experimental line TVx 289-4G was aggressive and grew over both rices, depressing yield, especially that of the early maturing IR9782-111-2-1-2. Cowpea yields averaged 0.5 t/ha or 1.0 t/ha when expressed as equivalent monocropped area. Maize yields were low, but the higher yields following TVx 289-4G suggest that residual N from this cowpea was greater than from EG#3.

When grown in the sequences tested here, lablab was relatively easy to establish, grew slowly through DS, and was ready for rapid growth once rains started early in the following WS. When planted in December (short days), it flowered in January, and a small amount of seed was harvested on 19 Feb 1985. As the days became longer, flowering ceased and vegetative development became rapid. A spurt of growth occurred after a few light rains in late April and early May. At harvest, the crop had grown over the maize stalks (which were purposely left in the field to support lablab growth) and completely covered the plots. Mean herbage yield (dry) was 4.9 t/ha. All lablab herbage and maize residue were removed on 17 Jun, and the soil was prepared for rice and cowpea.

The treatments were modified and the second



11. Cropping pattern and rainfall during the growing season at IRRI, 1984-85.

Table 11. Grain yields of upland rice, cowpea, maize, and lablab. IRRI, 1984 WS to 1985 DS.

Cropping pattern	Grain yield (t/ha)
Rice	
IR9782-111-2-1-2 (monoculture)	1.5
IR43 (monoculture)	1.3
IR9782 + EG#3	0.5
IR9782 + TVx 289-4G	0.2
IR43 + EG#3	0.8
IR43 + TVx 289-4G	0.4
SE	0.1
Cowpea	
EG#3 + IR9782	0.5
EG#3 + IR43	0.4
TVx 289 + IR9782	0.6
TVx 289 + IR43	0.4
SE	0.1
Maize	
EG#3 + IR9782	0.9
EG#3 + IR32	0.8
TVx 289 + IR9782	1.6
TVx 289 + IR43	1.1
SE	0.2
Lablab	
EG#3 + IR9782	0.13[a]
EG#3 + IR43	0.14
TVx 289 + IR9782	0.16
TVx 289 + IR43	0.17
SE	0.02

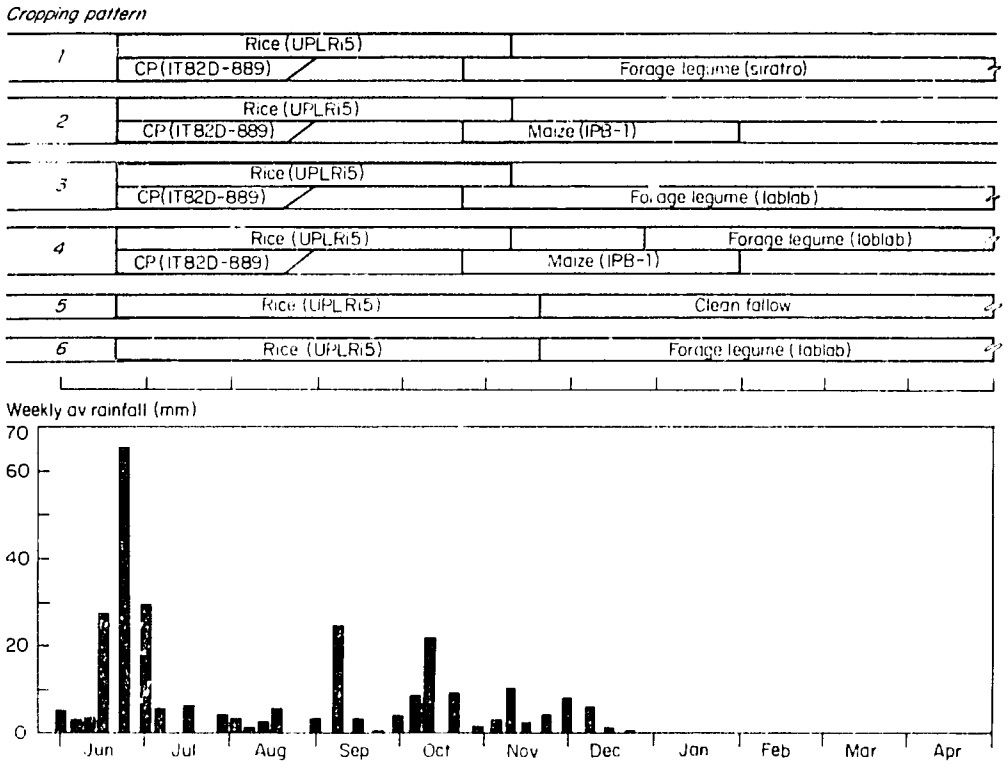
[a]Total dry matter yield of lablab was 4.9 t/ha. Differences attributable to preceding crops were not observed.

year was started with the sequences shown in Figure 12. Soil fertility was low, as was evident from the low monocropped rice yields (Table 12). Where rice was intercropped with cowpea, rice yields were higher than yields from monocropped rice. Expressed on a per hectare basis, the yield was 1.2 t/ha. In the previous year, crop residues (except for roots and 10-20 cm of stubble) were not returned to the soil. Although a legume, lablab was not well nodulated and apparently left little available N in the soil for the following rice crop. Cowpea line IT82D-889 used in 1985 WS is a comparatively poor N accumulator (Annual report for 1984); it is also not aggressive and did not grow

Table 12. Grain yield and TDMY of upland rice and cowpea in a rice + cowpea intercrop. IRRI, 1985 WS.

Cropping pattern[a]	Grain yield (t/ha)	TDMY (t/ha)
Rice		
Rice + cowpea	0.6	1.8
Rice (monocrop)	0.6	1.1
Cowpea		
Rice + cowpea	0.5	0.9

[a]Upland rice UPLRi5, cowpea IT82D-889.



12. Sequences of crops starting with upland rice in an experiment without N fertilizer or irrigation. IRRI, crop year 1985-86. CP = cowpea.

over rice as did TVx 289-4G. It exhibited N deficiency symptoms and poor early growth, although it did nodulate. The relatively higher intercropped rice yields were apparently due to extraction of soil N from a larger soil volume per plant and perhaps some residual N from cowpea.

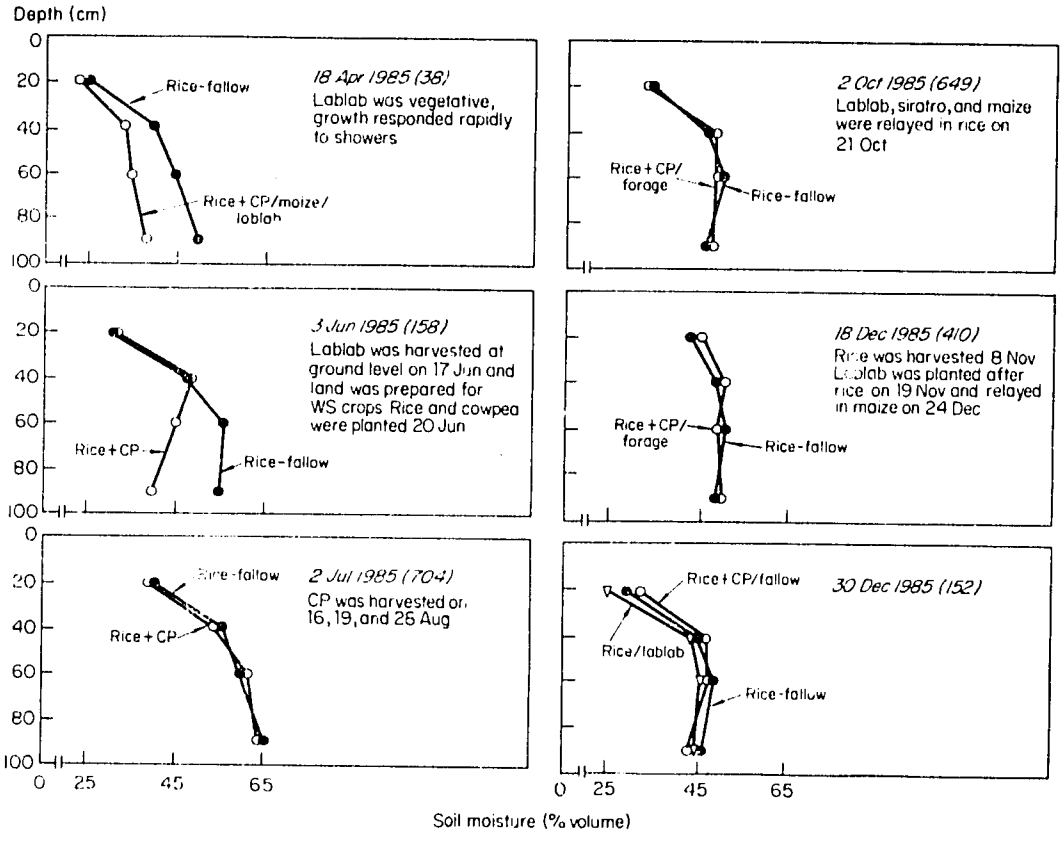
Available water to 100 cm in the soil on which the sequences were planted was approximately 175 mm. On 18 Apr, the depletion by maize and lablab of stored soil moisture was apparent (Fig. 13). By 3 Jun, water had infiltrated to 40 cm but not much deeper. By 2 Jul, however, soils under all treatments were fully recharged (except for extraction and evaporation from near the surface), and the lower parts of the profiles were at or near saturation. During the late WS (2 Oct-30 Dec) differences between moisture profiles were small. If rainfall is greatly in excess of evapotranspiration requirements of rice + cowpea early in WS, soil profiles recharge and WS crops will not suffer because forage extracts 75-100 mm more from the profile than is lost from a field fallowed during DS.

NITROGEN MANAGEMENT IN RICE-BASED CROPPING SEQUENCES

Multiple Cropping and Soil Chemistry/Physics Departments

A 1984 experiment studied the responses of WS irrigated rice to fertilizer N application following maize fodder (hybrid SMC-305), mungbean (CES1D-21), unweeded fallow, unweeded fallow + farmyard manure (FYM), and *Sesbania aculeata* green manure. DS maize was planted after rice to determine residual effects. The experiment was continued in 1985 with some modifications. The soil was Maahas silty clay, Andaqueptic Haplaquoll, fine mixed isohyperthermic. The soil had an initial pH of 6.2, 1.11% organic C, 0.121% total N, and 23 ppm available P (Olsen).

The effects of preceding crops and treatments on N responses in 1984 WS rice have been reported (Annual report for 1984). To study the residual effects, DS maize SMC-305 was sown on 12 Dec 1984 at 50- × 25-cm spacing. Inorganic N at 60

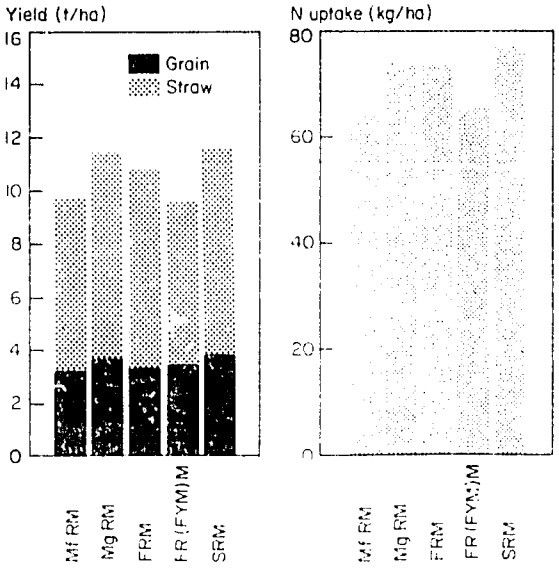


13. Soil moisture profiles, and rainfall and field operations between determinations. IRRI, 1985. CP = cowpea, + = intercropping, / = relay cropping. Date of determination is followed by rainfall between determinations in millimeters, in parentheses.

kg/ha was applied half at sowing and half at 40 DAS. Harvest was on 1 Apr 1985, and grain stover yields were recorded. Maize yields in different cropping sequences did not significantly differ regardless of N rate. However, the cropping sequence that included *Sesbania* green manure had more maize yield and N uptake than the other sequences (Fig. 14).

The same five sequences were repeated in 1985. Experimental units were again arranged in strip plots with cropping sequences in main plots and N levels in subplots. However, N rates were reduced from 0, 50, 100, and 150 kg/ha to 0, 35, 70, and 105 kg/ha because in 1984 WS rice did not respond beyond 50 kg N/ha. Maize fodder (SMC-305) and *S. aculeata* were sown on 23 Apr 1985 and mungbean (CES1D-21) on 24 Apr. Maize fodder received 50 kg N/ha; mungbean and *Sesbania* received no fertilizer. Maize fodder was harvested on 11 Jun and mungbean on 24 Jun. *Sesbania* biomass was recorded on 25 Jun. NPK accumulations in maize fodder, mungbean, and *Sesbania* yields are given in Table 13.

Sesbania green manure, weeds, 15 t FYM/ha, and 1/2 N as urea were incorporated between 25 Jun and 4 Jul. Rice (IR54) was transplanted on 8 Jul. Half the N was incorporated at planting; the remaining half was applied on 2 Sep. Rice was harvested on 16 Oct. More rice grain was obtained when rice followed green manure than when it followed maize fodder, mungbean, weedy fallow, and weedy fallow + FYM (Fig. 15). Without inorganic N, rice grain yield after the green manure was 4.6 t/ha. Lodging increased and yields declined as inorganic N rate increased. But in other cropping sequences, the yield increased significantly with successive increments of N up to 105 kg/ha. Rice yield with green manuring alone was com-



14. Residual effect of preceding crop in different cropping sequences on maize grain yield, straw yield, and N uptake. IRRI, 1984 DS. M = maize, Mf = maize fodder, Mg = mungbean, F = fallow, S = *Sesbania aculeata*, R = rice, R(FYM) = farmyard manure applied to rice.

parable to yields obtained from 105 kg N/ha in the remaining 4 cropping sequences, indicating a saving of 105 kg inorganic N/ha.

Sesbania accumulated about 100 kg N/ha and gave as much rice yield as 105 kg N/ha as urea and comparable N efficiency (Table 13), suggesting the need to monitor NH_4^+-N releases from *Sesbania* green manure. The following 3 cropping sequences

Table 13. NPK accumulation from *Sesbania aculeata*, farmyard manure, weeds, maize fodder, and mungbean. IRRI, 1985 WS.

Source	Quantity (t/ha)		Accumulation (kg/ha)			Remarks[a]
	Dry	Fresh	N	P	K	
Sesbania aculeata						
Shoot	6.1	31.6	99	15	156	Input
Root	0.8	1.7	7	1	10	
Farmyard manure	6.8	15.0	68	24	58	Input
Weeds	2.1	9.8	18	7	57	Input
Maize fodder	7.4	36.7	52	17	202	Removal
Mungbean						
Grain	0.6	--	--	--	--	Removal
Straw	2.6	--	57	8	88	

[a]Input = incorporated into soil, Removal = removed during harvest.

with 0 and 105 kg N/ha levels in the third replication of the experiment were monitored:

Sesbania (green manure) - rice - maize
Maize (fodder) - rice - maize
Fallow (weedy) - rice - maize

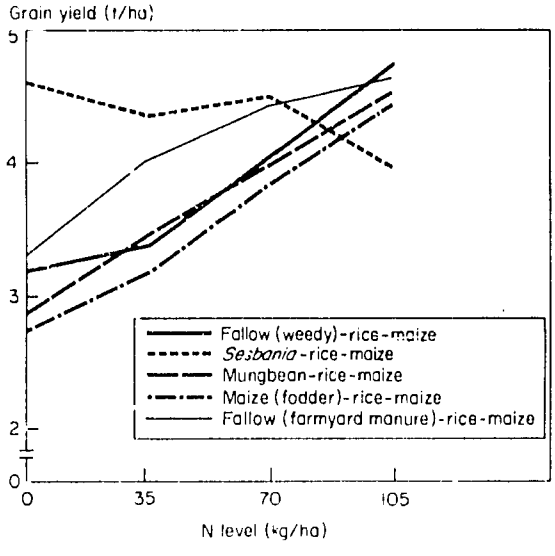
After incorporation of *Sesbania* green manure, NH_4^+-N in soil steadily increased to a peak in about 3-4 wk after transplanting and gradually declined to minimum about 3 wk later (Fig. 16). Much lower NH_4^+-N concentrations were observed in the other two crop sequences. Soil NH_4^+-N content was higher when inorganic N fertilizer was applied than when it was not. A sharp NH_4^+-N increase was reflected after the second N application was topdressed at 55 DT.

Green manure slowly but continuously maintained N supply during most of the rice season. The decline in NH_4^+-N concentration about 6-7 wk after transplanting suggests that N topdressing at 40-50 DT may be more efficient.

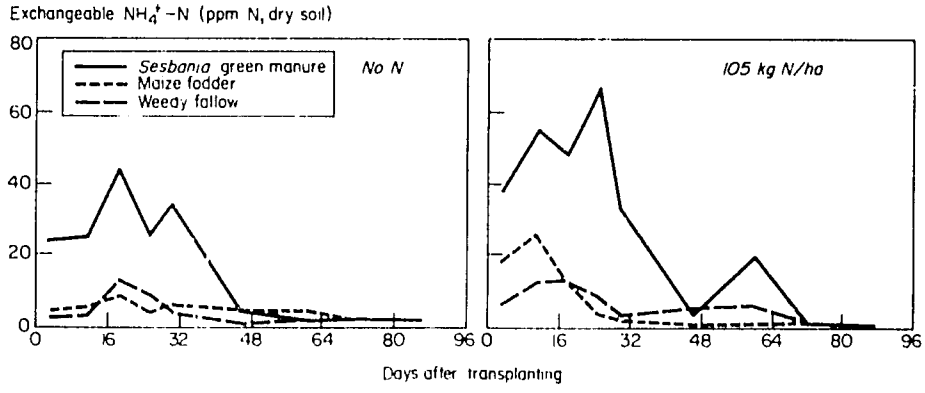
NITROGEN MANAGEMENT FOR SORGHUM

Multiple Cropping Department

A 1984 sorghum experiment showed that maximum response to N fertilizer by the main crop was only 1 t/ha above a control yield of 4 t/ha. The ratoon crop responded to N applied to the main



15. Rice grain yield after a fallow, green manure (*S. aculeata*), mungbean, maize fodder, and farmyard manure, IRRI, 1985 WS.



16. Effect of preceding crops (*Sesbania* green manure, maize fodder, and weedy fallow) on NH_4^+-N release in soil at different growth stages of succeeding rice. IRRI, 1985 WS.

crop, but only at levels exceeding 75 kg N/ha. The experiment was repeated in 1985, but the experimental field was flooded for 2 d after primary tillage to eliminate accumulated NO_3. The field was drained, rototilled, and planted on 4 Feb.

Sorghum (Cosor 3) was overseeded in 60-cm rows and irrigated immediately after seeding to ensure good emergence and thereafter to prevent drought stress. The crop was thinned to 200,000 plants/ha after emergence (8 Feb 1985). Weeds, birds, and insects were adequately controlled. The main crop was harvested between 6 and 10 May, and the ratoon crop between 10 and 20 Sep.

The experiment included a zero N control and all factorial treatment combinations of 7 N rates (25-175 kg N/ha) in increments of 25 kg N/ha and 2 application timings (1/3 applied at planting followed by 2/3 sidedressed at 25 DE, and all applied at 25 DE). Treatments were arranged in three replications of a randomized complete block design (RCBD).

The time of fertilizer N application did not influence the grain or N yields of the main or ratoon crop, either directly or through an interaction with rate. Therefore, only yield means are shown in Table 14. Main crop grain yield was regressed on N rate to obtain the equation

$$Y = 3.23 + 0.040\,N - 0.00012\,N^2 \qquad R^2 = 86\%$$
$$(0.23) \quad (0.005) \quad (0.00002)$$

The estimated maximum main crop yield was 6.6 t/ha at 167 kg N/ha.

Apparent N recovery by the main crop was high and linear (0.82%) to 100 kg N/ha. Estimated soil N in the control treatment was 53 kg/ha. Above 100 kg applied N/ha, apparent N recovery diminished. A positive trend in ratoon grain yield response to N applied to the main crop was observed, but the response was not significant. In the ratoon N yield, evidence of additional recovery from N rates exceeding 100 kg/ha applied to the main crop was not detected. Compared with 1984, N applied in 1985 was recovered almost exclusively by the main crop, leaving little for the ratoon crop. The contrasting results in these 2 yr suggest that if N recovery by the main crop is low because N is in excess of crop requirements, some N will be recovered by the ratoon crop.

Table 14. Sorghum main and ratoon crop grain and N yields.[a] IRRI, 1985.

N (kg/ha)	Grain yield (t/ha)		N yield (kg/ha)	
	Main	Ratoon	Main	Ratoon
0 (control)	3.0	1.5	47	33
25	4.4	1.3	75	33
50	4.9	1.4	99	29
75	5.4	1.5	112	31
100	6.1	1.5	138	30
125	6.1	1.7	145	34
150	6.6	1.6	140	32
175	6.4	1.6	159	33
N rate	**	ns	**	ns
Method	ns	ns	ns	ns
M × N	ns	ns	ns	ns
CV (%)	8	8	15	11

[a]Control is mean of 3 replications, others are means of 3 replications and 2 application times.

TILLAGE FOR LOWLAND RICE - LEGUME SEQUENCE

Multiple Cropping Department

A 5-yr experiment established in 1985 is examining the effects of tillage intensity on soil properties, yields, and growth of rice and legumes planted in sequence. Four factors are included in the experiment: 1) tillage for rice – the standard puddling practice at IRRI requiring many passes to thoroughly disperse soil particles, and a less intense and shallower sequence of practices (one plowing to 8-10 cm followed by 1 rototilling immediately after flooding) resulting in less soil dispersion; 2) two rice varieties (IR50 with moderate susceptibility to drought stress, and IR65 with moderate tolerance for drought stress); 3) tillage for the legumes (the standard plowing practice at IRRI followed by repeated rototillings to achieve a desired level of tilth, and 1 rototilling to 5 cm followed by rototilling in strips 10 cm wide and 10 cm deep before seed placement); and 4) 2 legume species (mungbean, which matures in 75 d and has a comparatively shallow, fibrous root system; and pigeonpea, which matures in 120 d and has a comparatively deep, taproot system).

The experimental design arranged split plots with partially confounded tillage treatments as main plots, and all factorial combinations of 2 rice varieties and 2 legumes as 4- × 5-m subplots. All treatments were replicated eight times. Main plots were bounded by bunds and separated by 1.5-m-wide buffer ditches. IR50 and IR65 were transplanted to the plots in 20-cm rows at 23 DAS and received a basal application of 30-13-0 kg NPK/ha, and 30 kg N applied at PI. The experiment was irrigated periodically to a depth of 10 cm. The buffer ditches were filled with water to the same depth as the water level in the main plots throughout the growing season. Water depth was accurately controlled by a wooden spillway imbedded in the bund at one end of each main plot. Plots were irrigated when the standing water level of half the main plots was zero. The experiment was irrigated eight times throughout the season.

Soil water potential was measured periodically in each main plot by tensiometers. Each set of tensiometers was installed at 10, 20, 30, and 40 cm. Soil penetrometer resistance to 60 cm was determined by a cone penetrometer every other week through the season. The modulus of rupture of dried puddled soils was determined on 4 samples from each main plot to a depth of 5 cm once a month.

Rice grain was harvested from a 6-m^2 area at the middle of each subplot. Preparations were made for legume cultivation in Jan 1986. Plots were kept flooded or saturated from about 1 wk after rice harvest to about 4 d before tillage started for legume cultivation.

Daily seepage and percolation losses were estimated for four periods when rainfall was zero (Table 15). During those periods, all plots had standing water. Evapotranspiration was estimated from potential evapotranspiration and a crop coefficient for stage of rice growth. Percolation losses were higher by 3.6 mm/d when soils were tilled at lower intensity.

On both 1 Aug and 6 Sep, mean soil moisture potentials at 10 and 20 cm were lower where tillage was less intense, but differences were not significant (Table 16).

Soil strength to 10 cm, as reflected in penetrometer determinations, was consistently lower in the

Table 15. Effect of tillage treatment on estimated seepage and percolation, IRRI, 1985 WS.

Period	DAS	Seepage and percolation (mm/d)	
		Conventional	Modified
26-29 Jul	57	1.2	5.8
4-7 Aug	66	3.6	8.3
23-28 Aug	87	5.7	8.9
4-6 Sep	96	5.5	7.6
Mean		4.2	7.8
		Δ3.6	

Table 16. Effect of tillage treatment on soil moisture potential, IRRI, 1985 WS.

Depth (cm)	Soil moisture potential (kPa)			
	1 Aug		6 Sep	
	Conventional	Modified	Conventional	Modified
10	0.89	0.07	−0.13	−0.02
20	0.38	−1.28	−0.08	−0.87
30	−3.52	−3.00	−1.98	−1.92
40	−6.29	−5.98	−5.57	−5.71

conventionally tilled plots. Below 10 cm, differences were not great. Representative soil penetration resistance profiles for two dates are shown in Figure 17. The differences in the tilled layer persisted for the duration of the rice crop. Dry soil strength, as reflected by modulus of rupture, was higher in the conventionally tilled plots (Table 17).

Neither tillage nor rice variety tested in 1984 WS affected rice grain yield significantly (mean yield 4.6 t/ha), suggesting that the extra percolation of 3.6 mm/d was neither detrimental nor beneficial.

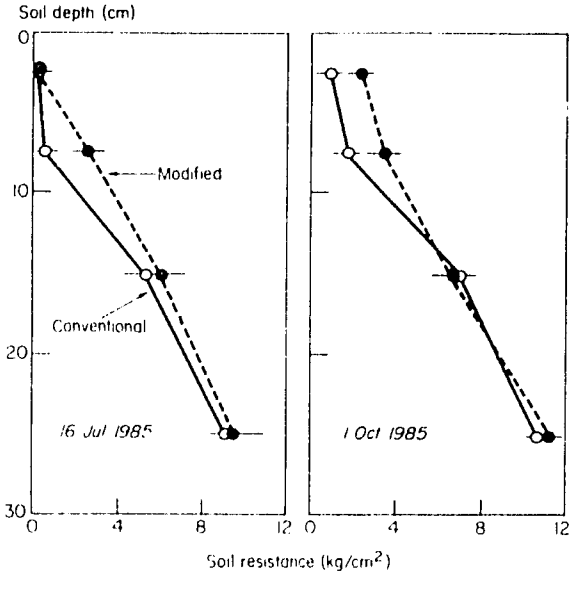
Table 17. Effect of tillage on modulus of rupture, IRRI, 1985 WS.

	Modulus of rupture (MPa)	
	Conventional	Modified
19 Jul	1.67	1.35**
16 Aug	1.55	1.27**
17 Sep	1.90	1.54*
Mean	1.71	1.39

PERFORMANCE OF SORGHUM AND MAIZE VARIETIES IN POSTRICE ENVIRONMENTS VARYING IN WATER AVAILABILITY

Multiple Cropping Department

In rice-based cropping sequences, upland crops such as maize and sorghum can be grown after rice. To assess their relative suitability for cultivation in DS, two sorghum and four maize cultivars were studied in environments varying in irrigation (applied by line source sprinkler system) and soil tilth (upland vs formerly puddled lowland). The lowland field was prepared by strip-rototilling (10 m wide, 6-8 cm deep) rows 60 cm apart in a former ricefield. The upland field was plowed and harrowed.



17. Penetrometer resistance early and late in WS on soil puddled by conventional IRRI practices and by modified practices, IRRI, 1985.

Cosor 3 and UPL SG5 (open-pollinated sorghums), IPB-1 and Early DMR Composite 1 (open-pollinated maizes), and Pioneer 6181 and SMC 305 (hybrid maizes) were sown in lowland fields on 29 Dec 1984 and in upland fields on 5 Jan 1985. Seed rates were adjusted to obtain 150,000 plants/ha for sorghum and 60,000 for maize. For both crops, 67 kg N/ha was basally incorporated. An additional 33 kg N/ha was sidedressed at hilling up (25 DE). Fields were maintained free of weeds and diseases.

Cumulative water applied by using a line source sprinkler system over the season was 324 mm in regime I, 288 in regime II, and 137 mm in regime III in the lowland experiment. Corresponding quantities in the upland experiment were 303, 254, and 104 mm. Rainfall during the crop season was 139 mm. The water table in the upland field was always deeper than 140 cm, whereas in the lowland field it receded from 20 to below 140 cm as the season progressed.

Grain yield and TDMY were determined at maturity. Grain yield from regime I and regime II did not differ between the upland and lowland experiments but was reduced in regime III (Table 18, 19). A similar response pattern was observed for TDMY. Both sorghum varieties produced less TDMY and grain yield than any maize variety. UPL SG5 produced more TDMY and grain yield than Cosor 3, regardless of regime. Maize hybrids had the maximum TDMY and grain yield in all regimes in the upland and lowland experiments. There was no difference between the two open-pollinated maize varieties in the lowland experiment. In the upland experiment, however, IPB-1 yielded more than Early DMR Composite 1 in

Table 18. Grain yield of 2 sorghum and 4 maize cultivars under 3 moisture regimes at 2 locations. IRRI, 1985 DS.

Cultivar	Grain yield (t/ha)							
	After lowland rice moisture regimes				After upland rice moisture regimes			
	I	II	III	Mean	I	II	III	Mean
Sorghum								
Cosor 3	3.89	3.66	2.45	3.33	4.54	4.78	2.98	4.10
UPL SG5	4.83	4.85	2.93	4.21	5.51	5.39	4.21	5.04
Maize								
IPB-1	6.46	6.73	3.52	5.57	8.23	7.89	1.02	6.72
Early DMR Composite 1	5.98	5.56	3.30	4.94	6.10	5.81	4.06	5.32
Pioneer 6181	7.24	8.45	4.40	6.69	7.69	8.07	4.26	6.68
SMC 305	7.00	6.94	4.32	6.09	8.28	8.18	4.47	6.97
Mean	5.90	6.03	3.49	4.87	6.73	6.69	4.00	5.81
Crop (C)		**				**		
Moisture regime (MR)		**				**		
MR × C		**				**		
Error (a)		0.674				0.229		
Error (b)		0.189				0.308		

regime I and regime II. In regime III, yields were not different.

Shortage of water had comparatively little influence on the maturity of Cosor 3, UPL SG5, or Early DMR Composite I (Table 19). Hybrid maize maturity was shortened by 10 d where water was deficient. Regardless of soil condition or water availability, maize hybrids were superior to the open-pollinated maizes and sorghum.

TEPARY BEAN

Multiple Cropping Department

Three tepary bean lines were planted at 2 plant densities (nominally 200,000 and 400,000 plants/ha) in 4 replications of a RCBD on 2 dates (17 Dec 1984 and 17 Jan 1985). The experiment was irrigated on 23 Dec, 28 Dec, and 23 Jan, receiving about 20 mm/application. Grain yield, TDMY, mean plant density at maturity, and percentage mortality are shown in Table 20. Except for seed color, differences among lines were either not significant or of only minor agronomic importance. Yields were higher in the 17 Jan planting, which can be explained in part by lower plant mortality. All varieties were affected by an unidentified disease that caused rapid wilting and death. Disease damage was more severe in the earlier planted treatments. Seeds were slow to emerge, taking 11 d to achieve 75% emergence, but 75% flowering was achieved by 24 DE when planted 17 Dec and by 23 DE when planted 17 Jan. Nodules did not develop even though inoculant was applied. Pods were mature (75% dry brown pods) at 52 DE when planted on 17 Dec and at 47 DE when planted on 17 Jan. Tepary bean may be suitable as a short-duration grain legume if disease can be controlled, and if inoculation will promote nodulation.

EFFECT ON SOYBEAN OF SHADING SEQUENCES SIMULATING RELAY CROPPING AND INTERCROPPING

Multiple Cropping Department

An experiment from February to May 1985 at IRRI studied the influence of time and duration of shading on soybean. Shading treatments were compared in a RCBD with four replications. Shading was imposed in one treatment set to simulate canopy development by a dominating intercrop (I). A second treatment set simulated gradually decreasing shading by a dominating but senescing first crop on relayed (R) soybean. An unshaded control was replicated twice within each block (Fig. 18).

Table 19. Maturity (DAS) of 2 sorghum and 4 maize cultivars under 3 moisture regimes at 2 locations. IRRI, 1985 DS.

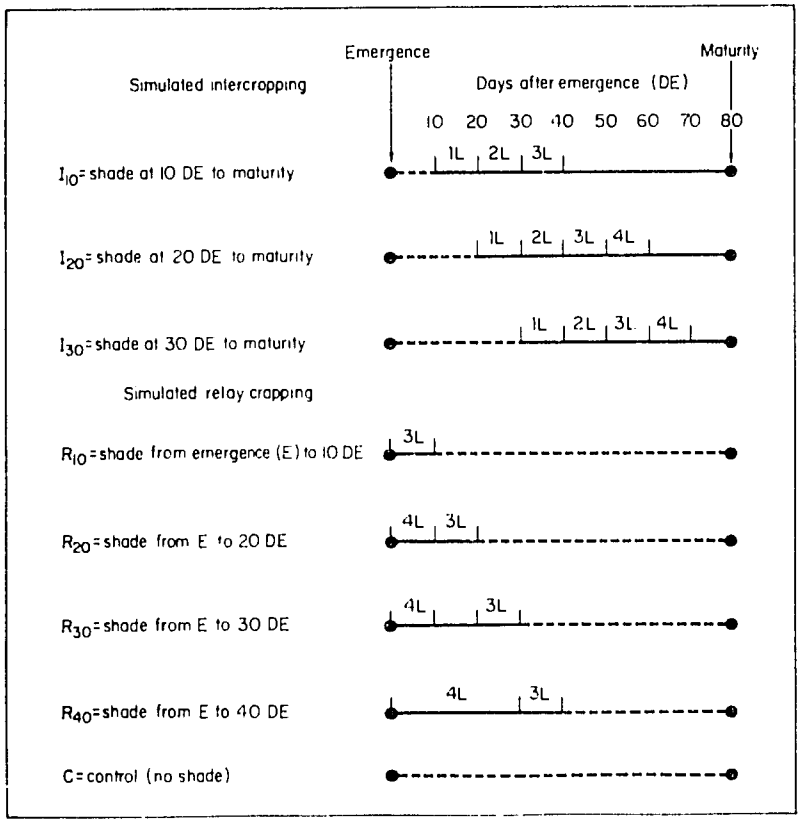
Cultivar	Maturity (DAS)					
	After lowland rice			After upland rice		
	I	II	III	I	II	III
Sorghum						
Cosor 3	98	98	97	97	97	95
UPL SG5	114	114	110	109	109	104
Maize						
IPB-1	114	114	107	110	110	104
Early DMR Comp 1	100	100	98	97	97	95
Pioneer 6181	121	121	109	119	118	108
SMC 305	124	124	113	119	119	113
Crop (C)		**			**	
Moisture regime (MR)		**			**	
MR × C		**			**	
Error (a)		1.10			7.5	
Error (b)		1.03			5.7	

Analysis of variance

Source of variation	*df*	*Mean square*	
		After lowland rice	*After upland rice*
Replication	3	0.634	19.383
Varieties (V)	5	1046.414**	948.058**
Sorghum vs maize	1	779.340**	855.560**
Among sorghum	1	1350.000**	726.000**
Maize, 3,4 vs 5,6	1	2120.020**	2310.190**
Maize 3 vs 4	1	912.670**	828.380**
Maize 5 vs 6	1	70.040**	20.170ns
Error (A)	15	1.110	7.451
Moisture regime (MR)	2	292.015**	210.290**
V × MR	10	26.481**	12.025*
(Sorghum vs maize) × MR	2	50.175**	10.645ns
(Among sorghum) × MR	2	6.000**	6.000ns
(Maize 3,4 vs 5,6) × MR	2	58.520**	22.940*
(Maize 3 vs 4) × MR	2	16.665**	9.375ns
(Maize 5 vs 6) × MR	2	1.040ns	11.165ns
Error (B)	36	1.032	5.662
Total	71		
CV (a)		1	3
CV (b)		1	2

Table 20. Mean seed yield of tepary beans planted at 2 population densities on 2 sowing dates. IRRI, 1984-85.

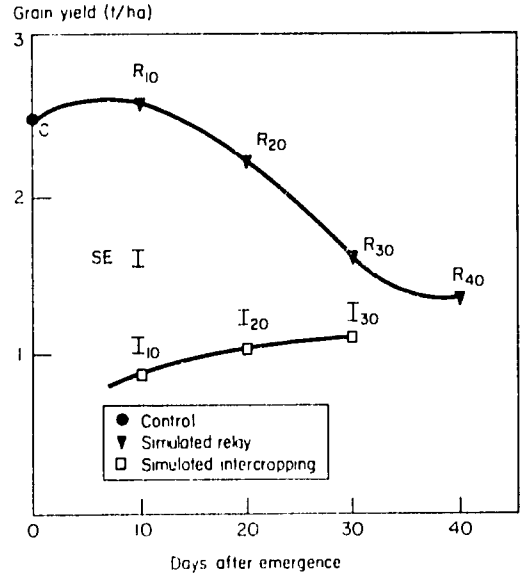
Plant density (plants/ha)	Grain yield (t/ha)		TDMY (t/ha)		Plants (thousand/ha)		Mortality (%)	
	17 Dec 1984	17 Jan 1985	17 Dec	17 Jan	17 Dec	17 Jan	17 Dec	17 Jan
200,000	0.47	0.61	1.15	1.10	155	175	22	13
400,000	0.58	0.73	1.62	1.76	304	330	24	17
SE	0.033		0.11					



18. Intercropping (I) and relay cropping (R) were simulated by covering soybean with 1-4 layers (L) of net as shown for these 8 treatments. IRRI, 1985 DS.

Shading was imposed by stretching 1-4 layers of gray-green 4-mesh nylon fishnet on frames 1 m above a plot. Light transmission was 74% through 1 net layer, 54% through 2 layers, 34% through 3, and 28% through 4. Transmission was determined between 1300 and 1400 h. The 2-, 3-, and 4-layer transmission reductions were similar to those determined at ground level in a maize population of 40,000 plants/ha at 30, 44, and 66 DAS, respectively.

Inoculated seeds of UPL SY-2, a locally adapted variety, were overseeded in 40-cm rows after incorporating 10-5-9 kg NPK/ha on well prepared soil. At 4 DE, the crop was thinned to 10 plants/m. Weeds were controlled with a preemergence application of butachlor (1.2 kg ai/ha) followed by hand weeding. Between the beginning seed and full seed stages of the crop, *Homono coffearia* Nietmer damaged many leaves in all treatments before being brought under control. Other insects were



19. Effect of length of simulated relay cropping and of simulated intercropping on soybean grain yield. IRRI, 1985 DS.

controlled. The experiment was irrigated weekly with an overhead rotary sprinkler system.

Mean maximum and minimum temperatures were 33 °C and 24 °C, respectively. Total rainfall and irrigation water applied were 314 mm, and mean daily solar radiation was 518 mWh·cm^2 per day.

Starting at 10 DE, random samples of 40 plants (2 m in 2 rows) per plot were taken every 10 d from selected treatments for determination of plant dry weight, leaf area, number of nodules, flowers per plant, and pods per plant. At maturity, grain yield samples were taken from a 6-m^2 area at the center of each plot.

Table 21. Leaf area index and specific leaf weight at 40 DE as affected by simulated intercropping and relay cropping.[a] IRRI, 1985 DS.

Treatment	Leaf area index	Specific leaf weight
Simulated intercropping starting at		
10 DE	2.3	2.7
20 DE	2.9	2.6
30 DE	2.9	2.9
Simulated relay cropping stopping at		
10 DE	3.0	3.4
20 DE	2.5	3.4
30 DE	2.7	2.9
40 DE	2.6	2.1
Unshaded control	3.1	3.2
SE	0.2	0.3

[a]Means of 4 replications.

Grain yield from unshaded control plants was 2.5 t/ha (Fig. 19). Yields decreased as duration of shading increased. Simulated intercropping reduced grain yield more than simulated relay cropping did.

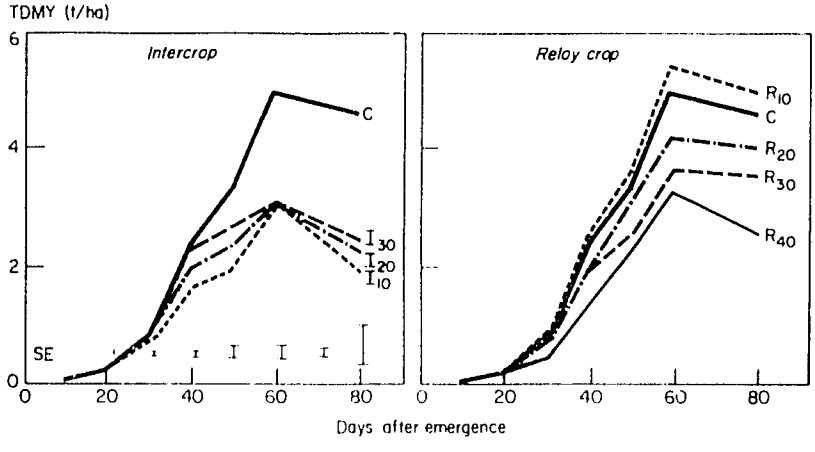
Shading had little effect on soybean phenology up to R6 (full seed), which occurred at 50 DE. From this stage onward, simulated intercropping delayed maturity by an average of 3 d.

Regardless of shading treatment, leaf area index (LAI) increased rapidly and was maximal at 40 DE (beginning seed). Only the intercrop treatment starting at 10 DE depressed LAI by more than 20% (Table 21). Significant reductions of specific leaf weight were observed at 40 DE, especially from treatments simulating relay cropping for 30 and 40 d (Table 21).

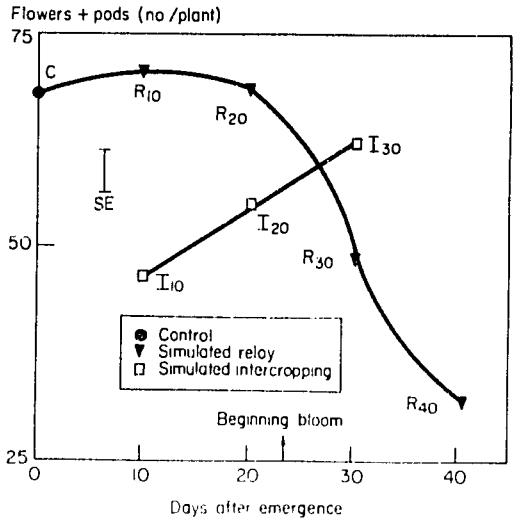
TDMY was similar in the very early stages of all treatments, but after 30 DE control plants produced more dry matter at a significantly faster rate (Fig. 20). Shading eventually depressed growth, the effect being more severe as shading duration increased.

Simulated relay cropping for 10 or 20 d had little effect on the number of flowers + pods observed at 40 DE (Fig. 21). Other treatments caused moderate to severe depression in numbers.

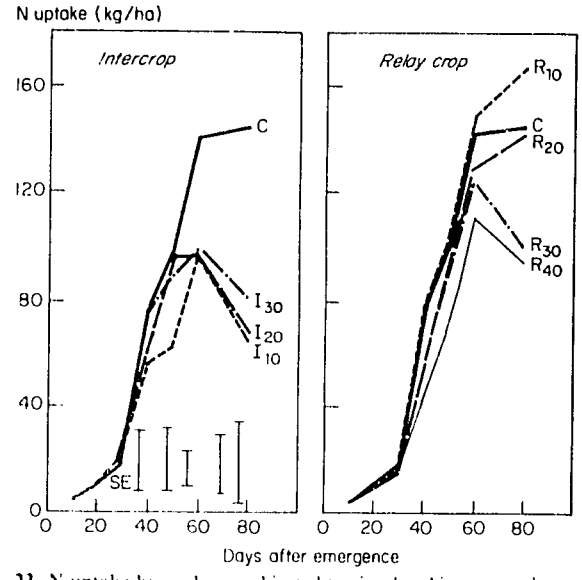
Simulated relay cropping reduced the number of nodules per plant at 30 DE, with reduction increasing as shading duration increased (Fig. 22).



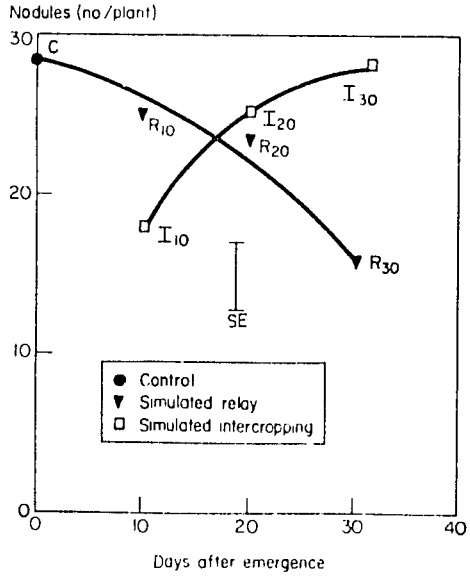
20. TDMY of soybean subjected to simulated intercropping and relay cropping. IRRI, 1985 DS. C = control.



21. Number of pods + flowers at 40 DE on soybean subjected to simulated intercropping and relay cropping. IRRI, 1985 DS.



23. N uptake by soybean subjected to simulated intercropping and relay cropping. IRRI, 1985 DS.



22. Nodule numbers at 30 DE on soybean subjected to simulated intercropping and relay cropping. IRRI, 1985 DS.

Simulated intercropping imposed at 10 DE depressed nodulation by one-third. Simulated intercropping depressed N accumulation more strongly than simulated relay cropping (Fig. 23). N accumulation was depressed to about the same level regardless of the time intercrop shading was imposed. N accumulation decreased as the simulated relay cropping duration increased.

FERTILITY MANAGEMENT FOR UPLAND RICE ON ACID SOILS

Multiple Cropping Department

Fertility management is one of the major challenges in improving and sustaining upland rice productivity in acid infertile upland soils in the tropics.

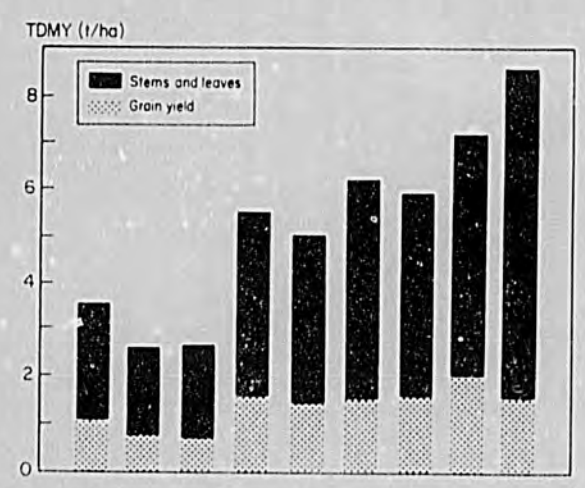
This study determined the response of upland rice to various macronutrients, lime, and manure on three acid, P-deficient sites in the Philippines. The soil and climate characteristics of the experimental sites are given in Table 22.

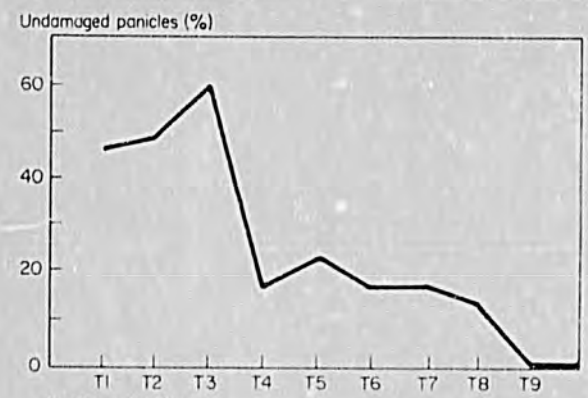
Cavinti. The trial at Cavinti, Laguna, was characterized by a long drought period at the vegetative stage and severe neck-blast (Bl) incidence during early grain filling. N application alone significantly reduced dry matter and grain yield compared with no fertilizer application (Fig. 24). P response to acid soil was demonstrated: treatment 4 (70 N + 20 P) gave higher dry matter and grain yield than the control treatment (T1) and N alone at both 35 N (T2) and 70 N (T3). NPK + lime in T8 produced the highest grain yield (2.0 t/ha), significantly higher than the yield (1.5 t/ha) of NPK + lime + manure (T9). No significant differences occurred in grain yield from T4 through T8 and between T9 and T1.

TDMY was highest in T9, significantly higher than in all other treatments. Moreover, panicle

Table 22. Comparative site characteristics of 2 acid upland ricefields in the Philippines. 1985.

Parameter	Mahipon, Cavinti, Laguna	Patrocinio and Anii, Claveria, Misamis Oriental
Topography	Rolling	Undulating
Climate	Type II-1; maximum rains from July to December or January	Type II-1; maximum rains from July to December
Rainfall (mm/yr)	3,300	2,200
Dominant land use	Coconut, tomato	Upland rice, maize, tomato
Soil		
pH (1:1 H_2O)	4.0	4.5-5.8
CEC (meq/100 g)	19-24	6-12
Available P (Bray 2) (ppm)	1.6-5.6	4.1-4.7
Exchangeable Al (meq/100 g)	6.8-10.7	0.5-3.0
Texture	Clay	Clay
Taxonomic classification	Palehumult	Dystropept





Fertilizer added (kg/ha)

	T1	T2	T3	T4	T5	T6	T7	T8	T9
N	-	35	70	70	35	70	70	70	70
P	-	-	-	20	10	20	20	20	20
K	-	-	-	-	10	20	20	20	20
Lime	-	-	-	-	-	-	500	2000	2000
Manure	-	-	-	-	-	-	-	-	3000

24. TDMY, grain yield, and panicles undamaged by Bl as affected by various fertilizers added to upland rice (UPLRi5) grown in an acid infertile soil. Cavinti, Laguna, Philippines, 1985.

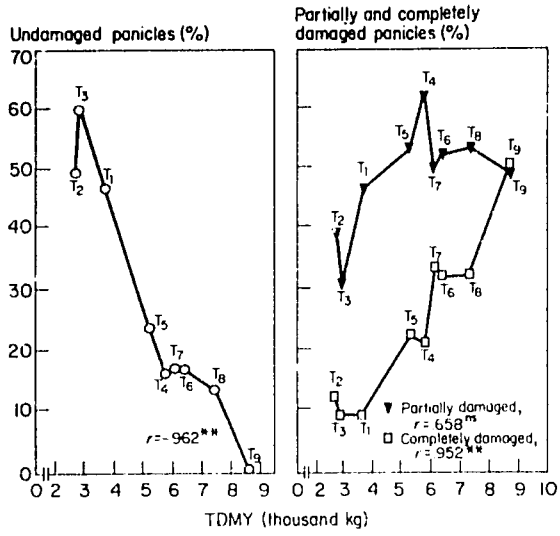
number, plant height, and LAI (at 70 DAS) were significantly higher in T9. N application alone had lower values than no fertilizer application for these characters.

At the earlier growth stages, the rice plants in T9 were most vigorous (at both 25 and 70 DAS) and were the tallest. At harvest, however, neck Bl and leaf scald (LSc) damage were significantly higher in T9 than in all other treatments (Fig. 24). Similarly, drought scores at 60 DAS were significantly higher in T9 than in all other treatments. The greater disease and drought susceptibility of rice in T9 apparently explains why T9 had the highest TDMY but lower grain yield than T8. Neck Bl was most severe in T9, with 100% damaged panicles at harvest (Fig. 24). Neck Bl was highly correlated ($r = 0.964$**) with TDMY. Conversely, the percentage of panicles undamaged by Bl was negatively correlated with TDMY ($r = -0.962$**) (Fig. 25).

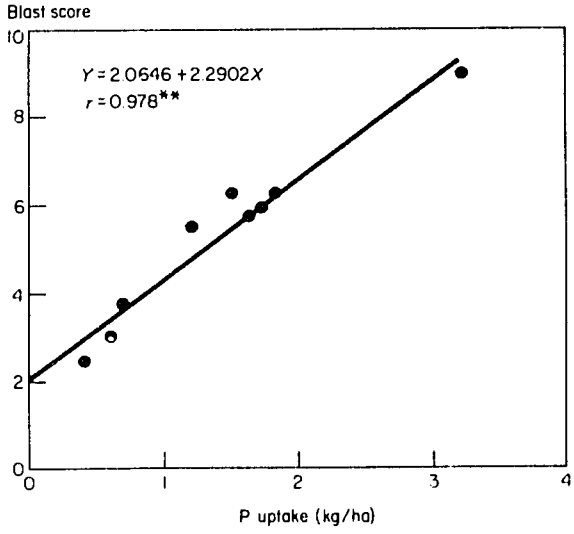
Leaf area was highly correlated with LSc incidence ($r = 0.949$**) and with drought susceptibility ($r = 0.968$**). Drought scores were highly correlated with TDMY ($r = 0.964$**). T9 had the highest LSc damage and drought susceptibility.

T9 had the highest total uptake of macronutrients and micronutrients. N and P uptake were highly correlated with Bl damage (Fig. 26, 27).

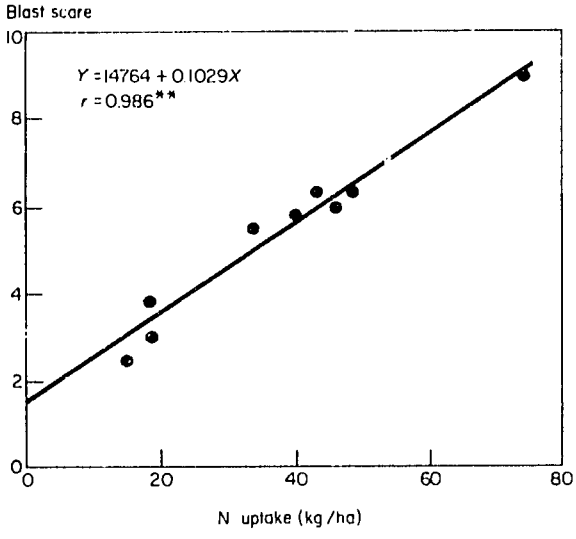
Analysis of nutrient percentage in rice tissue further revealed the relation of nutrients absorbed to disease susceptibility. Among the macronutrients, there were no significant differences among treatments in percentage nutrient content in the tissue. Among the micronutrients, however, there



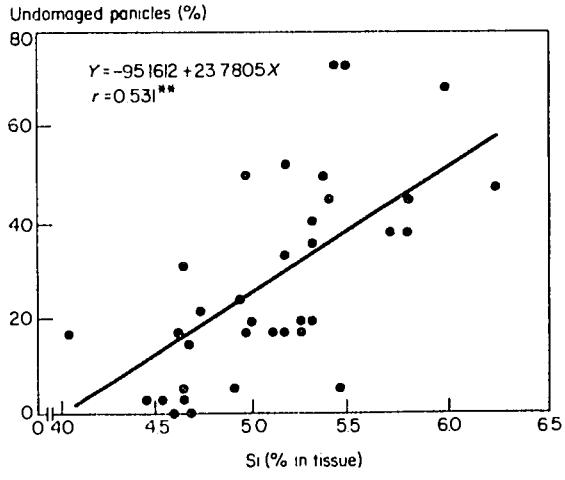
25. Relation of TDMY and panicle condition as affected by fertilizers applied to UPLRi5 grown in acid upland soils. Cavinti, Laguna, Philippines, 1985. T1-T9 are explained in Figure 24.



27. Correlation between blast damage and P uptake in UPLRi5 at 70 DAS in acid upland soils. IRRI, 1985.



26. Correlation between blast damage and N uptake in UPLRi5 at 70 DAS in acid upland soils. IRRI, 1985. 0 = no lesions, 9 = all leaves dead.



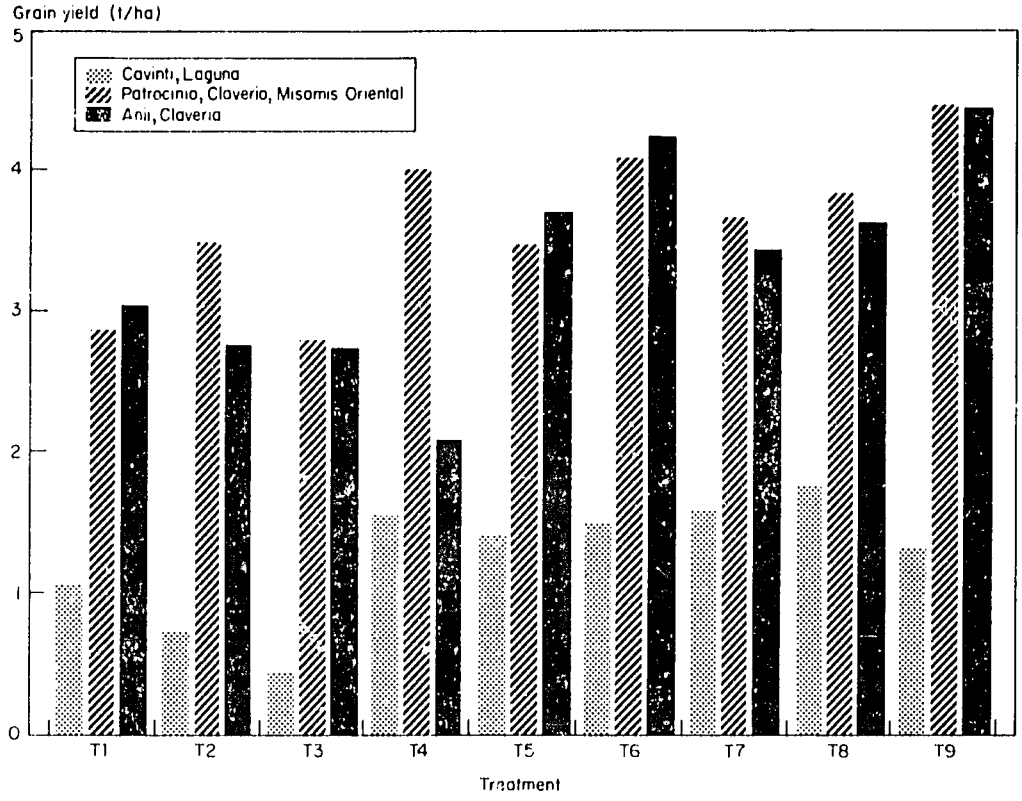
28. Panicles undamaged by blast as influenced by Si % in tissue of rice grown in infertile, acid upland soils. Cavinti, Laguna, Philippines, 1985.

were significant differences. Percentage Si in the tissue was significantly affected by the various fertilizer treatments.

The relation of Si percentage in the tissue and percentage panicles undamaged by Bl was significant (Fig. 28), suggesting that higher Si concentration in the tissue resulted in less neck Bl damage. When Si percentage values fell below 5%, Bl damage increased substantially. The critical deficiency level of Si percentage in the tissue was reported to be 5%.

The Mn percentage in the tissue was inversely correlated with Si percentage ($r = -0.441^{**}$), suggesting a competitive relationship.

Claveria. For comparative purposes, two trials were conducted in Claveria, Misamis Oriental. Growing conditions were favorable for the trials in



Fertilizer added (kg/ha)									
N	–	35	70	70	35	70	70	70	70
P	–	–	–	20	10	20	20	20	20
K	–	–	–	–	10	20	20	20	20
Lime	–	–	–	–	–	–	500	2000	2000
Chicken manure	–	–	–	–	–	–	–	–	3000

29. Comparative yield of UPLRi5 from the fertility management study at 3 sites, 1985 WS.

Anii and Patrocinio. Except for treatment 4, the yield response of UPLRi5 to the treatments was similar in both trials (Fig. 29). Yield differences at Anii varied from 2.1 t/ha to 4.5 t/ha, with T9 (having the highest fertilizer inputs) obtaining the highest values for grain yield, TDMY at 90 DAS, and plant height.

At Patrocinio, grain yield ranged from 2.8 t/ha to 4.5 t/ha. Grain yield was highest with T9 and lowest with T3. No significant yield differences occurred among treatments with 20 kg P/ha. But when P was reduced to 10 kg/ha (T5), yield reduction was significant.

Compared with Claveria, the Cavinti site represented a substantially adverse rice environment in 1985, necessitating further studies if grain yield of rice is to be improved.

Cropping systems program

Preproduction testing and technology transfer

Training and Technology Transfer Department

MULTILOCATION TRIALS ON NITROGEN FERTILIZER USE EFFICIENCY **430**
Dry season **430**
Wet season **431**
ADOPTION OF DRY SEEDED RICE TECHNOLOGY IN THE RAINFED LOWLANDS OF ILOILO AND SOUTH COTABATO, PHILIPPINES **432**

MULTILOCATION TRIALS ON NITROGEN FERTILIZER USE EFFICIENCY

Dry season. During 1985 dry season (DS), 26 on-farm N use efficiency trials were conducted in 7 provinces of the Philippines (Table 1). The only machine applicator tested was the plunger/auger.

At 29 kg N/ha, hand-placed urea supergranules (USG) gave a significantly higher yield than the researcher's split (2/3 basal and 1/3 applied at 5-7 d before panicle initiation [DBPI]) at 8 of 26 locations. In most other locations, hand-placed USG was numerically superior though not significantly better. Split application at relatively low N levels appears inefficient compared with USG.

At 58 kg N/ha, the researcher's split was compared with farmers' practice, prilled urea (PU) applied by the plunger/auger, and hand-placed USG. Farmers' practices varied from location to location but in most cases involved a split application, the first of which was applied at 2-3 wk after transplanting and the second at 1 wk after panicle initiation (PI). The exception was South Cotabato, where all N was applied at 35-40 d after transplanting (DT). The researcher's split gave significantly higher yields than farmers' practices at only 2 of 26 locations, suggesting little advantage of basal incorporation.

Application of PU by plunger/auger gave inconsistent results. At three locations, yields were significantly less than that obtained with the researcher's split. At three other locations, significantly higher yields were obtained with plunger/auger application. At the remaining 20 locations,

Table 1. Effect of N application method and rate on rice grain yield in 26 on-farm locations, Philippines, 1985 DS.

Location		Yield[a] (t/ha)							
		No N	29 kg N/ha		58 kg N/ha				80 kg N/ha
			RS	Hand-placed USG	FP	RS	Plunger/ auger PU	Hand-placed USG	RS
Nueva Viscaya	1	3.8 d	4.2 cd	4.9 abc	4.7 bc	5.3 ab	4.5 cd	5.4 ab	5.7 a
	2	4.3 d	4.7 cd	4.7 cd	5.2 bc	5.7 ab	5.2 bc	5.8 ab	6.0 a
	3	4.8 c	5.7 b	5.7 b	6.0 b	5.9 b	6.0 b	6.3 a	6.6 a
	4	4.0 d	4.6 c	4.6 c	5.3 b	5.5 b	5.5 b	5.6 b	6.0 a
	5	3.8 f	5.2 e	5.3 de	5.6 cde	6.2 ab	5.7 cd	5.9 bc	6.5 a
Nueva Ecija	1	4.2 d	5.0 c	5.7 b	5.9 ab	6.0 ab	5.6 b	6.3 a	6.3 a
	2	3.5 d	4.6 c	4.7 c	4.8 c	5.0 bc	4.7 c	5.4 ab	5.6 a
	3	3.1 d	4.1 c	4.3 bc	4.2 bc	4.7 ab	4.1 c	5.1 a	5.2 a
	4	3.7 c	4.3 b	4.6 ab	4.6 ab	4.8 ab	4.9 a	5.0 a	4.6 ab
Pangasinan	1	1.8 d	2.6 c	3.0 bc	3.1 bc	3.6 ab	4.1 a	3.9 a	4.3 a
	2	3.5 d	4.0 c	4.1 c	4.4 b	4.6 b	4.7 ab	4.7 ab	4.9 a
	3	2.3 g	3.1 f	3.5 e	3.7 de	4.0 cd	4.4 b	4.1 bc	4.9 a
Tarlac	1	2.1 f	2.6 e	2.9 de	3.2 cd	3.5 c	4.0 b	3.9 b	4.4 a
	2	3.5 f	3.9 e	4.1 d	4.3 cd	4.4 bc	4.6 ab	4.5 bc	4.7 a
Iloilo	1	2.8 e	3.5 d	3.7 cd	4.0 bc	3.9 bc	4.1 abc	4.2 ab	4.5 a
	2	2.4 d	2.8 c	3.4 b	3.8 a	4.0 a	3.8 a	3.9 a	4.1 a
	3	2.4 d	3.3 c	3.7 b	3.7 b	3.7 b	3.8 b	3.8 b	4.2 a
	4	2.2 e	2.9 d	3.5 c	3.7 bc	3.6 c	3.6 c	4.0 b	4.7 a
	5	1.8 d	2.2 d	2.9 bc	3.1 bc	2.7 c	3.8 a	3.5 ab	3.0 bc
	6	2.3 d	3.0 c	3.5 ab	3.1 bc	3.6 a	3.8 a	3.9 a	3.9 a
Leyte	1	4.6 c	5.6 b	5.7 b	5.7 b	5.7 b	6.0 ab	6.4 a	6.4 a
	2	4.8 b	5.4 ab	5.8 a	5.6 a	5.6 a	6.1 a	5.8 a	5.7 a
	3	3.7 c	4.5 a	4.2 abc	3.9 bc	4.4 ab	4.3 abc	3.9 bc	4.6 a
South Cotabato	1	2.5 c	3.4 b	3.5 b	4.2 a	4.3 a	4.2 a	4.5 a	4.7 a
	2	3.5 b	4.2 a	4.3 a	4.2 a	4.3 a	4.2 a	4.6 a	4.7 a
	3	4.1 b	4.6 ab	4.7 ab	4.8 ab	5.1 a	5.1 a	5.2 a	5.1 a

[a]Av of 4 replications. Separation of means in a row by Duncan's multiple range test at the 5% level. Researcher's split (RS) = 2/3 basal incorporated and 1/3 topdressed 5-7 d before panicle initiation. Farmer's practice (FP) = 1/2 applied 2-3 wk after transplanting and 1/2 at or after panicle initiation, except for South Cotabato, where all N was applied at 35-40 d after transplanting (DT). Hand-placed urea supergranules (USG) and plunger/auger applied prilled urea (PU) at 7 DT.

there was no significant difference between the 2 treatments. The variation in response was assumed to be related to metering differences.

Based on earlier research, hand-placed USG is likely to be most efficient in terms of N use. At 5 of 26 locations, hand-placed USG gave a significantly higher yield than the researcher's split, with an average yield advantage of 0.5 t/ha. At the 21 other sites, yields did not significantly differ. Therefore, at most locations and at 58 kg N/ha, the researcher's split and farmers' practices appear relatively efficient.

Finally, at 15 of 26 sites there was no significant increase in yield when the N level was increased from 58 to 80 kg N/ha using the researcher's split technique. That suggests that N recommendations for DS irrigated rice may be too high in some places.

Wet season. During 1985 wet season (WS), 19 on-farm trials in 4 provinces further evaluated techniques for improving N fertilizer use efficiency (Table 2). Treatments were applied mostly at 29 kg N/ha because of Philippine emphasis on reducing input costs. The plunger/auger was evaluated for application of PU, while the press wedge was used for USG application. The plunger/auger was an improved version of the one used in 1985 DS trials.

At 29 kg N/ha, the researcher's split yielded significantly better than the farmers' practices at only 1 of 19 locations; at 2 locations it yielded significantly less. The farmers' practices varied from location to location but in all cases involved a split application, the first of which was applied 2-3 wk after transplanting and the second about 1 wk after PI.

A recent recommendation of the Agronomy Department said that at low rates, all N should be applied at 5-7 DBPI. At 2 of 19 locations this technique yielded significantly higher at 29 kg N/ha than the researcher's split. At the remaining

Table 2. Effect of N application method and rate on rice grain yield from 19 on-farm locations, Philippines, 1985 WS.

Location		Yield[a] (t/ha)								
			29 kg N/ha						58 kg N/ha	
		No N	Prilled urea			USG			Prilled urea	USG
			FP	RS	5-7 DBPI	Plunger/ auger	Hand-placed	Press wedge	RS	Hand-placed
Camarines Sur	1	3.5 b	3.7 ab	3.8 ab	4.0 ab	4.0 ab	3.6 b	4.0 ab	4.2 a	4.2 a
	2	2.6 c	3.3 ab	3.1 bc	3.4 ab	3.1 bc	3.2 ab	3.2 ab	3.5 ab	3.6 a
	3	3.0 d	3.6 bc	3.7 bc	3.4 cd	3.3 cd	4.0 ab	3.5 c	4.3 a	4.4 a
	4	3.9 d	4.6 b	4.0 cd	4.4 bc	4.4 bc	4.7 b	4.5 b	4.5 b	5.2 a
	5	3.5 c	3.7 c	3.8 c	4.1 b	3.8 c	4.2 b	4.2 b	4.2 b	4.7 a
	6	2.9 e	3.7 c	3.6 c	3.7 c	3.3 d	3.9 bc	3.7 c	4.0 b	4.5 a
Bulacan	1	4.4 d	4.9 c	5.4 b	5.4 b	5.7 b	5.6 b	5.5 b	6.6 a	6.8 a
	2	4.3 c	5.0 b	5.4 ab	5.3 ab	5.1 ab	5.1 ab	5.1 ab	5.5 ab	5.7 a
	3	3.9 d	4.6 c	5.1 bc	5.1 bc	5.5 ab	5.1 bc	5.3 b	5.4 b	6.0 a
	4	4.5 e	5.1 d	5.2 d	5.4 cd	5.6 c	5.6 c	5.5 cd	6.0 b	6.5 a
Nueva Ecija	1	4.6 d	5.1 c	5.1 c	5.4 bc	5.3 c	5.5 bc	5.4 bc	5.8 ab	6.0 a
	2	3.5 d	4.0 c	4.3 bc	4.5 abc	4.4 bc	4.6 ab	4.3 bc	4.6 ab	4.9 a
	3	3.3 c	3.4 c	3.8 abc	3.9 ab	3.8 abc	3.4 bc	3.7 abc	3.7 abc	4.2 a
Iloilo	1	2.6 b	3.6 a	3.4 a	3.4 a	3.2 a	3.2 a	2.6 b	3.6 a	3.5 a
	2	3.0 c	3.2 de	3.3 cd	3.4 cd	3.4 cd	3.6 bc	3.3 d	3.8 ab	4.0 a
	3	3.2 c	4.2 a	3.6 bc	3.8 ab	3.5 bc	4.0 ab	3.6 bc	4.2 a	4.3 a
	4	1.9 d	2.4 ab	2.5 ab	2.3 abc	2.0 cd	2.2 bcd	2.3 bc	2.7 a	2.7 a
	5	2.3 d	2.8 bc	2.6 cd	3.0 b	2.4 cd	3.4 ab	3.1 b	3.7 ab	3.7 a
	6	2.8 d	3.3 c	3.2 c	3.3 c	3.2 c	3.7 b	3.4 bc	4.4 a	4.3 a

[a]Av of 4 replications. Separation of means in a row by Duncan's multiple range test at the 5% level. Researcher's split (RS) = 2/3 basal incorporated and 1/3 topdressed at 5-7 d before panicle initiation (DBPI). Farmer's practice (FP) = 1/2 applied 2-3 wk after transplanting and 1/2 at panicle initiation. Hand-placed USG, press wedge USG, and plunger/auger application of PU at 7 DT.

17 locations there was no significant difference. Similarly, at no location did the farmers' practices significantly outyield the single application at 5-7 DBPI. In fact, the latter resulted in significantly higher yields at 3 of 19 locations.

A single topdressing at 5-7 DBPI yielded significantly higher than plunger/auger placement at 3 of 19 locations. At the remainder there was no significant difference. Thus, at 29 kg N/ha in WS, the plunger/auger appears to be of little advantage.

At 29 kg N/ha, USG hand placement yielded significantly higher than the single topdressing at 5-7 DBPI at only 2 of 19 locations. There was no relative advantage of USG hand placement at the other 17 locations compared with a single application at 5-7 DBPI.

The USG press wedge was comparable to USG hand placement at all but 3 locations, where the latter gave a significantly higher yield.

At 58 kg N/ha, USG hand placement yielded significantly higher than the researcher's split at 5 of 19 locations. There was no significant difference at the other 14 locations.

With low N rates such as 29 kg N/ha, the most efficient technique for applying urea is to broadcast the full amount at 5-7 DBPI. Neither split application nor USG had any clear advantage over this method. At 58 kg N/ha, USG hand placement had an advantage over the researcher's split at the same locations, as in 1985 DS. However, based on DS and WS results, the researcher's split is as efficient as USG hand application at most locations.

ADOPTION OF DRY SEEDED RICE TECHNOLOGY IN THE RAINFED LOWLANDS OF ILOILO AND SOUTH COTABATO, PHILIPPINES

Dry seeding was introduced to rainfed lowland farmers in two Philippine provinces, Iloilo and South Cotabato, during the 1970s. Dry seeded rice (DSR) enabled earlier first crop establishment than was possible with transplanted or wet seeded rice. Despite vigorous extension efforts, adoption of the DSR technology package by farmers was neither uniform nor complete.

Logit and tobit models were employed to analyze quantitatively the factors influencing DSR adoption. In both provinces, area of rainfed lowland, household labor availability, and farmers' technical knowledge appeared to have a positive effect on DSR adoption probability. Extension contact, farmers' education level, and draft animal ownership were also influential in some circumstances.

A more detailed report of this study may be found in the section on Cooperative Programs.

Machinery development and testing

Agricultural Engineering, Soil Chemistry/Physics, Multiple Cropping, Agronomy, Training and Technology Transfer, and Plant Breeding Departments and Rice Farming Systems Program

TILLING 434
Minimum tillage puddler 434
Green manure incorporating knives 434
SEEDING AND TRANSPLANTING 435
Upland seeder 435
Drum seeder for pregerminated rice 436
Root-washed seedling transplanter 437
FERTILIZER PLACEMENT 437
Plunger-auger injector 437
WEEDING 438
Conical weeder 438
THRESHING 439
Maize thresher 439
GRAIN DRYING 439
Rotary drum dryers 439
Warehouse dryer 440
Rice hull carbonizer and charcoal briqueting 440
OTHER DEVELOPMENTS 441
Biogas generation from rice residues 441
Batch type biogas generation 442
Laboratory test tube mill 443
INDUSTRIAL EXTENSION 443

TILLING

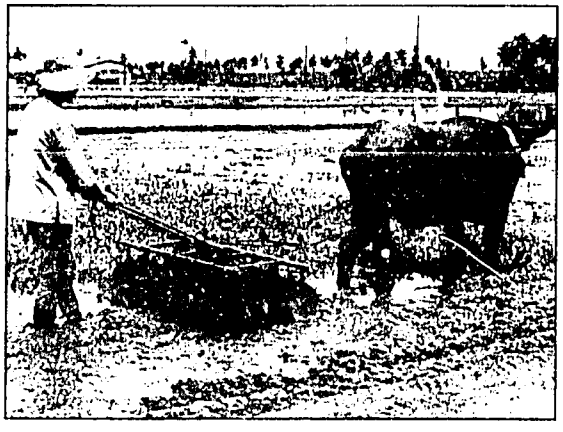
Agricultural Engineering and Multiple Cropping Departments

Minimum tillage puddler (*Agricultural Engineering*). Currently available lowland tillage implements sometimes work the soil to a greater depth than necessary, wasting fuel and power.

An animal-drawn rotary land preparation machine was developed to reduce power inputs in soft rice fields. When its cone-shaped rotor is rolled along a straight path, soil is displaced by blades located at different points on the cone. The machine tills the soil by displacing it with a horizontal back-and-forth action that limits the depth of tillage to the 10-12 cm topsoil layer.

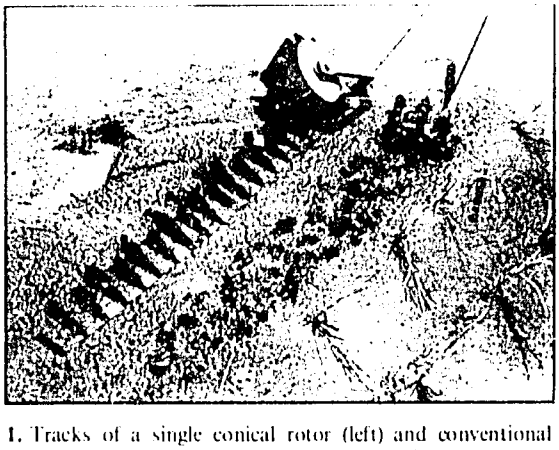
The horizontal displacement of soil by a single conical rotor rolling on soft soil is illustrated in Figure 1. As the rotor moves over the soil, blades on the large end of the cone move the soil in a slightly backward direction while blades on the smaller end move the soil forward. When a puddler with two conical rotors, mounted in tandem with opposite orientation (Fig. 2), is pulled across the ricefield, a rapid back-and-forth soil movement occurs. The rotors are mounted on oppositely inclined axles such that the bottom surfaces of the two rotors are parallel to the ground. Each rotor balances the soil action of the other, thus creating an even soil disturbance across the full width of the machine.

Tests with the prototype machine indicated more than two times the area covered compared with a conventional comb harrow without any increase in power requirement. Further tests are being conducted to assess where the machines may be advantageously used.

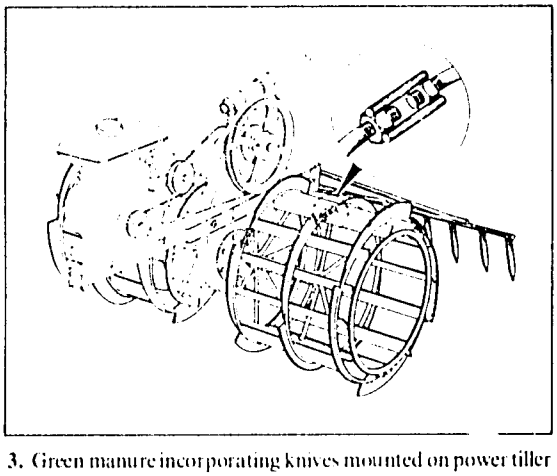


2. Prototype minimum tillage input cono-puddler for animal or power tiller operation. IRRI, 1985.

Green manure incorporating knives (*Agricultural Engineering and Multiple Cropping*). Incorporation of tall green manure crops is difficult with a power tiller plow, as tall plants tend to accumulate on it. We developed a knife assembly for the power tiller cage wheel (Fig. 3) that utilizes wheel slippage for slicing the crop into small pieces as the cage wheel tramples it, facilitating incorporation with the plow. In flooded, soft fields, both cage wheels can be equipped with knife assemblies, and a comb harrow can be used for green manure incorporation.



1. Tracks of a single conical rotor (left) and conventional weeder rotor (right) on soft field showing soil displacement. IRRI, 1985.



3. Green manure incorporating knives mounted on power tiller cage wheels. IRRI, 1985.

4. Green manure and straw incorporating knives being used with power tiller for incorporating tall *Sesbania* crop. IRRI, 1985.

The knives were tested for incorporating six green manure crops — *Sesbania*, *Crotalaria*, mungbean, cowpea, soybean, and indigo — at IRRI and in farmers' fields (Fig. 4). Further tests were conducted in farmers' fields on three types of soils: clay, clay loam, and sandy clay loam. The knives can be effectively used for incorporating 45- to 60-day-old green manure crops with a power tiller equipped with moldboard plow or comb harrow. Up to 30 t green manure/ha were incorporated in the soil.

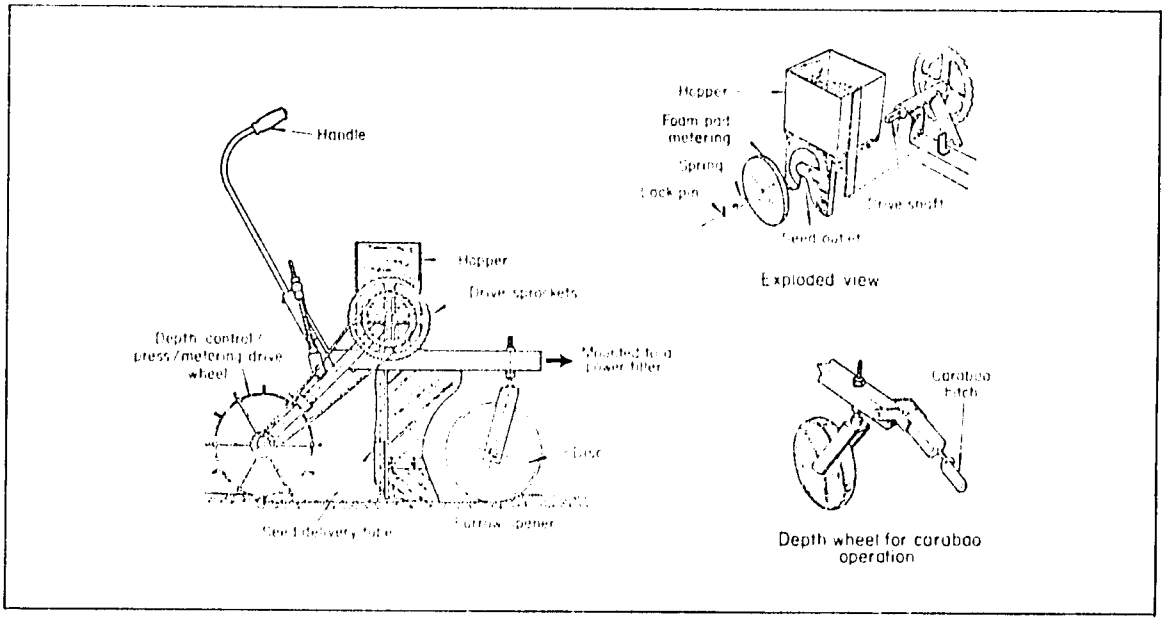
SEEDING AND TRANSPLANTING

Agricultural Engineering, Multiple Cropping, Soil Chemistry/Physics, and Agronomy Departments and Rice Farming Systems Program

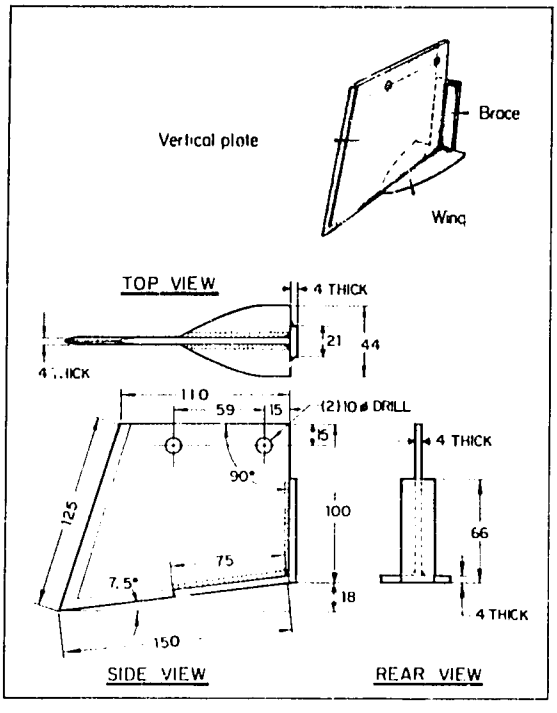
Upland seeder (*Agricultural Engineering, Multiple Cropping, Soil Chemistry/Physics, Agronomy, and Rice Farming Systems*). A seeder was designed for upland crops planted after rice (Fig. 5). It utilizes an inverted-T opener, initially developed at Massey University (Fig. 6). The opener creates seed grooves tolerant of a wide range of field conditions in previously tilled or untilled soils.

Emergence of various species, particularly those with small seeds, is sensitive to sowing depth and field moisture at seeding. A depth wheel ensures proper seed depth, serves as a press wheel to provide required seed-soil contact, and drives the seed metering mechanism. A simple assembly meters seeds with a high degree of accuracy and with minimum periodicity. A range of seed species can be metered without damage. The seed rate can be varied by changing the sprockets and the drive wheel.

In field trials at IRRI, groove formation, seed placement, depth control, and seed metering were generally satisfactory. In untilled soil, the disk



5. Schematic of the inverted-T multicrop seeder. IRRI, 1985.



6. Inverted-T groove opener. IRRI, 1985. All dimensions in millimeters.

coulter, running ahead of the opener, handled crop residues satisfactorily. In tilled soil (for carabao seeder), a small wheel replaced the disk coulter to maintain uniform depth.

Field trials with maize, soybean, and mungbean (Table 1) showed significant advantages in plant establishment and seed input saving in an upland field previously under sorghum. Three methods of land preparation and seeding were compared: 1) conventional tillage (one plowing followed by two harrowings), furrowing with lithao, and hand planting; 2) conventional tillage and sowing with the seeder; and 3) sowing by seeder in untilled soil.

Emergence of seeder sown plants was significantly higher than that of hand planted ones. Tillage had no significant effect on establishment. Maize establishment was 65% superior and mungbean over 300% better with seeder sowing than with hand sowing. Soybean results, although favoring the seeder slightly, were not clear.

Further seed fate analysis suggested that lower plant emergence with the traditional hand sowing method was due to uneven seed depth and seed cover, and that a large proportion of unemerged seeds actually remained ungerminated. Conversely, a significant proportion of unemerged seeds in seeder sown plots were still surviving at the subsurface soil level. Sowing moisture was low, and no irrigation was applied; with more moisture, more plants are expected to be established.

A number of seeder units adaptable for power tiller and carabao operation are being fabricated for wider testing on different soils. Future research and development includes

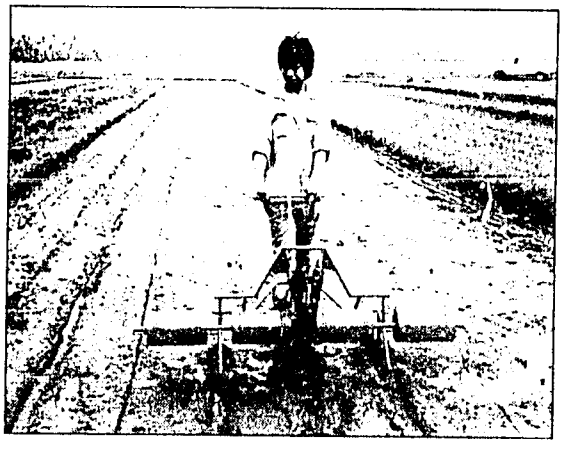
- addition of fertilizer application unit,
- fabrication of multirow units (with adjustable row spacing) for carabao and power tiller operation,
- development of seed-cum-fertilizer drill planter,
- evaluation of seeders for various upland seed species in rice-growing ecoclimatic zones, and
- adoption of the seeder metering units for lowland direct seeding of rice.

Drum seeder for pregerminated rice (*Agricultural Engineering and Agronomy*). Because of the increasing cost of transplanting, direct seeding is gaining popularity in the Philippines and other Asian countries. We continued our efforts to develop lowland seeders for pregerminated rice. A simple 8-row seeder (Fig. 7) was developed that is

Table 1. Effect of tillage and sowing methods on upland crop establishment. IRRI, 1985.

Soil status	Sowing method	Plant emergence (%)[a]		
		Maize	Soybean	Mungbean
Tilled[b]	Hand sown[c]	41 b (49)	29 b (39)	15 b (15)
Tilled[b]	Seeder sown[d]	67 a (77)	24 b (46)	49 a (65)
Untilled	Seeder sown[d]	69 a (73)	45 a (58)	46 a (56)

[a]Laboratory seed germination of maize = 97%, soybean = 47%, mungbean = 75%. Numbers in parentheses give subsurface surviving seedlings at 12 d after sowing. [b]Field UM2, IRRI, plowed once using a carabao, followed by 2 harrowings. [c]Seed furrows (grooves) made with lithao and hand sown. [d]Inverted-T seeder, power tiller and carabao operated.



7. Low-cost 8-row pull-type rice seeder. IRRI, 1985.

easy to fabricate by small metalworking shops. It has a centrally mounted single drive wheel with four cylindrical hoppers, two on each side of the wheel. The hoppers have two rows of holes each, spaced at the desired row spacing, through which seeds drop onto the soil surface in eight even rows. The cylindrical hoppers are mounted directly on the wheel axle and rotate along their axis whenever the machine is pulled.

The machine has two skids attached to the frame to distribute its weight and to help in maintaining a uniform distance between the soil and the hoppers. It has only a few parts and is expected to sell for less than US$50.00. Tests indicate that it can seed 50-75 kg seed/ha with 14% metering accuracy. The prototype weighs only 10 kg and can be easily transported to and from the field by rolling. The single, centrally mounted wheel permits convenient transport along levees. The seeder is being tested in farmers' fields in different parts of the Philippines.

Root-washed seedling transplanter (*Agricultural Engineering*). In 1980, IRRI introduced a successful transplanter for mat-type seedlings; however, many farmers utilize root-washed seedlings when transplanting by hand and find it difficult to prepare seedlings with a soil mat.

In cooperation with the scientists of the Chinese Academy of Agricultural Mechanization Sciences, we developed a manually powered transplanter that utilizes root-washed seedlings. Seedlings are carefully pulled out of the nursery soil and washed to remove all soil. They are stacked on a tray with the roots against the metal bottom. Picker fingers are forced through a metal comb against which the seedlings lie (Fig. 8). The picker fingers grasp two to four seedlings and insert them into the mud. As the picker fingers are withdrawn, the seedlings are released. The machine is then moved an appropriate distance and the operation repeated.

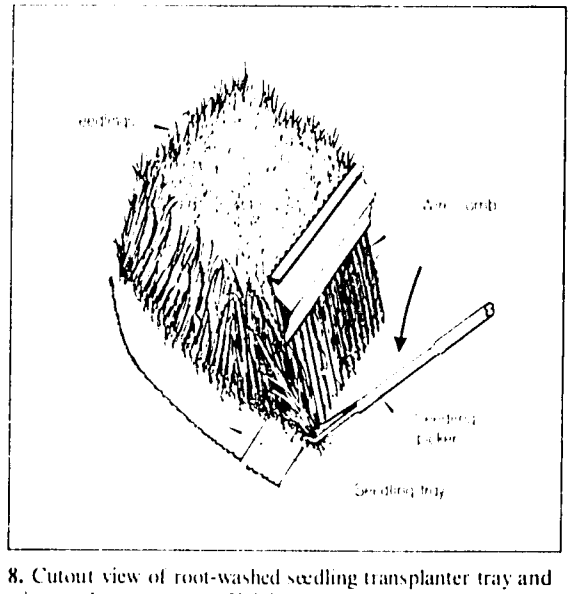
The transplanter will be tested in 1986 to compare it with the transplanter using mat-type seedlings and to redesign it to facilitate fabrication by small manufacturers.

FERTILIZER PLACEMENT

Agricultural Engineering, Agronomy, and Training and Technology Transfer Departments

Plunger-auger injector. The plunger-auger injector for commercially available fertilizers such as prilled and granulated urea (Fig. 9) has reached a fairly advanced stage of development. Three companies have manufactured 80 machines, which were released to cooperating institutions for tests at different locations in the Philippines. Twenty injectors were sold to farmers, who have agreed to provide feedback on its performance.

Design modifications were incorporated during the year to overcome problems encountered with the machine. The revised machine has performed well in field trials conducted by different IRRI departments and by four cooperating agencies of



8. Cutout view of root-washed seedling transplanter tray and wire comb arrangement. IRRI, 1985.

9. IRRI plunger-auger fertilizer injector operating in a farmer's field. 1985.

the Philippine Government. Farmer demonstrations and training programs were conducted in Laguna, Bicol, and Iloilo.

Most farmers prefer to apply fertilizer after weeding. We are now exploring the possibility of simultaneous weeding and fertilizer injection by mounting a set of weeding rotors on the injector skids.

Introduction of this machine will require extensive demonstration and training. Since benefits of fertilizer injection are not visible at the time of application, most farmers prefer to observe the results in demonstration plots before making a decision to purchase the machine. For this reason, close cooperation of the agricultural extension services will be critical.

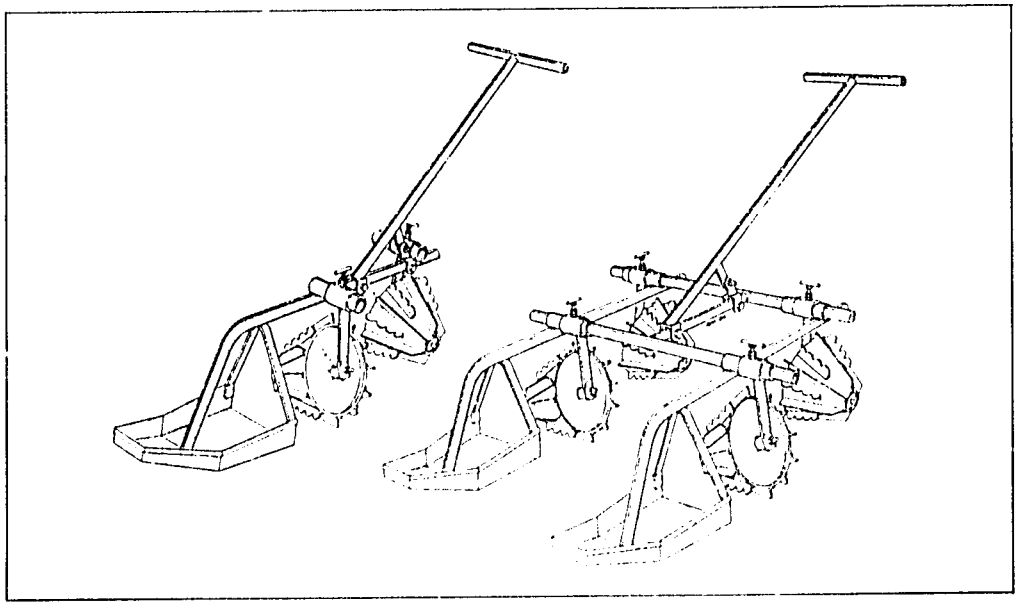
WEEDING

Agricultural Engineering Department

Conical weeder. A weeder with conical rotors was developed (Fig. 10) that requires less than one-half as much power to operate as conventional weeders. This weeder is based on the same principle used in the minimum tillage puddler. Variations in soft soil displacement due to the conical rotors are utilized to uproot and bury weeds within the 2-cm-deep weed root zone.

A 45° cone angle gave optimal performance on both soft and medium hard soils, having sufficiently aggressive single-pass weeding action to eliminate the need for back-and-forth movement.

A single row cono-weeder requires 4.4 kg pushing force compared with 11 kg required by conventional rotary weeders (Table 2). Because of their low power requirement, two-, three-, and four-row cono-weeders can be operated by one person. The three-row version requires a pushing force of 8 kg. The four-row version is not difficult to operate by pulling.



10. Single-row and double-row cono-weeders. IRRI, 1985.

Table 2. Pushing force of conventional and cono-weeders with 20° to 60° cone angles. IRRI, 1985.

Description	Av pushing force (kg)[a]	Weight of machine (kg)
Conventional weeder with 2 spiked wheels and 1 fluted roller, single row 130 mm	11.0	5.5
Weeder with 60° closed rotor, 20-mm nonserrated lugs × 145 mm, single row	6.9	4.5
Weeder with 45° closed rotors, 20-mm serrated lugs × 140 mm, single row	4.4	3.7
Weeder with 40° closed rotors, 20-mm nonserrated lugs × 140 mm, single row	5.2	3.9
Weeder with 20° closed rotors, 20-mm nonserrated lugs × 140 mm, single row	5.1	4.3

[a]Av of 12 trials conducted at 3 sites in Laguna. Site 1: Wawa, Laguna: hard soil, newly irrigated, clay loam, 10-12 cm hardpan, 1-2 cm water depth. Site 2: Hi-way, Calauan, Laguna: very soft soil, Antipolo clay loam, 8-10 cm hardpan, 1-2 cm water depth. Site 3: Labuin, Santa Cruz, Laguna: medium soft soil, sandy loam topsoil, 8-10 cm hardpan, 1-2.5 cm water depth.

THRESHING

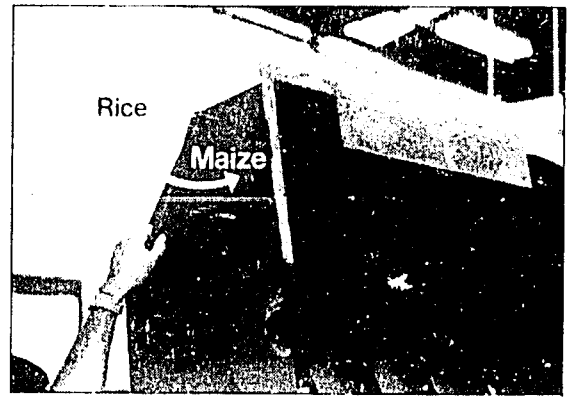
Agricultural Engineering Department

Maize thresher. The TH-8 rice thresher performed satisfactorily for shelling maize during the wet season harvest of 1985. It is convertible for maize use in a matter of minutes without special tools or additional parts. Only the switching of the return chute lever (Fig. 11) and closing of the thrower outlet (Fig. 12) are necessary for the conversion. Drum speed must be reduced to 545 r/min for maize.

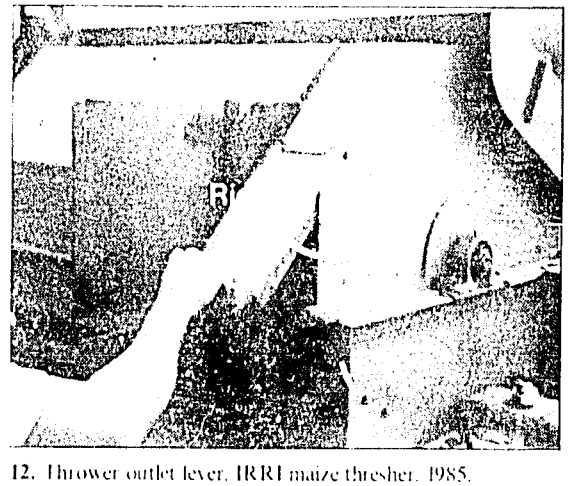
During maize shelling, the thrower outlet is closed (open for rice) and the return chute is directed to the screen tray (directed out of the machine for rice) to recover loose grains on the cleaning tray. The closed outlet prevents grain from being ejected from the machine.

The capacity is over 2.5 t/h. Unshelled losses average 1.6%. Breakage averages 3.4%.

The machine will be modified to solve problems common to rice and maize threshing, including the installation of a cross-flow fan to provide more even air velocity along the winnowing board.



11. Return chute lever, IRRI maize thresher, 1985.



12. Thrower outlet lever, IRRI maize thresher, 1985.

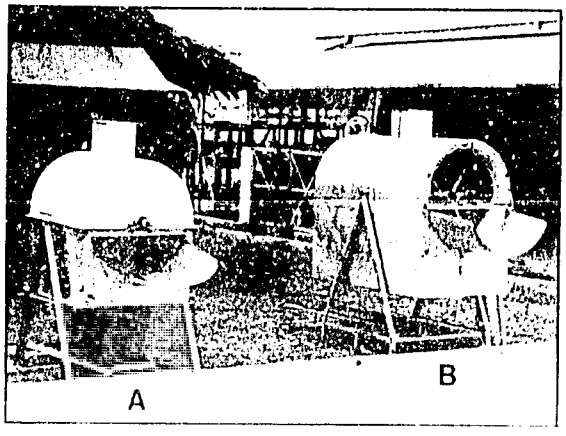
Future tests will involve the shelling of maize with husks in the farmers' fields, a procedure expected to reduce farmer expenditure in dehusking and transport.

GRAIN DRYING

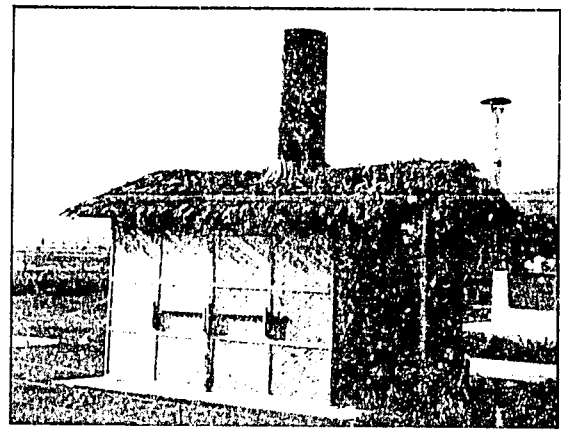
Agricultural Engineering Department

Rotary drum dryers. Two types of portable rotary drum dryers (Fig. 13) were designed and developed at IRRI for partial drying of grain immediately after harvest.

The direct-fired rotary drum dryer was fabricated from perforated black iron sheet so that the products of combustion from burning charcoal come into contact with the grain through the perforations. The drum is equipped with baffles for



13. Rotary drum dryers: A) direct-fired, B) indirect-fired. IRRI, 1985.



14. Warehouse dryer for individual farm use (1-t capacity). IRRI, 1985.

mixing the grain to avoid localized heating and to hasten the drying rate.

The indirect-fired rotary drum dryer was made of a petrol drum and is similar in construction to the direct-fired dryer. Heat can be supplied by direct burning of rice hulls, coconut husks, or other agricultural waste, as the products of combustion do not come into contact with the grain. Drying capacities are shown in Table 3.

Warehouse dryer. Dryers constructed in Mindanao, Philippines, were continuously monitored for on-farm drying performance. Several types of small- to medium-scale (1–4 t) multicommodity drying and storage facilities were designed. A dryer for the individual farmer (Fig. 14), a greenhouse, and "winged" dryers for medium-scale operation were made available.

Simple construction techniques were also developed using locally available materials to reduce costs and to make the technology available to farmers.

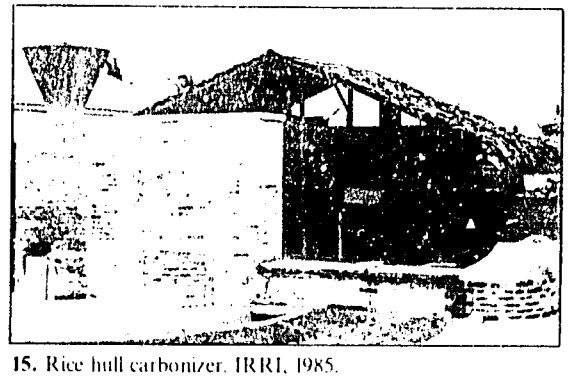
Rice hull carbonizer and charcoal briqueting. Rice hull charcoal briquets are potential fuel for direct-fired dryers (Annual report for 1984). Rice hull charcoal burns without smoke and produces less volatiles, which otherwise contaminate the drying material. Briqueting increases its bulk density.

A rice hull carbonizer (Fig. 15) was designed to be integrated into a rice mill for the production of char as solid fuel and hot flue gas for drying. The carbonizer, constructed from soil bricks, consists of two reactors. The primary reactor converts rice hulls into char. A rice hull spreader suspended from the feed hopper retards falling hulls, allowing them to burn initially during their downward movement. Rice hull chars are collected at the bottom and placed directly in a water bath to

Table 3. Average dryer capacities of rotary drum dryers.[a] IRRI, 1985.

Commodity dried (25 kg/batch)	Initial moisture content (% wb)	Final moisture content (% wb)	Drying time (h)
Rice	27-29	80	1.0
Maize	30-35	18	1.5
Peanut in pods (freshly harvested and washed)	60-65	40	2.0

[a]Drum or cylinder surface heated to 90 °C. wb = wet basis.



15. Rice hull carbonizer. IRRI, 1985.

prevent further combustion. The by-products of initial combustion in the form of volatile gases and particulates are ducted into the second reactor, a center tube furnace. The volatile gases and particulates are burned in this reactor, producing flue gases, which are then sucked by a centrifugal blower to batch dryers that can utilize the heat of combustion from the reactors. Air temperature available for drying is up to 70 °C.

To improve handling and increase the bulk density and calorific value of rice hull char, a simple briqueting technique (Fig. 16) uses ricefield soil with at least 50% clay content as binder. The mixture can be molded into desired shapes and sizes using simple, manually operated compacting devices.

The briquets are sun-dried 4-5 d or dried in a dryer. The charcoal briquets are used for drying systems, cooking, and other domestic uses. They produce a pale orange flame with a temperature reaching 900 °C.

OTHER DEVELOPMENTS

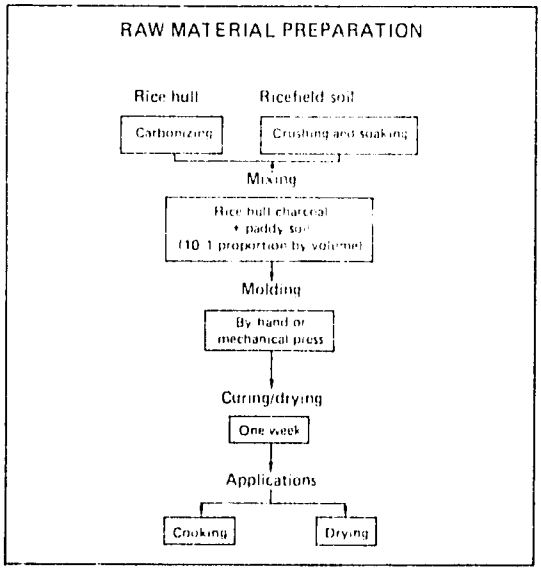
Agricultural Engineering and Plant Breeding Departments

Biogas generation from rice residues (*Agricultural Engineering*). Experiments were conducted to determine the biogas generation characteristics of agricultural wastes and residues (rice straw, rice hulls, maize stalks, and coconut husks) commonly available on small farms. Biogas production as affected by the inherent physico-chemical properties of substrate materials was measured, and the effects of material treatments to make conditions favorable for methane-producing bacterial growth were determined.

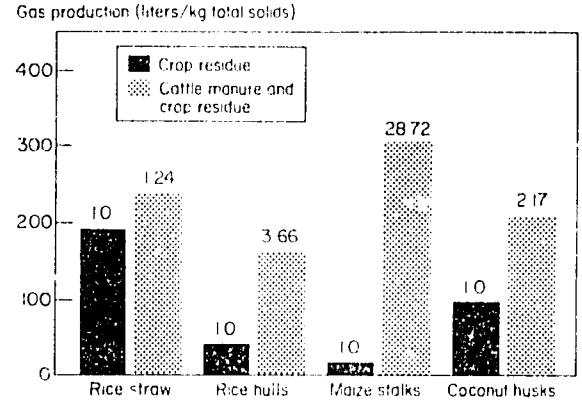
In general, crop residues have fair to poor gas production rates compared with animal manures because of their low biodegradability and high C-N ratio. However, production can be improved by combining the crop residues with animal manure (Fig. 17) at 1:1 dry matter ratio. The combination regulated the C-N ratio of the substrate materials, thereby increasing gas yield.

Pretreating crop residues by aerobic fermentation prior to loading in the digester increases the gas yield of coconut husks but is not favorable for rice straw (Table 4). Apparently, the high C-N ratio of coconut husk (107) is considerably reduced, favoring the growth of methane-producing bacteria. On the other hand, rice straw may lose significant amounts of volatile elements during pretreatment, resulting in reduced gas yield.

Available nitrogenous plants were substituted for manure. Water hyacinth and azolla were found to be potential sources for biogas production; combined with rice straw, they gave higher biogas production per unit of volatilized solids than did manure-rice straw combinations (Fig. 18).



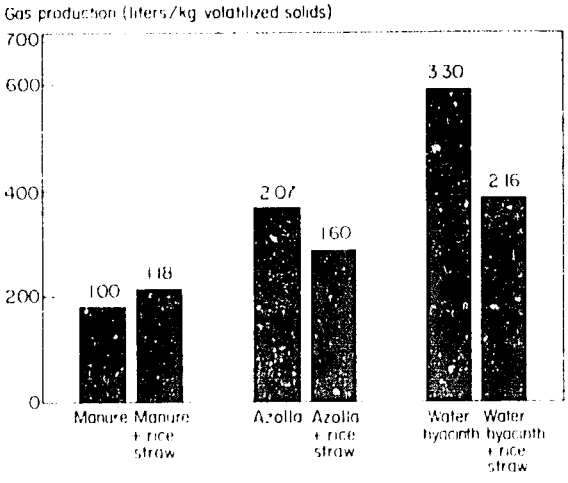
16. Flowchart for rice hull charcoal briqueting. IRRI, 1985.



17. Effect of the addition of cattle manure on biogas yield of crop residue. IRRI, 1985. Figures over the bars represent production index based on pure crop residue.

Table 4. Effect of pretreatment on gas yield of coconut husk and rice straw. IRRI, 1985.

Feed material	Total biogas production (liters)	Total solids (g)		Production (liters)	
		Loaded	Volatilized	Per kg total solids	Per kg volatilized solids
Rice straw	146.6	750.0	603.0	195.5	243.1
Pretreated rice straw	60.8	750.0	525.8	81.1	115.6
Manure and rice straw	215.2	890.1	734.1	241.8	293.1
Manure and pretreated rice straw	187.3	890.1	728.3	210.4	257.2
Coconut husk	13.9	747.6	719.9	18.6	19.3
Pretreated coconut husk	29.9	312.9	258.5	95.6	115.7
Manure and coconut husk	56.5	913.6	738.7	61.8	76.5
Manure and pretreated coconut husk	131.3	633.8	532.3	207.2	246.7

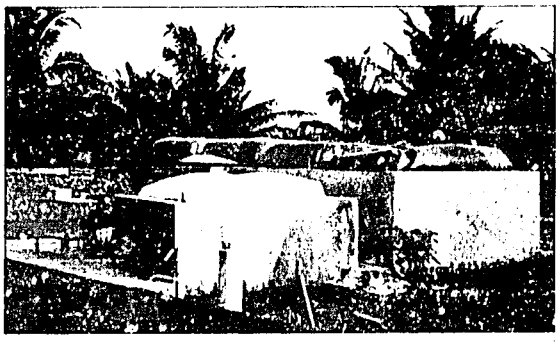


18. Biogas yield using azolla and water hyacinth as N source. IRRI, 1985. Figures above bars are production indexes relative to manure alone.

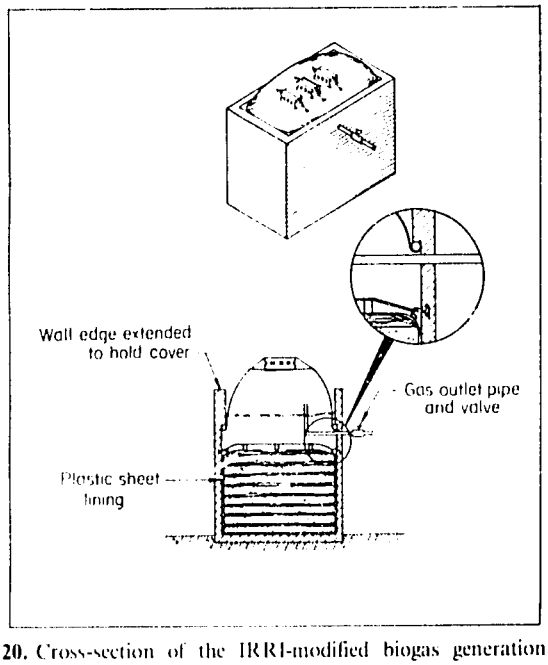
Batch type biogas generation (*Agricultural Engineering*). The Korean biogas generation system was modified to suit local conditions and to provide improved gas production and recovery performance, simpler construction, and reduced investment cost.

The IRRI-modified system (Fig. 19, 20) has a digester tank constructed with the top edge (30-36 cm) extended inside to form a lid where the four sides of the flexible cover are anchored by PVC pipes. A thin vinyl plastic sheet lining placed before loading the substrate is effective in minimizing gas leakage. It wraps up the substrate material, leaving an open area at the top where gas accumulates.

The rubberized cover and gas storage bags were replaced with a canvas tarpaulin designed as cover



19. The Korean biogas generation system (foreground) and the IRRI-modified system (background). IRRI, 1985.



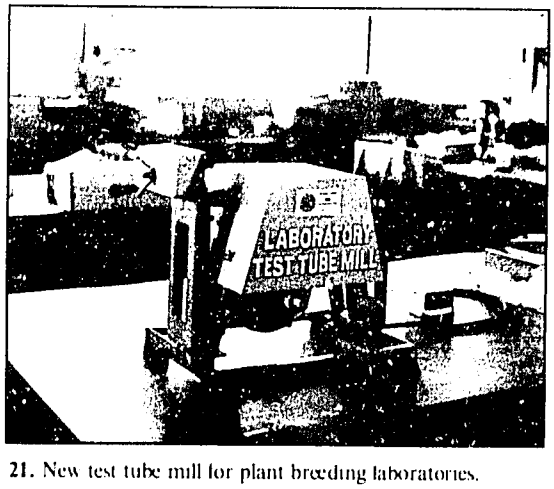
20. Cross-section of the IRRI-modified biogas generation system showing major structural modifications and substrate loading techniques. IRRI, 1985.

and gas storage dispenser. A metal pipe and valve extends through one wall to serve as a gas outlet. Biogas is tapped by applying pressure to the cover, which has straps attached to concrete blocks.

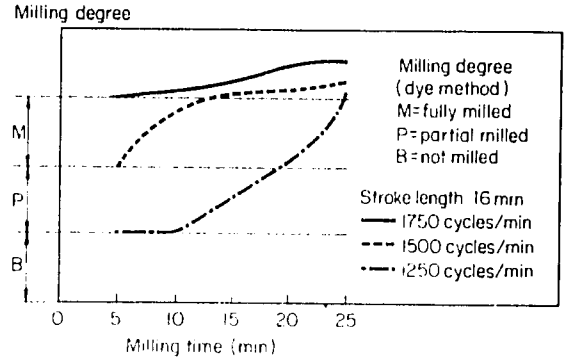
The substrate materials (crop residues and animal manure) are piled in alternate layers inside the tank and secured by tying a nylon rope across the top. PVC pipes are inserted in the hem of the tarpaulin for anchoring. Water is used to seal the top edges of the tank from gas loss. Effective gas production extends from 50 to 70 d, depending on the substrate material used and the ambient conditions. The biogas can be used for cooking, lighting, or pumping water.

Under tropical conditions the biogas digester should be underground or provided with a roof and insulated walls to stabilize substrate temperatures for more constant gas production over a longer period.

Laboratory test tube mill (*Agricultural Engineering and Plant Breeding*). Plant breeders mill a large number of small rice samples for assessing grain quality during breeding of new varieties. Some years ago, we developed a laboratory test tube mill for small samples. In it, 48 test tubes, each with 3-g hulled rice mixed with an abrasive material, are shaken vigorously for 40 min at 860 cycles/min. This machine has been used for many years at IRRI and other rice research institutions.



21. New test tube mill for plant breeding laboratories.



22. Performance of laboratory test tube mill as affected by oscillating frequency and milling time.

An improved test tube mill was developed with six times greater milling capacity than the earlier machine (Fig. 21). It has two boxes, each with a capacity for 35 test tubes. The boxes are mounted on two pivoted links and are oscillated through connecting rods from a camshaft at 1,500 cycles/min with a 16-mm stroke. The pair of test tube boxes, connecting rods, and mounting links are precisely balanced against each other to minimize vibration. Sealed ball bearings are used for longer life and to eliminate periodic lubrication.

The compact machine is powered by a 3/4 hp electric motor. The milling performance at three different operating speeds is given in Figure 22. The machine has been rated for operation at 1,500 cycles/min and can mill 70 hulled samples of 3 g each in 10 min.

INDUSTRIAL EXTENSION

Agricultural Engineering Department

Projects in the Philippines concentrated on training of engineers and manufacturers and on the development and promotion of low-cost equipment suitable for small farmers. Various items of equipment were fabricated in Indonesia, Burma, India, and Thailand. See the section on Cooperative Programs for more information.

Training programs

RESEARCH-ORIENTED PROGRAMS 446
REGULAR COURSES 446
SPECIAL COURSES 449
COURSE TRANSFER TO NATIONAL PROGRAMS 451
INSTRUCTIONAL RESOURCES 452
REVIEW OF IARC TRAINING PROGRAMS 452
TWENTY-FIFTH ANNIVERSARY ACTIVITIES 452
SCHOLARS AND FELLOWS WHO COMPLETED TRAINING IN 1985 452
Visiting scientists, postdoctoral scientists, collaborative research scientists 452
Research fellows 453
Research scholars 454
Nondegree scholars and fellows 455
PARTICIPANTS IN REGULAR COURSES 456
PARTICIPANTS IN SPECIAL COURSES 460

IRRI offers three types of training: 1) research-oriented programs, 2) regular courses, and 3) special courses. In 1985 a total of 585 persons from 41 countries participated in these activities.

RESEARCH-ORIENTED PROGRAMS

Research-oriented training includes the visiting scientist and postdoctoral fellowship programs, degree programs, and special nondegree research programs.

- Visiting scientist and postdoctoral scientist fellowships are designed to enable senior researchers of national programs to learn new methodologies and pursue in-depth research using IRRI's modern facilities on problems relevant to their home countries. Candidates who come to IRRI to pursue a research project as part of a collaborative research program with a sponsoring agency are designated collaborative research scientists. Most of them come from developed countries with which IRRI has collaborative research and training programs.
- The degree programs include MS and Ph D studies. The scholars complete their course requirements at selected universities and come to IRRI to conduct thesis or dissertation research, supervised by an IRRI scientist who generally serves on the student's advisory committee.
- Participants in special nondegree research programs generally come to IRRI to work on special problems for 3-12 mo.

In 1985 there were 253 participants in research-oriented programs. Their distribution by country and department of specialization is given in Tables 1 and 2. Of the 253, 101 completed their training in 1985: 4 visiting scientists, 13 postdoctoral scientists, 8 collaborative research scientists, 18 PhD fellows, 32 MS scholars, and 26 nondegree scholars.

During the year, IRRI entered into collaborative graduate programs with four more universities: Chonnam National University, Korea; University of Calabar, Nigeria; Andhra Pradesh Agricultural University, India; and Universiti Kebangsaan Malaysia. As of 1985, IRRI had collaborative graduate programs with 24 universities. Under these agreements the scholars complete their course work at the university and conduct their thesis or dissertation research at IRRI. The universities are

Cairo University, Egypt
University of Calabar, Nigeria
University of Dar es Salaam, Tanzania
Bangladesh Agricultural University
University of the Philippines at Los Baños
Central Luzon State University, Philippines
Visayas State College of Agriculture, Philippines
University of Cantho, Vietnam
Andhra Pradesh Agricultural University, India
Indian Agricultural Research Institute
Universiti Kebangsaan Malaysia
Universiti Pertanian Malaysia
Universiti Pertanian Bogor, Indonesia
Chonnam National University, Korea
Post-Graduate Institute of Agriculture, University of Sri Lanka
Kasetsart University, Thailand
Asian Institute of Technology, Thailand
Justus Liebig University Giessen, Federal Republic of Germany
Agricultural University of Wageningen, The Netherlands
University of Gent, Belgium
Catholic University of Leuven, Belgium
Cornell University, USA
University of Florida, USA
Utah State University, USA

REGULAR COURSES

Regular courses are offered every year. In 1985, IRRI offered 10 regular courses (see following descriptions), 2 of which were new. The courses are highly oriented to research methodology and production. Half of the time is spent in lectures on basic aspects and half in the field and laboratories working on practical problems.

- *Genetic Evaluation and Utilization (GEU).* The most efficient method to obtain economic advantages for the farmer is the screening and manipulation of genetic material for response or resistance to the environment. To this end, the GEU course covers the various types of rice culture, techniques of screening for varietal resistance or tolerance, hybridization methods, and evaluation of progenies.

Table 1. Research-oriented scholars and fellows by country. IRRI, 1985.

Country	Visiting scientists	Postdoctoral scientists	Collaborative research scientists	Ph D fellows	MS scholars	Nondegree	Total
			Asia				
India	9	15	0	8	1	2	35
China	0	0	5	5	20	2	32
Bangladesh	0	1	0	8	17	0	26
Philippines	4	4	0	3	9	2	22
Thailand	1	1	0	5	10	2	19
Vietnam	0	0	4	1	3	10	18
Burma	0	1	0	0	12	1	14
Korea, Republic of	0	0	1	7	0	2	10
Pakistan	1	0	0	4	3	2	10
Japan	0	3	1	2	1	0	7
Indonesia	0	1	0	2	0	1	4
Malaysia	0	0	0	1	0	3	4
Nepal	0	0	0	4	0	0	4
Sri Lanka	1	0	0	2	0	1	4
Hong Kong	0	0	0	1	0	0	1
Subtotal	16	26	11	53	76	28	210
			Africa				
Tanzania	0	0	0	0	3	0	3
Ghana	0	1	0	0	1	0	2
Kenya	0	0	0	0	1	0	1
Sierra Leone	0		0	1	0	0	1
Zaire	0	1	0	0	0	0	1
Subtotal	0	2	0	1	5	0	8
			Latin America				
Brazil	0	0	0	0	3	0	3
Mexico	0	0	0	0	2	0	2
Cuba	0	0	1	0	0	0	1
Colombia	0	0	0	0	1	0	1
Chile	0	0	0	0	1	0	1
Ecuador	0	0	0	0	1	0	1
Guyana	0	0	0	0	1	0	1
Subtotal	0	0	1	0	9	0	10
			North America and Europe				
Federal Republic of Germany	0	0	4	3	0	0	7
Netherlands	0	0	1	1	4	0	6
United States	0	0	1	5	0	0	6
United Kingdom	0	1	2	0	0	1	4
Belgium	0	0	0	1	0	0	1
Subtotal	0	1	8	10	4	1	24
			Middle East				
Iran	0	0	0	0	1	0	1
Total	16	29	20	64	95	29	253

- *International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER).* In relation to agronomic management, inorganic fertilizers constitute a major input expenditure. Therefore, the INSFFER course treats the concepts in related sciences that focus on the differences in crop response to soil fertility and fertilizers. A major part of the course deals with N fixation through the utilization of biological organisms such as azolla and emphasizes the application of organic fertilizers.
- *Cropping Systems Training Program (CSTP).* In addition to increasing yields, increasing cropping intensity is another method to pro-

Table 2. Research-oriented scholars and fellows by department, IRRI, 1985.

Department	Visiting scientists	Postdoctoral scientists	Collaborative research scientists	Ph D fellows	MS scholars	Nondegree	Total
Plant Breeding	2	3	2	8	18	2	35
Plant Pathology	3	2	1	13	8	8	35
Agronomy	1	4	2	8	9	2	26
Agricultural Economics	0	3	2	7	7	2	21
Entomology	0	3	1	5	9	3	21
Plant Physiology	3	2	1	3	7	4	20
Multiple Cropping	2	2	2	2	7	1	16
Soil Microbiology	0	4	1	3	4	0	12
Soil Chemistry/Physics	2	2	4	2	1	0	11
Agricultural Engineering	0	0	3	0	6	1	10
Rice Farming Systems	1	1	0	5	3	0	10
International Rice Germplasm Center	1	1	0	0	5	2	9
Training and Technology Transfer	1	0	0	2	3	0	6
Water Management	0	1	1	1	1	0	4
Director General's Office	0	0	0	1	0	2	3
International Rice Testing Program	0	1	0	2	0	0	3
Communication and Publications	0	0	0	0	0	2	2
Chemistry	0	0	0	0	1	0	1
Statistics	0	0	0	1	0	0	1
Others	0	0	0	1	6	0	7
Total	16	29	20	64	95	29	253

duce additional economic benefits. An intensive, diversified multiple cropping program is also advantageous in circumventing the single crop risk factor and generating additional commodity markets. For over 10 yr, the CSTP has developed human resources proficient in developing new rice-based cropping patterns and component technologies.

- *Statistical Procedures and Computer Applications in Agricultural Research (SPCAAR, new).* This 2-mo course familiarizes participants with the use of the microcomputer and appropriate software for conducting statistical analyses and managing agricultural research data. In addition, it updates the trainees on new statistical procedures and techniques with application to agricultural research.
- *Agricultural Engineering.* This 3-wk course was initiated in 1975 to complement IRRI's on-farm machinery development program. It is offered to cooperators of IRRI's farm machinery program and includes all aspects of design, manufacture, and field testing of IRRI-designed machines. Participants attend lectures and do field and practical work on the assembly of IRRI farm machines to develop competence in their operation and maintenance. There were two sessions in 1985.
- *Integrated Pest Management (IPM).* Another major economic input in rice production is that incurred with the reliance on chemical tactics for pest protection. The IPM course promulgates the integration of pest control strategies that consider the interaction of crop management, ecological factors, and the environment to effect crop protection. The course emphasizes cost-efficient management strategies that rely on natural biological and environmental occurrences.
- *Upland Rice Training Course (URTC).* This course was established to discover, implement, and advance production methodologies and practices that lead to yield increases in upland environments. It deals with the crop ecology and physiology of upland rice, water conservation, blast resistance, and drought and problem soils inherent in upland agroecosystems.
- *Irrigation Water Management (IWM).* Water in the right amount and at the right time is an important requirement in producing high

yields and subsequent economic gains. This course enhances the engineering, agronomic, economic, socio-institutional, and communication knowledge and skills associated with sound irrigation practices.

- *Farming Systems Socioeconomic Research (FSSR).* On-farm research with a farming systems perspective is an efficient tool for designing and adapting agricultural technology to small farmers' conditions. This course also integrates humanistic or social science aspects of the small farmers' circumstances in evaluating the suitability of new agricultural technology. It focuses on on-farm research, but methodologies for economic evaluation of research station experiments and assessing the broader impact of increased agricultural productivity are also studied.
- *Editing and Publications (EdPub, new).* The Communication and Publications Department, in collaboration with the International Development Research Centre of Canada and the University of Toronto Press, sponsored a 4-mo course addressing the practical aspects of editing, revising, illustrating, designing, and supervising publications. The primary objective of the course is to popularize research findings.

The numbers of participants in these programs by country are given in Table 3.

SPECIAL COURSES

Special courses are offered on an ad hoc basis. There were 10 given in 1985. Like the regular courses, special courses are half lecture and half practical.

- *Cowpea-Soybean Production (Cow/Soy).* Cowpea and soybean components of cropping systems were treated in a special course implemented by IRRI, the International Institute of Tropical Agriculture, the Philippine Council

Table 3. Participants in regular nondegree training programs[a] by country. IRRI, 1985.

Country	Participants (no.)											
	GEU	INSFFER	CSTP	SPCAAR	Agricultural Engineering		IPM	URTC	IWM	FSSR	EdPub	Total
					I	II						
Bangladesh			1		1	1			3	2		8
Bhutan	1		1				1					3
Burma	1	2	2	1				2	2	1		11
China	3	4	2	1	2	1	4			2	1	20
Ethiopia	1											1
India	4	4		1	1		2	3	4	1		20
Indonesia	4	2	2	2	2	1	2	1	3		2	21
Iran	1	1			1				1			4
Korea, Republic of	2		1	1							1	5
Malagasy	2	1	1				1					5
Malaysia	1	1	1	1			1	1	1	1		8
Mexico	1							1				2
Nepal			2				2					4
Pakistan										2		2
Philippines	1	2	7	1	5	2		1	4	3	1	27
Sierra Leone			1									1
Solomon Islands							1					1
Sri Lanka	1	2	2	1	3	6	1	1	2	2		21
Tanzania							1					1
Thailand	1	2	2	1		1	1	4	2	2	2	18
Vietnam	2	2	1			3	4	1		1		14
Total	26	23	26	10	15	15	21	15	22	17	7	197

[a]GEU = Genetic Evaluation and Utilization, INSFFER = International Network on Soil Fertility and Fertilizer Evaluation for Rice, CSTP = Cropping Systems Training Program, SPCAAR = Statistical Procedures and Computer Applications in Agricultural Research, IPM = Integrated Pest Management, URTC = Upland Rice Training Course, IWM = Irrigation Water Management, FSSR = Farming Systems Socioeconomic Research, EdPub = Editing and Publication.

for Agriculture and Resources Research and Development, and the University of the Philippines at Los Baños (UPLB). The 6-wk course was designed for research workers assigned to improvement programs in these commodities and for extension supervisors responsible for field testing of improved lines of these crops in Asian countries.

- *Varietal Testing and Improvement of Upland Crops and Preproduction Training in Cropping Systems.* Three courses associated with cropping systems were offered. One candidate from Thailand and another from the Philippines were exposed to on-the-job training for a 2-mo period in preproduction techniques. Four candidates — one each from Burma, Indonesia, Nepal, and Thailand — were instructed in techniques involved with the varietal improvement of upland crops. Sixteen people from various national systems were exposed to skills in varietal testing of upland crops through lectures and a practical monitoring tour.
- *Monitoring Susceptibility Levels of Rice Insect Pests to Insecticides (MonSus).* Two sessions examined toxicology techniques associated with establishing benchmark levels of insect susceptibility to pesticides. The course, conducted in conjunction with the Food and Agriculture Organization, was designed to assist national systems in monitoring insect resistance to pesticides.
- *Basic Rice Production Course (BRPC).* A special 3-mo rice production course was designed and implemented to meet the research and extension needs for technology transfer to subsistence farmers in Bhutan, Burma, Ghana, Malagasy, Papua New Guinea, Surinam, Tanzania, and Zambia. The course focused on the fundamentals of rice production technology.
- *Special Rice Production Course (SRPC).* At the request of the Indian Government, a special rice production course was designed and implemented to meet the needs of senior state extension personnel in rice production technology, and in communication and extension. The 15-wk course was attended by 19 officials of the states of Assam, Kerala, Madhya Pradesh, Madras, Orissa, Punjab, Tamil Nadu, and West Bengal.
- *Weed Science.* Because of the increasing reliance on herbicides to control weeds, a special course in weed science was instituted in 1985. The course taught the principles of weed management as well as the judicious use of herbicides to effect economic savings and environmental protection.
- *Genetic Resources and Conservation Management (GRCM).* To keep up with recent advances in seed science, a course — sponsored by the Dipartimento Cooperazione e Sviluppo, Ministero Affari Esteri, Rome; the Universita degli Studi della Tuscia, Viterbo, Italy; and the International Board for Plant Genetic Resources — was established to provide firsthand experience in field collection, gene bank management, and documentation along with the characterization, evaluation, and utilization of crop germplasm. The course also addresses basic knowledge and skills in rejuvenation, preservation, and monitoring of seed viability during storage. It was designed to develop competent managers for germplasm centers, and it extended into 1986.
- *Improving Income and Employment in Rice Farming Systems (Prosperity).* The IRRI-UPLB-Asian Development Bank Prosperity Through Rice project emphasizes improvement of rice yields at lower cost using multiple and mixed cropping to maximize resources and returns and using the whole rice plant to augment farm income. A 2-ha farm demonstrates opportunities for maximizing income and employment for small rice farmers through an integrated farming system involving crops, livestock, fish, and rice by-products. An 11-d orientation-training program for senior planning officers of ministries of agriculture enabled them to replicate in their own countries demonstration farms along the concept of Prosperity Through Rice. The course, offered twice, was composed of lectures, field demonstrations, and field trips on 1) basic plant, soil, water, air, and sunlight resources and their relation to production; 2) management of factors of production; 3) design of rice farming systems based on considerations of ecology,

economics, and employment generation; 4) harvesting and postharvest processing; 5) biomass utilization; and 6) project management and implementation.

The number of participants in these programs by country is given in Table 4.

The IRRI Academic Council reviewed and approved two new special courses for 1986:

- *Implementation of Systems Analysis and Simulation for Rice Production*
  Objectives: To provide knowledge and practical experience in applying and adapting simulation models for research and extension; and to develop and implement modules of rice growth and pest and disease action as aids in evaluating production potentials and developing supervised control systems.
  Venues: Center for Agrobiological Research, Agricultural University of Wageningen, Netherlands, 2 Feb-28 Mar 1986; IRRI, January 1987
  Number of participants: 32
- *Training and Technology Transfer*
  Objective: To develop a cadre of human resource specialists to perform the various aspects of planning, execution, and evaluation of training programs.
  Venue: IRRI, 6 Oct-12 Dec 1986
  Number of participants: 10

COURSE TRANSFER TO NATIONAL PROGRAMS

A program of in-country training and course transfer was instituted for both regular and special courses. Both the rice production and farming systems courses were conducted in Bhutan and Pakistan, as well as at IRRI.

Table 4. Participants in special nondegree training programs[a] by country. IRRI, 1985.

Country	Participants (no.)												
	Cow/Soy	Varietal Test	Varietal Imp	Pre prod	Mon I	Sus II	BRPC	SRPC	Weed science	GRCM	Prosperity I	Prosperity II	Total
Bangladesh		1				1						1	3
Bhutan							2						2
Burma			1				1		1	1	1		5
China	2					1			1	2	1	1	8
Cuba									1				1
Ethiopia										1			1
Ghana							1			1			2
India	2					1		19		2	2	1	27
Indonesia	2	2	1			1				1	1	1	9
Japan					1								1
Korea, Republic of	1				1								2
Malagasy							2						2
Malaysia	1				1				2	1			5
Nepal		2	1						1				4
Pakistan											1	1	2
Papua New Guinea							2						2
Philippines	9	7		1	1					1	6	4	29
Sri Lanka	1	2				1			1	1	1	1	8
Surinam							1						1
Taiwan, China					1								1
Tanzania							3						3
Thailand	3	2	1	1	1						1	1	10
Vietnam	2									1	2	1	6
Zambia							1						1
Total	23	16	4	2	6	5	13	19	7	12	16	12	135

[a]Cow/Soy = Cowpea-Soybean Production, Mon Sus = Monitoring Susceptibility Levels of Rice Insect Pests to Insecticides, BRPC = Basic Rice Production Course, SRPC = Special Rice Production Course, GRCM = Genetic Resources and Conservation Management, Prosperity = Improving Income and Employment in Rice Farming Systems.

A model of course adaptation and transfer was developed and is being pilot-tested in transferring rice production practices to Bhutan. Courses were offered in-country in the elevated region at Wangdiphodrang and in the lowland district at Gaylephug.

INSTRUCTIONAL RESOURCES

The new training and technology transfer complex provides resources to document and produce course materials for nondegree courses.

Materials are generated in an adaptable, modular, programmed, copublication format to provide a mechanism for adoption and adaptation by national systems. Print, slide-tape, and computer media are available to meet various demands and training methodologies.

REVIEW OF IARC TRAINING PROGRAMS

A review of the training programs of the 13 international agricultural research centers (IARCs) was undertaken by the Technical Advisory Committee in 1984. Dr. A. H. Bunting, professor emeritus of the University of Reading, U.K., headed the three-person review team. Their report commended IRRI's pioneering work in training and agricultural education and the creation of IRRI's Academic Council and alumni associations. It also stated that training at IARCs has had a profound effect on the participants and on their superiors.

The review team made the following major recommendations:

- The centers offering training programs in a particular country should work together and develop a coordinated training program for that country. While this might be difficult to implement, it would help national programs review their requirements in relation to each center's training programs.
- The centers should assess country needs before they formulate training programs, and they should work more closely with the universities to help them strengthen their training programs.
- The donors that normally operate in many countries could make a more valuable contribution if they would act in concert within each country and in close association with the IARCs and universities offering training programs. Within each center, training should be funded separately from research.

TWENTY-FIFTH ANNIVERSARY ACTIVITIES

In commemoration of IRRI's 25th Anniversary, the second edition of the IRRI Alumni Book was published. Alumni associations were organized in the Philippines, Pakistan, Thailand, and Indonesia.

On 16 Oct 1985, the Training and Technology Transfer Center (TTTC) was inaugurated by His Excellency Kiyoshi Sumiya, Ambassador Extraordinary and Plenipotentiary of the Embassy of Japan in the Philippines. The center is a dual-purpose, three-storey building: the ground floor is a training complex, and the second and third floors are dormitories with 50 rooms for scholars, visiting scientists, and lecturers.

SCHOLARS AND FELLOWS WHO COMPLETED TRAINING IN 1985

An asterisk (*) indicates completion of the MS degree and two asterisks (**) denote completion of the Ph D degree during the year.

Visiting scientists, postdoctoral scientists, collaborative research scientists

Agricultural Economics

Leslie Laufer. USA. Effect of development on women.

Tirso Paris. Philippines. Cropping systems economics.

Zenaida F. Toquero. Philippines. Rice postproduction technologies in the Philippines: a review of empirical evidence.

Kyi Win. Burma. Impact of the Whole Township Rice Program in Burma.

Agricultural Engineering

Y. H. Joo. Korea. Biogas production utilization and benefits.

Agronomy

P. C. Gupta. India. 1) Organization and implementation of upland rice training course, preparation of training manual and resource

book; 2) Influence of crop establishment on growth and yield of five upland genotypes.

P. K. Sharma. India. Soil physical edaphology studies in lowland rice-based cropping systems.

Chemistry

Lou Yukun. China. Quality assessment of Chinese rice.

Entomology

Im Dae Jeon. Korea. Use of insect pathogens for the control of rice insect pests.

Z. R. Khan. India. Host-plant resistance specifically to study the biochemical interactions between rice and green leafhopper and white-backed planthopper.

Y. Yoshiyasu. Japan. Azolla insect pests (taxonomy and life cycle).

R. Velusamy. India. Development of rice varieties having stable resistance to the brown planthopper.

Plant Breeding

F. S. Ye. China. Inheritance of resistance to green leafhopper.

Ram Nath Kaw. India. Breeding for cold tolerance.

C. F. Zhao. China. Breeding methods and operations.

Plant Pathology

Narceo Bajet. Philippines. Interaction and localization of the tungro viruses in host and vector.

P. Vidhyasekaran. India. 1) Use of toxin produced by *Helminthosporium oryzae* in evolving disease resistant rice germplasm employing tissue culture, 2) Toxin production by *Xanthomonas campestris* pv. *oryzae*.

Plant Physiology

D. S. Brar. India. Improvement of salt tolerance of rice by tissue culture.

M. Tsuchiya. Japan. Growth response of different rice varieties to low nitrogen.

Soil Chemistry

Damaso Toro Castillo. Cuba. Characterization of problem soils and ameliorations.

Eckehard Eichwald. Germany. Setting up soil physics laboratory.

H. Yamauchi. Japan. Effects of excess silica on clay minerals.

Soil Microbiology

Do Van Cat. Vietnam. Cross of azolla species.

D. N. Nayak. India. Ecology of associative nitrogen-fixing bacteria associated with rice.

Water Management

Nenita Tapay. Philippines. Evaluation of levels of participatory approach to improve operations and management in national and communal irrigation systems.

Research fellows

Agricultural Economics

Patricia Boyland**. USA. Measuring effects of mechanical tillage in Indonesia, the Philippines, and Thailand.

Charles Crissman**. USA. Production of rice and IRRI rice technology: an output distribution approach.

Linda Crissman**. USA. Rural migration as a response to technology-induced structural change.

S. Mathema**. Nepal. Evaluation of the impact of cropping systems research in Nepal.

Agronomy

Sadafumi Koda**. Japan. Soil physical edaphology studies in lowland rice-based cropping systems.

Communication and Publications

Mahfuzul Haque**. Bangladesh. The relative effectiveness of two extension publications in English and Cebuano in the transfer of information on rice technology among Philippine rice technicians.

Entomology

Bu Keun Chung**. Korea. Comparison of sensitivity to insecticides in the brown planthopper populations screened by combinations of different insecticides and methods.

Multiple Cropping

Jae Ho Kim**. Korea. Effects of physical environment on initial adoption of rainfed rice technique in Cagayan Province, Philippines.

Charoen Siri-Udompas**. Thailand. Effects of crop proportion, nitrogen, plant density, cowpea cultivars, and water on intercropped rice and cowpea.

David Woo**. Hong Kong. An evaluation of tropical ricefield mapping and monitoring capability of LANDSAT data in Ifugao Province, Philippines.

Plant Breeding

Surjit Singh**. Malaysia. Effects of lime and phosphate on growth and nutrient uptake of lowland rice (*Oryza sativa* L.) varieties on an acid sulfate soil.

Plant Pathology

Hen Je Cho**. Korea. Rice nematodes.

M. A. Hossain*. Bangladesh. Etiology and ecology of *Erwinia chrysanthemi* Burkholder, McFadden & Dimock 1953, a causal organism of foot rot disease of rice.

Wan Hae Ye**. Korea. Partial resistance to blast.

Plant Physiology

Abdur Rashid Gomosta**. Bangladesh. Factors affecting elongation of deep water rice under submergence.

Taha Abou Zeid**. Egypt. Physiological studies of salt tolerance.

Soil Microbiology

K. Adachi**. Japan. Cellulose-decomposing nitrogen-fixing bacteria.

P. K. Chand**. India. Somatic culture and protoplast from symbiont-free sporophytes/spores azolla.

Thomas Kroeck**. Germany. Effect of rice plant on azolla growth.

Training and Technology Transfer

Md. Abdul Rashid*. Bangladesh. Influence of seedling age and nitrogen level on the growth and yield of three rice varieties grown on a saline soil.

Research scholars

Agricultural Economics

Shamsul Alam*. Bangladesh. Factors affecting production and marketable systems of rice in Barisal District, Bangladesh.

Julius Kigalu*. Tanzania. Assessing the effects of selected levels of mechanization technologies on small-scale rice production systems, Central Luzon, Philippines: a case study.

Celso Tautho*. Philippines. Adoption and productivity of modern rice varieties in dryland areas of Zamboanga del Sur, Philippines.

Agricultural Engineering

G. W. Kilasara*. Tanzania. Construction and evaluation of modified multicrop thresher model IRRI-PAK.

F. Mwombeki*. Tanzania. Auger metering studies for fine prilled urea.

Agronomy

Manuel Donoso*. Ecuador. Cultural management for irrigated and rainfed lowland rice.

M. Yodkeaw*. Thailand. Influence of organic matter addition and flooding on uptake.

Ferdous Ara-Zapata*. Bangladesh. Effect of root xylem vessel diameter on leaf water potential and root.

Entomology

Narong Chantaraprapha*. Thailand. Food preference and aquatic predators of the rice caseworms, *Nymphula depunctalis* (Zeller) and *Paraponyx* (= Nymphula) *fluctuosalis* (Zeller) and *Paraponyx* (= *Nymphula*) *diminutalis* (Snellen).

Marcos Gerding*. Chile. Oviposition and development of the Angoumois grain moth *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechidiidae) on rice genotype.

Maung Myint*. Burma. Impact of levels of varietal resistance on populations of the green leafhopper *Nephottetix virescens* (Distant) and its natural enemies.

International Rice Germplasm Center

Md. A. K. G. Haque*. Bangladesh. Cooperative study of root characteristics of aus and hill rices in Bangladesh.

Multiple Cropping

Dario Alfonso Morel*. Brazil. Moisture content of the soil and tillage area for upland crops after lowland rice.

Glen O. Fernandez*. Philippines. Stochastic modeling of daily weather variables.

Plant Breeding

Alberto Davalos*. Colombia. Selection for efficiency in phosphorus utilization in rice (*Oryza sativa* L.).

D. R. Khan*. Pakistan. Inheritance of cold tolerance at anthesis in rice (*Oryza sativa* L.) and its relationship with some agronomic traits.

Rob Mulder*. The Netherlands. Incomplete resistance in rice to bacterial blight.

Jiang Ying Peng*. China. Isozymic variability in relation to heterosis in rice.

Yu Zhi Hong*. China. Inheritance of resistance to blast (*Pyricularia oryzae* Cavara) in some rice varieties.

Plant Pathology

Wu De Xi*. China. Performance of rice cultivars having *Xa-4a* and *Xa-4b* genes for bacterial blight resistance.

Z. S. Yin*. China. Inoculum potential of sheath blight caused by *Rhizoctonia solani*.

Xie Guan Lin*. China. Variation of colony morphology and its relation to virulence of *Xanthomonas campestris* pv. *oryzae*.

Plant Physiology

Ramon Cineo Castro*. Mexico. Cultural management of very early maturing rice cultivars.

Dai Qui Dai*. China. Cultural management of very early maturing rice cultivars.

Ryoji Ohkawara*. Japan. "In vitro" selection of aluminum cell tolerant lines.

Habib Abul Quayyum*. Bangladesh. Varietal differences in rice in response to different light intensities.

Rice Farming Systems

Carlos Abon*. Philippines. Studies on the cultural management of soybean after lowland rice.

Mario Agustin*. Philippines. Effect of inoculation and fertilizer application on seed yield of soybean after rice.

Soil Microbiology

Anon Sooksavut*. Thailand. Phosphorus application in acid sulfate soils and effect on microbial activities in the soil.

Maria Lourdes de Liva*. Brazil. Use of ^{15}N in associative nitrogen fixation.

Nondegree scholars and fellows

Agricultural Economics

Markanday Ajay. United Kingdom. Analysis of data from consequences of small farm.

P. Panichagon. Thailand. Profiles of resource use patterns in northeast Thailand.

V. Ramachandran. India. Comparative analysis of resource use in rice production systems of Thailand, Indonesia, and the Philippines.

Agricultural Engineering

A. M. El-Sirafy. Egypt. Farm machinery.

Agronomy

Pham Sy Tan. Vietnam. Fertility management practices.

Communication and Publications

S. Ahmed. Pakistan. On-the-job training in audiovisual and photography technique.

S. A. Karunaratne. Sri Lanka. On-the-job training in graphics and audiovisual production.

Bao Chu Li. China. Four-month orientation/study period with Communication and Publications Department.

Teodorico Clemente. Philippines. On-the-job training in audiovisual and photography techniques.

S. M. Sinha. India. On-the-job training in graphics and audiovisual techniques.

Entomology

A. H. Bahagiawati. Indonesia. Varietal screening of insect pests.

Hartini Ramlan. Indonesia. Bacterial blight of rice.

International Rice Germplasm Center

Noor D. Hidayat. Seed technology and management.

Plant Breeding

Bui Chi Buu. Vietnam. Deep water rice in the Cuu Long Delta.

F. M. Faiz. Pakistan. Screening for insect resistance.

Plant Pathology
L. Y. Chuan. Malaysia. Tungro serology.
N. Ibrahim. Malaysia. Tungro serology.
H. K. Khan. Vietnam. Sheath blight screening.
A. A. Mohammed. Somalia. Virus, bacterial and fungal rice diseases.
C. Y. Moi. Malaysia. Tungro serology.
Wei Da Wei. China. 1) Rice sheath blight and similar disease caused by *Rhizoctonia* spp. 2) The pathogens from two types of lesion of rice sheath blight and their distribution.

Plant Physiology
Yvonne Pinto. India. Studies on somatic cell culture.
W. C. Y. Ryu. Korea. Cold tolerance.

Soil Chemistry/Physics
M. B. Baber. Pakistan. Problem soils.

Director General's Office
Virginia Mabesa. Philippines. Preparation of IRRI's Alumni Book.
Wilhelmina Tanyag. Philippines. Evaluation of IRRI's staff development program.

PARTICIPANTS IN REGULAR COURSES

Genetic Evaluation and Utilization
(4 Feb-24 May 1985)

Bhutan
Ganesh Bahadur Chettri

Burma
U Kan Myint

China
Qing-sheng Jin
Bolin Liu
Pei Fang Zhang

Ethiopia
Worku A. Kassa

India
Kanailal Pande
Sudarsan Sasmal
Mitha L. Tawar
Suppiah Vairavan

Indonesia
Satoto
Oman Suherman
R. Widarto Yitnoprastowo
Syahrul Zen

Iran
Ahmad Eshragi

Korea
Jae-Chul Koh
Young Seop Shin

Malagasy
Eugene Rabary
Roland Rakotonirainy

Malaysia
Ismail B. Muhammod Nor

Mexico
Salvador Medina Chavez

Philippines
Imelda C. Atabay

Sri Lanka
Mohammed Fahim

Thailand
Orapin Watanesk

Vietnam
Do Dinh Duc
Nguyen Thi Se

International Network on Soil Fertility and Fertilizer Evaluation for Rice
(4 Feb-24 May 1985)

Burma
U Kyi
U Tun Kunt

China
Guo Wang-mo
Liu Qing-ping
Luo Xiao-chuan
Xie Liang-shang

India
Rati Ranjan Das
S. Ekambaram
A. K. Misra
B. V. Nisal

Indonesia
Asyiardi
Lamhi Hutauruk

Iran
Seyed Yaghob Nirsoleimani

Malagasy
Raymond Rabeson

Malaysia
Hasim Bin Harun

Philippines
Mauricia Bunoan
Wilfredo B. Sanidad

Sri Lanka
Vinitha Abeykoon
Willoru M. P. T. Bandara

Thailand
Kunnika Naklang
Jarunee Nugranad

Vietnam
Tran Dinh Ninh
Pham Ti Kim Mon

Cropping Systems Training Program
(4 Feb-28 Jun 1985)

Bangladesh
Abul Bashar Mohammad Shahjahan

Bhutan
Tek Bahadur Ghaley

Burma
U Hla Kyaing
U Wan Maung

China
Chen Jiansheng
Zheng Xiao Wu

Indonesia
Budiarto
Rizaldi Boer

Korea
Kyeong Beom Min

Malagasy
Jacqueline Rakotoarisoa Rebelolala

Malaysia
Mohammad Zaney B. Rashid

Nepal
Surya Prasad Shrestha
Mahesh Lal Vaidya

Philippines
Jose N. Abot, Jr.
Danilo C. Cabardo
Bonaparte P. Gaid
Crisologo T. Japos
Wilson A. Micua
Juan Leopardas Miranda
Reynaldo Ruiz Versula

Sierra Leone
Abu Bakarr Yarmah

Sri Lanka
K. M. Seneviratna Banda
Kumbukege Kularatna Perera

Thailand
Mantana Suravech
Songsak Tepsarn

Vietnam
Bach Trung Hung

Statistical Procedures and Computer Applications in Agricultural Research
(4 Feb-5 Apr 1985)

Burma
U Soe Myint

China
Lin Erda

India
Mahesh Kumar

Indonesia
Evy Juliantini
Dailami Jamin

Korea
Oh Dae Geun

Malaysia
Che Jaffar Sulong

Philippines
Aida M. Tusara

Sri Lanka
Anthony M. Tirimanne

Thailand
Saowanee Pisithpun

Agricultural Engineering I
(27 May-14 Jun 1985)

Bangladesh
Md. Helal Uddin Sarkar

China
Xue Qinglin
Quan Zhongyu

India
Mangal Singh

Indonesia
Syamsir Salim
Syamsuri

Iran
Salmasi Emani

Philippines
Miguelito M. Abalos
Clemente G. Abrina
Vicente F. Barroga
Leonardo A. Gappi
Victor N. Piamonte

Sri Lanka
G. K. Ariyaratna
Karunatilake Banda Ekanayake
B. H. Suraweera

Agricultural Engineering II
(18 Nov-6 Dec 1985)

Bangladesh
Md. Amir Hossain

China
Sun Hao Xun

Indonesia
Imam Uddin Firmansyah

Philippines
Virgilio P. Anaud
Reynaldo A. Rivera

Sri Lanka
Upendra Ariyaratne
M. M. R. F. Fernando
L. M. C. Gooneratne
Ranjith S. Hikkaduwe
M. S. Kumarasinghe
Ariyaratne W. Managae

Thailand
Paitoon Sake

Vietnam
Nguyen Bong
Nguyen Nguyet Chieu
Nguyen Van Nhuong

Integrated Pest Management
(22 Jul-19 Nov 1985)

Bhutan
Dalbahadur Chettri

China
Wen Liping
Chen Yue-tian
Shi Niu
Cheng Xiao Wen

India
Pravati Samal
Dinesh Kumar Garg

Indonesia
Ashol Hasyim
Supriyatin

Malagasy
Jean Joseph Randiamananoro

Malaysia
Mohiddin Bin Buang

Nepal
Bir Chandra Mandal
Singh Raj Kumar

Solomon Islands
Andrew Pulomana

Sri Lanka
Sithy Faheemah Mohamed Sulaiman

Tanzania
Jacob Cuthbert Mbapila

Thailand
Parkpian Arunyanart

Vietnam
Tran Thai Hoa
Vu Bich Trang
Gnhiem Le Dung
Ha Quang Hung

Upland Rice Training Course
(22 Jul-8 Nov 1985)

Burma
Daw Mya Mya (Miss)
Daw Mya Mya (Mrs.)

India
Jagdish Chandra Bhatt
Majumder Nanda Dulal
Sinha Pramod Kumar

Indonesia
Damar Alamsyah

Malaysia
Muda Mohd. Hassan

Mexico
Jesus Humberto Rodriguez Avila

Philippines
Demetria S. Cornelio

Sri Lanka
Edmund Rajapaksa Pathirage

Thailand
Winai Sooksamran
Ratanaporn Sookthep
Songpon Tuamjaroen
Manoth Wongseree

Vietnam
Tran Nhu Nguyen

Irrigation Water Management
(26 Aug-4 Oct 1985)

Bangladesh
Md. Ruhul Amin
K. M. Anwar Hossain
Golam Mowla

Burma
Daw Khin Hla Way
Daw Khin Hla Lay

India
Chitta Ranjan Biswas
Gorachand Biswas
K. V. Selvaraj
Subedar Singh

Indonesia
Phuliken Bangun
Marjuhar Manalu
Sadjiyo Soemartono

Iran
Abolghasem Hassani

Malaysia
Mohd. Kasim Mahmod

Philippines
Honorio M. Encarnacion, Jr.
Nelson F. Espaldon
Orlando C. Hondrade
Prudencio B. Santos

Sri Lanka
Wijeratne B. M. Arachchige
Landage Ananda Wickramasinghe

Thailand
Sathorn Ruengjiraurai
Seni Wichitsiri

Farming Systems Socioeconomic Research
(14 Oct-13 Dec 1985)

Bangladesh
A. S. M. Nazrul Islam
Manjur Ahmed

Burma
U Myint Thein

China
Huang Ji-kun
Shi Zhaolin

India
M. L. Chakraborty

Malaysia
Mohd. Yusoff bin Ayob

Pakistan
Munir Ahmad
Ali Mohd Khushk

Philippines
Virginia Aboyo
Eddie E. Delavin
Digna P. Narvacan

Sri Lanka
YC Piyaseeli
Ariyawathi Gunatilake

Thailand
Chailit Setabutara
Danai Taipanich

Vietnam
Nguyen Manh Cuong

Editing and Publications
(12 Aug-29 Nov 1985)

China
Shen Hong

Indonesia
Sahibul Munir
Teresita Suselo

Republic of Korea
Kyung Han Ryu

Philippines
Ma. Alexandrina Dormitorio

Thailand
Tasanee Pattamatate
Tuenchai Usuk

PARTICIPANTS IN SPECIAL COURSES

Cowpea-Soybean Production
(21 Oct-29 Nov 1985)

China
Ding Guoching
Wang Yantong

India
M. G. Rajappa
Suresh Chandra

Indonesia
Djoeber Pasaribu
Husin Toha

Republic of Korea
Yun Ho Moon

Malaysia
Zalilah Bt Modh Ali

Philippines
Cristobal Antolin
Alfonso Deocadez
Cecilia Reyes

Rustica Gaid
Nilda Juguan
Fernando Palsario
Basilio Austria
Francisco Java
Marcela Necesito

Sri Lanka
K. M. C. Bandara

Thailand
Suvit Pinthongkom
Suwat Terapontanakorn
Kanyarat Muenvanitchakul

Vietnam
Nguyen Tan Hinh
Hoang Ngoc Binh

Varietal Testing of Upland Crops
(7 Jan-2 Feb 1985)

Bangladesh
Muhammed Murshedul Alam

Indonesia
Deddy Priatna Saleh
Reino Ambar Arumi

Nepal
Ramji Khadka
Narayan Bahadur Thapa

Philippines
Gilbert Blaquera Barbero
Carolina R. Cardines
Edgardo Blasco de la Torre
Robert B. Olinares
Fernando Palsario
Reynato N. Rozul
Jose P. Vioya

Sri Lanka
Wasantha Chitral
Rukunayaka S. Wijesekara

Thailand
Penkae Nattribhop
Preecha Prammanee

Varietal Improvement of Upland Crops
(14 Oct 1985-15 Feb 1986)
Burma
U Myint Soe

Indonesia
Nurnayetti

Nepal
Ananda Ratna Sthapit

Thailand
Dhiti Sindhunakorn

Preproduction Training Course
(14 Oct-15 Dec 1985)

Philippines
Robert B. Olinares

Thailand
Praves Saengpetch

Monitoring Susceptibility Levels of Rice Insect Pests to Insecticides I
(4-14 Sep 1985)

Japan
Shozo Endo

Republic of Korea
Si Woo Lee

Malaysia
Asma Ahmad

Philippines
Cecilio Diloy

Taiwan, China
Lie Shiow Lai

Thailand
Wantana Telvapuchom

Monitoring Susceptibility Levels of Rice Insect Pests to Insecticides II
(18-28 Sep 1985)

Bangladesh
A. T. M. Shamsuddin

China
Wei Cen

India
Dinesh Kumar Nagia

Indonesia
Harnoto

Sri Lanka
Sakuntala Sivasupramaniam

Basic Rice Production Course
(26 Aug-29 Nov 1985)

Bhutan
Ran Bahadur Rai
Sangye Thinley

Burma
U Pe Than

Ghana
John Kwadwo Osei

Malagasy
Jean Baptiste Rajaonarison
Rakotoson Razafintsalana

Papua New Guinea
Oswald Latain
Otto Conrad Liran

Surinam
Roy Kalloe

Tanzania
Elizabeth Johnson Maeda
Raymond Mgaza Mghoghe
Bernard Marcus Milanzi

Zambia
Albert Richard Kasongo

Special Rice Production Course
(22 Jul-31 Oct 1985)

India
A. Arthanari
Cola Rajagopal Balagopal
Neelakanda N. Balakrishnan
Avtar Singh Bhaur
R. Dhakshinamoorthy
T. N. Gnanasekaran
R. Jayadevan
Sarat Chandra Mahapatra
T. P. Rama Chandran Nair
Prabhat Ranjan Nath
Vadivelan Palaniappan
Jamna Prasad Patel
P. K. Ravindran Pillai
Lakshman Chandra Porel
Suruliraj Ratnam
Subramaniam Ganapathi Sankaran
Balkarn Singh
Kuttiappagounder Srirangan
C. P. Sumathikuttyamma

Weed Science
(22 Jul-27 Sep 1985)

Burma
U Khin Maung Myint

China
Ni Hanwen

Cuba
Alvaro Niceto Garcia Rubial

Malaysia
Ho Nai Kin
Norlia Bt Razali

Nepal
Jagat Devi Ranjit

Sri Lanka
Lakshman Amarasinghe

Improving Farm Income and Employment in Rice Farming Systems I
(21-30 Jan 1985)

Burma
U Kyaw Tin

China
Wu Xeen

India
Bhaskar Barua
B. Mandal

Indonesia
Haeruddin Taslim

Pakistan
Mian M. Aslam

Philippines
Jay H. Chung
Benjamin Donor
Benjamin B. Gonzales
Jan J. M. Maas
Harpal Singh
Conrado R. Nora

Sri Lanka
S. L. Amarasiri

Thailand
Vichien Sasiprapa

Vietnam
Tran Xuan Luu
Ta Minh Son

Improving Income and Employment in Rice Farming Systems
(1-11 Oct 1985)

Bangladesh
Ziauddin Ahmed Khan

China
Gan Xiasong

India
P. N. Mathur

Indonesia
Sridodo

Pakistan
M. Yousaf

Philippines
Danilo Isada
Ricardo Ona
Toru Shibuichi
Souphanh Savady

Sri Lanka
M. P. Dhanapala

Thailand
Niran Tongpan

Vietnam
Mai Van Thiet

Cooperative programs

International Rice Testing Program

International Rice Testing Program

1984 NURSERY RESULTS 466
Yield nurseries 466
Observational nurseries 466
Nurseries for specific stresses 467
1985 NURSERY DISTRIBUTION 467
Use of IRTP nursery entries 472
MONITORING VISITS AND WORKSHOPS 472
IRTP IN LATIN AMERICA 477
IRTP IN AFRICA 478

1984 NURSERY RESULTS

IRTP composed 1,301 sets of 23 types of nurseries in 1984 and sent them to 53 countries cooperating in the network. Of 2,747 entries, 1,350 came from national programs and 1,397 from IRRI.

Yield nurseries. Top ranking entries for the maturity groups of irrigated rices — very early (IRYN-VE), early (IRYN-E), and medium (IRYN-M) — are shown in Tables 1, 2, and 3. Some rices performed well in several regions. The nursery reports show yield and yield components by site and region. Table 4 shows yields of best performing entries in the rainfed shallow water yield nursery (IRRSWYN). The top-ranking entries for the two maturity groups of upland rices — early (IURYN-E) and medium (IURYN-M) — are shown in Tables 5 and 6.

Observational nurseries. The outstanding entries in the observational nurseries (IRON, IURON,

Table 1. Best performing entries in the fifth International Rice Yield Nursery – Very Early (IRYN-VE) based on overall and regional mean yield, 1984.

Region	Designation	Origin	Days to flowering	Yield (t/ha)
Overall (45 trials)	C1158-7	Philippines	95	4.6
	IR50	IRRI	86	4.6
	IR13539-100-2-2-2-3	IRRI	94	4.5
	BG367-4	Sri Lanka	90	4.4
	IR25588-7-3-1	IRRI	85	4.4
	IR29692-65-2-3	IRRI	87	4.4
	UPR103-80-1-2	India	83	4.4
East Asia (8 trials)	C1158-7	Philippines	100	5.9
	IR50	IRRI	89	5.8
	IR13539-100-2-2-2-3	IRRI	99	5.8
	UPR103-80-1-2	India	87	5.5
	IR25924-51-2-3	IRRI	90	5.4
Southeast Asia (12 trials)	UPR231-28-1-2	India	78	3.7
	UPR231-28-1-2-TCA2	India	79	3.6
	C1158-7	Philippines	83	3.6
	IR25588-7-3-1	IRRI	77	3.4
	BG367-4	Sri Lanka	79	3.3
	IR29692-65-2-3	IRRI	91	3.3
South Asia (20 trials)	IR50	IRRI	88	4.4
	BG367-4	Sri Lanka	95	4.3
	C1158-7	Philippines	98	4.3
	IR13539-100-2-2-2-3	IRRI	98	4.3
	IR29692-65-2-3	IRRI	89	4.2
	UPR103-80-1-2	India	86	4.2
West Asia and North Africa (2 trials)	UPR103-80-1-2	India	102	9.8
	IR28128-45-2	IRRI	105	9.7
	Palghar 31-1-3	India	106	9.0
	IR25588-7-3-1	IRRI	103	8.9
	Mallika Sel.	Nepal	108	8.8
Sub-Saharan Africa (2 trials)	UPR254-35-3-2	India	87	5.4
	UPR103-80-1-2	India	81	5.4
	C1158-7	Philippines	92	5.3
	IR13539-100-2-2-2-3	IRRI	89	5.3
	AS19789	India	88	5.2
Latin America (1 trial)	Palghar 31-1-3	India	93	6.9
	Mallika Sel.	Nepal	98	6.7
	TKM9	India	90	6.5
	IR25588-7-3-1	IRRI	91	6.4
	RNR1446	India	93	6.4

Table 2. Best performing entries in the 12th International Rice Yield Nursery – Early (IRYN-E) based on overall and regional mean yield, 1984.

Region	Designation	Origin	Days to flowering	Yield (t/ha)
Overall (41 trials)	BG380-2	Sri Lanka	100	5.1
	KAU1727	India	94	5.1
	C1321-9	Philippines	94	5.0
	IR13240-108-2-2-3	IRRI	91	5.0
	UPL Ri-4	Philippines	92	5.0
East Asia (3 trials)	IR25840-64-1-3	IRRI	102	7.3
	IR13240-108-2-2-3	IRRI	109	7.1
	AD9246	India	98	7.0
	Milyang 49	Korea	109	6.8
	Taichung sen 16	Taiwan, China	112	6.8
	UPL Ri-4	Philippines	109	6.8
Southeast Asia (13 trials)	KAU1727	India	87	4.1
	UPLRi4	Philippines	84	4.1
	B3981c-Pn-165-2-1	Indonesia	88	4.0
	IR36	IRRI	99	4.0
South Asia (17 trials)	C1321-9	Philippines	101	5.3
	IR18348-36-3-3	IRRI	99	5.3
	UPLRi4	Philippines	99	5.3
	BG380-2	Sri Lanka	106	5.2
	KAU1727	India	101	5.2
West Asia and North Africa (1 trial)	KAU1727	India	112	10.3
	Si-pi 692033	Taiwan, China	113	10.2
	IR29725-109-1-2-1	IRRI	105	9.7
	IR31802-48-2-2-2	IRRI	103	9.4
	IR13429-299-2-1-3	IRRI	112	9.3
Sub-Saharan Africa (4 trials)	BG380-2	Sri Lanka	89	6.4
	IR21015-72-3-3-3-1	IRRI	84	6.3
	BW295-5	Sri Lanka	94	5.8
	C1321-9	Philippines	84	5.8
	Si-pi 692033	Taiwan, China	85	5.7
Latin America (3 trials)	BG380-2	Sri Lanka	93	5.8
	IR13240-108-2-2-3	IRRI	81	5.4
	Taichung sen 16	Taiwan, China	84	5.2
	KAU1727	India	86	4.9
	IR25840-64-1-3	IRRI	81	4.8

IRRSWON, IRDWON, IFRON, and ITPRON) as determined by their overall phenotypic acceptability ratings are shown in Table 7. Several entries were resistant to or tolerant of one or more important stresses at trial locations.

Nurseries for specific stresses. Tables 8 and 9 list the best performing entries in nurseries established for specific stresses. Insect nurseries include those for brown planthopper (IRBPHN), whitebacked planthopper (IRWBPHN), and stem borer (IRSBN). Disease nurseries include those for bacterial blight (IRBBN), rice blast (IRBN), and rice tungro (IRTN). Nurseries for other stresses include those for alkalinity and salinity (IRSATON), acid upland and lowland soils, and cold tolerance (IRCTN).

1985 NURSERY DISTRIBUTION

A total of 1,707 sets of 28 types of IRTP nurseries were composed and distributed to 49 countries in the IRTP network (Table 10). Test entry sources appear in Table 11. The nurseries include 17 for different cultural types and 11 for stress tolerance.

Table 3. Best performing entries in the 12th International Rice Yield Nursery – Medium (IRYN-M) based on overall and regional mean yield, 1984.

Region	Designation	Origin	Days to flowering	Yield (t/ha)
Overall (25 trials)	IR21820-154-3-2-2-3	IRRI	100	4.7
	IR25587-133-3-2-2-2	IRRI	107	4.6
	IR4744-295-2-3	IRRI	99	4.6
	BG379-2	Sri Lanka	103	4.5
	IR28118-138-2-3	IRRI	111	4.5
Southeast Asia (8 trials)	IR25587-133-3-2-2-2	IRRI	101	5.5
	IR21820-154-3-2-2-3	IRRI	95	5.4
	IR27316-96-3-2-2	IRRI	93	5.4
	X.3-D. T.	Vietnam	93	5.4
	IR19672-140-2-3-2-2	IRRI	99	5.2
	IR28118-138-2-3	IRRI	104	5.2
South Asia (12 trials)	IR21820-154-3-2-2-3	IRRI	102	4.3
	IR4744-295-2-3	IRRI	104	4.3
	BG379-2	Sri Lanka	108	4.2
	IR24637-38-2-2-1	IRRI	109	4.2
	IR28118-138-2-3	IRRI	117	4.2
	UPR254-85-1-TCA8	India	104	4.2
Sub-Saharan Africa (3 trials)	IR22082-41-2	IRRI	98	4.9
	BW295-4	Sri Lanka	109	4.6
	IR19672-140-2-3-2-2	IRRI	105	4.6
	IR21820-154-3-2-2-3	IRRI	101	4.6
Latin America (2 trials)	X.3-D. T.	Vietnam	105	5.7
	UPR254-85-1-TCA3	India	106	5.4
	RNR74229	India	107	5.3
	RNR74802	India	105	4.9
	IR4744-295-2-3	IRRI	105	4.8

Table 4. Best performing entries in the fourth International Rainfed Rice Shallow Water Yield Nursery (IRRSWYN) based on overall and regional mean yield, 1984.

Region	Designation	Origin	Days to flowering	Yield (t/ha)
Overall (13 trials)	BR11	Bangladesh	113	4.0
	BR51-74-6/J1	Bangladesh	118	4.0
	BR4	Bangladesh	114	3.7
	IR19083-22-2-2	IRRI	108	3.7
	IR13146-45-2-3	IRRI	112	3.6
Southeast Asia (9 trials)	BR11	Bangladesh	106	3.9
	BR51-74-6/J1	Bangladesh	113	3.8
	BR4	Bangladesh	109	3.7
	IR14136-45-2-3	IRRI	107	3.7
	IR19083-22-2-2	IRRI	105	3.7
South Asia (4 trials)	BR51-74-6/J1	Bangladesh	129	4.4
	BR11	Bangladesh	128	4.2
	IR13564-95-1	IRRI	124	3.9
	Cisadane	Indonesia	128	3.8
	IR10781-143-2-3	IRRI	111	3.8
	IR19256-88-1	IRRI	114	3.8

Table 5. Best performing entries in the 10th International Upland Rice Yield Nursery – Early (IURYN-E) based on overall and regional mean yield, 1984.

Region	Designation	Origin	Days to flowering	Yield (t/ha)
Overall (13 trials)	IR9761-19-1	IRRI	78	2.9
	NDR84	India	79	2.7
	HPU741	India	70	2.6
	NDR102	India	76	2.6
	OR164-5	India	76	2.6
	RAU4004-127	India	70	2.6
Southeast Asia (6 trials)	IR9761-19-1	IRRI	82	2.7
	OR164-5	India	80	2.5
	RP1158-90-1	India	82	2.4
	IRAT104	Ivory Coast	71	2.3
	NDR84	India	83	2.3
	NDR119	India	76	2.3
	RP1158-85-1	India	81	2.3
South Asia (6 trials)	RAU4004-127	India	68	3.3
	NDR84	India	75	3.2
	IR9761-19-1	IRRI	74	3.0
	NDR102	India	73	3.0
	RAU4004-105	India	68	2.9
Latin America (1 trial)	HPU741	India		3.6
	NDR80	India		3.4
	IRAT110	Ivory Coast		3.2
	IR9729-67-3	IRRI		3.2
	NDR119	India		3.1

Table 6. Best performing entries in the 10th International Upland Rice Yield Nursery – Medium (IURYN-M) based on overall and regional mean yield, 1984.

Region	Designation	Origin	Days to flowering	Yield (t/ha)
Overall (9 trials)	BR319-1	Bangladesh	89	3.3
	UPLRi7	Philippines	85	3.2
	IR12979-24-1 (Brown)	IRRI	86	3.1
	IR6023-10-1-1	IRRI	97	3.0
	IR43	IRRI	101	3.0
Southeast Asia (7 trials)	BR319-1	Bangladesh	89	3.1
	UPLRi5	Philippines	99	3.1
	C894-21	Philippines	99	3.0
	IR12979-24-1 (Brown)	IRRI	87	3.0
	UPLRi7	Philippines	86	3.0
Latin America (2 trials)	IR6023-10-1-1	IRRI	94	3.9
	IR12979-24-1 (Brown)	IRRI	83	3.8
	IR43	IRRI	94	3.8
	UPLRi7	Philippines	83	3.7
	BR319-1	Bangladesh	87	3.6

Table 7. Entries that received best phenotypic acceptability ratings in the 1984 observational nurseries.

Nursery	Designation	Mean phenotypic acceptability score	Mean days to flowering
International Rice Observational Nursery (IRON)	IR29725-117-2-3-3	4.5	87
	IR25898-57-2-3	4.6	83
	IR29725-45-1-1-3	4.6	85
	IR31847-22-2-3-3	4.6	84
	IR31847-67-2-1-1-2	4.6	83
	IR29708-113-3-2-3	4.7	84
	IR31787-85-3-3-3-2	4.7	87
	IR32358-122-2-1-2	4.7	96
	IR29692-117-1-2-2	4.8	86
	IR29692-34-1-3-2-2	4.8	84
	IR29725-40-3-2-3	4.8	86
	IR32296-72-3-3-2	4.8	90
	IR32307-107-3-2-2	4.8	93
	IR24632-60-3-3-2	4.8	91
	IR25840-81-3-2	4.8	95
	IR25840-83-3-2	4.8	94
	IR64	4.8	95
International Upland Rice Observational Nursery (IURON)			
1. Medium duration, intermediate or tall stature	UPLRi7	4.6	89
	UPLRi3	4.8	100
	UPLRi5	4.8	101
2. Medium duration, short stature	ITA162	5.1	96
	ITA212	5.1	106
	IR43	5.3	103
3. Short duration, intermediate or tall stature	B3619c-TB-8-1-4	5.4	86
	IRAT144	5.4	88
	Mallika Sel.	5.4	86
4. Short duration, short stature	No entry with score > 5.5		
International Rainfed Rice Shallow Water Observational Nursery (IRRSWON)	IR21836-90-3	3.3	114
	IR13146-45-2-3	3.9	111
	IR5853-198-1-2	3.9	103
	IR10781-143-2-3	3.9	111
	IR19083-22-2-2	4.0	108
	IR21141-24-2	4.0	108
	IR31429-14-2-3	4.0	104
	IR18272-27-3-1-2-2	4.1	99
	BRB11-448-1-4	4.1	106
	IR21567-16-3	4.1	106
	IR46	4.1	106
	IR4819-77-3-2	4.1	107
International Rice Deep Water Observational Nursery (IRDWON)	BKNFR76035-108-1	4.6	141
	IR31338-30-2-1	4.6	128
	NC493	4.6	123
	BKNFR76035-112-1	4.7	143
	ITA7403-110-1-5	4.7	125
	IR13259-185-2E-P4-3	4.7	127
	BKNFR76035-108-2	4.8	143
	BKN6988-52-1-3-0	4.8	124
	DWCT156-1-2-0	4.8	124
	IR29159-16-2-1-3	4.8	115
	RD19	4.8	152

continued on opposite page

Table 7 continued.

Nursery	Designation	Mean phenotypic acceptability score	Mean days to flowering
International Floating Rice Observational Nursery (IFRON)	RD19	4.0	163
	BR4	5.0	136
	Leb Mue Nahng 111	5.0	166
	IR11288-B-B-118-1	5.3	136
	SPR7232-2-3-1-0	5.3	145
International Tide-Prone Rice Observational Nursery (ITPRON)	LA29'72NFU-14-3-1-1	2.7	135
	CR149-3244-198	2.8	125
	BR111-140-1-1	3.0	129
	B2433B-KN-2-3-3-2-1	3.0	110
	B2791B-MR-196-2-3-1-12	3.2	113
	RP975-109-2	3.3	126
	B3063C-PN-151-2	3.6	113
	B3752G-KP-108-3	3.6	117
	B1043D-SM-29-6-1-1	3.8	117
	Chato	3.8	105
	CR1002	3.8	112
	GEU76043-0-2K-17-2	3.8	118

Table 8. Best performing entries in the 1984 insect and disease nurseries.

Insects

IRBPHN (International Rice Brown Planthopper Nursery). Entries rated resistant in the greenhouse test at most locations:

PTB33	IR17494-32-1-1-3-2	IR56
Rathu Heenati (Acc11730)	IR19660-46-1-3-2-2	IR9846-23-2
Balamawee (Acc8919)	IR19661-23-3-2-2	IR9852-22-3
BG367-2	IR21912-131-3-3	Mawee (Acc31482)
Hondarawala (Acc15634)	IR25603-20-2-1-3-2	RP1756-121
IR13540-56-3-2-1	C711130	

IRWBPHN (International Rice Whitebacked Planthopper Nursery). Entries rated resistant in the greenhouse test at all 13 locations:

IR13475-7-3-2	IR15527-21-2-3	IR17307-11-2-3-2
IR2035-117-3	IR15529-253-3-2-2-2	IR17492-18-6-1-1-3-3
IR13458-117-2-3-2-3	IR15797-74-1-3-2	WC1240 (Acc13742)

IRSBN (International Rice Stem Borer Nursery). Entries rated resistant at both vegetative and flowering stages across locations:

IR15723-45-3-2-2-2	IR19735-5-2-3-2-1	IR58
IR15795-151-2-3-2-2	IR43	IR9828-23-1

Diseases

IRBBN (International Rice Bacterial Blight Nursery). Entries rated resistant across locations at 2 dates of scoring (14 and 21 d after inoculation):

BR161-2B-53	B4143D-PN-51-4	IR54
BR171-2B-8	IR2798-88-3-2	RP633-76-1

IRBN (International Rice Blast Nursery). Entries rated resistant in almost all of 21 locations with high degree of blast incidence:

BG379-2	IRAT146	TOX475-NIB1-NK1-LS3-B1
ITA133	Carreon	Fukunishiki
Ta-poo-cho-z	IR17525-7-19-1-3-3-2	IRAT144

IRTN (International Rice Tungro Nursery). Entries rated resistant in the greenhouse test at all 4 locations:

ARC11554	Pankhari 203
Naria Bachi	Utri Merah

Table 9. Entries with best phenotypic or tolerance ratings in the 1984 IRTP stress screening nurseries.

IRSATON (International Rice Salinity and Alkalinity Tolerance Observational Nursery). Entries with highest tolerance ratings at both vegetative and maturity stages:		
Salinity	*Alkalinity*	
ROK5	IR8	
IR4563-52-1-3-6	Pokkali	
PNL5-1-1-1	IR9764-45-2-2	
Pokkali	IR52	
IR30175-3-3-3	IR50	
IR2153-26-3-5-2	ROK5	
IR43	MI-48	
Acid Upland Soils. Entries with good phenotypic acceptability ratings in certain locations:		
IR10206-29-2	Azucena	IR10198-66-2
IR6023-10-1-1	Salumpikit	BG35-2
P1274-6-8M-1-3M-1		
Acid Lowland Soils. Entries with average phenotypic acceptability ratings better than 4.0 at 60 kg P treatment:		
BW267-3	IR9764-45-2-2	P1369-4-16M-1-2M-4
B2149b-Pn-26-1-1	MRC172-9	P1391-6-11M-1-1B
IR46	P1274-6-8M-1-3M-1	Suakoko 8 (2526)
IR9217 58-2-2		
IRCTN (International Rice Cold Tolerance Nursery). Entries with average phenotypic acceptability ratings better than 5.4 in 23 trials:		
K39-96-1-1-1-2	C15309 (Acc. 00955)	Chechon-chun-shun 1 (Acc. 04532)
Ching-shi 15 (Acc. 36852)	China 1039	IR24312-R-R-19-3-B
Tatsumi mochi		

A total of 2,736 entries were distributed around the world.

A new nursery, the International Rice Ufra Screening Set (IRUSS), was initiated in response to the need for identifying varieties and breeding lines resistant to this important nematode problem in deep water rice. Another nursery, designated as the International Rice Salinity Tolerance Yield Nursery (IRSTYN), was begun to assess the yield performance of breeding lines or varieties found tolerant of salinity stress in the earlier observational nurseries relating to that problem. The yield nursery for rainfed shallow water lowland conditions (IRRSWYN) was divided into two maturity groups — early and medium.

In Asia, 1,208 sets went to national programs. Sub-Saharan Africa received 335 sets, of which 63 went to WARDA for distribution to member countries. Fifty-nine nursery sets went to the national programs in West Asia and North Africa, 93 to 12 countries in Latin America, 3 to 2 countries in Europe, and 9 to 2 countries in Oceania.

Use of IRTP nursery entries. National rice improvement programs continue to use IRTP materials. Often, outstanding entries in stress-screening nurseries are used as donors in hybridization programs (Table 12). Twenty-eight entries were most frequently utilized for further yield testing in various countries (Table 13).

Three IRTP entries were named as varieties and released to farmers in 1985: Gama 318 from Indonesia, named Avinash in Karnataka State of India; IR841-67-1-2 from IRRI, named EMPASC104 in Brazil; and P881-19-22-4-1-1B-CR1 from CIAT, named CR1821 in Costa Rica.

MONITORING VISITS AND WORKSHOPS

The IRTP monitoring program continued to play an important role in forging interactions among rice scientists around the world involved in varietal improvement. The following monitoring tours took place in 1985:

- Upland rice in Indonesia in conjunction with the second International Upland Rice Conference
- Rice in saline soils in India, Pakistan, and Thailand
- Deep water rice in Bangladesh, India, and Thailand
- Upland rice in Cameroon, Ivory Coast, Liberia, and Nigeria

Table 10. IRTP nurseries dispatched from IRRI in 1985.[a]

Region and country	Nurseries for different cultural types																	Screening for specific stresses											Total
	Yield							Observational																					
	Y_{01}	Y_{02}	Y_{03}	Y_{04}	Y_{05}	Y_{06}	Y_{07}	O_{01}	O_{02}	O_{03}	O_{04}	O_{05}	O_{06}	O_{07}	O_{08}	O_{09}	O_{10}	S_{01}	S_{02}	S_{03}	S_{04}	S_{05}	S_{06}	S_{07}	S_{08}	S_{09}	S_{10}	S_{11}	
East Asia																													
China	9	7	2	2	1	1		9	10	8	3	2	2	1				5	2	1	1	9	9	8		8	5	4	109
Japan																		1											1
Korea	1							2										2	1			4	4	1		1	1		17
Taiwan	2							1										1					1			2	1		8
Southeast Asia																													
Burma		1	1	1			1				1			1	2			1	2	1	1		2	2		1	1	1	20
Indonesia	3	2			1			1	1		2	1	1	1	3	3	3	2		3	2	4	2	2	1	5	2	1	46
Malaysia	2	3	4		1	3	3	1	1	1	1	1	2	2								1	1	1	1	1	1	1	32
Philippines	4	5	4	11	13	12	12	5	5	4	14	14	11	11	2	2	3	3	4	3	7	1	1	1	2	2	1	1	158
Thailand	6	6	2	3	3	9	9	6	6	6	5	5	9	9	6	4	2	4	4	6	2	5	6	5	3	2	1		134
Vietnam	5	5	5	2	2	3	2	3	4	3	3	2	2	2	5	5	3	2	4	4	3	4	4	2	3	5	4	1	92
South Asia																													
Bangladesh	8	6	8	3		4	4	10	10	10	3	3	4		4	3	1	6	4		2	4	4	4	3	1			109
Bhutan			2								1	1						1				1	1						7
India	23	19	14	15	7	2	5	20	20	18	16	8	5	9	10	4	2	19	14	1	2	18	21	16	7	16	11	14	336
Nepal	3	2	2	2	4	5	5	2	2	2	3	3	5	5				6				4	4	2		1	2	2	66
Pakistan	2	5	4	1	2	1	1	2	4	3	2	2	2	2	1			2	8			1	1				3	4	53
Sri Lanka				1		1		1	1	1	2	1	1		1	1	1		3	2		1	1			1			20
West Asia and North Africa																													
Egypt	2	2						2	2	2									4			2	2					2	20
Iran	4							4	4	4								1				2	2	1				1	23
Iraq	1	1		1	1			1			1								1										7
Turkey	3							1	1										2				2						9
Sub-Saharan Africa																													
Burundi	1	1	1	1	1			1	1	1	1	1						1											11
Cameroon	2	1	3			1		1	1	1	1	1						5				2	2						21
Guinea Bissau								1	1										1	1									4
Liberia (WARDA)	2	3	3					2	2	2			5	5	6	3	2	5	2	6		6	6					3	63
Malagasy	1		1	1	1	1	1								1			1											8
Nigeria	3	5	3	3	2	2	2	13	13	11	10	10	10	10	1	1		3		3	11	4	4	3					127
Sierra Leone								1	1	1			1	1															5
Somalia	1	1	1					1	1	1																			6
South Africa	1																												1
Tanzania	6	6	5	2		1		2	2		4	4	1	1	1			2	3			1	1						44
Uganda				1	1		1	1	1	1												1	1						8
Zaire											3	3										4							10
Zambia	4	3	4			2	1	1	1	1	1		2	1				3			1		2						27

continued on next page

Table 10. continued.

Region and country	Nurseries for different cultural types																													
	Yield							Observational										Screening for specific stresses											
	Y_{01}	Y_{02}	Y_{03}	Y_{04}	Y_{05}	Y_{06}	Y_{07}	O_{01}	O_{02}	O_{03}	O_{04}	O_{05}	O_{06}	O_{07}	O_{08}	O_{09}	O_{10}	S_{01}	S_{02}	S_{03}	S_{04}	S_{05}	S_{06}	S_{07}	S_{08}	S_{09}	S_{10}	S_{11}	Total
Latin America																														
Argentina									1	1																				2
Brazil	1							1			1	1	1									1	1							7
Colombia	2	1	1	1	1			3	3	3	2	2								1	1	2	2							25
Dominican Republic	1																		2			1	1							5
Ecuador		1						1	1	1					1															5
El Salvador	1																													1
Honduras																						1	1							2
Jamaica	1							1	1	1																				4
Mexico	2	2		3	3	1	1	1	1		4	4	1	1				2	2	1		4	4							37
Panama					1							1																		2
Surinam		1																												1
Uruguay																						1	1							2
Europe																														
Hungary																		1												1
Italy																						1	1							2
Oceania																														
Solomon Islands	1	1						1	1		1	1														1				7
Vanuatu						1	1																							2
Total	108	90	70	54	45	50	51	103	103	87	85	71	65	62	44	26	17	79	63	33	33	90	95	48	20	47	33	35	1707

[a] Y_{01} = International Rice Yield Nursery-Very Early (IRYN-VE), Y_{02} = International Rice Yield Nursery-Early (IRYN-E), Y_{03} = International Rice Yield Nursery-Medium (IRYN-M), Y_{04} = International Upland Rice Yield Nursery-Early (IURYN-E), Y_{05} = International Upland Rice Yield Nursery-Medium (IURYN-M), Y_{06} = International Rice Rainfed Shallow Water Yield Nursery-Early (IRRSWYN-E), Y_{07} = International Rice Rainfed Shallow Water Yield Nursery-Medium (IRRSWYN-M), O_{01} = International Rice Observational Nursery-Very Early (IRON-VE), O_{02} = International Rice Observational Nursery-Early (IRON-E), O_{03} = International Rice Observational Nursery-Medium (IRON-M), O_{04} = International Upland Rice Observational Nursery-Early (IURON-E), O_{05} = International Upland Rice Observational Nursery-Medium (IURON-M), O_{06} = International Rice Rainfed Shallow Water Observational Nursery-Early (IRRSWON-E), O_{07} = International Rice Rainfed Shallow Water Observational Nursery-Medium (IRRSWON-M), O_{08} = International Rice Deep Water Observational Nursery (IRDWON), O_{09} = International Floating Rice Observational Nursery (IFRON), O_{10} = International Tide-Prone Rice Observational Nursery (ITPRON), S_{01} = International Rice Cold Tolerance Nursery (IRCTN), S_{02} = International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON), S_{03} = Acid Lowland Soils Screening Set (ACID LOWLAND), S_{04} = Acid Upland Soils Screening Set (ACID UPLAND), S_{05} = International Rice Blast Nursery-Upland (IRBN-UPLAND), S_{06} = International Rice Blast Nursery-Lowland (IRBN-LOWLAND), S_{07} = International Rice Bacterial Blight Nursery (IRBBN), S_{08} = International Rice Tungro Nursery (IRTN), S_{09} = International Rice Brown Planthopper Nursery (IRBPHN), S_{10} = International Rice Whitebacked Planthopper Nursery (IRWBPHN), S_{11} = International Rice Stem Borer Nursery (IRSBN).

Table 11. Origin and types of entries in the 1985 IRTP nurseries dispatched from IRRI.

Nursery[a]	Sets dispatched (no.)	Entries[b] (no.)	Entries from							
			National programs				IRRI			
			Improved		Traditional		Improved		Germplasm bank	
			No.	%	No.	%	No.	%	No.	%
			Yield							
Irrigated										
IRYN-VE	108	23	12	52	0	0	11	48	0	0
IRYN-E	90	26	15	58	0	0	11	42	0	0
IRYN-M	70	27	14	52	0	0	13	48	0	0
Rainfed Upland										
IURYN-E	54	21	17	81	0	0	4	17	0	0
IURYN-M	45	18	11	61	0	0	7	39	0	0
Rainfed Lowland										
IRRSWYN-E	50	24	3	12	0	0	21	88	0	0
IRRSWYN-M	51	27	15	56	0	0	12	44	0	0
			Observational							
Irrigated										
IRON-VE	103	70	20	29	1	1	49	70	0	0
IRON-E	103	179	82	46	6	3	91	51	0	0
IRON-M	87	105	56	53	0	0	49	47	0	0
Rainfed										
IURON-E	85	111	82	74	1	1	27	24	1	1
IURON-M	71	179	115	64	5	3	57	32	2	1
IRRSWON-E	65	26	19	73	0	0	7	27	0	0
IRRSWON-M	62	174	76	44	4	2	94	54	0	0
IRDWON	44	87	54	62	1	1	31	36	1	1
IFRON	26	22	18	82	3	14	1	4	0	0
ITPRON	17	62	43	69	6	10	9	15	4	6
			Stress screening							
Diseases										
IRBN-Upland	90	40	31	77	2	5	7	18	0	0
IRBN-Lowland	95	318	184	58	9	3	124	39	1	0
IRBBN	48	215	104	48	2	1	109	51	0	0
IRTN	20	160	70	44	6	4	84	52	0	0
Insects										
IRBPHN	47	236	53	22	0	0	172	73	11	5
IRWBPHN	33	97	20	21	9	9	58	60	10	10
IRSBN	35	75	28	37	2	3	43	57	2	3
Problem soils										
IRSATON	63	90	22	24	1	1	67	74	0	0
Acid Lowland	33	81	25	31	0	0	56	69	0	0
Acid Upland	33	65	36	55	2	3	27	42	0	0
Temperature tolerance										
IRCTN	79	178	75	42	4	2	46	26	53	30
Total	1,707	2,736	1,300	48	64	2	1,287	47	85	3

[a]For explanation of acronyms, see footnote to Table 10. [b]Local checks not included.

Table 12. Utilization of 1985 IRTP nursery entries.[a]

Region and country	Used for			
	Hybridization	Yield testing		
		Local	State	National
East Asia				
China	48	12	9	1
Korea	13			
Southeast Asia				
Malaysia	2	6		
Philippines				14
Thailand	27	26		49
Vietnam	2	17	12	2
South Asia				
Bangladesh	6			
Bhutan	2	4		
India	35	26	3	
Nepal		7		151
West Asia				
Turkey	1	4		
Sub-Saharan Africa				
Cameroon		3	13	
Oceania				
Solomon Islands		11		
Europe				
Hungary	13			
Total	149	116	37	217

[a]Based on data received as of 23 Jan 1986.

Table 13. IRTP entries that were frequently utilized for further yield testing in various countries[a] (frequency = 3-5).

BG367-4	IR29692-65-2-3
BR153-2B-10-1-3	IR29692-99-3-2-1
BW295-5	IR3179-25-3-4
Chianung sen yu 26	IR35546-52-3-3-2
CN540	IR4819-77-3-2
C662083	IR50
IR18348-36-3-3	IR5629-64-3
IR19274-26-2-3-1	IR5873-9-1
IR21015-80-3-3-1-2	IR60
IR21178-39-P1	PAU50-B-25-1
IR25588-7-3-1	Si-pi 692033
IR25621-135-1-1	UPLRi4 (C1000-4)
IR25924-51-2-3	UPR103-80-1-2
IR25924-92-1-3	
IR29658-69-2-1	

[a]Based on data received as of 23 Jan 1986.

The global IRTP advisory committee met at IRRI in June. The planning meeting of regional IRTP for Africa was held at IITA in January, and that for Latin America and the Caribbean at CIAT in August.

Table 14. Data returned from IRTP nurseries for Latin America distributed in 1984.

Nursery[a]	Entries (no.)	Sets dispatched	Data returned
Yield			
VIRAL-T	24	45	26
VIRAL-F	21	6	1
Observational			
VIOAL	184	57	27
VIOAL-SNF	49	31	10
VIOAL-HB	83	11	4
Climate and soil			
VIOSAL	61	8	1
VITBAL	37	10	3
Total	459	168	72

[a]VIRAL-T = International Rice Yield Nursery – Medium Maturing, VIRAL-F = International Rice Yield Nursery – Semi-deep Water, VIOAL = International Rice Observational Nursery, VIOAL-SNF = International Rice Observational Nursery = Unfavored Upland, VIOAL-HB = International Rice Observational Nursery – Hoja blanca, VIOSAL = International Rice Salinity and Alkalinity Tolerance Observational Nursery, VITBAL = International Rice Low Temperature Nursery.

IRTP IN LATIN AMERICA

IRTP activities in Latin America in 1985 continued to focus on providing national programs with improved germplasm to overcome major constraints. In addition to the global nurseries, nurseries specific to the region were distributed.

The number of nursery sets distributed in Latin America in 1984 and the number for which data were returned are shown in Table 14.

Promising entries from different nurseries tested are listed in Table 15.

In 1985, 170 sets of 6 IRTP nurseries were distributed to national programs in Latin America (Table 16). A total of 458 entries — mostly from CIAT, the IRTP global nurseries, and national programs of 7 Latin American countries — were distributed.

Table 15. Promising entries from the 1984 IRTP-Latin America nurseries.

Nursery	Promising lines
VIRAL-T (Yield-medium maturing)	*Irrigated* – P2025F4-159-3-1B, P2053F4-99-4-1B, P2231F4-45-8-1B, P2192F4-39-5-1, IR4422-98-3-6-1, IR25909-11-2-2-3-2
	Favored upland – P2231F4-138-2-1B, P2231F4-138-6-2-1, IR25909-11-2-2-3-2, P2025F4-159-3-1B
VIOAL (Observational)	*Irrigated* – P2189F4-64-1B-1B, P2778F4-82-2, P3299F4-86, P3082F4-60-3, P2182F4-49-1B-1B
	Favored upland – P3299F4-7, P3059F4-25-3, P3083F4-61, P2231F4-138-2-3, P3081F4-78, P2231F4-45-8-1
	Tolerant of Fe toxicity – J-104, P2851F4-15-6, BR153-2B-37-1-3, P3299F4-7, P3293F4-96, P2863F4-79-6, P2217F4-45-7-1B
VIOAL-SNF (Observational, unfavored upland)	P1035-5-6-1-1-1M, P1332-3-8M-1-1B, IRAT112, P2030F4-235-1B-1B, IR14632-212-2, IRAT104, IR5105-156-2-3
VIOAL-HB (Observational – Hoja Blanca)	Taichung sen yu 285, P3304F4-5, P2766F4-36-2-4, IR17492-18-6-1-1-33, IRAT120, IRAT121, IRAT122, IRAT124, Taipei 309
VITBAL (Observational – low temperature)	IR9965-53-3, S201, IR19743-25-2-2, HPU5010-PLP-21-2-1B, M101, HR1619-5-2-1-3-1

Table 16. IRTP nurseries for Latin America distributed in 1985.

Nursery, ecosystem[a]	Sets (no.)	Entries (no.)	Origin of entries		
			CIAT	IRRI	National programs
Yield					
VIRAL-T	44	13	10	3	–
VIRAL-F	5	26	–	26	–
Observational					
VIOAL	48	259	149	69	41
Irrigated – arid	2	178			
– tropical	6	123			
– temperate	6	71			
Rainfed	1	123			
Favored upland	2	111			
Moderately favored upland	2	111			
VIOAL-SNF	37	81	57	24	–
Climate and soil					
VIOSAL	10	38	–	38	–
VITBAL	7	41	–	22	19
Total	170	458	216	182[b]	60

[a]For explanation of acronyms, see footnote to Table 14. [b]Includes 27 entries selected from 1983 nurseries.

Table 17. Regional IRTP-Africa nurseries distributed in 1985.

Ecology, nursery	Entries (no.)	Sets dispatched (no.)	Recipient countries (no.)
African upland rice			
Preliminary screening set (AURPSS)	150	11	8
Observational nursery (AURON)	100	35	16
Advanced varietal trial (AURAVT)	17	41	16
African irrigated rice			
Preliminary screening set (AIRPSS)	150	14	9
Observational nursery (AIRON)	100	40	16
Advanced varietal trial (AIRAVT)	17	45	14
Total	534	186	

Table 18. Entries from the 1984 IRTP nurseries in Africa.

Nursery[a]	Promising entries
Irrigated yield	
IRYN-Very early	UPR103-80-1-2, AS688, Mallika Sel., BG367-4
IRYN-Early	BW295-5, BG380-2, IR21015-72-3-3-3-1, C1321-9
IRYN-Medium	IR22082-41-2, RNR74229, RTN16-2-1-1-1, BR153-2B-10-1-3
Irrigated observational	
IRON-Very Early	IR29725-76-6-3-3-2, IR32296-72-3-3-2, IR32358-122-2-1-2, TKM9
IRON-Early	C702015, ECIA31-104-2-1-6, Iri 346, IR25840-64-1-3, IR25840-83-3-2, IR28210-68-4-1-3, IR28211-43-1-1-1-2, IR28222-23-1-3-3-2, IR31787-122-1-2-2-3, IR31796-12-3-1-1, IR31802-48-2-2-2, IR31834-77-3-1-2
IRON-Medium/Late	BG379-2, CPI-C14, P2016-F4-116-1B-1B
Rainfed lowland yield	
IRRSWYN	BR4, IR4819-77-3-2, IR10781-143-2-3, BR11, IR4829-89-2
Rainfed upland observational	
IURON	UPLRi7, BR4, B3913B16-20ST-28, IRAT104, IR8192-166-2-2-2, IR8073-65-6-1, ITA186, IR3007B-TB-22-2-3-3-1
Stress screening	
Acid upland	Azucena, IAC1246, IRAT104, IR12979-24-1, IR5440-1-1-3, IR7835-28-2-4, Salumpikit, IRAT112, ITA235, Katakchikon (Acc. 25880), ITA141, TOX936-397-9-1-2
Blast (IRBN)	Fukunishiki, BG367-9, Raminad Str. 3, BG379-2, Huan-sen-goo, IRAT110, IRAT134, IRAT144, IRAT146, IR10029-26-2, IR24637-38-2-2-1, IR9782-111-2-1-2, IR9828-41-2-1, IR9852-18-1, IR9852-22-3, IR9852-98-2-2-2-3, ITA232, P1274-6-8M-1-3M-1, Ta-poo-cho-z, TOx475-NIB1-NK1-LS3-B1
Cold tolerance (IRCTN)	Hsin-hsin-Pa I-Ku (Acc. 04864), IR18476-55-2, IR18476-86-3-3, B2982B-SR-62-3-1-4, B2983B-SR-85-3-2-4, B2983G-SR-2-9, B2983G-SR-43-7, Latsika B

[a]For explanation of acronyms, see footnote to Table 10.

From the 459 nursery entries distributed in 1984, 202 were selected by national programs for further yield testing and 23 were used as parents in hybridization work. Three varieties were released in Latin America in 1985, two by the rice program of EMPASC, Brazil, for irrigated ecosystems — EMPASC104, which corresponds to IR841-67-1-2, and CICA8 — and one by the rice program of Costa Rica — CR1821, a sister line of CR201.

IRTP IN AFRICA

In 1985, 335 sets of 25 types of IRTP global nurseries were sent to 13 countries in Sub-Saharan Africa. In addition, 186 sets of 6 types of regional (IRTP-Africa) nurseries were distributed to 16 African countries (Table 17). Promising entries from the 1984 IRTP trials in Africa are listed in Table 18.

Cooperative programs

International Network on Soil Fertility and Fertilizer Evaluation for Rice

Agronomy Department

NITROGEN FERTILIZER EFFICIENCY FIELD TRIALS **480**
Irrigated rice **480**
Medium deep water rice **480**
Deep water rice **481**
INTERNATIONAL TRIALS **481**
Irrigated lowland rice **481**
Rainfed lowland rice **482**
Deep water rice **483**
Rainfed upland rice **483**
Long-term fertility trial in irrigated rice **484**
Sources of phosphorus **485**
Azolla **485**
Integrated use of inorganic and organic N fertilizersl **485**
Hand- and machine-applied fertilizers **486**
Soil fertility management of acid upland soils (pH<5) **486**
INSFFER TRAINING COURSE **487**
SITE VISIT TOURS AND WORKSHOPS **487**

479

NITROGEN FERTILIZER EFFICIENCY FIELD TRIALS

Irrigated rice. The sixth trial of the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) was continued in 1985 dry season (DS) and wet season (WS) at IRRI. In both seasons, N application significantly increased grain yields, but no fertilizer source-rate interactions were significant. Sulfur-coated urea (SCU) and urea supergranules (USG) gave significantly higher yields than prilled urea (PU) applied either as local best split (BS) (1/2 topdressed at 10 d after transplanting [DT], 1/2 topdressed at 10 d after panicle initiation [DAPI]) or standard BS (2/3 broadcast and incorporated [B&I] without water, 1/3 topdressed at 5-7 d before panicle initiation [DBPI]) (Table 1). However, standard BS gave significantly higher yield than local BS.

In DS, the optimum rate was 87 kg N/ha (Table 1). In WS, increasing N levels significantly increased yields.

Medium deep water rice. N efficiency trials in medium deep water (50 cm depth) were continued at IRRI. Three sources of N (PU, SCU, and USG) at 3 rates (29, 58, and 116 kg N/ha) were applied in 3 ways: B&I, B&I followed by (fb) foliar spray of urea solution, and deep placement (DP). Water depth was increased 5 cm/d starting at 30 DT and maintained at 50 cm until harvest.

Two rices were used: photoperiod-insensitive IR21071-53-2-3-2E-P2 in DS and photoperiod-sensitive IR11288-B-B-69-1 in WS.

At 29 kg N/ha, IR21071-53-2-3-2E-P2 yielded significantly more than the control in DS, the highest yield advantage (2.1 t/ha) being with SCU (Table 2). Grain yields at 58 and 116 kg N/ha did not differ significantly from that at 29 kg N/ha. Foliar spraying of urea solution following PU B&I gave no advantage over a full dose of PU B&I.

In WS, IR11288-B-B-69-1 yielded significantly higher than the nonfertilized control with higher N rates. PU B&I at increasing N rate increased grain yield. No significant differences were observed among SCU B&I, USG DP, and PU B&I fb foliar spray of urea solution at 5-7 DBPI.

Table 1. Effects of source, rate, and method of N fertilizer application on yield of IR60. Sixth trial of INSFFER (irrigated), IRRI, 1985 dry season (DS) and wet season (WS).

Treatment[a]	Yield (t/ha)	
	DS	WS
No fertilizer N	2.8	2.9
Source and application method		
PU local BS	4.7 c	3.8 c
PU standard BS	5.7 b	4.2 b
SCU	6.2 a	5.0 a
USG	6.1 a	4.8 a
N rate (kg/ha)		
29	–	3.8 c
58	5.0 b	4.6 b
87	5.9 a	5.0 a
116	6.1 a	–

[a]PU = prilled urea, BS = best split, SCU = sulfur-coated urea, USG = urea supergranule. PU local BS = 1/2 topdressed at 10 d after transplanting, 1/2 topdressed at 10 d after panicle initiation; PU standard BS = 2/3 B&I without standing water, 1/3 topdressed at 5-7 d before panicle initiation. [b]Within a source or rate, means in a column with a common letter are not significantly different at the 5% level by DMRT.

Table 2. Effects of source, rate, and method of N application on grain yield of 2 rice cultivars at 50 cm water depth, IRRI, 1985 DS and WS.

Treatment[a]	Yield (t/ha)	
	IR21071-53-2-3-2E-P2 (DS)	IR11288-B-B-69-1 (WS)
No fertilizer N	1.9 d	1.3 d
	29 kg N/ha	
PU B&I	3.4 b	1.8 c
2/3 PU B&I fb 1/3 foliar spray of urea solution 5-7 DBPI	3.7 ab	2.5 ab
SCU B&I	4.0 ab	2.2 bc
USG 10-12 cm DP	2.8 c	2.2 bc
	58 kg N/ha	
PU B&I	3.7 ab	1.9 c
2/3 PU B&I fb 1/3 foliar spray of urea solution 5-7 DBPI	3.4 b	2.4 ab
SCU B&I	4.0 ab	2.2 bc
USG 10-12 cm DP	4.0 ab	2.8 a
	116 kg N/ha	
PU B&I	4.0 ab	2.7 a
2/3 PU B&I fb 1/3 foliar spray of urea solution 5-7 DBPI	3.6 b	2.5 ab
SCU B&I	4.0 ab	2.2 bc
USG 10-12 cm DP	4.3 a	2.5 ab

[a]B&I = broadcast and incorporated, fb = followed by, DBPI = days before panicle initiation, DP = deep placement.

Deep water rice. The second INSFFER trial for deep water rice was continued in 1985 in deep water (max 100 cm) ponds at IRRI using photoperiod-sensitive IR11288-B-B-69-1 in WS. Three sources of N (PU, SCU, and USG) at 3 rates (29, 58, and 116 kg N/ha) were applied in 3 ways: B&I, B&I fb foliar spray of urea solution, and DP.

Flash flooding brought about by monsoonal rain caused the experimental site to be submerged for 3 d, resulting in poor crop stand. Tillering, panicle production, and yield of the standing crop were drastically reduced (Table 3). No significant differences were observed among N sources, rates, and application methods.

INTERNATIONAL TRIALS

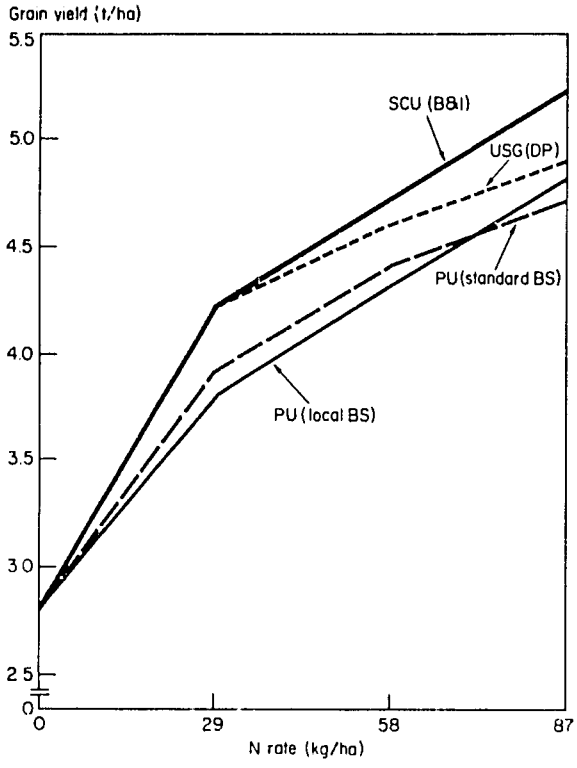
Two hundred twenty sets of fertilizers and field-books were sent to 64 collaborators from 20 participating national programs in 1985. Twelve collaborative research trials were conducted in 1985. They included N fertilizer efficiency trials in four major rice environments; a long-term fertility trial in irrigated lowland rice; P sources in flooded rice; azolla use in lowland rice; acid lowland nursery; integrated use of inorganic and organic N fertilizers in lowland rice; comparison of hand- and machine-applied N fertilizers in lowland rice; and two long-term fertility trials on soil fertility management of rainfed upland rice soils with pH 5-7 and pH <5. The latter trials are more recent ones, in line with current thrusts in rice research at IRRI. INSFFER is placing increasing emphasis on integrated nutrient management through proper combinations of inorganic and organic fertilizers.

Irrigated lowland rice. Collaborators at 18 sites in 5 countries reported the results of the 1984 sixth international trial on N fertilizer efficiency in irrigated lowland rice. All 18 trials showed significant response to N. Average responses of irrigated rice to SCU B&I and to USG DP were similar and higher than responses to either local BS or standard BS PU at low N rates (Fig. 1). At 29 kg N/ha, SCU and USG resulted in 40% more yield than PU.

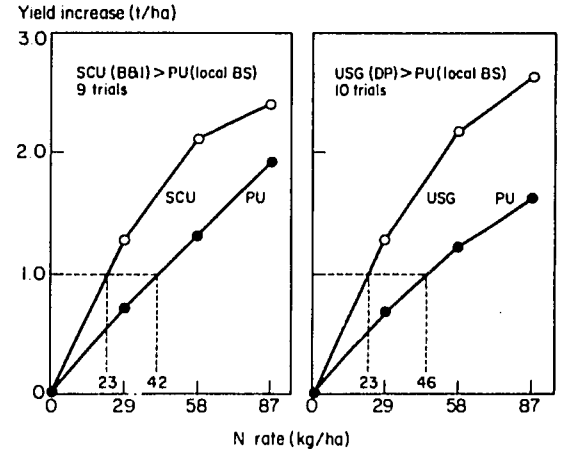
Regression analysis using the multifertilizer response model (MRM) and fertilizer testing model (FTM) showed that SCU B&I was superior to PU local BS in 50% of the irrigated lowland rice trials, and USG DP in 56% of the trials. For a yield increase of 1 t/ha, 45% less N was required if

Table 3. Effects of source, rate, and method of N application on yield and some agronomic characteristics of IR11288-B-B-69-1 at 100 cm water depth. IRRI, 1985 WS.

Treatment	Grain yield (t/ha)	Tillers at harvest (no./m²)	Panicles at harvest (no./m²)	Panicle length (cm)	Unfilled spikelets (%)
No fertilizer N	1.3 bcd	134 b	92 a	23.9 a	18 a
		29 kg N/ha			
PU B&I	1.8 a	74 c	53 b	23.9 a	17 a
2/3 PU B&I fb 1/3 foliar spray of urea solution 5-7 DBPI	1.6 ab	112 bc	71 ab	24.3 a	16 a
SCU B&I	1.8 a	130 b	98 a	24.7 a	18 a
USG 10-12 cm DP	1.6 ab	116 bc	85 ab	23.1 a	17 a
		58 kg N/ha			
PU B&I	1.5 abc	94 bc	70 ab	23.7 a	19 a
2/3 PU B&I fb 1/3 foliar spray of urea solution 5-7 DBPI	1.7 a	106 bc	70 ab	24.7 a	16 a
SCU B&I	1.5 abc	134 b	104 a	22.8 a	18 a
USG 10-12 cm DP	1.3 bcd	143 ab	97 a	22.7 a	19 a
		116 kg N/ha			
PU B&I	1.7 a	116 bc	91 a	25.3 a	16 a
2/3 PU B&I fb 1/3 foliar spray of urea solution 5-7 DBPI	1.2 cd	90 bc	68 ab	24.6 a	17 a
SCU B&I	1.2 cd	144 ab	82 ab	24.5 a	15 a
USG 10-12 cm DP	1.0 d	189 a	105 a	24.0 a	19 a



1. Average yield responses of irrigated lowland rice to forms of urea and rates of application. Data are averages of 1 DS and 17 WS trials at 18 sites in 5 countries. Sixth international trial on N fertilizer efficiency in irrigated lowland rice, INSFFER, 1984.



2. Estimated average yield response of irrigated lowland rice to SCU (B&I), USG (DP), and PU (local BS) in trials where yield responses to test fertilizers were significantly greater than to PU. Sixth international trial on N fertilizer efficiency in irrigated lowland rice, INSFFER, 1984.

applied as SCU, and 50% less if applied as USG (Fig. 2).

In the fifth international trial on N fertilizer efficiency in irrigated lowland rice, 148 trials were conducted from 1981 to 1984 at 80 sites in 12 countries. Regression analysis using MRM and FTM showed that 139 trials responded significantly to N. Yield responses to SCU B&I and USG DP were significantly greater than to PU BS in 40% of the responsive trials (Table 4).

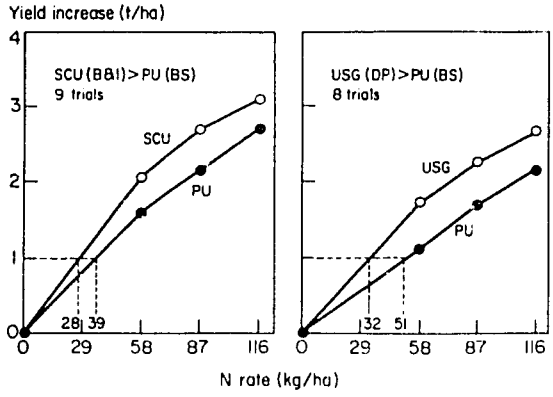
Estimated average yield responses to SCU, USG, and PU during DS and WS are shown in Figures 3 and 4. To produce a yield increase of 1 t/ha, 28% less N was necessary if applied as SCU during DS, and 49% less if in WS. To produce a yield increase of 1 t/ha, 37% less N was necessary if applied as USG during DS, and 53% less if in WS.

Rainfed lowland rice. In the third international trial on N fertilizer efficiency in rainfed lowland rice, MRM and FTM analyses of 48 trials at 30 sites in 9 countries from 1981 to 1984 showed that 46 trials had significant responses to applied N. Yield responses to SCU and USG were significantly greater than to PU in 35% of the responsive trials (Table 5). An increase of 1 t/ha required 57% less N if applied as SCU, and 62% less as USG (Fig. 5).

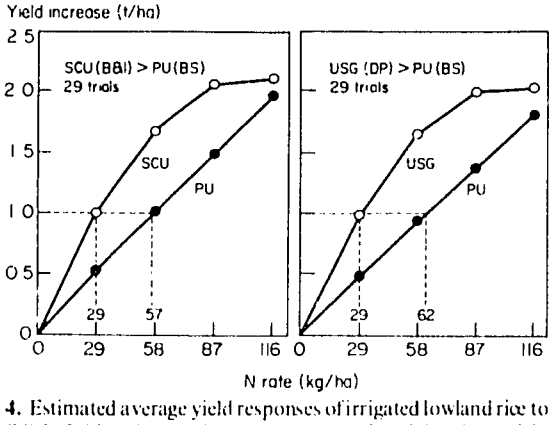
Table 4. Number of trials in 12 countries by response category when SCU and USG were compared separately with PU. Fifth international trial on N fertilizer efficiency in irrigated lowland rice, 1981-84.

Country	Trials (no.)			
	Total	Response category[a]		
		SCU > PU	USG > PU	No response
Bangladesh	5	2	2	0
Burma	6	0	0	1
Cameroon	1	0	0	0
China	11	5	5	0
India	39	20	23	1
Indonesia	35	8	11	2
Nepal	4	0	0	2
Pakistan	1	1	0	0
Philippines	33	14	10	2
Sri Lanka	1	0	0	0
Thailand	1	0	1	0
Vietnam	11	5	4	1
Total	148	55 (40)[b]	56 (40)[b]	9

[a]FTM linear differential estimate of quadratic function was used to classify individual trials into response categories. [b]Values in parentheses are percentages out of 139 trials where positive N response was obtained.



3. Estimated average yield response of irrigated lowland rice to SCU (B&I), USG (DP), and PU (BS) in trials where yield responses to test fertilizers were significantly greater than to PU. Fifth international trial on N fertilizer efficiency in irrigated lowland rice, INSFFER, 1981-84 DS.



4. Estimated average yield responses of irrigated lowland rice to SCU (B&I), USG (DP), and PU (BS) in trials where yield responses to test fertilizers were significantly greater than to PU. Fifth international trial on N fertilizer efficiency in irrigated lowland rice, INSFFER, 1981-84 WS.

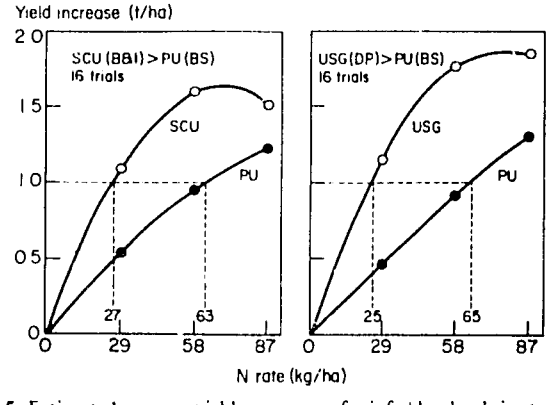
Deep water rice. In the second international trial on N fertilizer efficiency in deep water rice, the effectiveness of PU B&I, SCU B&I, USG DP, and foliar application of PU in combination with basally applied PU was compared in nine trials conducted in three countries from 1982 to 1984.

Average responses of deep water rice to different urea forms and rates of application were significant at all sites. Highest yields were from USG DP at low and medium N rates, while the lowest were with foliar application of PU combined with basal application, especially at medium and high N rates (Fig. 6). At high N rate, grain yields from PU B&I, SCU B&I, and USG DP were comparable.

Table 5. Number of trials in 9 countries by response category when SCU and USG were compared separately with PU. Third international trial on N fertilizer efficiency in rainfed lowland rice, 1981-84.

Country	Trials (no.)			
	Total	Response category[a]		
		SCU > PU	USG > PU	No response
Bangladesh	4	2	0	0
Burma	4	2	2	0
India	22	5	5	0
Indonesia	2	1	1	0
Nigeria	1	0	0	1
Philippines	10	3	5	1
Sri Lanka	2	2	1	0
Thailand	2	1	1	0
Vietnam	1	0	1	0
Total	48	16 (35)[b]	16 (35)[b]	2

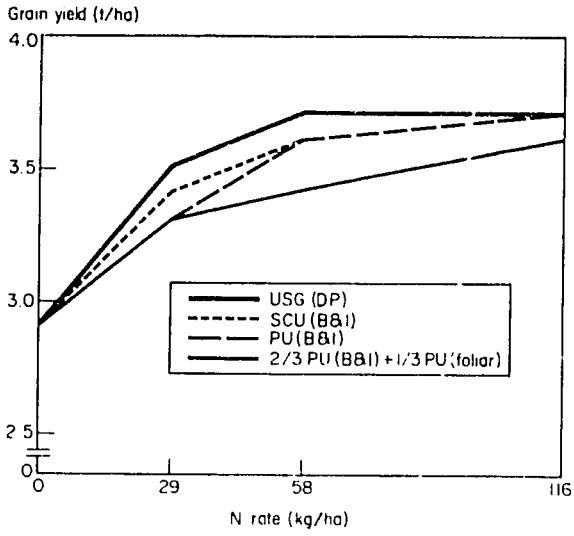
[a]FTM linear differential estimate of quadratic function was used to classify individual trials into response categories. [b]Values in parentheses are percentages of the 46 trials where positive N response was obtained.



5. Estimated average yield responses of rainfed lowland rice to SCU (B&I), USG (DP), and PU (BS) in trials where responses to test fertilizers were significantly greater than to PU. Third international trial on N fertilizer efficiency in rainfed lowland rice, INSFFER, 1981-84.

Rainfed upland rice. In the first international trial on N fertilizer efficiency in rainfed upland rice, 13 sets of fertilizers and fieldbooks were sent to 7 collaborators in 6 countries in 1984. However, only the results from the lone trial conducted by the IRRI Agronomy Department have been submitted and summarized.

The effectiveness of the different N sources and their application methods was evaluated on an acid upland soil (pH 4.1) in Caliraya, Laguna, Philip-



6. Average yield response of rice to forms of urea and rates of application. Data are averages of 9 trials conducted at 4 sites in 3 countries. Second international trial on N fertilizer efficiency in deep water rice, INSFFER, 1982-84.

pines, in 1984 WS. Similar yield increases were observed for all N sources and rates of application (Table 6). The highest yield of 1.3 t/ha was observed in basal, surface broadcast application of PU + 10% DCD and in $(NH_4)_2SO_4$ recommended split at 80 kg N/ha.

Long-term fertility trial in irrigated rice. Response to continuous application of N and combinations involving N averaged higher during DS than WS. For P, K, and PK, however, responses during DS and WS were comparable (Fig. 7). A significant response to N alone was observed in 91 of 122 trials since 1976, with an average yield increase of 1.4 t/ha over the control in DS and 1.2 t/ha in WS (Table 7). P alone increased yields significantly (0.8 t/ha) in 25% of the trials, and K alone increased yields by 0.8 t/ha in 12% of the trials. Yield responses from the NP treatment were significantly higher than with N alone in both seasons. Yield responses from NK, however, were similar to those from N alone.

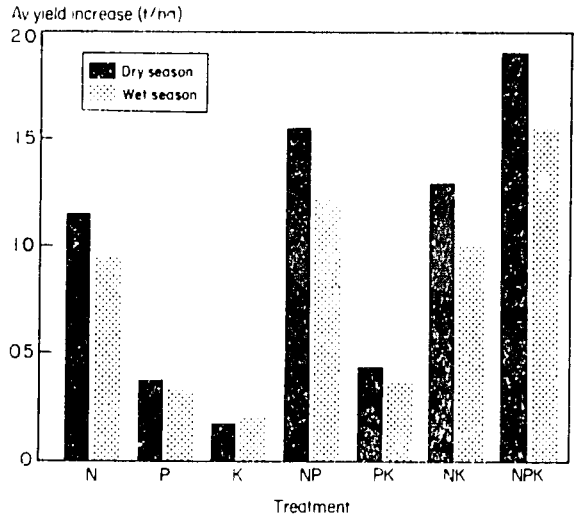
N remains limiting at all sites in Indonesia. Yield responses from NPK + Zn at suspected Zn-deficient sites were lower than those from NPK alone. At Lanrang and Maros, yield responses from N and NK were comparable.

Results from 2 Philippine sites showed that N remains limiting; 86% of all trials conducted in the

Table 6. Yields of 13 treatments tested in the first international trial on N fertilizer efficiency in acid upland rice under rainfed condition. Caliraya, Laguna, Philippines, INSFFER, 1984 WS.

N source[a]	N rate (kg/ha)	Application method	Grain yield[b] (t/ha)
Control	0	--	1.0
PU	40	Basal, surface broadcast	1.1
PU	40	Recommended split[c]	1.1
PU + 10% DCD	40	Basal, broadcast & incorporated	1.1
PU + 10% DCD	40	Basal, surface broadcast	1.3
PU	40	Farmer's split[d]	1.2
AS	40	Basal, surface broadcast	1.2
AS	40	Recommended split	0.9
AS + 10% DCD	40	Basal, broadcast & incorporated	0.9
AS + 10% DCD	40	Basal, surface broadcast	1.1
SCU (forestry grade)	40	Basal, broadcast & incorporated	1.1
PU	80	Recommended split	1.0
AS	80	Recommended split	1.3
CV (%)			18

[a]PU = prilled urea, DCD = dicyandiamide, AS = ammonium sulfate, SCU = sulfur-coated urea. [b]Values not significantly different at the 5% level by DMRT. [c]3/8 N 10 d after rice emergence (DARE), 3/8 N 30 DARE, and 1/4 N at panicle initiation (PI). [d]1/3 N 30 DARE, 2/3 N at PI.



7. Average yield increases with N, P, and K treatments in 54 DS and 68 WS trials. International long-term fertility trial in irrigated lowland rice, INSFFER, 1976-84.

Philippines gave significant response to N alone. However, the percentage of trials responsive to P increased from 33% in 1983 to 41% in 1984. At Luisiana, the yield response to P has been con-

Table 7. Significant yield responses to N, P, and K applied individually or in combination, averaged over number of responsive trials. International long-term fertility trial in irrigated lowland rice, INSFFER, 1976-84.

Treatment	WS			DS		
	Trials (no.)		Av yield response (t/ha)	Trials (no.)		Av yield response (t/ha)
	Total	Responsive to treatment		Total	Responsive to treatment	
N	68	48	1.2	54	43	1.4
P	67	18	0.7	54	12	0.9
K	67	9	0.8	54	5	0.7
NP	68	57	1.4	54	46	1.8
PK	66	22	0.8	54	20	0.9
NK	67	49	1.2	54	43	1.5
NPK	67	58	1.7	54	51	2.0
NPK + Zn[a]	18	12	1.5	14	7	1.7

[a] Additional treatment tested in suspected Zn-deficient sites.

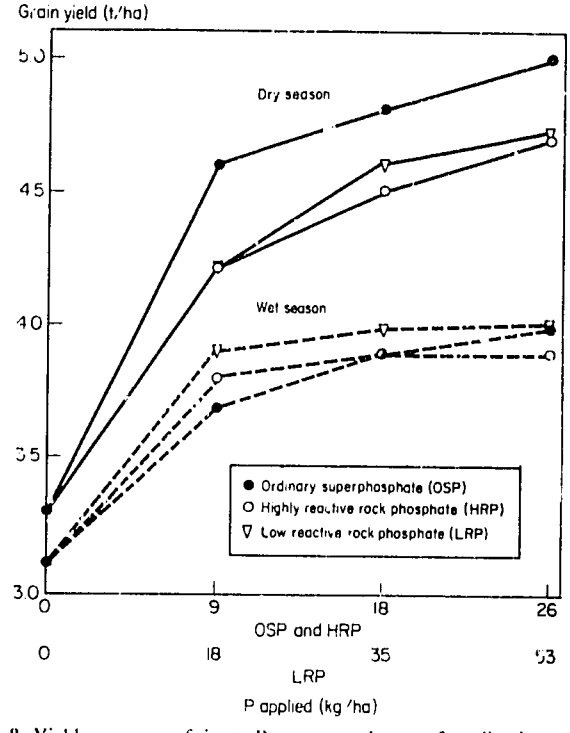
sistently significant beginning with the 13th cropping season.

At three sites in China, N applied singly or in combination gave significant yield increases, especially during DS. P and K were effective only when combined with N. Yields from N alone were comparable to those from NP, NK, and NPK treatments.

Sources of phosphorus. In the international trial on sources of P in flooded rice, average yield responses from 56 P-responsive trials at 22 sites in 10 countries from 1977 to 1984 showed that rice response to different P sources and rates of application was higher during DS than during WS (Fig. 8). Ordinary superphosphate (OSP) gave higher yields during DS than highly reactive rock phosphate (HRP) and less reactive rock phosphate (LRP). HRP and LRP produced similar yields. However, all P sources were equally effective during WS.

Azolla. In 15 trials in the third international trial on azolla use in rice at 13 sites in 7 countries in 1983-84, 30 kg urea N/ha plus 1.5 t fresh azolla/ha, as well as 2 full crops of azolla, 1 crop incorporated before and 1 crop after transplanting, increased rice yield the same as did 60 kg urea N/ha (Table 8).

Integrated use of inorganic and organic N fertilizers. In the international trial on integrated use of inorganic and organic N fertilizers in lowland rice, 22 sets of experimental materials were sent to 15 collaborators in 7 countries in 1984. So far, results from only nine trials conducted at three



8. Yield responses of rice to P sources and rates of application. Data are averages of 17 P-responsive DS and 39 P-responsive WS trials. International trial on P sources in flooded rice, INSFFER, 1977-84.

sites in India and four sites in the Philippines have been received and summarized.

For combined sources of N, one-third to one-half of N required is applied as azolla and fresh straw; the remaining N requirement is applied as inorganic fertilizer, either PU in splits or USG DP.

Table 8. Yield responses of irrigated lowland rice to N fertilizer and azolla application.[a] Third international trial on azolla use in lowland rice, INSFFER, 1983-84.

Treatment[b]	Average grain yield (t/ha)
No N, no azolla	2.7 d
30 kg N/ha, all basal, broadcast and incorporated	3.5 c
60 kg N/ha urea, 3 splits	4.1 a
30 kg N/ha urea, basal + 1.5 kg fresh azolla/m² incorporated BT	4.1 a
30 kg/ha urea, basal + 1.5 kg fresh azolla/m² incorporated 3 weeks AT	4.0 ab
Azolla grown and incorporated, one crop each BT and AT	4.0 ab
Azolla grown and incorporated BT and again inoculated AT but not incorporated	3.7 bc
Azolla grown twice AT, each crop incorporated when full cover	3.7 bc

[a]Data are averages of 15 trials conducted at 13 sites in 7 countries. [b]BT = before transplanting, AT = after transplanting.

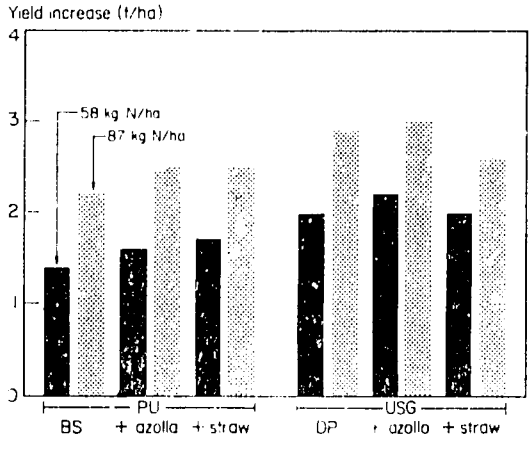
The combined inorganic and organic sources of N produced yields comparable to those with pure inorganic fertilizers (Fig. 9). The yields of azolla and straw combined with PU were comparable; both were higher than from PU alone at 58 and 87 kg N/ha. However, the yield from azolla was higher than that from straw when applied with USG at both N rates.

Hand- and machine-applied fertilizers. In the international trial comparing hand- and machine-applied N fertilizers in lowland rice, the mean response to N was significant in six of the seven trials in three countries in 1984. Of the six trials, five were conducted in DS.

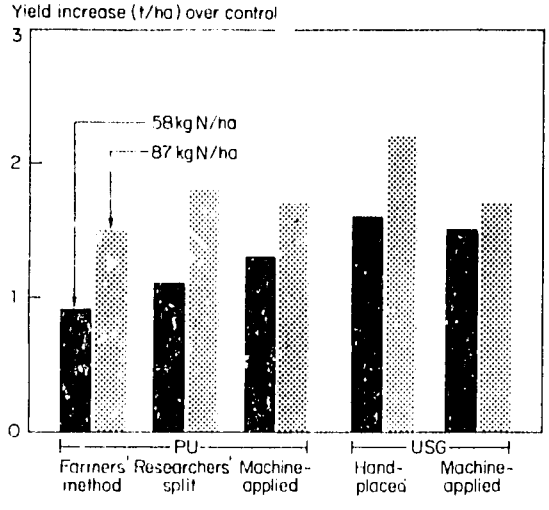
Regardless of N form and method of application, average yield increases over the control ranged from 0.9 to 1.6 t/ha at low N rate and from 1.5 to 2.2 t/ha at high N rate. Average yield responses across all responsive sites showed that machine-applied and hand-placed fertilizers gave comparable yields except with USG at 87 kg N/ha (Fig. 10).

Soil fertility management of acid upland soils (pH <5). Five sets of fertilizers and fieldbooks were sent to three collaborators in two countries in 1984. Only the results of a trial conducted by IRRI's Agronomy Department in an acid upland soil (pH 4.1) in Caliraya, Laguna, have been reported.

Three P sources — triple superphosphate (TSP), Christmas Island phosphate rock (CIPR), and fused magnesium phosphate (FMP) — with varying levels of P and lime were tested. Without lime, only TSP at the highest rate significantly increased yield over the control (Table 9). With lime, TSP was more effective at medium and high P rates. No significant yield advantage was observed with increased lime application at the same level of P.



9. Average yield increases of irrigated lowland rice due to PU (BS) and USG (DP) alone or with azolla and straw at 2 rates of N. Data are averages of 9 trials conducted at 3 sites in India and 4 sites in the Philippines. First international trial on integrated use of inorganic and organic N fertilizers in irrigated lowland rice, INSFFER, 1984.



10. Yield responses of rice to PU and USG at 2 N rates applied with different methods and tested at 6 N-responsive sites in 3 countries. First international trial comparing hand- and machine-applied N fertilizers in lowland rice, INSFFER, 1984.

Table 9. Yields of 16 treatments in the first international trial on P and lime interaction in acid upland rice soils under rainfed condition. Caliraya, Laguna, Philippines, INSFFER, 1984 WS.

P source[a]	P rate (kg P/ha)	Lime rate (t/ha)	Grain yield (t/ha)
Control	0	0	0.9 f
TSP	8.8	0	0.8 f
TSP	17.6	0	1.1 cdef
TSP	35.2	0	1.3 bcde
–	0	0.75	1.2 cdef
TSP	8.8	0.75	1.1 cdef
TSP	17.6	0.75	1.5 abc
TSP	35.2	0.75	1.6 a
–	0	1.50	1.0 ef
TSP	8.8	1.50	1.2 cdef
TSP	17.6	1.50	1.4 abcd
TSP	35.2	1.50	1.6 ab
CIPR	17.6	0	1.0 def
CIPR	35.2	0	1.1 def
CIPR	52.8	0	1.0 def
FMP	17.6	0	1.2 cdef
CV (%)			20

[a]TSP = triple superphosphate, CIPR = Christmas Island phosphate rock, FMP = fused magnesium phosphate.

To obtain substantial yield increases from the less soluble CIPR and FMP, liming would be necessary.

INSFFER TRAINING COURSE

Twenty-three participants representing 20 organizations in 11 countries (Burma, China, India, Indonesia, Iran, Malagasy, Malaysia, Philippines, Sri Lanka, Thailand, and Vietnam) attended the seventh INSFFER course from 4 Feb to 24 May 1985.

The trainees underwent practical and theoretical training on experimentation, site characterization, soils, fertilizers, azolla and soil microbiology, statistics, rice production, economics, technical report writing, and seminar presentation. They carried out the following INSFFER trials at IRRI during 1985 DS: the sixth international trial on N fertilizer efficiency in irrigated lowland rice, comparison of hand- and machine-applied PU and USG in lowland rice under good water control, and the first international trial on integrated use of inorganic and organic N fertilizers in lowland rice under good water control. Visits to experiments in farmers' fields and experiment stations supplemented classroom and practical activities.

SITE VISIT TOURS AND WORKSHOPS

An INSFFER site visit tour and workshop was held in Australia 8-16 Apr 1985. Among the 58 participants representing 13 countries, 17 were active INSFFER collaborators from 11 countries. This activity was sponsored jointly by the Australian Centre for International Agricultural Research (ACIAR), the Commonwealth Scientific and Industrial Research Organization (CSIRO), and IRRI.

Future plans for INSFFER and for interaction between ACIAR and INSFFER were taken up. The 3-d tour included visits to the different CSIRO laboratories in Canberra, experimental fields of the Agricultural Research Institute of the New South Wales Department of Agriculture in Wagga Wagga, Yanco, Whitton, and the CSIRO Centre for Irrigation Research in Griffith.

The papers presented and discussions during the workshop were focused on N fertilizer use efficiency in rice. Of the 22 papers, 7 were country reports. The proceedings of the workshop will be published.

Cooperative programs

Asian Rice Farming Systems Network

Rice Farming Systems Program and Agricultural Economics Department

NATIONAL PROGRAMS **490**
COLLABORATIVE RESEARCH **490**
Cropping pattern testing **490**
Varietal testing **491**
Long-term cropping pattern and fertilizer studies **492**
Rice - wheat cropping systems **495**
Cropping pattern testing **495**
International Rice - Wheat Integrated Trials (IRWIT) **495**
Crop-livestock systems research **496**
On-farm research in Carosucan and Malanay **496**
Animal health management in rice-livestock **497**
Multiple uses of livestock **497**
Rice straw utilization **498**
Nutritive value of locally available fodder **498**
Pesticide residues in rice and intercrops fed to ruminants **498**
Grain + forage legume intercropping **498**
Field evaluation of forage grasses **498**
Fodder trees and shrubs **499**
Herbage yield and quality of leucaena **499**

The Asian Rice Farming Systems Network (ARFSN) is a scheme for scientists at IRRI and throughout Asia to work together to identify rice-based farming systems for different environments. The program continued on-going collaborative cropping systems research and development with emphasis on cropping pattern testing, varietal testing of upland crops, rice - wheat cropping systems, long-term fertilizer and cropping pattern trials, and crop-livestock systems. Plans were made for collaboration on green manuring, women in rice farming, and rice-fish systems.

NATIONAL PROGRAMS

The research methodology developed and refined by IRRI and network scientists is used in Bangladesh, Bhutan, Burma, China, India, Indonesia, Korea, Malagasy, Malaysia, Nepal, Pakistan, the Philippines, Thailand, Sri Lanka, and Taiwan, China — with modifications to suit their organizational structure, available manpower, and financial resources. Bangladesh and Nepal joined Thailand, the Philippines, and Indonesia in expanding their cropping systems to farming systems; Bangladesh included livestock and fisheries in the program; and Nepal added livestock and agroforestry.

The number of rice-based cropping or farming systems research sites increased from 194 in 12 countries to 236 in 13 countries: 136 in rainfed, 74 in irrigated, 45 in upland, 3 in deep water, and 22 in partially irrigated areas.

The work was concentrated on the design and testing of cropping patterns to increase production and cropping intensity, plus some component technology research. At some sites where the intensity was already high, research was focused on increasing productivity. The work at crop-livestock research sites included design and testing of cropping patterns and animal systems.

National programs in Bangladesh, the Philippines, Nepal, Sri Lanka, Indonesia, and Thailand continued to expand the preproduction (multilocation testing and pilot production) phase. Bangladesh expanded multilocation testing in rainfed areas, started multilocation testing in various areas, and began a pilot production program. Thailand implemented preproduction programs using mungbean - rice, direct seeded rice, and peanut - rice.

The Philippines continued to expand cropping systems production programs, Nepal added several districts in the terai and inner terai, and there was a large production program for rice - soybean in Indonesia.

COLLABORATIVE RESEARCH

Cropping pattern testing. Forty-five sites representing the major rice environments in Asia were involved in cropping pattern testing (Table 1). We monitored the environment and the crop, and economic performance of the different patterns. In most cases the focus was to increase production,

Table 1. Number of cropping or farming systems sites involved in cropping pattern testing in ARFSN, 1985.

Location	Sites (no.)				
	Rainfed lowland	Partially irrigated	Irrigated	Rainfed upland	Total[a]
Philippines	4	–	4	4	12
Burma	1	3	–	–	4
Taiwan, China	–	–	3	–	3
China	–	–	6	–	6
Malaysia	1	–	–	–	1
Indonesia	1	–	–	1	2
Sri Lanka	1	2	–	–	3
Bangladesh	1	–	–	1	1[a]
Thailand	2	–	2	–	4
Nepal	3	1	1	–	3[a]
Pakistan	–	–	1	–	1
India	–	–	5	–	5
Total	14	6	22	6	45

[a]Some sites belong to more than one category.

net income, and cropping intensity. At some sites, we increased the production of each crop in the pattern and the income of the total system.

Table 2 indicates the number of crops in farmers' predominant patterns and the experimental pattern, and the promising patterns. In most cases, the experimental patterns were better in total production and income than farmers' patterns. The promising patterns were better agronomically and economically.

Varietal testing. Varietal testing in the network is in collaboration with the Philippine Institute of Plant Breeding (IPB), Thai Field Crops Research Institute, Indonesian Central Research Institute for Food Crops, other national programs, and the International Institute of Tropical Agriculture (IITA). The breeding activities of IPB and IRRI-IITA projects and the screening activities at IRRI are presented in the section on cropping systems. Seeds of promising entries from these projects are

Table 2. Crops in farmers' predominant patterns and the experimental pattern, and promising cropping patterns. 1985.

Site	Crops (no.) in pattern		Promising cropping pattern[a]
	Farmers'	Tested	
	Rainfed lowland		
Bacnotan, Philippines	1	2-3	rice - tobacco - maize
Tumauini, Philippines	1-2	2	mungbean - rice rice - rice
Wakema, Burma	1-2	2	jute - rice - soybean rice - sunflower
Kota Bharu, Malaysia	1-2	2	rice - peanut
Siaton, Philippines	1-2	2	rice - mungbean
Katupotha, Sri Lanka[b]	1-2	2	rice - mungbean rice - cowpea
Bireun Aceh[c]	1	2	rice - soybean
Ratna Nagar, Nepal[c]	1-2	2-3	rice - maize
Maasin, Philippines	1-2	2	rice - rice
Phayao, Thailand[b]	1	2	mungbean - rice
Srisaket, Thailand	1	2	peanut - rice
Screepur, Bangladesh	1	2	black gram - rice (local)
	Rainfed lowland (with cooler temperature)		
Pumdi Bhumdi, Nepal[c]	2-3	2-3	rice - wheat - maize rice - maize
Sukchaina, Nepal[c]	2	2	rice - chickpea rice - wheat
Screepur, Bangladesh	1-2		rice (local) - rice (BR11 or BR10)
	Partially irrigated		
North Nawin, Burma	1	2	rice - sunflower maize - cotton
Bandarawela, Sri Lanka[b]	2	2-3	rice - potato - bean rice - tomato - bean
Patheingyi, Burma	1	2	cotton - rice mungbean - rice
Yezin, Burma	1-2	2-3	rice (DSR) - peanut rice - potato
	Rainfed upland		
Trece Martires, Philippines	2-3	2-3	banana + rice - peanut
Batumarta, Indonesia[b]	2-3	4	rice + maize/cassava/ peanut or soybean
Manito, Albay, Philippines	2	2-3	rice - sweet potato - mungbean
Jaimindan, Philippines	1-2	4	rice + maize - maize + peanut

continued on next page

Table 2 continued.

Site	Crops (no.) in pattern		Promising cropping pattern[a]
	Farmers'	Tested	
	Irrigated		
Beijing, China	1-2	2	wheat - rice (DSR)
Mahaweli H, Sri Lanka	2	2-3	rice - onion/chilies rice - soybean
Changsha, China	2-3	2-3	rape - rice - rice vegetables - soybean + maize - rice
Parsa, Nepal[c]	2-3	3	rice - maize - maize rice - wheat - rice
Shoaxing, China	2-3	2-3	broad bean + maize - rice barley - rice - rice
Ratna Nagar, Nepal[c]	2	3	rice - wheat - mungbean rice - wheat - maize
Kashiung, China	2-3	2-3	rice - vegetable - maize
Changhwa, China	2-3	3	rice - soybean - wheat rice - rice - wheat
Yunlin, China	2-3	3	rice - mungbean - maize sesame - rice - maize
Daska, Pakistan[c]	2	2	rice - sunflower
Ubon, Thailand	2	3	rice + fish - rice
Guimba, Philippines	2	3	rice - rice - mungbean
Dipolog, Philippines	2	2-3	rice - rice - mungbean
Compostela, Philippines	2	2-3	rice - mungbean - rice

[a]DSR = dry seeded rice. [b]Used for multilocation testing. [c]Used for multilocation and/or pilot production program.

multiplied at IRRI for distribution to the network. National breeding programs also send promising materials for inclusion in the testing.

In 1985, we received and multiplied seed of 7 maize varieties from Thailand, Indonesia, Vietnam, and IPB; 23 mungbean varieties from the Asian Vegetable Research and Development Center, Pakistan, China, Thailand, Burma, Indonesia, and IPB; 5 soybean varieties from Thailand; 10 peanut varieties from IPB; and 5 rice bean varieties from Indonesia. We also multiplied 10 most promising pigeonpea and 10 sorghum varieties from our varietal evaluation at IRRI. These entries will replace those in the 1985-86 varietal testing.

A total of 165 trials before rice (35 mungbean, 31 cowpea, 23 bush sitao *Vigna unguiculata* ssp. *sesquipedalis*, 10 soybean, 11 peanut, 2 sorghum, and 53 maize) and 268 trials after rice (51 mungbean, 34 cowpea, 32 bush sitao, 37 soybean, 39 peanut, 15 sorghum, 48 maize, and 12 pigeonpea) were also distributed to different cropping systems sites in Nepal, Burma, Bangladesh, China, Thailand, Vietnam, Indonesia, Sri Lanka, and the Philippines for 1985-86.

Varieties were tested before and after rice in eight countries in 1984-85. Data were received from the Philippines, Thailand, Burma, Vietnam, Indonesia, and China, and several promising varieties were identified. The most promising varieties are presented in Tables 3 and 4.

Long-term cropping pattern and fertilizer studies. Long-term studies were started in 1984 to determine the effects of continuous cropping using different crop rotations on the soil and on crop performance, and to determine residual effects of fertilization and other soil amendments on cropping pattern performance. Collaborators in Bangladesh, China, Indonesia, Burma, India, Nepal, and Taiwan, China, designed location-specific cropping patterns and fertilizer treatments, but data collection is uniform.

BRRI is studying four irrigated cropping patterns and three rainfed lowland patterns; fertilizer treatment is the same, and the interdisciplinary team monitors the diseases, weeds, and insect population. Nepal conducted four cropping patterns with three fertilizer rates; there is also an ongoing rice - rice - wheat cropping pattern with

Table 3. Upland crop varieties better than the check or highest yielding across locations when planted before lowland rice, 1984-85.

Component	Philippines	Nepal	Indonesia	China
		Mungbean		
Grain	IPB M79-13-60 Pag-asa 1 IPB M79-9-82 Pag-asa 3	IPB M79-22-12 Pag-asa	IPB M79-9-94 IPB M79-22-62 IPB M79-9-82	
Fodder	IPB M79-22-62 IPB M79-17-79 IPB M79-13-60		IPB M-79-22-62 IPB M-79-9-94 IPB M-79-9-82	
		Cowpea		
Fresh pods	TVx 136-16D2 EG#2 All season	TVx 1850-01E EG#2 TVx 136-16D2		
Grain	TVx 136-16D2 TVx 4677-08E TVx 4573-02D	EG#2 TVx 1850-01E TVx 136-16D2		
Fodder	TVx 4577-02D TVx 1850-01E TVu 3629			
		Bush sitao		
Fresh pods	BS_1 (6-14RxAS) BS_3 (6-14RxAS)	BS_1 (6-14RxAS) BS_3 (6-14RxAS) LBBS#1		
Fodder	BS_1 (6-14RxAS) BS_3 (6-14RxAS)	BS_3 (6-14RxAS) BS_1 (6-14RxAS) LBBS#1		
Grain			Arjuna XC#1 Early DMR Comp2	
		Soybean		
Grain		Guntur 7207-1	7207-1 7521-26-2 Guntur	
		Peanut		
Grain		UPL PN4 UPL PN2 CES 2-25		
		Maize		
Green ears	Phil. DMR Glut. Comp. Popn 41C Los Baños Lagkitan			Phil. Supersweet #9 Dan Ju #6
Fodder	Phil. DMR Glut. Comp. Popn 41C Los Baños Lagkitan			Sweet Comp. #1 Hawaiian Supersweet #9

different fertilizer levels. In Indonesia, four experiments were established in lowland and upland conditions: 1) effectiveness of partially acidulated phosphate rock on year-round cropping patterns at four research sites, 2) crop and soil response to time and P treatment at four research sites, 3) controlled-release N fertilizers in upland cropping at five research sites, and 4) evaluation of effects of crop residue management on soil and production of rice and soybean in year-round cropping patterns at three experiment stations.

Most cropping pattern trials in China are long-term (3-6 yr) with rotation of different cropping patterns. Experiments are being conducted by the Institute of Soil and Fertilizer of Hunan Academy of Agriculture at four locations and by the China

Table 4. Upland crop varieties better than the check or highest yielding across locations when planted after lowland rice, 1984-85.

Component	Philippines	Thailand	Vietnam	Burma	Indonesia
			Mungbean		
Grain	Pag-asa 3 IPB M79-13-29 IPB M79-13-45	IPB M79-9-82 Pag-asa 1 IPB M79-13-45	IPB M79-9-82 IPB M79-13-29 IPB M79-13-45 Pag-asa 3		
Fodder	CES 1T-2 IPB M79-13-29 Pag-asa 3		IPB M79-9-82 Pag-asa 2 IPB M79-13-29		
			Cowpea		
Fresh pods	TVx 289-4G TVx 4661-07D TVx 1948-01E			TVx 3381-02F Vita 7 TVx 4678-03E TVx 2724-01F	TVx 1948-01E TVx 289-4G TVx 3381-02F
Grain	TVx 3410-02J TVx 2724-01F TVx 1948-01E	TVx 4661-07D TVx 3671-14C-01D TVx 2724-01F		TVx 2724-01F Vita 7 TVx 3381-02F	
Fodder	TVx 1948-01E Tvx 4659-03E TVx 2724-01F	TVx 289-4G TVx 4661-07D		TVx 4678-03E Vita 7 TVx 3381-02F	
			Bush sitao		
Fresh pods	BS_1 (6-14RxAS) EG BS_2 BS_7				BS_1 (6-14RxAS) BS_3 (6-14RxAS) EG BS_2
Fodder	BS_1 (6-14RxAS) BS_7				BS_1 (6-14RxAS) EG BS_2 BS_3 (6-14RxAS)
			Soybean		
Grain	7207-1 ACC-2120 7521-26-2	Guntur 7207-1 7521-26-2		Guntur 7207-1 7521-26-2	
			Peanut		
Grain	UPL PN-2 UPL PN-4 CES2-25	UPL PN-4 CES102 CES103 M10		M-10 UPL PN-2 CES101	UPL PN-4 CES2-25 CES102
Fodder	UPL PN-2 UPL PN-4 PI 118200	UPL PN-4 CES101 CES103		M-10 CES101 UPL PN-2	CES102 UPL PN-4 M-10
			Sorghum		
Grain	UPL SG-5 CS110 CS137	UPL SG-5 CS116 CS182		CS110 CS336 UPL SG5	CS182 UPL SG5 CS110
Fodder	CS182 UPL SG5 CS110			CS110 UPL SG5 CS253	CS182 UPL SG5 CS110
			Maize		
Grain	Early DMR Comp 1 XC #1 Ranjuna	XC #1 Pirsabak 7930 Arun 2			
Green ears	Los Baños Lagkitan Glut. Syn 41 Phil. Supersweet #1				

continued on opposite page

Table 4 continued.

Component	Philippines	Thailand	Vietnam	Burma	Indonesia
Fodder	Glut. Comp. popn 41C XC #1				
			Sweet potato		
Tubers	G 145r-4 Tinipay G53r-17b				
Fodder	G53r-17b G113-2b Tinipay				

National Rice Research Institute. Taiwan is conducting a long-term trial with three cropping patterns and three fertilizer managements. India began participating in the network in 1985, and long-term cropping pattern trials are being conducted at 23 research institutions.

Rice - wheat cropping systems. One of the major cropping systems in subtropical countries is rice - wheat. In 1983, IRRI and the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) started collaborative research to identify profitable rice - wheat systems in different rice environments and to identify the best varieties of rice and wheat to satisfy the crop rotation needs of farmers. Collaboration involves temperate (China and Korea), subtropical (Bangladesh, Nepal, Bhutan, Pakistan, and China), and tropical (Philippines, Thailand, Indonesia, Burma, Sri Lanka, Vietnam, and Malaysia) countries in cropping pattern testing and in international rice - wheat integrated trials.

Cropping pattern testing. Cropping patterns involving rice, wheat, and other crops are tested in Nepal, Bangladesh, Pakistan, China, India, and Taiwan. In Nepal, the most promising in terms of returns and yield are rice - wheat - maize and rice - maize in Pumdi Bhumdi, rice - chickpea and rice - wheat in Sukchaina, and rice - wheat - rice and rice - maize - maize in Ratna Nagar. In Bangladesh, increased production and income over existing farmers' systems were achieved by adding wheat at the rainfed site in Rajshahi (rice - wheat), the irrigated site in Rangpur (rice - rice - wheat), and the rainfed site in Ishurdi (mungbean - rice - wheat). Substitution of wheat at the irrigated site in Hathazari also increased income and production of the farmers' existing cropping systems.

In Changwa, Taiwan, 15 different cropping patterns were tested; the most promising were rice - soybean - wheat, rice - rice - wheat, and rice - sorghum - wheat. Of the six cropping patterns tested at the Tongxian cropping systems site in Beijing, dry seeded rice - wheat showed the highest yield. Most sites in northern, northeastern, and northwestern India have rice - wheat systems.

International Rice - Wheat Integrated Trials (IRWIT). The main objective of IRWIT is to identify varieties of rice and wheat with multiple resistance to pests and diseases to fit the rice - wheat system. Trials are conducted at the experiment station, and promising materials are tested at cropping systems sites. Rice entries come from the IRRI International Rice Testing Program and wheat from the CIMMYT Wheat Program. National breeding programs have contributed half of the wheat entries. In tropical countries with no local checks, five entries from the Philippine IPB and five from CIMMYT were in each trial.

There are two sets of trials for rice and wheat. For rice, one set is early maturing and the other early-medium maturing. For wheat, one set is early and the other medium maturing.

In crop year 1983-84, we distributed 31 sets of rice trials to 15 countries. Eight early sets were sent to the temperate and high elevation countries (China, Korea, Bhutan, Nepal, and Egypt), and 23 sets of early and medium maturing varieties were sent to subtropical and tropical countries (Burma, Philippines, Thailand, Vietnam, Bangladesh, Nepal, Pakistan, Sri Lanka, Indonesia, and Malaysia). For wheat, 31 sets of early and medium maturing varieties were sent to the same countries.

The top rice grain yielders were IR42 in Wakema

and Yezin and Milyang 54 in Patheingyi, Burma. However, Milyang 54 was outyielded by a local variety, Pelita I-1. In the Philippines, the outstanding varieties were BR51-282-8 in Isabela, IR36 in Los Baños, and RP825-45-1-3 in Nueva Ecija. RP825-45-1-3 was also the most promising variety in Chieng Rai and Chumpae, Thailand, and Bairawaha, Nepal. At two other test sites in Thailand (Chiang Mai and Muang Prae) and in Jessore, Bangladesh, IR54 was the highest grain yielder. In Joydebpur, IR13540-56-3-2-1 was the top yielder.

UP262 was the most promising among the early maturing CIMMYT wheat entries in Joydebpur, Jamalpur (Bangladesh) Muang Prae, Milyang (Korea), and Isabela; it was outyielded by local varieties in Bangladesh and Korea. At other test sites, the outstanding entries were Nacozari 76 in Rupandehi (Nepal) and Jessore, Sonalika in Dokri (Pakistan) and Changsa, Hunan (China), Sonka Inia in Khon Khaen (Thailand), and C213-15 in Los Baños.

In the medium maturing group, the highest yield level (4.6 t/ha) was obtained in Bangladesh. The most promising varieties were Pavon 76 in Joydebpur, Dokri, and Chieng Rai; Ciano 79 in Jamalpur and Kathmandu (Nepal); Glennson 81 in Hunan and Sichuan (China), and Wakema; and Tyrant S in Jessore and Yezin. However, Glennson 81 in China and Tyrant S in Bangladesh were outyielded by the local varieties. C213-15 was the highest yielding entry in Los Baños.

Crop-livestock systems research. Collaborative research on crop - livestock systems started in 1984 at IRRI and the Philippine Institute of Animal Science (IAS) and on-farm in Santa Barbara, Pangasinan, Philippines; Batumarta, South Sumatra, Indonesia; Pumdi Bhumdi, Kaski, Nepal; and Ban Phai, Khon Kaen, Thailand. The work at IRRI concentrates on dual-purpose food-forage cropping systems and on forage crop management. IAS works on feed technology and pesticide residues.

The midhill site in Nepal involves milk buffalo, oats after rice in single rice crop areas, planting of napier on the sides of terraces, and planting of leucaena. In Thailand farmers grow one rice crop and raise cattle; upland crops are introduced to replace rice in upper fields, and after rice in lower fields; forage grasses, legumes, and leucaena are introduced in the homestead and vacant areas. The most promising cropping system after 4 yr of research at the upland transmigration site in Indonesia is rice + maize intercrop, with cassava relayed on the maize rows followed by soybean or peanut after harvesting maize and rice, then followed by cowpea and rice bean. At the edge of the terrace, setaria grass is planted to prevent soil erosion and provide feed. The team expanded their whole-farm work to include cattle for draft and fattening.

On-farm research in Carosucan and Malanay. Research in the Philippines is conducted in two lowland rice growing areas in Santa Barbara, Pangasinan: Malanay (irrigated) and Carosucan (rainfed). Rainfall starts in May or early June, peaks in August, and ends in late September or October, with 4-5 wet mo and 2-3 dry mo. Soil is clay loam to sandy loam with pH 6.7-7.9.

Carosucan has about 56% heavy and 44% light soils. The average landholding is 1.6 ha. Monocropped rice predominates; depending on rainfall after harvest in November, some farmers plant mungbean, tomato, peanut, or watermelon, but most fields are left fallow. IR42 and other medium maturing rice varieties are grown in heavy soils, and IR36 and early maturing varieties in light soils. Cattle and carabao average 1.4/farm, or a stocking rate of 1 mature animal or animal unit (AU)/ha.

There were 18 cooperators in Carosucan and 4 treatments: 1) 1 animal plus intervention with a 0.5-1 ha farm, 2) 2 animals (one for draft and 1 for fattening) plus intervention with a 1.1-2 ha farm, 3) control for (1), and 4) control for (2). Interventions included daily feeding with 2 kg leucaena or other legume forage, provision of urea-molasses-mineral blocks, establishment of improved forage, and animal health care. Utilization of fibrous crop residues, especially rice straw, was recorded and related to actual farm grain and residue outputs.

After 300 d of feeding, liveweight gains of cattle apparently did not reflect differences due to farm size or intervention. In December 1985, we provided the farmers with 2 kg rice bran/d to feed the animals for 50 d before marketing.

The livestock cooperators were also crop cooperators in Carosucan. We continued the cropping pattern and component technology trials to

determine the stability of the pattern and further refine the various components. Rice - mungbean and rice - cowpea were tested using early maturing IR60. We conducted fertilizer trials; variety trials of early maturing cowpea, mungbean, and bush sitao in the heavy soils before rice; rice weed control; and variety trials of early and medium maturing rice varieties.

In 1985-86 dry season (DS), 67% of the farmers in Carosucan planted mungbean and cowpea after rice; before the project, fewer than 10% had planted upland crops.

IR60 yielded significantly higher than IR36 and IR62, which the farmers were using. In heavier soils, IR42 gave a yield and fodder advantage over the same variety under farmers' management.

Early maturing legume crops planted before rice were tested to identify varieties for cropping pattern use. Mungbean varieties IPB M79-13-60 and IPB M79-22-117 looked promising. Green pod yield showed that cowpea TVx 133-16D1 and bush sitao BS#6 were the most promising cultivars.

For early maturing rice, 40 kg N/ha was the most economical level, while 30 kg N/ha was most appropriate for medium maturing cultivars, compared with the cropping pattern recommendation of 20 kg N/ha.

Rotary weeding followed by selective hand weeding 21 d after emergence was the most promising treatment for early maturing rice in light soils. In the heavy soils with the medium maturing variety IR48, butachlor at 1.5 kg ai/ha 3 d before transplanting plus hand weeding 21 d after transplanting was the most economical treatment. However, the use of herbicides to control grasses and sedges is not likely to be adopted by farmers because of the direct input cost (labor is more abundant at the site). In addition, weed-free fields would deprive the farmers of feed for ruminants.

In the early maturing group, IR60 outyielded the other entries. In terms of fodder yield, IR19743-25 yielded 12% more than IR60 and was 7 d earlier. Of the medium maturing cultivars, IR42 was significantly outyielded by IR21820-154 in fodder production but was 2% higher in grain production. This promising line also matures 16 d earlier than IR42.

The 118-ha irrigated site in Malanay is about 83% lowland and 17% upland. About 35% of the area is fully irrigated, 29% partially irrigated, and 19% rainfed. The average landholding is 1.3 ha. Two high yielding rice crops are grown in the irrigated areas. Yields are generally about 3-5 t/ha, and farmers use the recommended technology. Upland and partially irrigated areas are planted to rice, peanut, maize, cowpea, string bean, and tomato. Cattle and carabao holdings average 1.1/household, or a stocking rate of 0.92 AU/ha.

There were 20 livestock cooperators in Malanay and 4 treatments: 1) 2 animals (1 for draft and 1 for fattening) plus intervention with 0.5-2 ha farms, 2) 3 animals (1 for draft and 2 for fattening) plus intervention with 2.1-3.5 ha farms, 3) control for treatment (1), and 4) control for treatment (2). The technology intervention was the same as in Carosucan.

After 300 d of feeding, the liveweight gains did not reflect differences due to intervention and farm size. In mid-April, we provided the experimental animals with supplemental rice bran for 45 d. The animals responded well, with gains of 0.55 kg/d compared with 0.12 kg/d for the controls. This shows that even minimal supplemental feeding could produce better liveweight. The experimental animals were sold, and income ranged from ₱1,808 to ₱1,950/head. DS and wet season (WS) fertilizer trials showed that 80 and 60 kg N/ha were the most economical levels, respectively. In varietal trials during WS, IR218150-85-3-2 gave the highest yield.

Animal health management in rice-livestock. Cattle and carabao being raised by farmer-cooperators in Santa Barbara were examined for health status, and a survey was made on livestock health management. Proper health management was given low priority in overall farm activity. Few farmers were aware of the harmful effects of infectious diseases and gastrointestinal parasites. Serological tests indicated negative reactions of both livestock species for brucellosis and leptospirosis.

Multiple uses of livestock. Ruminants are used for draft, draft-fattening, draft-breeding, and fattening. Especially in Malanay, carabao are more important as draft animals than cattle. Use of carabao for draft peaks in July and January, the land preparation periods. Cattle for draft, especially in Carosucan, are fully utilized in July-August. Cattle for fattening are also used for draft,

but much less than carabao. Bulls are used for farm operations more often than cows, heifers, or yearlings.

Labor input in the case of livestock shows that more time is devoted to cattle than carabao (480.5 vs 292.63 h/yr). Labor inputs are in feeding management, tethering, and grazing.

Rice straw utilization. In Carosucan, farmers plant only one rice crop. Most of the rice straw was used for livestock feed during DS. Straw yield per farm (fresh after harvesting rice) ranged from 6.7 to 38.7 t in Malanay. However, only about 30% of farmers utilized the straw for livestock, because flooding had made most straw moldy and unfit for animal feed. Most farmers burned the straw and plowed it underground.

Nutritive value of locally available fodder. Continuing work on evaluating indigenous feed sources including weeds is conducted at IAS. About 24 in vivo digestion trials were completed. Five grasses were evaluated, plus three legumes, nine grass-legume mixtures, and three fibrous crop residues. In general, digestibility of feedstuffs differed only by 2-3% higher in carabao for ether extract (fat) and crude fiber, but higher in cattle for N-free extract.

To improve the value of feeds by physicochemical means, a substitute was sought for NaOH in treating rice straw. A weed, *Amaranthus spinosus*, was ashed and extracted with water to make a potash solution that was added to straw as a K source. Some treatments also received additional urea and molasses.

Detergent fiber analyses are continuing. Most forage samples showed about equal cellulose and hemicellulose contents. Cellulose values for some grasses and crop residues were higher than those for crude fiber.

Pesticide residues in rice and intercrops fed to ruminants. Among the pesticides monitored (diazinon, azinphos-ethyl, monocrotophos, benomyl, butachlor, BPMC + chlorpyrifos, and carbofuran), only carbofuran and BPMC + chlorpyrifos were detected. ^{14}C-labeled carbofuran was incorporated in the feed at levels simulating actual amounts in harvested straw. The feeds were given to lactating goats for 7 consecutive days, and samples of milk, urine, and feces were collected for 22 consecutive days and analyzed for pesticide residue. Carbofuran was eliminated rapidly through the urine, feces, and milk. After withdrawal of contaminated feed, however, there were still some detectable levels in milk, possibly due to the high affinity of carbofuran for lipids.

Grain + forage legume intercropping. Food grains intercropped with legumes provide both food and animal fodder. Some forage legumes are especially useful in persisting through DS. One upland trial was run at the start of DS and another after rainfed lowland rice, both at IRRI in 1984-85. In both, maize (DMR Composite No. 1) and sorghum (UPL SG-5) were intercropped with siratro *Macroptilium atropurpureum*, schofield stylo *Stylosanthes guianensis* and verano stylo *S. hamata*, centrosema *C. pubescens*, and cowpea *Vigna unguiculata*. Land preparation was thorough for the upland site, but the lowland site had no tillage except a furrow for seeding. All crops were planted simultaneously, with intercrops alternating 0.75 m apart with the main crop in 4- × 5-m plots replicated 3 times.

Maize yielded only 0.5 t/ha vs 2.2 t/ha for sorghum; both grain yields were unaffected by the legume intercrops in the lowland. Siratro yielded 3.4 t/ha dry matter (DM) fodder with 0.5 t maize stover. Siratro yielded 2.8 t/ha DM plus 3.3 t sorghum stover, giving the highest biomass total of 6.1 t/ha excluding grain. Schofield stylo yielded 2.1 and 1.5 t DM/ha with maize and sorghum. Cowpea yielded 0.4 t DM/ha with maize or sorghum plus cowpea dry grain of 0.04 and 0.07 t/ha, respectively.

In upland, grain yield of sorghum was significantly reduced from 6.3 to 3.7 t/ha with siratro and to 3.7 t/ha with cowpea. Maize yield was not affected by any of the intercrops, averaging 6.3 t/ha.

Cowpea gave a grain yield of 0.3 and 0.8 t/ha, added to its stover of 0.9 and 1.3 t DM/ha, with maize and sorghum, respectively. Siratro gave the highest fodder yield of 7.8 t DM/ha added to 5.1 maize stover. This was similar to 8.1 t siratro/ha + 3.9 t sorghum stover/ha, although the latter was significantly reduced ($P<.05$) from 8.0 t/ha as the sole crop. Schofield stylo yielded 3.2 and 2.00 t DM/ha with maize and sorghum; centrosema, 1.4 and 0.9 t/ha, respectively.

Field evaluation of forage grasses. Forage

grasses were planted in 4- × 5-m upland plots with 3 replications to identify those adapted to vacant areas. Drought tolerance, herbage yield, and vegetative regrowth were emphasized.

One-year DM yields (in t/ha) in descending order were andropogon *Andropogon gayanus*, 36.7; napier *Pennisetum purpureum*, 26.1; *Paspalum plicatulum*, 26.1; guinea *Panicum maximum* cv. hamil, 25.3; setaria *Setaria anceps* cv. nandi, 24.3; setaria cv. kazungula, 20.8; para grass *Brachiaria mutica*, 16.5; common guinea, 12.5; ruzi grass *Brachiaria ruziziensis*, 12.4; signal grass *Brachiaria decumbens*, 11.8; alabang X *Dicanthium aristatum*, 10.0; and star grass *Cynodon plectostachyus*, 6.4.

Sixteen forage grasses were established in 0.4-m-wide × 0.3-m-high bunds. They were planted on the 2 top edges of the bund with 3 replications, each 6 m long.

Ten months' data with harvesting interval of 30-60 d revealed napier with highest fodder yield of 1.1 kg DM linear meter, equivalent to 41.3 t DM/ha compared with 11.8 t/ha for the control (0.2 kg DM/m). The other grasses with significantly higher yield over the control were (in kg DM/linear m): alabang X, 0.7; para grass, 0.6; setaria cv. nandi, 0.6; setaria cv. kazungula, 0.5; and ruzi grass, 0.4.

Fodder trees and shrubs. Trees and shrubs with potential fodder value are being evaluated at IRRI. The same could serve to provide planting materials and seeds. Some of these include kakawate *Gliricidia sepium*, kamatsile *Pithecellobium dulce*, anabiong *Trema orientalis*, malunggay *Moringa oleifera*, and ipil-ipil *Leucaena leucocephala*. Depending on the species, 2 to 3 loppings were carried out from 3 replications of 6-m single row plots planted 1 m apart. Fresh herbage yields (leaves including pencil size twigs or stems) in grams per tree were 2,669 for leucaena; anabiong, 951; kamatsile, 794; kakawate, 1,189; and malunggay, 852.

Herbage yield and quality of leucaena. Four leucaena cultivars (Peruvian, Cunningham, K8, and K67) were tested under 2 cutting lengths (30 and 150 cm) and 3 cutting frequencies (30, 45, and 60 d) to estimate herbage yield. After 135 d, Cunningham produced the highest herbage DM yield, followed by K8, K67, and Peruvian in descending order. A cutting length of 30 cm produced higher DM yields at first, but that of 150 cm at 60-d cutting intervals produced higher DM yield in succeeding harvests.

Cooperative programs

Cooperative country projects

Plant Physiology, Plant Breeding, Water Management, Training and Technology Transfer, and Agricultural Engineering Departments and Tissue Culture Facility

KOREA-IRRI COLLABORATION ON RICE COLD TOLERANCE **502**
- Cold tolerance screening nursery **502**
- Observational yield trials **502**
- Screening for low air temperature tolerance **502**
- Pedigree nursery for cold tolerance **503**

SCREENING VIETNAMESE CULTIVARS FOR LOW TEMPERATURE TOLERANCE **503**
- Evaluation for cold hardiness at seedling stage **503**
- Cold tolerance at panicle initiation (meiosis) and anthesis **503**

NITROGEN RESPONSE OF HETEROTIC F_1 RICE HYBRIDS IN KOREA **504**

IDENTIFICATION OF HETEROTIC COMBINATIONS IN FOUR COUNTRIES **504**

HYBRID SEED PRODUCTION IN THE PHILIPPINES AND KOREA **506**

ANTHER CULTURE COLLABORATION WITH KOREA **506**

INFORMAL TISSUE CULTURE COLLABORATION WITH PERU, MEXICO, AND WARDA **506**

NORTH BANGLADESH TUBEWELL SYSTEM **507**
- Increasing effective water use **507**
- Crop production and income **507**
  - Rice area and MV use **507**
  - Green manure and rice yield **507**
  - Cropping pattern and income **508**

ADOPTION OF DRY SEEDED RICE TECHNOLOGY IN THE RAINFED LOWLANDS OF ILOILO AND SOUTH COTABATO, PHILIPPINES **508**
- Development of technology and analytical tools **509**
- Adoption of DSR **510**
- Labor availability **510**
- Farm size **511**
- Farmer knowledge and extension contact **511**
- Credit **512**
- Tenancy **512**
- Farmer's age and education **512**
- Draft animal ownership **512**

INDUSTRIAL EXTENSION 512
Philippines 512
Tillage equipment 512
Irrigation pumps 513
Indonesia 515
Burma 515
India 515
Thailand 515
IRRI-NATIONAL PROGRAM COOPERATION 515
Burma 515
China 515
Democratic People's Republic of Korea 516
Egypt 516
Indonesia 516
Republic of Korea 516
Malagasy 516
Pakistan 516
Philippines 516
Sri Lanka 517
Thailand 517
MISSIONS TO AFRICA 517
PROSPERITY THROUGH RICE 517
Low cost yield-increasing technology 517
Farming systems and biomass utilization 518
Training 518

501

KOREA-IRRI COLLABORATION ON RICE COLD TOLERANCE

Plant Physiology and Plant Breeding Departments

Cold tolerance screening nursery. The cold tolerance screening nursery subjects rice plants in the field to a 17-25 °C water temperature gradient throughout the growth stages. Entries with outstanding performance in several traits (earliness, fertility, intermediate culm length, good panicle exsertion, phenotypic acceptability, and no leaf discoloration) included IR20913-B-60, IR9202-25-1-3, Sangpungbyeo, SR11027-B-B-127, Kuchum Janack, Che Eu Hung, Chun Lum 4, Chun Nen Tsan, HR4467-8-4-2-1, and Lien Chan Ze Thou. Janack, a cultivar from Bhutan, was found to be a good source of lodging resistance. A total of 1,102 entries were screened in the 1985 growing season. A computer listing of the different plant traits for all entries from 1978 to 1985 is available. Different entries showed excellent performance for specific traits.

Fertility was identified as the most important character in selecting for low temperature tolerance in this nursery. The three entries whose fertility at the inlet was greater than 90% were IR20913-B-60, IR9202-25-1-3, and Sangpungbyeo. Since the day temperatures were relatively high, fertility percentage was generally high and could not be used as a selection criterion for cold tolerance at heading. Greenhouse screening, however, provided valuable data for this character.

Short growth duration is most important to avoid low temperature damage during early autumn. Entries with fewer than 100 d to heading and less than 10% heading delay at the inlet (where the water temperature was 17 °C) were China 1039, JKAU(K)450-126-10, JKAU(K)450-126-2, JKAU(K)450-172-6, JKAU(K)450-172-10, JKAU(K)450-172-11, K333, K335, K39, K39-96-1-1-1-2, Matsumae, Jo 80-24-R-R-R-123-2, Jo 80-42-R-R-R-35-2, Jo 80-42-R-R-R-35-3, Ryongseong, SR10120-B-104-3-1, and TK5331-R-R-R-R-28-1-B. Among them the K39-, JKAU(K)-, and TK5331 lines had high fertility at the inlet (>51%). Four entries were developed from the rapid generation advance (RGA) program at IRRI, which selects for earliness.

Spikelets per panicle is an important yield component. High spikelet number (>160/panicle) was observed in B2983G-Sr-43-7, B2983b-SR-13-4-1-10-2-2-3, Gangju Kuchum, Gasmal 735, HR3820-22-4-4-3, IR20900-B-30, IR9202-23-2-1-3, Juku, Kuchum, RP1848-54-2-3-1, SR11027-B-B-127, and YR3583-7-3-7; these will be good sources of high spikelet number type.

Plant type is scored by phenotypic acceptability, a visual assessment of the plant's performance that includes all other traits. Entries with phenotypic acceptability scores of 1 were B2983G-Sr-2-9, Bir-Ze-Goo, Chau Fon Thou, Che Eu Hung, Chiagbyeo, China 1039, Chun Lum 4, Chun Lum U Le Thou, Chun Nen Tsan, HR4467-8-2-4, IR15579-135-3, IR15579-24-2, IR20910-B-67, IR7167-33-2-3-3-1, IR9202-25-1-3, IR9202-33-4-2-1, Jinjubyeo, Lien Chan Ze Thou, Ta-Ton-Shun, and Tainung Sen Yu. These entries had both good plant type and low water temperature tolerance.

Discoloration of the leaves is most serious when the young seedlings are subjected to low temperatures, as is the case when the cold spell during spring lasts for a few days after transplanting. Entries that showed no discoloration or least discoloration were HR3790-9-1-4-2, Iri 369, Latsika C, Rax 102-64B-5, SR10988-B-B-36, SR11010B-402, T1668, Sangpungbyeo, YR3484-25-3, and YR4194-31-3-2-3. These entries had a fertility score greater than 80% with 17 °C water temperature.

Observational yield trials. At high N level (200 kg N/ha), the high yielders were B2983b-Sr-13-4-1-10-1-2-2, YR1654-16-1-2-4-B-2, YR2404-15-4-9-3-2, IR8866-30-3-1-4, SR10989-B-B-38, and SR11010B-403. The high yielders at low fertilizer level (100 kg N/ha) were Pungsanbyeo, YR1654-16-1-2-4-B-2, and SR10649-B-504. IR8866-30-3-1-4 was in the yield trials for 3 yr and consistently showed high yields. These entries are suitable for national testing programs. The first set of entries can be used to produce maximum yields, while the latter entries are suited to low input programs.

Screening for low air temperature tolerance. Day temperatures greater than 20 °C are needed for anthesis in rice. The 187 entries from the International Rice Cold Tolerance Nursery were subjected to 18-20 °C air temperature at flowering in the temperature-controlled greenhouse. Entries

with >65% fertility were Diamante Inia, Barkat, Quella Inia, Tatsumi-Mochi, Chun Lum U Le Thou, CI 1561-1, Suweon 303, and Rodina. These entries are useful germplasm for low air temperature tolerance at heading. This screening is more efficient than the 17 °C water gradient or the late planting method, which subject only the long growth duration entries to low air temperature.

Pedigree nursery for cold tolerance. A total of 24 F_2 crosses and 11 F_3 bulked populations were grown in the pedigree nursery using continuously flowing water at 20 °C. One thousand ninety-four plants from the F_2 and 570 lines from the F_3 were selected.

SCREENING VIETNAMESE CULTIVARS FOR LOW TEMPERATURE TOLERANCE

Plant Physiology Department

Vietnam has about 2.5 million ha of rice subjected to cold damage every year. Modern rice cultivars cannot be planted because of their susceptibility to low temperature. In northern Vietnam, 27,110 ha of rice seedlings died in 1976 because of low temperature.

In northern Vietnam two rice crops are grown in a year. The first crop from November to June suffers from cold air temperature causing injury to about 1.8 million ha/yr at the seedling and transplanting stages and 60,000 ha at flowering. From November to March the low minimum air temperature coupled with low sunshine hours requires cold-tolerant cultivars, especially at the seedling and flowering stages. The most common symptoms of cold injury in Vietnam are stunting of seedlings, leaf wilting, degeneration of spikelets, poor grain filling, high sterility, delayed growth, and death. The selection and introduction of cold-tolerant rice cultivars would increase the stability of rice production.

The rice cultivars of Vietnam were evaluated to identify cold-tolerant cultivars for planting or for use as parents in breeding. Of the 1,640 traditional rice cultivars of Vietnam in the IRRI germplasm bank, 620 were used.

The cultivars were tested for cold tolerance at the seedling stage. Seedlings at the 3-leaf stage were subjected to 10 °C for 4 d in the cold room and then were transferred to the greenhouse. Cold tolerance was assessed 7 d after taking them out of the cold room, based on withering, dried leaves, stunting, and survival percentage compared with the resistant check.

Another set of plants was subjected at night to 17 °C for 15 d when the auricle distance between the last 2 leaves was 0 cm, i.e., at panicle initiation. The depression in number of fertile spikelets and fertility percentage caused by low temperature stress was used as a measure of cold stability.

A third set was placed in the phytotron at 17 °C for 10 d in natural sunlight when around 10 cm of the panicle had exserted. They were scored 30 d from flowering based on panicle exsertion and percentage of sterile grain.

Evaluation for cold hardiness at seedling stage. Most of the cultivars tested showed stunting caused by cold air treatment. Around 27% of the plants died, 53% showed no increase in height, 15% had very little increase, and 5% showed appreciable increase in height.

The entries that showed appreciable increase in height also showed high percentage of survival, similar to the check varieties.

Of 609 entries, 132 showed cold hardiness at the seedling stage. A large percentage of cultivars used in the mountains of Vietnam did not have cold tolerance at the seedling stage.

Cold tolerance at panicle initiation (meiosis) and anthesis. The rice plant is most sensitive to low temperature at the panicle initiation stage. The outstanding entries with tolerance for 17 °C air temperature at panicle initiation are shown in Table 1. Only Bong Sen (Acc. no. 10861) received a *Standard evaluation system for rice* score of 1. Tep Trang and Ban Ren were relatively tolerant at the panicle initiation and seedling stages.

Anthesis is the second most sensitive stage to low temperature. Nondehiscence of the anthers because of low temperature generally results in high sterility. The following had the best tolerance: Bong Sen, Kreng Menh, Nep Da, Choke Kok, Nep Den, Bat Ngoat, Ban Ren, Tep Trang, and Khau Mua Venh.

Data for sterility resulting from low temperature at panicle initiation and anthesis showed the preceding cultivars to be most promising. The best was Bong Sen, with excellent scores at panicle initiation and anthesis. These cultivars can be used

Table 1. Vietnamese cultivars score[a] for cold tolerance at meiosis and anthesis. IRRI, 1985.

Accession no.	Variety	Spikelet fertility[b]	Panicle exsertion[c]	Anthesis[c]
10861	Bong Sen	1	3	3
06230	Tunsart E 45	3	5	5
12104	Kreng Menh	3	3	3
16731	Minh-Soc	3	5	5
17006	Nep Da	3	3	3
17011	Cam	3	7	5
24084	Choke Kok	3	5	3
24149	Nep Den	3	3	3
24153	Tau Dung	3	5	5
24193	Bat Ngoat	3	3	3
29718	Ban Ren[d]	3	5	3
29909	Tep Trang[d]	3	5	3
56043	Dau Do	3	7	5
56045	Dau Hen	3	5	5
56049	Di Do	3	5	5
56050	Do Tan	3	5	5
56051	Du Bao	3	5	5
56067	Hien Do Muon	3	5	5
56086	Khau Mua Venh	3	5	3

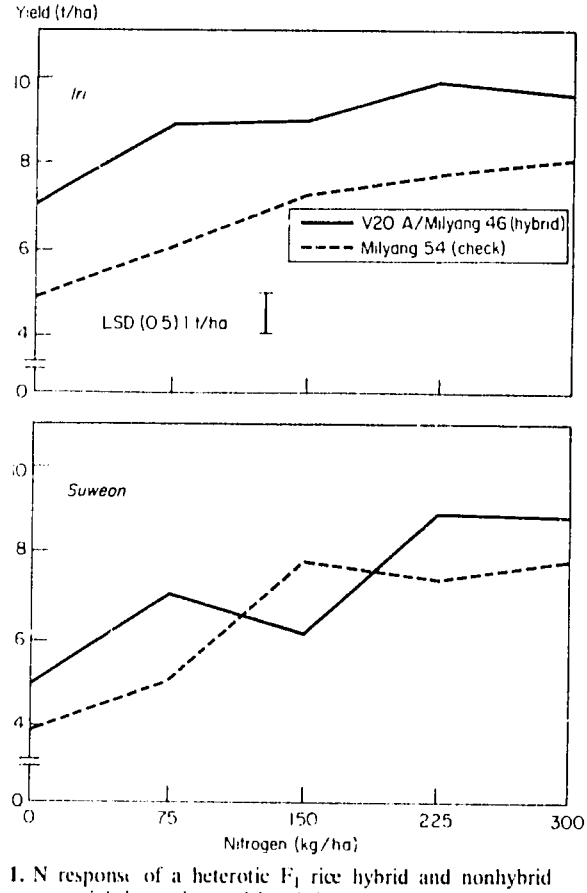
[a]By the SES. [b]Result from 17 °C treatment at panicle initiation. [c]Low temperature (17 °C) treatment at heading. [d]Also cold tolerant at seedling stage.

as donor parents in breeding programs for cold tolerance.

NITROGEN RESPONSE OF HETEROTIC F_1 RICE HYBRIDS IN KOREA

Plant Breeding Department

Three hybrid combinations developed at IRRI for Korea were compared with 2 nonhybrid varieties at 5 N levels (0, 75, 150, 225, and 300 kg N/ha) at 2 locations (Suweon and Iri) in Korea. The hybrid V20A/Milyang 46 was superior to the best pureline variety Milyang 54 at all N levels at the 2 locations except at Suweon at 150 kg N/ha, where it yielded significantly lower than the check variety (Fig. 1). This anomaly at Suweon was caused by the inoculation of only the 150 kg N/ha entries with 3 isolates of bacterial blight *Xanthomonas campestris* pv. *oryzae*. The hybrid was found highly susceptible, whereas the check variety was resistant. Generally speaking, the hybrid used applied N more efficiently than the nonhybrid check.



1. N response of a heterotic F_1 rice hybrid and nonhybrid commercial rice variety at Iri and Suweon, Korea, 1985.

IDENTIFICATION OF HETEROTIC COMBINATIONS IN FOUR COUNTRIES

Plant Breeding Department

During 1985, we evaluated 67 F_1 rice hybrids developed at IRRI against the best commercial

Table 2. Promising F_1 rice hybrids identified in 1985.

Hybrid or check	Yield (t/ha)
1985 dry season	
IR46828A/IR13524-21-2-3-3-2-2	5.4 a
IR46831A/IR54	5.0 a
IR36	4.4 b
IR58	4.4 b
1985 wet season	
Set 1	
IR46828A/IR64	5.1 a
IR46828A/IR13524-21-2-3-3-2-2	5.1 a
IR46830A/IR9761-19-1	5.0 a
IR35546-52-3-3-2	4.7 ab
IR28150-84-3-3-2	4.5 ab
IR64	4.5 ab
IR54	3.9 b
IR58	2.5 c
Set 2	
IR21845-90-3A/IR64	5.1 a
IR54752A/IR13419-113-1	5.1 a
IR28150-84-3-3-2	4.8 a
IR64	4.3 a
IR58	2.4 b

[a]Within a set, numbers followed by a common letter are not significantly different at the 5% level by DMRT.

varieties and elite breeding lines in replicated yield trials in India, Indonesia, the Philippines, and Korea. Some of these F_1 hybrids showed significant superiority over IR58, IR36, and IR54 and numerical superiority over IR64 and the newly developed elite breeding line IR28150-84-3-3-2 (Table 2). IR46831A/IR54 and four others were also evaluated in the irrigated rice replicated yield trial during wet season (WS) at IRRI along with 365 breeding lines and varieties developed through the pedigree method. IR46831A/IR54 ranked 20th among the 370 entries. These hybrids, however, do not possess an adequate level of resistance to some diseases and insects. New hybrids are being developed by using newly developed cytoplasmic male sterile (CMS) lines.

Some F_1 hybrids (Table 3) developed at IRRI and evaluated in national programs showed 11-68% yield superiority over the best check. The hybrids, however, are not yet acceptable because of either inadequate disease and insect resistance or poor grain quality. None of the hybrids developed at IRRI and tested in 1984 or 1985 was superior to the best available check variety at Cuttack, Bangalore, and Coimbatore in India in 1984; Kapurthala and Punjab in India in 1985; Maligaya, Philippines, in 1985; or Suweon, Milyang, and Namyang in Korea in 1985. Results of the 1985 trials at several other locations are not yet available.

Some hybrids developed from new CMS and restorer lines showed better performance in the observational yield nursery. They will be further evaluated in replicated yield trials in 1986.

Table 3. Some heterotic F_1 combinations showing positive standard heterosis in more than 1 location in trials conducted outside IRRI, 1984-85.

Hybrid	Yield[a] (t/ha)						
	India					Indonesia	Korea
	1	2	3	4	5	6	7
IR46831A/IR54	5.9 (18.0)	6.8 (25.9)		6.2 (29.2)	9.8 (12.6)	–	–
V20A/Milyang 46	5.8 (16.0)	6.4 (20.0)				5.8 (41.5)	10.0 (11.1)
V20A/IR9761-19-1 (Wei You 64)	7.0 (20.7)	6.5 (20.0)					
V20A/IR54	6.4 (28.0)		5.9 (15.7)			5.0 (42.8)	–
MR365A/IR13524-21-2-3-3-2	5.8 (16.0)	6.7 (24.0)				–	–
V20A/IR13419-113-1	7.0 (20.7)					6.9 (68.3)	
MR365A/IR54	6.0 (20.0)	-	–	6.3 (31.2)			
IR747B2-6-3/IR50	5.9 (78.0)			6.2 (29.2)			

[a]1 = Patna, Bihar; 2 = Kapurthala, Punjab; 3 = Aduthurai, Tamil Nadu; 4 = Maruteru, Andhra Pradesh; 5 = New Delhi; 6 = Sukamandi; 7 = Iri. Figures in parentheses indicate positive standard heterosis (%) over the best check used in the trial.

Six F_1 rice hybrids were evaluated along with 63 breeding lines and varieties in an observational cold tolerance yield nursery in Banaue, Philippines, a high altitude (1,200 m) location. The highest yielding entries in this trial were two F_1 hybrids V20A/Milyang 46 (4.2 t/ha) and Wei You 64 (3.9 t/ha) compared with the best yielding elite line IR40094-1-5-2 (3.5 t/ha) and local check Pinidua (2.5 t/ha). Since the parents of these hybrids are not known for cold tolerance, it is possible that the increased vigor of F_1 hybrids itself was responsible for their better adaptation to cold weather conditions.

HYBRID SEED PRODUCTION IN THE PHILIPPINES AND KOREA

Plant Breeding Department

Hybrid seed yields in 13 CMS multiplication (A/B) and 30 hybrid seed production (A/R) plots at IRRI continued to be low (7–493 kg/ha) during 1985 (Table 4). The low seed yields were caused by one or a combination of factors: lower outcrossing potential of the newly developed CMS lines used for seed production, high incidence of tungro and other virus diseases in the seed production plots, reduced area for the CMS parents and increased area for the male parent to increase the pollen load and reduce the chances of contamination with foreign pollen, nonsynchronous flowering of the parental lines, and other weather-related problems. As experienced earlier, seed yields were lower in WS than in dry season.

Hybrid seed production techniques were also tested in small plots at Iri using the CMS lines developed in China (V20A and Zhen Shan 97A) and IRRI (IR46828A, IR46830A, and IR54756A). Seed yields ranged from 70 kg/ha to 1.47 t/ha. The outcrossing rate on the new CMS line IR54756A developed at IRRI was higher than on those developed during 1983 (e.g., IR46828A and IR46830A).

A special project on hybrid rice seed production in the tropics was initiated.

Table 4. Seed yields and outcrossing rate on cytogenetic male sterile lines obtained at IRRI, 1985.

Season	Seed production plots (no.)		Seed yield range (kg/ha)		Seed set range (%)	
	A/B	A/R	A/B	A/R	A/B	A/R
Dry	9	20	30-450	13-493	4-25	5-39
Wet	4	10	7-142	10-203	4-22	5-18

ANTHER CULTURE COLLABORATION WITH KOREA

Tissue Culture Facility

The collaborative project with the Rural Development Administration (RDA) of Korea on the use of anther culture techniques for the production of homozygous cold-tolerant lines from F_1 hybrids that started in the latter part of 1983 was pursued. Of the 23 SR crosses subjected to anther culture, 18 responded with a total green plant production of 7,138. Among these, 2,953 lines (41.4%) were autodiploids. Around 1,200 lines have so far been sent back to RDA for screening in their cold tolerance and blast nurseries.

INFORMAL TISSUE CULTURE COLLABORATION WITH PERU, MEXICO, AND WARDA

Tissue Culture Facility

In our joint project with Peru, we are doing anther culture of eight F_1 hybrids to obtain lines that will be adapted to Peruvian conditions. In 1985 we regenerated 726 plants from our Peruvian materials, and anther culture-derived lines with sufficient seeds will be sent back to Peru for testing and selection.

The collaborative project with Mexico is principally on the regeneration of somaclonal variants with reduced plant height from varieties planted by Mexican farmers.

Reduced plant height and shift from photoperiod sensitivity to photoperiod insensitivity through somaclonal variation are among the major characters that we want to achieve in ROK 5 and ROK 10 from the West Africa Rice Development Association (WARDA). Several lines that had undergone preliminary tests at IRRI were found promising. Final testing of these tissue culture-derived lines will be done by WARDA.

NORTH BANGLADESH TUBEWELL SYSTEM

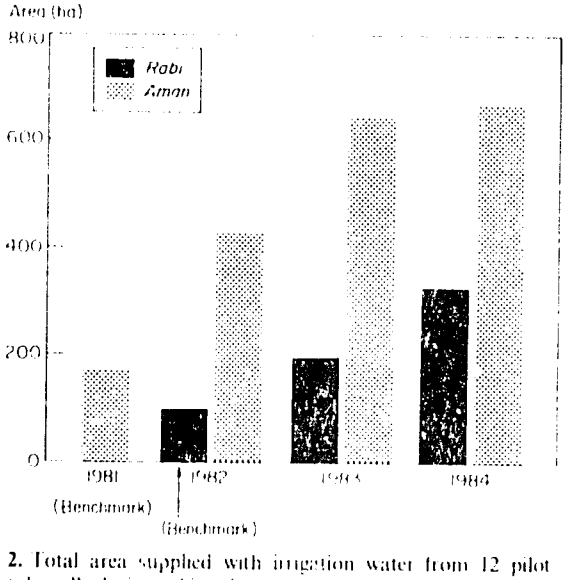
Water Management Department

The North Bangladesh Tubewell System is one of two irrigation systems in which research on increasing irrigation effectiveness and crop production is conducted by a multidisciplinary group of scientists and professionals from the Bangladesh Rice Research Institute and the Bangladesh Water Development Board (BWDB) in collaboration with IRRI. The main experiments are conducted in a group of 12 selected (pilot) tubewell areas representing the whole system, which consists of 378 deep tubewells operated by BWDB for more than 20 yr.

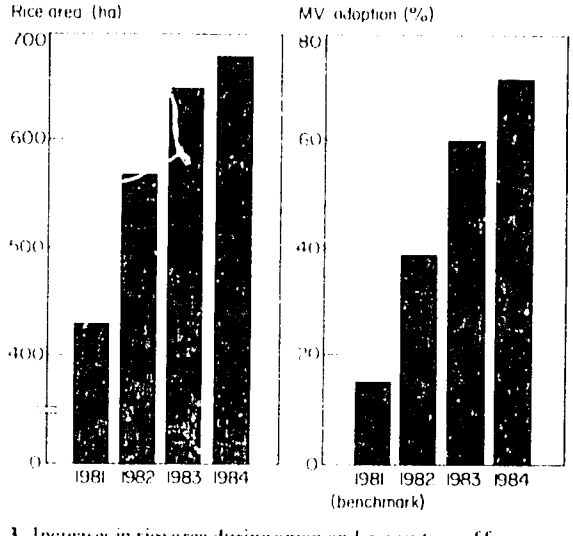
Increasing effective water use. Lack of reliability in water supply was the main reason for farmer disinterest and a major limitation to improving the low capacity utilization of the tubewells. In the 12 pilot tubewells, water supply reliability was improved by reducing the high water conveyance losses in the main canal, improving the level of supervision of pump operation, and enhancing farmer organizational activities to utilize the water in an orderly and systematic manner. The results are shown in Figure 2. By 1984, the area benefiting from the 12 tubewells had increased by about 220% in rabi and by 300% in aman compared with the respective benchmark seasons. Water use in rabi is mostly for growing wheat, whereas all water for aman is used for rice.

Crop production and income. *Rice area and MV use.* In 1981 aman, when benchmark data were collected, many parts of the service area of the 12 tubewells were found uncultivated, and only 15% of the rice area was planted to modern varieties (MVs). To benefit from the more reliable water supply from the tubewells, farmers were encouraged to grow irrigated MVs (BR10 or BR11) in aman. As the timeliness and reliability of irrigation water improved, the rice area in aman increased significantly; adoption of MVs exceeded 70% in 1984 because farmers were convinced of the greater returns possible from their use in areas with reliable water (Fig. 3). The average yield advantage achieved in the 12 tubewell command areas during aman by farmers who grew MVs (BR4, BR10, or BR11) over those cultivating local varieties ranged from 1.3 t/ha in 1981 to 2.3 t/ha in 1982 and 1984.

Green manure and rice yield. In 1982, green manure crops Sesbania and sunhemp were introduced in cropping pattern trials as aus crops to be grown from early summer rains (without irrigation) in between two irrigated grain crops, i.e., wheat in rabi and rice in aman. Green manure was expected to be beneficial not only from the soil



2. Total area supplied with irrigation water from 12 pilot tubewells during rabi and aman, North Bangladesh Tubewell Irrigation System, Bangladesh, 1981-84.



3. Increases in rice area during aman and percentage of farmers using MVs during aman in the command area of 12 pilot tubewells, North Bangladesh Tubewell Irrigation System, Bangladesh, 1981-84.

nutritional point of view but also in improving the structure and water holding capacity of the sandy soil in the area. A number of progressive farmer cooperators quickly picked up the idea; in 1983 aus, green manure crops were grown on about 20 ha within the 12 pilot areas. In 1984, the practice expanded to about 48 ha and also to substantial areas under other tubewells as more and more farmers, through the initiatives of BWDB extension workers, became interested.

In 1983, the average yield of the fields with green manure was 1.8 t/ha higher than the average yield of those without green manure. The higher yield was achieved with use of 52% less N. The yield difference in 1984 aman was about 1 t/ha in favor of fields with green manure, with 58% less N use.

Cropping pattern and income. Experiments with alternative crops for aus were conducted in the command areas of three tubewells to determine the economic returns expected from three-crop patterns involving irrigated rabi wheat and irrigated MV aman rice. For each pattern, chemical fertilizer inputs were used at two levels: the recommended level and the farmers' level. All wheat trials used the popular Sonalika variety.

The results are shown in Table 5. The wheat - green manure (sunhemp) - BR11 rice pattern, grown in the rabi-aus-aman sequence, gave the maximum net return for both recommended level and farmers' level of fertilizer use. For this pattern, the net return from the recommended fertilizer level was about 11% less than that at the farmers' level because of higher costs involved in the recommended practice relative to the benefits obtained. At the farmers' level, wheat - millet - BR11 rice gave the second highest net return, only 7% less than that for the most profitable pattern. Despite low mungbean yields, wheat - mungbean - BR10 rice produced the second highest net return for the recommended fertilizer level, but about 11% less for the farmers' level because of the low yield of BR10. But if a decent mungbean crop could be grown in aus, for which appropriate varieties would be essential, returns from this pattern would be much higher. Wheat - green manure (*Sesbania*) - BR4 rice had the lowest return at both the recommended and farmers' fertilizer levels, mostly because the yield of each crop in this pattern was the lowest among the four patterns tested.

ADOPTION OF DRY SEEDED RICE TECHNOLOGY IN THE RAINFED LOWLANDS OF ILOILO AND SOUTH COTABATO, PHILIPPINES

Training and Technology Transfer Department

With the availability of early maturing varieties, IRRI began on-farm cropping systems research in favorable rainfed lowland areas in the mid-1970s to identify opportunities for crop intensification. Research was initially undertaken in Pangasinan and Iloilo. On-farm testing of modern rainfed rice technology was subsequently undertaken in Mindanao and several other parts of the country in cooperation with the Philippine Ministry of Agriculture and Food (MAF).

Table 5. Results of collaborative experiments on yields and economic performance of 4 cropping patterns conducted in command areas of tubewell nos. 63, 118, and 126, North Bangladesh Tubewell System, 1984.

Cropping pattern	Av grain yield[a] (t/ha)		Total cost[d] ($/ha)		Gross return[d] ($/ha)		Net return[d] ($/ha)	
	At recommended fertilizer level[b] (RF)	At farmers' fertilizer level[c] (FF)	RF	FF	RF	FF	RF	FF
Wheat - green manure (sunhemp) - BR11 rice	3.15-[e]-5.75	2.96-[e]-5.53	664	457	1696	1618	1033	1160
Wheat - green manure (*Sesbania*) - BR4 rice	2.51-[f]-5.22	2.28-[e]-4.27	665	456	1485	1248	820	793
Wheat - mungbean - BR10 rice	2.82-0.15-5.36	3.05-0.15-4.57	583	583	1608	1493	1026	911
Wheat - finger millet - BR11 rice	2.78-1.3-5.33	2.72-1.30-4.89	815	598	1781	1678	966	1080

[a]Av of 9 replications, 3 in each tubewell area. [b]RF = 80-60-40 kg NPK for wheat, 20-60-40 for mungbean, 60-20-20 for millet, and 80-60-40 for rice. [c]FF = 54-64-32 kg NPK for wheat, 40-41-23 for BR11, 42-42-13 for BR4, 38-41-23 for BR10, 42-49-34 for millet, and 20-55-44 for mungbean. [d]Converted at the Dec 1984 exchange rate: Tk 25.13 = US$1.00. [e]Av green plant weight = 14.6 t/ha. [f]Av green plant weight = 8.8 t/ha.

Development of technology and analytical tools. Based on cropping systems research and multilocation trials throughout the Philippines, the rainfed lowlands of Iloilo and South Cotabato were identified as areas highly suited to crop intensification through the use of early maturing varieties, dry seeding of the first rice crop at the beginning of WS, short turnaround time between crops, and the introduction of a second rice crop. Variants of this technology included the use of an upland crop instead of the second rice crop in drier areas, and the addition of an upland crop to a two-rice-crop pattern where moisture was adequate.

In Iloilo and South Cotabato, crop production programs were designed to promote mass extension of this highly promising technology package to farmers. The KABSAKA Project in Iloilo was supported by a $12 million World Bank loan, while the KASATINLU Project in South Cotabato was based on a MAF extension campaign.

By the 1981 growing season, the production programs of the KABSAKA and KASATINLU Projects covered 6,300 ha (4,600 farmers) and 800 ha (650 farmers), respectively. The great majority of these farmers dry seeded the first rice crop. However, closer examination of farmers' fields supported by discussions with farmers revealed a varied pattern of dry seeded rice (DSR) adoption by farmers in the study areas. Furthermore, those who adopted DSR varied in the extent to which they adopted other components of the KABSAKA and KASATINLU technology packages. A study investigated the factors influencing farmers' adoption of DSR cropping patterns in the rainfed lowlands of Iloilo and South Cotabato, and the extent of such adoption.

Information about the socioeconomic characteristics of farmers in the study areas was obtained from interviews during 1982 (Table 6). Farmers were classified on the basis of their adoption or nonadoption of DSR. An adopter had DSR on at least some part of the rainfed lowland area of his farm, while a nonadopter did not use DSR on any part of his farm.

In Iloilo the study area was stratified by location before selection of respondents to have adequate representation from the agroclimatic zones where the KABSAKA Project was operating and where field trials for this study were located. Closer examination of the adoption model for Iloilo

Table 6. Characteristics of sample farmers in Iloilo and South Cotabato, Philippines, shown by mean values for continuous variables and distribution of farmers for discrete variables.

Variable	Unit	Iloilo			South Cotabato		
		All farmers (n=173)	Adopters (n=94)	Nonadopters (n=79)	All farmers (n=100)	Adopters (n=50)	Nonadopters (n=50)
Farmer's age	yr	48.52	47.85	49.32	45.03	45.90	44.16
Education	yr	6.47	6.38	6.57	6.97	6.58	7.36
Labor index[a]	index value	2.00	2.15	1.83	2.24	2.56	1.92
Draft animal index[b]	index value	1.01	1.05	0.95	1.15	1.40	0.90
Extension visits	visits/yr	26.63	30.26	22.32	13.89	18.14	9.64
Knowledge	score/8	2.46	3.20	1.57	3.58	4.15	3.01
Tenancy	% land owned	30.14	28.50	32.09	31.67	38.68	24.66
Rainfed lowland area	m^2	15,162	17,430	12,463	25,143	33,584	16,702
Knowledge (herbicide only)	score/3		1.34			1.94	
Area dry seeded	m^2		12,544			14,310	
Dry seeded rice seeding rate	kg/ha		115			128	
Credit	no credit	124	67	57	33	14	19
	credit	49	27	22	67	36	31
Tenancy dummy	not owner	118	64	54	42	29	13
	owner	55	30	25	58	21	37

[a]Represented availability of household labor, and was calculated as follows: $X_L = (L_{AF} \times 1.0) + (L_{CF} \times 0.7) + (L_{AP} \times 0.2) + (L_{CP} \times 0.1)$ where L_{AF} = number of adults (≥14 yr old) in the household who were available for full-time farm work; L_{CF} = number of children (<14 yr old) in the household who were available for full-time farm work; L_{AP} = number of adults in the household who were available for part-time work; and L_{CP} = number of children in the household who were available for part-time farm work. [b]Represented availability of draft animals for cultivation purposes, and was calculated as follows: X_D = number of working age *carabao* (water buffalo) owned + number of draft cattle owned.

revealed relatively poor predictive capability of the adoption status of the subset of Iloilo farmers located in Cabatuan. For this reason, it was decided to run the logit regression analysis again, with the same set of independent variables but excluding data from Cabatuan, on the assumption that somewhat different determinants of adoption may operate there.

In South Cotabato, the respondents were selected randomly.

Using data from interviews, quantitative models were developed separately for Iloilo and South Cotabato to describe the adoption of DSR. The analytical procedures involved logit analysis to identify the determinants of adoption and non-adoption where the dependent variable was dichotomous, and tobit analysis to examine the extent to which farmers adopted technology. Both analyses were included because different factors might influence the decisions to adopt and how much to adopt.

Adoption of DSR. There were both similarities and differences among locations in the factors influencing DSR adoption (Table 7). In all three sets of data (Iloilo, Iloilo less Cabatuan, and South Cotabato), farmers with more labor, larger rainfed lowland areas, and better knowledge of KABSAKA or KASATINLU technology had a greater probability of adopting DSR in 1982.

Labor availability. The importance of labor was probably caused by the difficulty of weed control in DSR. DSR adoption in Iloilo and South Cotabato entailed a significant increase in labor costs, in particular those associated with hand weeding (Table 8). A farmer planning to adopt DSR needed either an adequate supply of household labor or sufficient cash reserves to employ laborers. DSR may not be suited to poorer farmers with low household labor availability.

The tobit model results for Iloilo showed that farmers with more household labor were likely to sow more of their rainfed lowland area to DSR. Cases of 100% adoption were few, demonstrating that farmers hesitated to rely wholly on DSR because of its inherent riskiness and large labor requirement.

In South Cotabato, the alternatives to DSR were not limited to wet seeded and transplanted rice. Maize is well adapted to the rainfed lowland environment in that province, which differs markedly from Iloilo in having lighter soils and more evenly distributed rainfall, leading to less severe flooding. Maize is also substantially less labor intensive than DSR. Soybean and mungbean can also be grown in the rainfed lowland environment of South Cotabato. Farmers are thus in a good position to adjust their crop choices and cropping patterns to suit their labor resources. Land preparation is less labor-demanding on light-textured soils, and farmers use preemergence herbicide with greater effectiveness in this environment.

Studies have shown that modern rice technologies tend to increase rather than decrease labor requirements and that a shortage of family labor

Table 7. Summary of results from models describing dry seeded rice (DSR) adoption in Iloilo and South Cotabato, Philippines, 1982.[a]

Explanatory variable	Iloilo			South Cotabato	
	All farmers (n=173)		Less Cabatuan (n=141)	All farmers (n=100)	
	Logit model	Tobit model	Logit model	Logit model	Tobit model
Farmer's age					
Education				(***)	
Labor index	*	+	+	ƒ	
Draft animal index		(+)			*
Extension visits			*	*	+
Knowledge	***	***	***	*	**
Credit					
Tenancy					
Rainfed lowland area	*	+	ƒ	***	

[a]Symbols represent significance level of 0.1% (***), 1% (**), 5% (*), 10% (+), and almost 10% (ƒ). Symbols in parentheses denote inverse relationship between DSR adoption and the explanatory variable.

Table 8. Labor costs for wet seeded rice (WSR) nonadopters and DSR adopters, first crops, Iloilo, Philippines, 1982 and 1983.

Item	Labor cost ($/ha)							
	Ajuy		Cabatuan		New Lucena		Miag-ao	
	WSR	DSR	WSR	DSR	WSR	DSR	WSR	DSR
			1982[a]					
Land preparation	55.49	51.71	46.16	46.75	51.95	47.34	41.09	38.61
Seeding	2.24	5.19	3.90	5.08	3.54	5.19	2.13	2.72
Fertilizer or pesticide application	5.79	6.61	5.55	5.90	5.55	6.61	2.60	2.72
Hand weeding	16.53	25.50	3.66	31.52	7.08	44.04	4.01	33.06
Harvest	54.90	60.68	77.80	60.33	87.25	82.17	40.97	53.96
Total	134.95	149.69	137.07	149.58	155.37	185.35	90.80	131.07
			1983[b]					
Land preparation	44.55	38.00	44.55	38.00	44.55	38.00	33.55	28.55
Seeding	2.82	4.36	2.82	4.36	2.82	4.36	1.36	2.18
Fertilizer or pesticide application	4.27	4.82	4.45	4.64	4.45	4.90	2.09	2.45
Hand weeding	0	8.45	0.73	30.64	0	6.45	0.82	27.00
Harvest	74.73	85.27	72.27	75.00	60.09	70.36	78.00	75.36
Total	126.37	140.90	124.82	152.64	111.91	124.07	115.82	135.54

[a]$1 = ₱8.47 as of 30 Jun 1982. [b]$1 = ₱11.00 as of 30 Jun 1983.

can inhibit their adoption. The results in Iloilo and, to a lesser extent, South Cotabato suggest that adoption of DSR is likely to increase rather than decrease on-farm employment, especially in environments where weed control through herbicides is unreliable.

Farm size. The finding that farmers with more rainfed lowland area tended to adopt DSR more readily than smaller farmers is consistent with some past studies on technology adoption.

In Iloilo, the relationship between landholding and adoption was considerably weaker in the absence of data from Cabatuan. In Cabatuan, DSR had only recently been introduced. Similarly, the introduction of DSR to South Cotabato began only in the late 1970s. Based on the theory of delayed adoption by small farmers, this observed effect of farm size (rainfed lowland area, in particular) may disappear over time.

In Iloilo, the larger farmers probably adopted DSR because of their capacity to absorb a crop failure. In Ajuy, where rainfall is more reliable and more conducive to double cropped rice, the differences in farm size between adopters and nonadopters was quite small; even smaller farmers recognized the value of DSR and decided to adopt it.

In South Cotabato, the reluctance to adopt was more likely related to the high cost of weed control in DSR rather than the risk of crop failure. Although almost all DSR farmers used pre-emergence herbicide, one or more hand weedings were usually required at a later stage. Larger farmers were better able to hire labor for hand weeding and, if necessary, to replant in the event of crop failure.

The initial caution of smaller farmers in South Cotabato and parts of Iloilo could be overcome by further technical refinement in DSR technology through research by government and international research bodies. In addition, early adopters can fine-tune technology to specific environments and influence other farmers to adopt. Early adopters experimenting with a new technology absorb much of the risk.

Farmer knowledge and extension contact. Farmer knowledge of the KABSAKA or KASATINLU technologies was an important factor influencing the decision to adopt and the extent of adoption in both Iloilo and South Cotabato. However, it is difficult to ascertain to what extent greater technical knowledge by farmers actually influenced the decision to adopt. The acquisition of technical knowledge after adoption cannot be discounted.

Frequency of extension contact and knowledge index were very weakly correlated with adoption in Iloilo and not correlated in South Cotabato.

Nevertheless, it appears that extension was contributing in ways not directly reflected in the knowledge index. Observations of extension activities revealed that the decision to adopt DSR can be encouraged by persuasive arguments on the potential benefits of technology that were put forward by local extension workers and reinforced by their supervisors, who regularly attended meetings of farmer groups. There also appears to be some group pressure on a farmer to participate in the KABSAKA or KASATINLU Projects.

The nonsignificance of extension contact in the Iloilo adoption models that included Cabatuan farmers reflects the low profile of extension in that municipality. The finding that DSR adopters had a lower level of extension contact than nonadopters cannot be explained by available information.

With the exclusion of Cabatuan data, extension contact had a positive influence on DSR adoption in Iloilo, as it did in South Cotabato. The complexities of the DSR technology appear to necessitate regular extension support. Simpler technologies, such as modern varieties, have been observed to spread rapidly with or without extension advice, provided the variety has characteristics favored by farmers.

Credit. Credit availability did not appear to inhibit adoption of DSR. Considering the cash requirement for herbicide and hand weeding, this finding might be considered surprising. However, there are no government credit programs that cater directly to farmers wishing to dry seed rice. The existing government rice production program, Masagana 99, was geared toward the irrigated rice crop, and use of its funds for DSR is an unlikely prospect under existing institutional arrangements.

Tenancy. Tenancy status did not appear to influence the decision to adopt DSR or the extent to which DSR was adopted in either Iloilo or South Cotabato. Although some farmers claimed that they were not allowed to adopt DSR because of their landlords' aversion to its riskiness, such influence was not widespread, probably because landlords and tenants have developed agreements on input and output sharing that make DSR favorable for both parties.

Farmer's age and education. The age of farmers in both Iloilo and South Cotabato influenced neither the decision to adopt nor the extent of adoption, consistent with the majority of recent studies.

Contrary to results from most other studies, in South Cotabato, more educated farmers were less likely to adopt DSR. More consistent with other studies, the educational level of Iloilo farmers did not influence DSR adoption.

Draft animal ownership. Based on the logit models, draft animal ownership did not influence the decision to adopt DSR in either Iloilo or South Cotabato. Tobit analysis, on the other hand, revealed that animal ownership was a significant explanatory variable when the extent of adoption was considered, but with opposite directional effects in Iloilo and South Cotabato.

Early and thorough land preparation are key ingredients to the successful establishment of DSR. Farmers with more animals are able to prepare their land more quickly and effectively than those with fewer animals. In South Cotabato, the increase in adoption associated with more draft animals followed this logic. The opposite effect was found in Iloilo, but only at the 10% level of significance; perhaps animal ownership had no influence because of the relatively higher animal to land ratio in Iloilo.

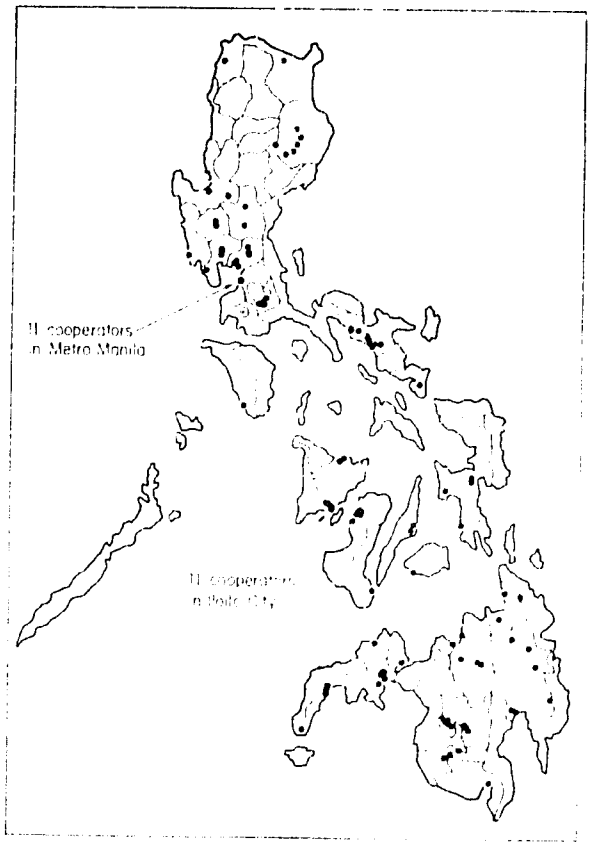
INDUSTRIAL EXTENSION

Agricultural Engineering Department

Philippines. The MAF-IRRI Program has 12 trained engineers working with farmers and more than 200 small-scale manufacturers in the major agricultural areas of the country (Fig. 4). High priority has been given to the development and promotion of low-cost equipment suitable for small farmers, including manual and animal-powered equipment.

The program received a Presidential Award for its development of a thresher sheller that converts the popular axial-flow thresher to a maize sheller. Ten manufacturers are now producing this item.

Tillage equipment. Land preparation often causes delays in crop establishment and is therefore a major obstacle to increasing cropping intensity. We tested six land preparation technologies to compare field performance, cost, and estimated delays in crop establishment. The floating rototiller was the most economical (Table 9). Developed by



4. MAF-IRRI cooperating manufacturers, Philippines

small-scale Filipino entrepreneurs, it consists of a boat-like body with a front-mounted puddling wheel providing both traction and tillage. The tiller has gained substantial acceptance in the Western Visayas and Mindanao, especially in waterlogged areas where neither the water buffalo nor the conventional two-wheel tractor is satisfactory. The floating rototiller results in lower land preparation cost and fewer delays for normal as well as waterlogged conditions.

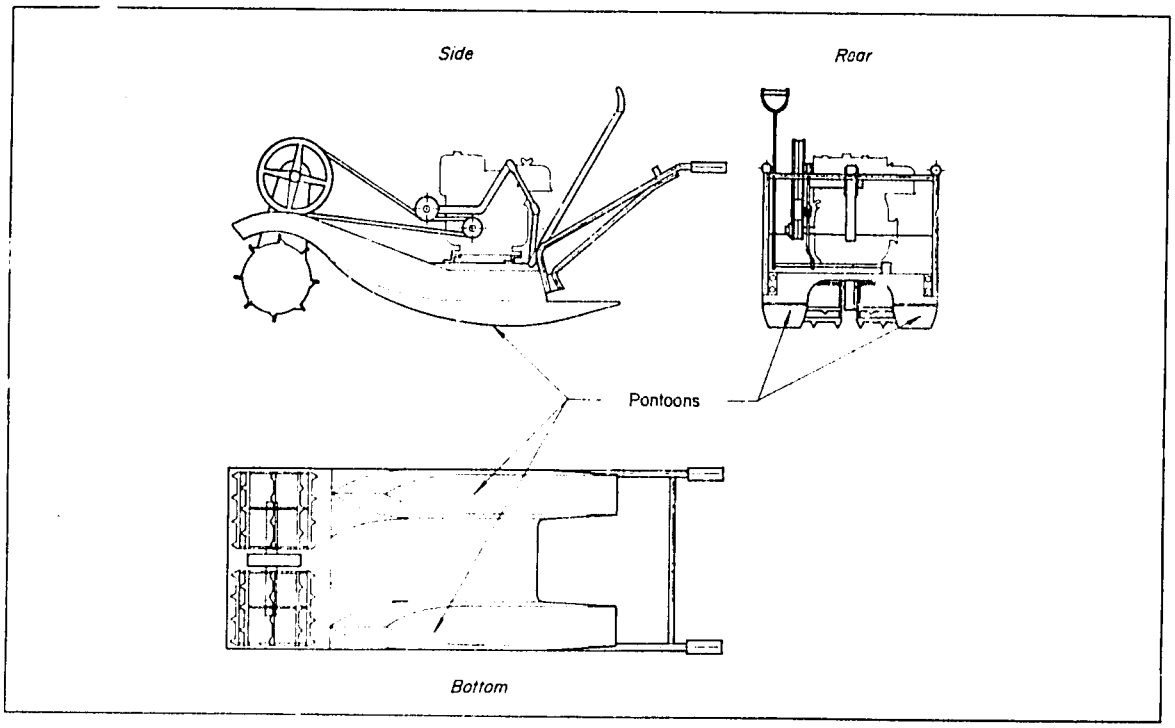
Acceptance of the floating rototiller has been limited by two problems. First, control of its forward speed requires strenuous effort by the operator to hold it back in relatively dry areas and to push it forward in muddy areas of the same field. Second, the tiller's belly creates furrows that reduce the rate of decomposition of straw and weeds while increasing the difficulty of harrowing and leveling. To reduce these problems, we collaborated with a manufacturer to develop a modified design having two pontoons separated by an open tunnel (Fig. 5). The curvature of the pontoons closely balances the drag and traction to give a convenient forward speed nearly constant for widely varying field conditions. The curvature also provides a rocking point that allows the operator to raise or lower the puddling wheel by pushing down or pulling up on the handles, thereby controlling the depth of tillage and forward speed and avoiding bogging down in excessively muddy areas. The combination of pontoons and tunnel results in more uniform tillage, which minimizes the furrowing problem.

We expect the modified floating rototiller to be accepted by farmers for both normal and waterlogged fields. It may be particularly appropriate for swampy areas in Africa.

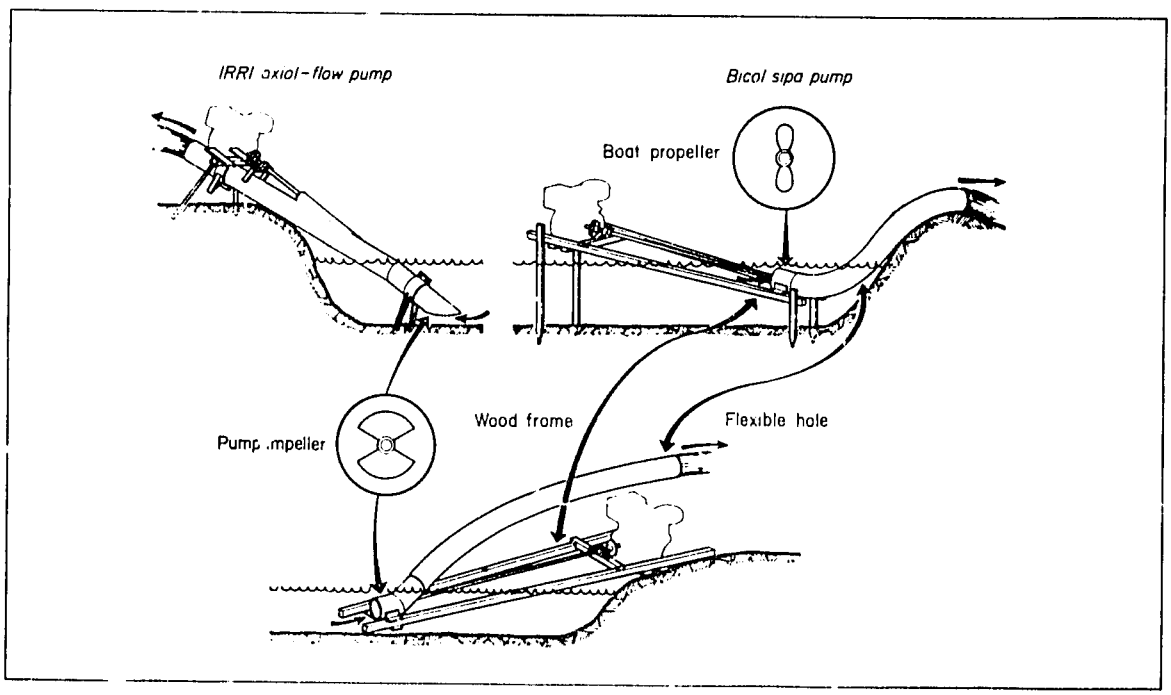
Irrigation pumps. We developed the *sipa* pump (Fig. 6), which costs 50% less than the axial-flow pump without sacrificing performance. This design incorporates features developed by farmers and manufacturers in the Bicol region of the Philippines, the main point being a flexible discharge hose made from used urea sacks or canvas, thereby minimizing costly metal tubing. The IRRI-designed impeller is used because its efficiency is

Table 9. Benefit-cost ratios for alternative tillage technologies at 3 levels of annual utilization, IRRI, 1985.

Technology	Benefit-cost ratio with annual utilization of		
	25 d/yr	50 d/yr	75 d/yr
Water buffalo + moldboard plow	0.26	0.44	0.59
Two-wheel tractor + moldboard plow	0.83	1.11	1.26
Two-wheel tractor + disk plow	0.91	1.23	1.41
Two-wheel tractor + spiral plow	0.91	1.23	1.41
Two-wheel tractor + cage wheels and harrow	0.99	1.33	1.52
Floating rototiller	1.37	1.81	2.04



5. MAF-IRRI floating rototiller, 1985.



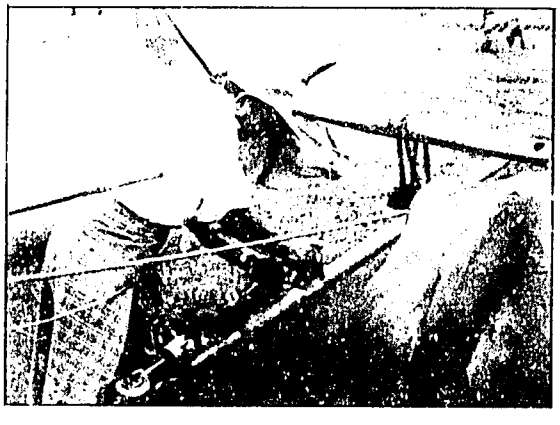
6. Evolution of the MAF-IRRI *sipa* pump from the IRRI axial-flow pump and Bicol *sipa* pump, 1985.

more than twice that of the boat propellers commonly used by Bicol farmers. The sipa pump is attractive for both rainfed and irrigated farms, where improved control of irrigation and drainage results in substantial yield increases.

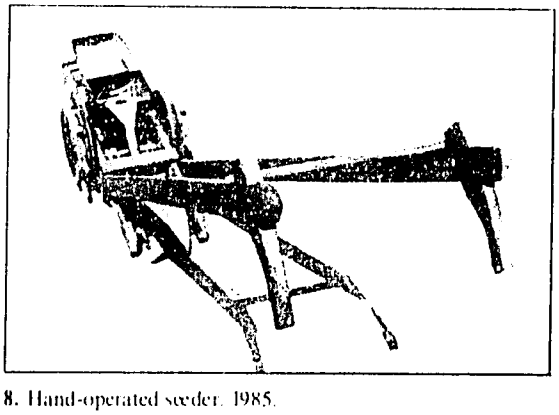
Indonesia. Over 1,000 threshers have been fabricated in West Sumatra, and over 2,000 axial-flow pumps have been manufactured in Java.

Burma. Animal-powered equipment such as a reaper and seeder have been developed in Burma. The draft of animal-powered implements is being measured (Fig. 7). A hand-operated seeder has been developed (Fig. 8) as well as a hand-powered Archimedes screw for lifting water (Fig. 9).

India. Ten manufacturers now fabricate IRRI-designed equipment in the southern states of India. Reapers, threshers, and transplanters are being introduced.



7. Measurement of draft, 1985.



8. Hand-operated seeder, 1985.

9. Archimedes screw being used to pump water in Burma, 1985.

Thailand. The inclined plate planter is well established in Thailand, with over 800 units sold in 1985. The cyclone seeder and improved water buffalo plow are now under commercial production. Emphasis was in the northeast region, where mechanization has not been practiced to any extent. The program in Thailand is now functioning without assistance from IRRI.

IRRI-NATIONAL PROGRAM COOPERATION

Various departments

Below are listed other significant cooperative country projects.

Burma. Three IRRI scientists worked with Burmese colleagues on the development of early maturing rice varieties and new cropping systems for the different Burmese rice environments. This work, along with that on the design and adaptation of bullock-drawn farm implements, has opened opportunities for two or even three rice crops annually. Burmese scientists attended short course at IRRI, and some undertook graduate training in Canada.

China. The Chinese Academy of Agricultural Sciences (CAAS) and IRRI strengthened research relating to resistance breeding and diversification of the genetic makeup of hybrids. IRRI continued to cooperate in the development of the China National Rice Research Institute (CNRRI) at Hangzhou and the National Germplasm Conservation Center. Shuttle breeding programs with CNRRI were continued, and cooperation was

extended in establishing the National Azolla Research Center at Fuzhou. With Academia Sinica, we cooperated in tissue culture and haploidy research. IRRI initiated new research initiatives with the Chinese Academy of Agricultural Mechanization Sciences (CAAMS) and CAAS on the economics of agricultural mechanization, and with CAAMS on postharvest technology and farm machinery development. Twenty-five Chinese MS and Ph D scholars studied at the University of the Philippines at Los Baños and conducted research at IRRI in 1985; 30 participated in short-term training.

Democratic People's Republic of Korea. Annual food grain production is about 9 million t in the Democratic People's Republic of Korea (DPRK). DPRK hopes to increase that to 10 million t in 1986 and 15 million t by 1995. During an IRRI team's first visit to DPRK in 1985, cooperation was proposed in breeding for early maturity and resistance to blast and bacterial blight, hybrid rice and tissue culture, and tidal wetlands. DPRK proposes to send students to participate in IRRI degree and nondegree training programs, and promote the exchange of scientists, germplasm, and information.

Egypt. Two IRRI scientists in Egypt helped identify IR lines with resistance to Egyptian races of blast. IRRI participated through an extension liaison scientist in *Mabrouk-1*, a production intensification program with a goal of 10 t ha. Plans were made to establish an irrigated rice production training center for other African countries in cooperation with the National Rice Institute being constructed at Sakha.

India. Collaborative research with the All-India Coordinated Rice Improvement Project is carried out in accordance with annual work plans developed with the Indian Council of Agricultural Research (ICAR). Collaborative research covers germplasm exchange and evaluation, pest and disease monitoring, soil fertility management, varietal testing, and agricultural machinery. During 1985, an International Agricultural Research Centers (IARCs)-ICAR joint program for developing more profitable and productive rice farming systems was initiated. The IARCs participating in this program are the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), CIMMYT, Centro Internacional de la Papa, and IRRI. Thirty-five visiting scientists, post-doctoral fellows, and graduate scholars from India worked at IRRI during 1985. In addition, 47 Indian scientists participated in short-term courses.

Indonesia. IRRI and the Agency for Agricultural Research and Development (AARD) planned an upland rice research and training program at the Sukarami Research Center. On-farm management of water use is the focus of a new cooperative irrigation management project covering nearly 250,000 ha in the Jatiluhur area. The development and local manufacture of implements to streamline the production and postharvest phases of rice farming systems are priorities of the farm machinery program.

Republic of Korea. IRRI cooperation included screening for disease and insect resistance and pest monitoring. We evaluated IRRI lines for resistance to bacterial blight and virus diseases, and IRRI and commercial Korean varieties for resistance to blast. Insect studies concentrated on susceptibility of insect pests to insecticides, resistance of Korean and IRRI varieties to white tip nematodes, and biological differences between Korean and Philippine planthoppers.

Malagasy. The IRRI-Madagascar Rice Research and Training Project was begun in 1984. In 1985 seven scientists were trained in five IRRI training courses and a special basic rice production course was conducted at IRRI. Two hundred twenty-eight introduced and indigenous cultivars were tested in 21 trials at 10 sites, and technology evaluation of improved rice farming systems was initiated on groups of farms in different parts of the country.

Pakistan. IRRI and the Pakistan Agricultural Research Council jointly undertook a program for biological control of rice pests. IRRI cooperates with the University of Agriculture, Faisalabad, in a joint MS and Ph D educational program. A monitoring tour enabled scientists from other countries to observe recent progress in the control of soil salinity in Pakistan.

Philippines. IRRI began cooperation in developing a plan for a Philippine Rice Research Institute and in identifying areas of collaborative research. The Philippine Seed Board released IRRI lines as IR64 and IR65. Since 1982 we have held semiannual technology transfer workshops

with officials of MAF. In March 1985 the first off-site workshop was held at the Maligaya Rice Research and Training Center in Central Luzon. MAF's management recommendations for transplanted irrigated and rainfed lowland rice culture were reviewed and refined.

Sri Lanka. IRRI and Sri Lanka strengthened collaboration in germplasm collection, rice breeding, weed control, and cropping systems improvement. A joint postgraduate program was developed with the University of Peradeniya. IRRI will cooperate with the Mahaweli Development Authority to develop improved rice technologies for 1 million ha recently brought under irrigation through a well-planned, well-executed, large irrigation project.

Thailand. Cooperative research is being intensified in improving yields of rainfed lowland rice, particularly in northeast Thailand and in saline areas, and in the improvement of grain quality. A shuttle breeding program was developed to speed the development of deep water rice varieties, and we collaborated with Australian and Thai scientists in studies of the unique physiology of the deep water rice plant.

MISSIONS TO AFRICA

Various departments

In late 1985, IRRI sent missions to East and Central Africa (Tanzania and Malawi) and West Africa (Guinea, Ghana, and Nigeria) to identify on-farm agronomic constraints and ways in which IRRI could help alleviate them; document rice policies that influence research and production; identify opportunities for and the preconditions necessary to establish rice research and production programs; and establish a framework in which IRRI could cooperate with national programs. The International Institute of Tropical Agriculture in Nigeria, WARDA in Liberia, and IRRI entered into a 5-yr agreement to implement the recommendations made in the areas of training, networking, and technical assistance.

PROSPERITY THROUGH RICE

Various departments

Net and stable income mean more than yield to South and Southeast Asian rice farming families, which typically consist of five or six members on a holding of less than 1 ha. Population pressure on land tends to be high in irrigated areas, where there are large numbers of landless agricultural laborers. Therefore the greatest challenge to rice research and development agencies is to increase the purchasing power of rice farmers by providing them with greater opportunities for skilled on-farm and off-farm employment. In 1983 IRRI joined with other Los Baños institutions and formed, with financial support from the Asian Development Bank, the Prosperity Through Rice Project to

- demonstrate how to reduce production costs without lowering yield;
- demonstrate ways to optimize the employment and income potential of rice farming systems through the most efficient use of available land, water, labor, and capital;
- demonstrate how to make value-added products from rice straw, bran, and hulls; and
- share with national program officers the best available information on whole-plant utilization and income-maximizing methods.

IRRI's cooperators in this venture are the University of the Philippines at Los Baños, the Philippine Council for Agriculture and Resources Research and Development, the Forest Research Institute, and the Forest Products Research and Development Institute.

We do our research and training on a demonstration farm that includes rice-based cropping patterns, livestock, azolla propagation, mushroom culture, compost making, home vegetable gardening, and biogas generation. In 1985 we studied farming systems components and ways to increase yield at minimum cost, and we demonstrated several whole-plant utilization technologies. We also experimented with a low-cost solar dryer and an improved village rice mill.

Low-cost yield-increasing technology. The major components of the rice yield demonstration were varietal choice, timing of crop establishment, nutrient management, pest management, and cropping pattern.

Varieties used in the demonstration utilized soil N efficiently, were responsive to fertilizer N, and had built-in resistance to pests and diseases. The crop was established so that it received maximum solar radiation at reproduction and ripening, and escaped major pest and disease pressures.

We increased profits through a 40% reduction in fertilizer N requirement using split applications of N: two-thirds applied basally at planting without standing water, and one-third topdressed 5-7 d before panicle initiation.

We monitored pest populations regularly and held pesticide application to a minimum. Under Los Baños conditions, however, weed management was most economical with commercial herbicide such as butachlor at 0.75 kg ai/ha or 2,4-D at 0.5 kg ai/ha at preemergence.

The choice and management of the nonrice crop is critical to ensure high profitability. For the second consecutive year, the rice - rice - off-season tomato pattern gave the highest gross margin of 10 patterns tested. This cropping sequence provided continuous utilization of farmland and generated year-round employment.

Farming systems and biomass utilization. Two major activities during 1985 were crop intensification and crop-livestock integration. We tried several cropping patterns in an attempt to match harvests with the most favorable local markets for each crop. In addition to three rice crops, we tried raising fish between two rice crops, and two successive rice crops followed by a crop of hybrid maize, sweet maize, or mungbean.

Rice biomass and other crop residues are fed to livestock in an integrated crop-livestock operation that includes cattle, swine, goats, and both broiler and laying chickens.

Some of the livestock manure and crop residues are used to generate biogas or are composted for organic fertilizer. Azolla is also grown as an organic fertilizer, and rice straw used as a substrate in mushroom growing is ultimately composted.

We use the rice biomass as a raw material for value-added products as well as for animal feed, compost, or biogas generation. We use rice straw to make paper; rice hulls are used to make charcoal and solid or hollow building blocks, and to fuel crop dryers.

Training. The first Prosperity Through Rice Course was held in January 1985 for 16 senior officers from 9 countries and was repeated in October. The course teaches the concept of a rice refinery for efficient utilization of the rice biomass, maximization of income and employment through crop integration with livestock and aquaculture, and methods for maximizing production using low-cost, farm-grown inputs. Scientists from the Carlsberg Laboratory, Copenhagen, Denmark, assisted in dealing with biomass utilization and presented a proposal for establishing mini-rice refineries in villages for preparing value-added products from crop residues.

Cooperative programs

Communication and publications

Communication and Publications Department

PUBLICATIONS **520**
SUPPORT TO IRRI SCIENTISTS **520**
INITIATION OF *RICE ABSTRACTS* **520**
MICRO AND MACROPHOTOGRAPHY LABORATORY **520**
BOOK FAIRS **520**
INTERNATIONAL AGRICULTURAL RESEARCH CENTERS PUBLICATIONS CATALOG **520**
RESEARCH ON EFFECTIVENESS OF MATERIALS IN ENGLISH AND LOCAL LANGUAGES **521**

PUBLICATIONS

We distributed more than 75,000 copies of major publications in 1985. About 30% were free, mostly to key Third World libraries, and the remainder were sold.

Nineteen major publications in English were released in 1985. A full listing is found in the section on Publications and Seminars. In addition, 25 translations of IRRI books were copublished by cooperators in national programs:

- Field problems of tropical rice (Bengali, Bikol, Cebuano, Farsi, French, Hiligaynon, Ilokano, Pampango, Punjabi, Tagalog, Thai, Waray editions)
- A farmer's primer on growing rice (Bahasa Indonesia, Bahasa Sunda, Bengali, Bikol, Kiswahili, Marathi, Pampango, Spanish, Tagalog editions)
- Fundamentals of rice crop science (Chinese, Vietnamese)
- An illustrated guide to integrated pest management in rice in tropical Asia (Bahasa Indonesia)
- Adoption, spread, and production impact of modern rice varieties in Asia (Japanese)

Four issues of the *IRRI reporter* were published and distributed to about 16,000 rice workers. Six issues of the *International rice research newsletter* and the subject index for 1984 were published. One issue of the *International upland rice newsletter*, and one issue of a new periodical, the *International azolla newsletter*, were published. Sixteen issues of the IRRI research paper series came out. See Publications and Seminars for a complete listing.

SUPPORT TO IRRI SCIENTISTS

In 1985, the department produced 130,000 slides, 42,000 black and white photos, and 8,000 pieces of artwork. We arranged 16 exhibits, released 2 video films, and printed about 18 million pages in house.

INITIATION OF *RICE ABSTRACTS*

Agricultural improvement agencies in developing countries often lack the funds to subscribe to international scientific journals. *Rice abstracts* (RA) from the data base of CAB International has been published for several years, but most of its circulation has been in highly developed countries.

IRRI and the Asian Development Bank initiated a cooperative program with CAB in 1985 to provide bimonthly RA subscriptions to libraries of 1,000 key rice improvement programs in developing nations for 3 yr. RA will now carry a dual imprint, CAB and IRRI.

MICRO AND MACROPHOTOGRAPHY LABORATORY

The Eastman Kodak Co. has helped IRRI establish a state-of-the-art micro and macrophotography laboratory, and arranged a special 2-1/2 week training course for 5 IRRI staff.

The equipment includes a camera for light-scanning macrophotography — one of about a dozen such units in the world. The camera allows us to capture both detail and depth of field in a macrophotograph (Fig. 1).

The unit will enable IRRI to take high-quality photos to help rice workers and farmers identify problems of rice such as insects, diseases, or weed seeds. IRRI will also provide transparencies to national agricultural improvement programs to use in their own educational materials.

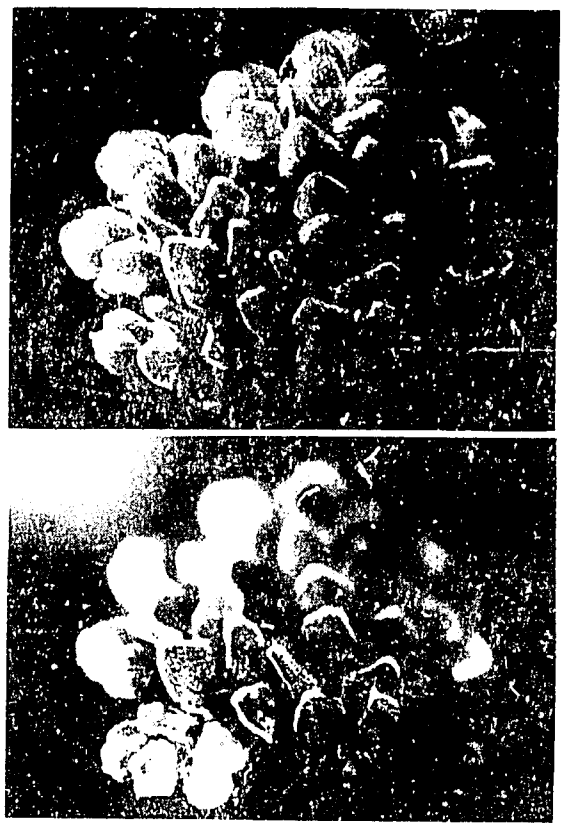
The lab will also be used to train national information specialists in micro and macrophotography.

BOOK FAIRS

For the third year, IRRI, the German Agency for Technical Cooperation (GTZ), and the Consultative Group on International Agricultural Research (CGIAR) sponsored an exhibition of center publications at the Frankfurt Book Fair. IRRI assisted ICRISAT in a center exhibition at the New Delhi World Book Fair. We arranged 1985 exhibitions of our publications at other fairs in China, India, Libya, Mexico, and Zimbabwe.

INTERNATIONAL AGRICULTURAL RESEARCH CENTERS PUBLICATIONS CATALOG

IRRI published a 1985 edition of *Publications of the international agricultural research and de-*



1. The scanning macrophotograph of an azolla plant (top) has greater detail than the conventional photograph of the same specimen

velopment centers and handled its world distribution on behalf of all centers. The catalog includes educational materials published by all CGIAR centers, as well as those of non-CGIAR centers.

The 691-page catalog includes 162 pages of a detailed subject index. It is probably the largest compilation of titles on Third World agriculture in existence.

We distributed 5,500 copies of the 1984 Catalog.

RESEARCH ON EFFECTIVENESS OF MATERIALS IN ENGLISH AND LOCAL LANGUAGES

In 1985 IRRI and Araneta University finished an evaluation of the effectiveness of *A farmer's primer* and the poster *Natural enemies of insect pests of rice* in English vs Cebuano, the major dialect in two regions of Leyte and Southern Leyte, Philippines. The Philippines is essentially an English-speaking country, and all respondents know English.

We pretested knowledge levels in rice farming, biological control of insect pests of rice, and attitude toward biological control among 88 extension workers. Tests for half of the technicians were conducted in English; the others were tested in Cebuano.

We then gave one group the primer and poster in English, and the other group the same items in Cebuano. Forty-five days later we post-tested.

The increase in knowledge level of both groups was significantly higher after the intervention, but the knowledge gain and attitude change of the extension workers exposed to Cebuano editions of both publications were significantly higher (.01 level) than those of the group exposed to the English materials.

Cooperative programs

Technology sharing

COLLABORATION WITH ADVANCED INSTITUTIONS **524**
TRAINING **525**
CONFERENCES, WORKSHOPS, AND MEETINGS **526**

COLLABORATION WITH ADVANCED INSTITUTIONS

Various departments

Progress in science and technology is moving so rapidly that no single institution can initiate research on every frontier of science. Collaborative programs allow IRRI to tap upstream technology — the scientific expertise and equipment available in advanced institutions in developed and in some developing countries — to solve the downstream problems of small-scale rice farming.

For example, sophisticated measurement techniques and equipment (upstream research) are being used in a Laguna farmer's field to better understand the problem of minimizing the loss of N fertilizer. Australian scientists from the Commonwealth Scientific and Industrial Research Organization (CSIRO) work with IRRI agronomists on the downstream project.

Similarly, IRRI scientists developed a serology technique that enables rapid and accurate diagnosis of tungro and other virus diseases from dry leaf samples collected in remote areas. The work was made possible by electron microscopes and facilities contributed by the Government of the Netherlands. With the electron microscopes we visually confirmed the presence of the virus — its size, shape, and concentration — throughout the purification process to produce antiserum.

Wild rices have been found to be remarkable reservoirs of genetic resistance. Screening of 49,000 rices showed that only 2.6% of the cultivated vs 53% of the wild rices carry resistance to green leafhopper. We will put that resistance to use in farmers' fields through wide hybridization, or the crossing of wild and domestic rices — the focus of a new cooperative genetic engineering program with the Rockefeller Foundation.

Fifteen IRRI departments had 90 such special projects with institutions and international agencies in developed and developing countries in 1985. Projects in which the research was conducted primarily at a location other than IRRI are listed in Table 1.

Research organizations in Australia, France, the Federal Republic of Germany, the Netherlands, the United Kingdom, and the United States seconded scientists to work at IRRI on specific collaborative research projects.

Table 1. Collaborative research projects conducted primarily outside IRRI, 1985.

Project	Collaborating institution
Plant breeding	
Maintenance and improvement of the nutritional value of rice through greater understanding of factors controlling grain protein content	University of Durham, UK
Seed production technology for hybrid rice	University of Tuscia, Italy
Transfer of cytoplasmic male sterility through protoplast fusion and regeneration in rice	University of Nottingham, UK
Mechanisms of salinity tolerance in rice	University of Sussex, UK
Application of tissue culture techniques in the development of salinity tolerance in rice	Colorado State University, USA
Application of protoplast fusion techniques to the development of wide crosses in rice	University of Nottingham, UK
Somatic embryogenesis from seed	University of Viterbo, Italy
Plant protection	
Methods for the isolation and characterization of botanical pesticides for rice	Justus Liebig University, Giessen, Federal Republic of Germany
Applications of botanical pesticides	University of Hawaii, USA
Use of pheromones of rice insect pests for crop protection	Tropical Development Research Institute, UK
Microbial agents for the control of brown planthoppers and green leafhoppers	Boyce Thompson Institute, USA
Chemical basis of resistance of rice to brown planthoppers	USDA Western Regional Research Center, USA
Characterization of biotypes of of brown planthopper and green leafhopper	International Centre for Insect Physiology and Ecology, Kenya
Production of monoclonal antibodies for use in rice virus epidemiology	USDA, Maryland, USA
Characterization of rice viruses	National Agriculture Research Center, Japan
Tarsonemid mite-associated rice virus and rice discoloration	Hokkaido University, Japan
Genetics of blast resistance in indica rices	National Institute of Agricultural Sciences, Japan
Epidemiology of *Pyricularia oryzae*	Justus Liebig University, Giessen, FRG
Partial resistance to rice diseases	University of Wageningen, Netherlands

continued on opposite page

Table 1 continued.

Project	Collaborating institution
Developing isogenic lines for bacterial blight resistance	Tropical Agriculture Research Center, Japan
The molecular basis of the interaction between rice and the bacterial blight pathogen	University of Birmingham, UK
Evaluation of chemicals for bacterial blight control	University of Ghent, Belgium
Genetics and ultrastructure of bacterial blight infection and resistance induction	Kansas State University, USA
Seed transmission of rice pathogens	Institute of Seed Pathology (DGISP), Denmark
Plant physiology, plant nutrition, and soil fertility	
Physiology of submergence tolerance in deep water rice	University of Western Australia, Australia
Identification of characteristics of certain rice varieties able to utilize soil nitrogen efficiently	University of California, USA
Photosynthesis and respiration as related to dry matter production in field-grown rice	University of Hamburg, FRG
Abscisic acid in rice plants and water use efficiency	Institute of Plant Breeding, UK
Methods for quantitative field assay of ammonia losses from rice paddies	CSIRO Division of Plant Industry, Australia
Fertilizer formulation and application methods to increase fertilizer nutrient efficiency for rice	International Fertilizer Development Center, USA
Nitrogen dynamics and balance in wetland rice soils	Justus Liebig University, Giessen, FRG
Effects of organic amendments on physical and chemical properties of rice soils	University of Hamburg, FRG
Use of micromorphological methods in studies of effects of rice soil puddling	National Research Center, Italy
Water and nitrogen availability for legumes grown following a rice crop	University of Reading, UK
Decomposition of organic compounds in paddy soils	University of Hamburg, FRG
Natural abundance of ^{15}N in rice and its application to studies of nitrogen fixation	International Atomic Energy Agency, Austria
Physico-chemical "finger-printing" for azolla identification	Washington State University, USA
Effect of shading by rice canopy and other factors on nitrogen fixation in azolla	Justus Liebig University, Giessen, FRG

Table 1 continued.

Project	Collaborating institution
Agricultural economics and food policy	
Role of sociology in technology development for rice improvement	University of Wageningen, Netherlands
Technical and price efficiency in rice production	National University, Singapore
Postharvest technology and food processing	
Optimizing the nutritional contribution of rice in rice-based diets	National Institute of Agricultural Sciences, Denmark
Varietal differences in feed value of rice straw fed to ruminants	La Trobe University, Australia
Agricultural mechanization	
Development of rice husk gasifier	University of California, USA
Agroecology, meteorology, and environment	
Systems analysis and simulation modelling for rice production	Agriculture University, Wageningen, Netherlands
Location and configuration of major rice producing environments	Dartmouth College, USA

TRAINING

Long before the term technology transfer came into vogue, IRRI was committed to the sharing of research results with and between national programs. In fact, the technology sharing or transfer concept is at the heart of IRRI. Five of our six statements of purpose are directed to that goal. The first purpose, of course, is to conduct research on rice production and management for the benefit of the people of Asia and other areas. The remaining five all relate directly to technology sharing: publish and disseminate research findings, distribute improved plant materials, educate promising young scientists, operate an information center and library, and hold periodic local, regional, or international conferences.

We conducted our first training course in 1964. Since our founding we have sponsored more than 60 international conferences and workshops. We have coordinated international networks such as the International Rice Testing Program and the Asian Rice Farming Systems Network. And we have actively cooperated with national research programs through bilateral collaborative agreements.

The year 1985 saw significant changes in our training programs and the expansion of our collaborative work in Africa.

The hallmark of IRRI training programs has always been training of researchers. Theory and practice ensure that our trainees can conduct problem-solving research. Although that has been a successful formula in knowledge transfer, it has not always permitted the ready tailoring of information and training to the specific needs of various national programs.

Recently we began to teach teaching methods in addition to course content. This will enable trainers to tailor courses to meet in-country needs, whether to train researchers or extension workers, who can in turn teach the farmers.

In Bhutan, for example, we are developing an in-country rice production course. The adaptation of the course began in 1984 with the assignment of a Bhutanese scientist at IRRI to work with the Training and Technology Transfer Department to learn the course basics. Then he and his colleagues in Bhutan prepared field materials for the first program while IRRI trainers prepared course materials.

The first course in 1984 was conducted by IRRI staff with support from their Bhutanese counterparts. In 1985 it was conducted jointly, with IRRI serving more of a support role in course evaluation. We have begun a similar program to adapt and transfer a longer rice production course for Burma.

All IRRI courses reflect technology or expertise developed at the Institute, and respond to needs expressed by national program cooperators or recognized by IRRI staff. See the section on Training Programs for more details.

CONFERENCES, WORKSHOPS, AND MEETINGS

The following conferences, workshops, and meetings were held in 1985.

January	
16-17	BOSTID Research Grants Program Meeting
21-30	Orientation and Training Program on Improving the Income and Employment Potential of Rice Farming Systems
February	
15	IRRI Academic Council
18-25	Internal Program Review
26	Audit/Nominating Committee
28-8 March	Second International Conference on Upland Rice (Indonesia)
27	Program Committee
28-1 March	Full Board Meeting
March	
11-14	Korea-IRRI Work Plan Meeting
11-15	Workshop on Varietal Improvement of Upland Crops for Rice-Based Farming Systems (Thailand)
14-15	Technology Transfer Workshop (MRRTC, Nueva Ecija)
20-21	Thailand-IRRI Work Plan Meeting
31-6 April	Workshop on the Use of Azolla (China)
April	
8-17	INSFFER Monitoring Tour (Australia)
10-13	Women in Rice Farming Systems Project Design Workshop
22-10 May	USAID Asia Bureau of Agricultural and Rural Development Officers' Conference
May	
27-31	International Rice Genetics Symposium
June	
1-5	International Rice Research Conference (1985)
6-8	25th Anniversary Symposium on Rice Farming Systems: Accomplishments and Unfinished Tasks
10-14	International Rice Commission of FAO (IRC)
12-14	Center Directors Meeting
17-25	Technical Advisory Committee Meeting

July	
30	Academic Council Meeting
August	
12-14	Executive Committee (IRRI Board of Trustees)
September	
2-7	Small-Farm Equipment For Developing Countries: Past Experiences and Future Priorities
16-28	Farming Systems Socioeconomic Research Monitoring Tour/ Workshop
21-2 October	Salinity Monitoring Tour (Pakistan, India, and Thailand)
30	Women in Rice Farming Systems: Philippine Component
October	
1-11	Training on Prosperity Through Rice
14-16	Full Board Meeting
November	
3-14	Deepwater Rice Monitoring Tour (Thailand, India, and Bangladesh)
18-21	BNF-UNDP Advisory Committee Meeting
22-23	MAF-IRRI Technology Transfer Workshop

Research support services

LIBRARY AND DOCUMENTATION CENTER 530
EXPERIMENTAL FARM 530
ANALYTICAL SERVICE LABORATORIES 532
Output 532
Research 532
Available soil P 533
Hot water-extractable boron 533
Urea nitrogen in floodwater 533
Ammonium nitrogen 533
Computerization 533
Additional analysis 534
PESTICIDE RESIDUE LABORATORY 534
PHYTOTRON 534
SEED HEALTH UNIT 534

Publications and seminars

PUBLICATIONS 536
SEMINARS 546

Finances 550

Staff changes 551

Weather summary 553

Research support services

LIBRARY AND DOCUMENTATION CENTER

In 1985, the library issued the following publications:

- *25 years of IRRI theses and dissertations: an abstract bibliography*
- the 25th anniversary issue (1984 supplement) of the *International bibliography of rice research*
- the 1985 supplement to *Theses and dissertations on rice available in the library of the International Rice Research Institute*
- 12 issues of the library list of recent accessions (January to December)

These publications were distributed without charge to about 600 libraries and documentation centers in the rice-producing world. Many were also sold to subscribers.

The rice literature search service became operational in 1985. With the assistance of the Statistics Department, IRRI's scientific staff and their assistants were trained to make literature searches. In addition to a terminal, a printer was installed in the library. The 1985 data were activated so that a search now includes all materials being processed.

In addition to the continuous entry of current rice information, retrospective information was stored. The 1970-85 data are now in the system; rice information covering 1951-69 was prepared for entry.

Numerous requests for information and photocopying services were received in 1985, notably for literature on genetics and breeding, postharvest technology, azolla, and tissue culture. Assistance was furnished in library organization and management, selection and acquisition of agricultural materials, and the processing of special materials such as microfilm, maps, pamphlets, and ephemera.

Within IRRI, the number of books and journals borrowed reached an all-time high. Researchers and students from the Los Baños community, Metro Manila, and Central Luzon also used the library facilities. The demands were not for rice literature alone, but for information in other disciplines as well.

The addition of 4,584 monographs (books, pamphlets, and reprints) increased the total monograph collection to 73,895. An additional 117 serial titles were added through subscriptions, exchanges, and gifts.

Maps, translations, and microfilms were also added. The catalogue card production was 18,500.

In 1985, the library acquired the entire collection of theses and dissertations on rice of the library of Himachal Pradesh Krishi Vishva Vidyalaya, India, and the master's theses and doctoral dissertations on rice from the library of Louisiana State University, USA.

Circulation of tables of contents of newly received journals to keep the scientists informed of the latest publications on rice was continued within IRRI and to several stations in Indonesia, Bangladesh, and Africa. Citations of Japanese and Chinese publications were also forwarded to CAB International.

The library also took care of staff and scholar needs with regard to book purchases and binding services.

EXPERIMENTAL FARM

Deepening of canals in the upland areas was begun, but delays were caused by the bogging down of the old backhoe and the late arrival of a new one. All main drainage canals were widened and made fully functional.

Culverts were installed between blocks UC and UF up to the newly developed area in UB so that water coming from upland fields UX, UW, UQ, UR, and UL could be diverted to the Cambantog River, thus minimizing floodwater at the corner of UA, which had been a perennial problem. Culverts were installed from the corner of UA across the newly developed road separating IRRI and BIOTECH to ease the flow of floodwater coming from UV, UW, UO, UM, UI, and UB. Likewise, flooding at the lower portions of series 600, 700, and 800 in the lowland area was remedied by installing culverts and widening the canals of private fields.

An additional 5-ha lot of the University of the Philippines was converted to lowland at no cost to the University on the condition that IRRI be allowed to use it but will vacate it when the University needs it.

Provision was made to supply the newly constructed International Rice Germplasm Center screenhouse with irrigation water low in B content by establishing an underground connection at the middle of UO, where the water source is the reservoir at UT.

Azolla and *Sesbania* propagation plots were maintained as sources of N for our production plots.

Hay was turned into compost as a source of organic matter for the production plots.

More than 229 ha were prepared and planted during 1985, an increase of 43.5 ha over 1984. Major users were Plant Breeding (35%), Experimental Farm (17%), International Rice Germplasm Center (10%), Agronomy (10%), and Entomology (9%).

A total of 39.4 ha was planted for seed multiplication and for rice for IRRI employees during the Christmas season. The following varieties and selections were planted: IR841, IR62, IR442, IR56, IR52, C22, IR28150-84-3-3-2, IR18348-36-3-3, Malagkit Sungsong, IR58, and IR64. Almost 177 t of rice were produced on the farm, 109 t of which were for seed and 68 t for milling.

The various IRRI departments turned over to the Experimental Farm almost 268 t of rice for milling.

During the year, almost 174 t of fertilizer valued at almost $39,966 was used on the farm (Table 1).

For insecticides and sticker, over $51,959 was spent in 1985 (Table 2).

Table 1. Fertilizer use and value, IRRI, 1985.

Kind	Quantity (kg)	Value[a] ($)
$(NH_4)_2SO_4$	69,900	12,334
Solophos	25,000	4,980
Muriate of potash	6,700	1,520
Urea	45,800	14,138
Complete (14-14-14)	26,300	6,803
Zinc oxide	2	2.50
Triple superphosphate	120	1,896
Total	173,822	39,966

[a]US$1 = ₱17.96.

Table 2. Insecticide use and value, IRRI, 1985.

Kind	Quantity	Value ($)
Diazinon 5-G	10,680 kg	9,359
Diazinon G	375 kg	423
Diazinon 10-G	370 kg	587
Phenthoate	885 kg	936
MIPC WP	631 kg	4,698
Sevin 85S	16 kg	148
Acephate	176 kg	2,528
Applaud-Qufrofezin 25WP	45.2 kg	967
Monocrotophos 168	1,682 liters	12,687
Chlorpyrifos 31.5	1,016 liters	9,151
Monocrotophos 202R	593 liters	6,310
Marshal 150EC	72 liters	1,543
BPMC 50EC	234 liters	1,420
Ethylan 45EC	13 liters	119
Propoxur 20EC	3 liters	30
BPMC 50EC	95 liters	358
Tenac sticker	128 liters	333
Benomyl 50WP	4 kg	200
Methyl parathion 50EC	57 liters	155
Shellcarb 50WP	2 kg	15
Total		51,970

To control weeds in the experimental and production plots as well as those growing on levees, ditches, and roadways with the use of chemicals, over $9,855 was spent (Table 3).

Farm income for 1985 amounted to $55,785 (Table 4), which was derived from the sale of farm products. In addition, we had in our storeroom at year's end 16,047 kg of rough rice for milling valued at $3,127 and 108,988 kg of rice for seed valued at $24,522.

The amount of $249,399 was spent for contract labor in 1985, with 59% paid to bird watchers, 26% for planting and weeding, and 15% for land preparation.

A total of 15,597 rats were killed by flame throwing (58%), electric fence (21%), and digging, mowing, baiting, and trapping operations (21%).

Table 3. Herbicide use and value, IRRI, 1985.

Kind	Quantity	Value ($)
Butachlor-MPMT, G	4500 kg	4426
Butachlor-MPMT, EC	114 liters	1125
Paraquat	184 liters	2241
MCPA, G	3875 kg	1200
MCPA, EC	112 liters	516
Thiobencarb, D	600 kg	363
Total		9870

Table 4. Farm income, IRRI, 1985.

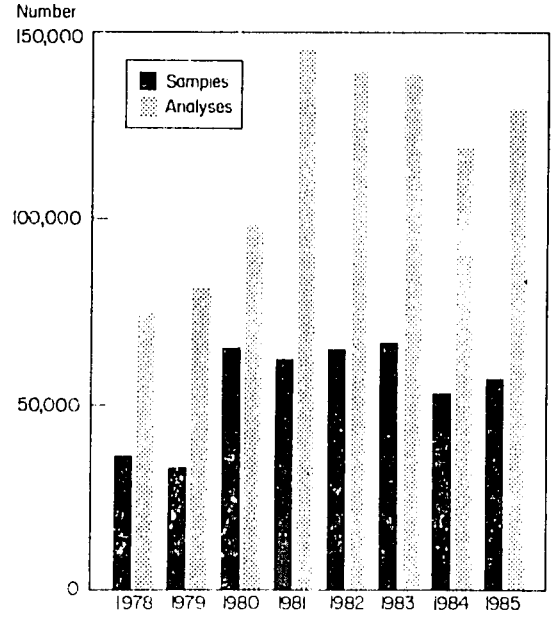
Item	Quantity (kg)	Value ($)
Seeds		
IR29	37	8
IR36	1,023	285
IR42	658	133
IR43	263	85
IR48	44	14
IR50	103	38
IR56	24	7
IR60	2,970	895
IR62	17,626	5,250
IR64	19,031	5,848
IR65	74	22
IR18348-36-3-3	22	6
IR841	352	106
UPLRi5	176	55
Rough rice for milling	150,991.72	27,425
Milled rice	47,431.14	13,731
Yellow flint maize	1,983	297
Glutinous rice	198	71
Supersweet maize		1,176
Sorghum		87
Soybean		25
Mungbean		62
Wheat		118
Rice bran	243.5	37
Total		55,785

Sustained baiting was done in the experimental fields, along the banks of creeks, underneath the coconut trees, along fence lines, and in nearby farmers' fields. Better rat control was observed during 1985 because of the use of energizers, which are nonlethal electric barriers that may be powered by either a 12-V automobile battery or by solar batteries.

We have found the Super 60 (G316) model donated by the New Zealand manufacturer the most effective in preventing rats from entering the experimental plots. These energizers are quite suitable for research station use where experimental trials have high value, but at present prices are too costly for general farm use.

ANALYTICAL SERVICE LABORATORIES

Output. The Chemical Analysis Laboratory (CAL) ran 129,626 analyses on 56,552 samples of soil, plant, fertilizer, and aqueous solutions. These numbers are consistent with the leveling-off trend during the past 5 yr (Fig. 1).



1. Total number of samples and analyses run by the IRRI Chemical Analysis Laboratory, 1978-85.

Program areas relying on analytical data provided by CAL were soil and crop management (75.2%), GEU (8.8%), cropping systems (6.6%), control and management of rice pests (3.5%), water management (2.3%), constraints on rice yields (1.9%), and climatic environment (1.7%).

Income for services rendered amounted to $40,562. The subsidy was $21,300 — 34% of the total expenses.

The Mass Spectrometer Laboratory ran a total of 9,752 $^{15}N/^{14}N$ ratio analyses on ^{15}N-labeled $(NH_4)_2SO_4$ derived from soil, plant, and floodwater samples from the N research program. The income received amounted to $6,478 and the subsidy was $5,690 or 42%.

The Radioisotope Laboratory counted ^{14}C activity in 3,048 samples (2,547 soils, 176 gases, 320 plants, and 5 herbicides). The major user was the research program on management of organic manures.

Research. Because of the large number of samples requiring analysis, CAL has opted for rapid, inexpensive analytical methods. Research initiated in 1984 on improvement of methods was continued in 1985. Priority was given to investigation of sources of error, modification and refine-

ment of existing analytical procedures, testing of new methods, and real time data acquisition.

Available soil P. Olsen extractable P is analyzed by the method proposed by the Agricultural Development and Advisory Service of the Ministry of Agriculture, Fisheries, and Food, England, which uses polyacrylamide instead of activated C for removing interference due to organic matter, and ascorbic acid instead of $SnCl_2$ for reducing the phosphomolybdate complex. At CAL, the colorimetric determination is automated using a Technicon AutoAnalyzer Model I system. The results were compared with those of the Soil Chemistry/Physics research laboratory, which employs the conventional manual colorimetric method.

The causes of observed variations in the test results between the two laboratories were traced to differences in soil-to-extractant ratio, manner of shaking, and reducing agent used. The CAL method was refined to give test results that agree with those using the conventional Olsen P method.

Hot water-extractable boron. B toxicity has been identified as a major growth-limiting factor in several blocks of the IRRI farm, thus mandating a rapid and reliable method of testing soil for available B.

Hot water extraction using a hot plate is not convenient when working with a large number of samples because of uneven heating and nonuniform boiling. Variation in boiling time can cause significant errors. The Buchi 6-place digester was tested and found to be suitable because it allows uniform heating and automatic control of boiling time. An added advantage is its use of quartz flasks, which eliminate B contamination.

Most colorimetric methods of B analysis involve tedious manual procedures that are often not adaptable to automation. The manifold designed by Porter et al (1981) for a "hybrid" continuous flow system makes use of Azomethine-H prepared in situ in the determination of B and overcomes the effect of sample extract color by dialysis; the scheme is labor saving and less time-consuming than manual colorimetric methods. Porter's manifold was modified to suit CAL's Technicon AutoAnalyzer Model II. The results of the analysis employing the redesigned manifold agree closely with those of the curcumin method, the standard method used by the Soil Chemistry/Physics and Plant Physiology Departments.

Urea nitrogen in floodwater. The procedure for estimating urea N in floodwater is an adaptation of the standard method of Douglas and Bremner (1970) to the Technicon AutoAnalyzer I system. This procedure is based on the following reaction mechanism: Diacetylmonoxime (DAM) is hydrolyzed in the presence of strong acids to diacetyl. Diacetyl then reacts with urea in the presence of a catalyst and a color intensifying reagent like thiosemicarbazide, forming a red condensation product that can be measured at 480 mμ. The manifold used earlier gave absorbance peaks of standard checks that became progressively smaller with time. This was traced to the fact that DAM and the acid reagent were premixed in one reservoir and introduced into the manifold as a single reagent, causing early hydrolysis of the DAM and possible degradation of the hydrolysis product before reaction with urea could take place. The manifold was redesigned to prevent early hydrolysis and subsequent degradation of the color reagent, DAM.

Ammonium nitrogen. The colorimetric determination of NH_4-N used previously was based on the indophenol blue complex formed by the reaction of NH_4 with phenol in the presence of hypochlorite. Both reagent (phenol) and product (*o*-chlorophenol) are volatile and very poisonous. In addition, phenol is expensive. An alternative method that uses salicylate as the color reagent and that results in a less harmful product is available but employs the more expensive Technicon AutoAnalyzer Model II. To enable us to cope with the large number of requests for N analysis, we redesigned the manifold to suit the older model, of which we have three units. This manifold can be used for determining NH_4-N in aqueous, plant, and soil samples.

Computerization. Real time data acquisition by the North Star Horizon microcomputer from one Cahn electrobalance and one Technicon AutoAnalyzer Model II has been demonstrated to be feasible, but the existing microcomputer does not have the capacity to store data simultaneously acquired from more than two instruments. Additional hardware for simultaneous data acquisition from three Cahn balances and four autoanalyzer

systems and other measuring instruments is on order. We developed software for both data acquisition and for laboratory information management. The latter is entirely menu-driven and includes subroutines for analytical requirement compilation, data file updating, and report generation. It also has provision for manual data encoding.

Additional analysis. The following were added to the list of CAL's services: dithionite extractable Fe and Mn, available B, plant B, exchangeable acidity, exchangeable aluminum, P adsorption capacity, fertilizer P (citrate and water soluble), fertilizer K (citrate and water soluble), and particle size analysis (hydrometer method).

PESTICIDE RESIDUE LABORATORY

The Pesticide Residue Laboratory performed 1,031 analyses on 883 samples in 1985 (Table 5). Four hundred and ninety-nine samples were from the Agronomy Department for butachlor analysis. Entomology submitted 289 formulations of various pesticides and 59 soil and water samples for dissipation studies on carbofuran, carbosulfan, and monocrotophos. Twenty water samples from the IRRI Experimental Farm irrigation canals were tested for residues of regularly applied organophosphates and carbamates. Sixteen samples of rice seedlings were analyzed for carbofuran at the request of the Cereal Chemistry Department.

Cereal Chemistry submitted 20 samples of rice plant extracts for determination of insect resistance factors, and 9 aldononitrile acetate derivatives of cell wall sugars, while Plant Pathology sent 12 samples of bacterial extracellular polysaccharide derivatives for injection and quantitation.

PHYTOTRON

Fifty-six research projects of 12 departments used the Phytotron from 2 Jan to 17 Nov 1985. As in the past, the glasshouse room had the highest room usage (97%). The next most commonly used facilities were the 3SA-L naturally lighted cabinet (90%) and the Conviron artificially lighted cabinet (88%). For other rooms, usage ranged from 79% down to 22%. Downtime averaged 1.5 d.

Table 5. Analyses performed by the Pesticide Residue Laboratory, 1985.

Item	Analyses	GLC injections only
Butachlor	519	
Carbofuran	150	20
Diazinon	119	
Monocrotophos	93	
Isoprocarb	71	
BPMC	20	
Chlorpyrifos	20	
Carbaryl	20	
Carbosulfan	18	
Others	1	21
Total	1031	41

All requests for new and continuing Phytotron studies in 1985 were carried out.

The drying oven and leaf area meter were used heavily by phytotron users and other departments. The Plant Physiology Department used about 50% of the cold room for the long-term storage of rapid generation advance seeds.

The phytotron spent $111,435 for electricity and diesel fuel in 1985. This included the cost of energy shared by the Mass Spectrometer, Personnel/Scientific Storeroom Building, Soils Laboratory, and Tissue Culture Facility.

Sixty-one power interruptions were recorded in 1985 with a total duration of 75 h. The two standby generators of the Phytotron supplied emergency power during outages. No low power voltage (200V or less) occurred in 1985.

The annual maintenance checkup of facilities was performed by the Phytotron staff from 18 Nov to 31 Dec 1985. Mr. S. Nakamura of Koito Industries, Ltd., Japan, conducted the standard performance tests of the artificially and naturally lighted cabinets.

All moisturized double glass panels were replaced with single safety glass panels. New glass partitions were installed between glasshouse rooms. The whole glasshouse was resealed for leaks with Dow Corning silicon sealant.

SEED HEALTH UNIT

The Seed Health Unit (SHU) was organized to expedite the phytosanitary certification of rice for export from IRRI and to clear incoming rice seeds. In 1982, an IRRI staff member was deputized

Table 6. Outgoing seed lots for phytosanitary certification received from January 1984 to December 1985.

Activity	Seed lots examined (no.)		
	1984	1985	Total
Dry seed inspection[a]	255,070	136,328	391,398
Health tests[b]			
Untreated	2,024	3,272	5,296
Treated	1,689	1,540	3,229
Total	3,713	4,812	8,525

[a]Seed lots from IRTP were inspected by batch depending on the number of importing countries. [b]Include only seed samples used for routine seed health tests. Composite samples were used for IRTP. Samples used for health testing were derived from dry seed inspected seed lots.

Table 7. Incoming seed lots for postentry clearance received from January 1984 to December 1985.

Activity	Seed lots examined (no.)		
	1984	1985	Total
Dry seed inspection[a]	1,996	3,394	5,390
Health tests[b]			
Untreated	273	159	432
Treated	212	202	414
Total	485	361	846

[a]Seed lots from IRTP were inspected by batch depending on the number of importing countries. [b]Include only seed samples used for routine seed health tests. Composite samples were used for IRTP. Samples used for health testing were derived from dry seed inspected seed lots.

by the Philippine Plant Quarantine Service as a plant quarantine officer with authority for rice seeds only. This officer observes the certification requirements of the Philippine Plant Quarantine Service and that of the importing country.

SHU's quarantine certification steps include crop health inspection, dry seed inspection, routine seed health tests for general and specified pathogens, and phytosanitary seed treatment whenever necessary and permissible. Crop health inspection is done on all regular seed multiplication plots of the International Rice Germplasm Center, International Rice Testing Program, and Plant Breeding Department to gather records of diseases occurring in mother plants.

Between January 1984 and December 1985, SHU certified 391,398 outgoing seed lots and 5,390 incoming ones after field inspection, dry seed inspection, and seed health testing (Table 6, 7).

Publications and seminars

PUBLICATIONS

Under Institute Publications are listed the 23 major books produced by the Communication and Publications Department. Five of these were copublished in 25 multilanguage editions. Also listed are the 16 issues of the IRRI Research Paper Series. Subsequent sections list the output of individual scientists by department and the bibliographies produced by the Library and Documentation Center.

Institute publications

Major publications

An overview of upland rice research. Proceedings of the 1982 Bouaké, Ivory Coast, upland rice workshop. 566 p.

Genetic evaluation for insect resistance in rice - E.A. Heinrichs, F. Medrano, and H. Rapusas. 356 p.

Publications of the international agricultural research and development centers. 691 p.

Annual report for 1984. 504 p.

IRRI highlights 1984. 101 p.

Multilanguage publication in agriculture. Workshop report and description of participating agencies. 62 p.

An illustrated guide to integrated pest management in rice in tropical Asia - W.H. Reissig, E.A. Heinrichs, J.A. Litsinger, K. Moody, L. Fiedler, T.W. Mew, and A.T. Barrion (English and Bahasa Indonesia editions). 411 p.

International rice research: 25 years of partnership. 188 p.

Biotechnology in international agricultural research. 435 p.

Field problems of tropical rice (French, Tagalog, Waray, Pampango, Bengali, Hiligaynon, Cebuano, Farsi, Ilokano, Bikol, Thai, and Punjabi editions). 172 p.

Education for agriculture. Proceedings of the symposium on education for agriculture. 204 p.

A farmer's primer on growing rice (Pampango, Spanish, Bikol, Bahasa Indonesia, Bahasa Sunda, Bengali, Kiswahili, Marathi, and Tagalog editions). 221 p.

Wetland soils: characterization, classification, and utilization. 558 p.

The rice economy of Asia - R. Barker and R.W. Herdt with B. Rose. 324 p.

Rice diseases, 2d ed. - S.H. Ou. 380 p.

Parentage of IRRI crosses IR1-IR50,000.

Impact of science on rice. 303 p.

Insights of outstanding farmers. 114 p.

Soil physics and rice. 429 p.

Women in rice farming. 531 p.

IRRI alumni, 1985. 662 p.

Fundamentals of rice crop science - S. Yoshida (Chinese and Vietnamese editions). 269 p.

Adoption, spread, and production impact of modern rice varieties in Asia (Japanese edition). 54 p.

Research Paper Series

101. The economics of hybrid rice production in China, by He Giuting, A. Te, Zhu Xigang, S.L. Travers, Lai Xiufang, and R.W. Herdt. 14 p.
102. Rice ratooning, by J.S. Chauhan, B.S. Vergara, and F.S.S. Lopez. 19 p.
103. Growth and development of the deep water rice plant, by B.S. Vergara. 38 p.
104. FARIDPUR: a computer-assisted instruction model for rainfed lowland rice, by R.E. Huke. 14 p.
105. A reading and listening comprehension test in English for non-native speakers applying for training at IRRI, by E.P. Cervantes, D.R. Minnick, P.S. Goseco and R. Maminta. 13 p.
106. Rice grassy stunt virus 2: a new strain of rice grassy stunt in the Philippines, by P.O. Cabauatan, H. Hibino, D.B. Lapis, T. Omura, and T. Tsuchizaki. 8 p.
107. Physical losses and quality deterioration in rice postproduction systems, by Z.F. Toquero and B. Duff. 12 p.
108. Factors that affect the copublication of IRRI materials; a 12-country survey of translators and publishers, by V.L. Cabanilla and T.R. Hargrove. 13 p.
109. Classification of Philippine rainfall patterns, by R.A. Morris and F.M. Rumbaoa Jr. 19 p.
110. Contributions of modern rice varieties to nutrition in Asia, by J.C. Flinn and L.J. Unnevehr. 21 p.
111. Changes in rice breeding in 10 Asian countries: 1965-84. Diffusion of genetic materials, breeding objectives, and cytoplasm, by T.R. Hargrove, V.L. Cabanilla, and W.R. Coffman. 18 p.
112. Design parameters affecting the performance of the IRRI designed axial-flow pump, by M. Aban. 10 p.
113. Boron toxicity in rice, by M.T.C. Cayton. 10 p.

114. Energy analysis, rice production systems, and rice research, by J.C. Flinn and B. Duff. 10 p.
115. Production risk and optimal fertilizer rates: an application of the Random Coefficient Model, by J. Smith and G. Umali. 13 p.
116. Consumer demand for rice grain quality in Thailand, Indonesia, and the Philippines, by L.J. Unnevehr, B.O. Juliano, C.M. Perez, and E.B. Marciano. 20 p.

Administration

Greenland, D.J. 1984. Rice. Biologist 31(4):219-225.

Greenland, D.J. 1985. Physical aspects of soil management for rice-based cropping systems. Pages 1-16 *in* Soil physics and rice. International Rice Research Institute, Manila, Philippines.

Greenland, D.J. 1985. Upland rice. Outlook on Agriculture 14(1):26-29. Pergamon Press, U.K.

Greenland, D.J., and S.K. De Datta. 1985. Constraints to rice production and wetland soil characteristics. Pages 23-36 *in* Wetland soils: characterization, classification, and utilization. International Rice Research Institute, Manila, Philippines.

Morris, R.A., D.J. Greenland, and R.E. Huke. 1984. Remote sensing and rice research. Pages 33-54 *in* Application of remote sensing for rice production. A. Deepak and K. R. Rao, eds. A. Deepak Publishing, Hampton, Virginia, USA.

Swaminathan, M.S. 1984. New parameters and selection criteria in plant breeding. Pages 1-31 *in* Crop breeding. P.B. Vose and S.G. Blizt, eds. Pergamon Press, U.K.

Swaminathan, M.S. 1985. Achieving rural-urban harmony in agricultural development. Guest Lecture Ser. 3. Institute of Rural Management, Anand, Gujarat, India. 24 p.

Swaminathan, M.S. 1985. IRRI's research and training agenda. Pages 41-60 *in* Impact of science on rice. International Rice Research Institute, Manila, Philippines.

Agricultural Economics

Flinn, J.C., and B. Duff. 1985. Energy analysis, rice production systems and rice research. IRRI Res. Pap. Ser. 114. 11 p.

Flinn, J.C., and P.B. Shakya. 1985. A tobit analysis of the adoption and use rates of fertilizer on wheat in the Kosi Zone of Nepal. Indian J. Agric. Econ. 45(1):52-58.

Flinn, J.C., and L.J. Unnevehr. 1985. Contributions of modern rice varieties to nutrition in Asia. IRRI Res. Pap. Ser. 110. 21 p.

Mandac, A.M., and J.C. Flinn. 1985. Determinants of fertilizer use on rainfed rice in the Bicol Region, Philippines. Philipp. J. Crop Sci. 10(3):123-128.

Price, E.C., and T.R. Paris. 1985. The economics of small and large-scale soybean production in the Philippines. *In* Soybean in tropical and subtropical cropping systems. S. Shanmugasundaram and E.W. Sulzberger, eds. Asian Vegetable Research and Development Center.

Shakya, P.B., and J.C. Flinn. 1985. Adoption of modern varieties and fertilizer use on rice in the Eastern Tarai of Nepal. J. Agric. Econ. 36(3):409-419.

Sison, J., R.W. Herdt, and B. Duff. 1985. Mechanization employment and output. J. Philipp. Dev. 12(1).

Smith, J., and G. Umali. 1984. Fertilizer recommendations based on soil nitrogen levels: a total nutrient model. J. Agric. Econ. 35(2):231-241.

Smith J., and G. Umali. 1985. Production risk and optimal fertilizer rates: an application of the random coefficient model. IRRI Res. Pap. Ser. 115. 13 p.

Tautho, C.C., J.C. Flinn, and L.E. Velasco. 1985. Adoption and productivity of upland rice in Zamboanga del Sur, Philippines. Philipp. J. Crop Sci. 10(3):135-145.

Toquero, Z., and B. Duff. 1985. Physical losses and quality deterioration in rice production systems. IRRI Res. Pap. Ser. 107. 12 p.

Unnevehr, L.J., B.O. Juliano, C.M. Perez, and E.B. Marciano. 1985. Consumer demand for rice grain quality in Thailand, Indonesia, and the Philippines. IRRI Res. Pap. Ser. 116. 20 p.

Agricultural Engineering

Aban, M.M. 1985. Design parameters affecting the performance of the IRRI-designed axial-flow pump. IRRI Res. Pap. Ser. 112. 10 p.

Calilung, E.J., G.C. Salazar, C.L. Maranan, and R.E. Stickney. 1985. Comparison of axial-flow and centrifugal pumps for low-lift irrigation. Agric. Mech. Asia, Africa, and Latin America (AMA) 16(4).

Demegillo, J.A., C.L. Maranan, and Y.W. Jeon. 1985. Technical and economic evaluation of selected types of mechanical dryers. Philipp. Agric. Eng. J. 16(4), fourth quarter.

Gonzalo, B.C., and R.E. Stickney. 1985. MA-IRRI industrial extension program for small farm equipment. J. Philipp. Dev. 12(1).

Khan, A.U., F.U. Bautista, and A. Vasallo. 1985. Efficient fertilizer injector for paddy farmers. Philipp. Agric. Eng. 16(4):78-79.

Agronomy

Bhandari, D.C., and K. Moody. 1983. Ecology and management of weed communities in rice-based cropping systems. Pages 220-221 *in* Proc. National

Symposium on Advanced Frontiers of Plant Science. H.C. Arya, N. Sankhla, M.N. Tewari, N.S. Sekhawat, and S.D. Purohit, eds. University of Jodhpur, Jodhpur. India.

Calabio, J.C., and S.K. De Datta. 1985. Increasing productivity and protein content using early-maturing rices and efficient nitrogen management. Fert. Res. 6(1):73-84.

Craswell, E.T., S.K. De Datta, C.S. Weeraratne, and P.L.G. Vlek. 1985. Fate and efficiency of nitrogen fertilizers applied to wetland rice. I. The Philippines. Fert. Res. 6(1):49-63.

De Datta, S.K. 1985. Availability and management of nitrogen in lowland rice in relation to soil characteristics. Pages 247-267 *in* Wetland soils: characterization, classification, and utilization. International Rice Research Institute, Manila, Philippines.

De Datta, S.K. 1985. Fertilizer application and weed control technology for rice in a resource-scarce Philippine farmers situation. Monitor 13(8):2-5. Philippine Council for Agriculture and Resources Research and Development, Los Baños, Laguna, Philippines.

De Datta, S.K. 1985. Nutrient requirement for sustained high yields of rice and other cereals. Pages 71-94 *in* Proc. 19th International Potash Institute colloquium on potassium in the agricultural system of the humid tropics. International Potash Institute, 25-29 Nov 1985, Bangkok, Thailand.

De Datta, S.K., and D.S. Mikkelsen. 1985. Potassium nutrition of rice. Pages 665-695 *in* Potassium in agriculture. ASA, CSSA, SSSA, Madison, Wisconsin, USA.

Diop, A.M., and K. Moody. 1984. Effect of seeding depth and flooding regime on germination and growth of *Echinochloa glabrescens*. Philipp. J. Weed Sci. 11:65-69.

Elliot, P.C., D.C. Navarez, D.B. Estaño, and K. Moody. 1984. Determining suitable weed control practices for dry-seeded rice. Philipp. J. Weed Sci. 11:70-82.

Greenland, D.J., and S.K. De Datta. 1985. Constraints to rice production and wetland soil characteristics. Pages 23-36 *in* Wetland soils: characterization, classification, and utilization. International Rice Research Institute, Manila, Philippines

Keerthisinghe, G., S.K. De Datta, and K. Mengel. 1985. Importance of exchangeable and nonexchangeable soil NH_4^+ in nitrogen nutrition of lowland rice. Soil Sci. 140(3):194-201.

Mabbayad, M.O., K. Moody, and A.W. Ruscoe. 1985. The effect of 1,8-naphthalic anhydride and depth of seeding on rice tolerance to herbicides in greenhouse tests. Crop Prot. 4(2):195-200.

Malabuyoc, J.A., E.L. Aragon, and S.K. De Datta. 1984. Recovery from drought-induced desiccation at the vegetative growth stage in direct-seeded rainfed rice. Field Crops Res. 10:105-112.

Mamaril, C.P. 1984. The INSFFER Program, its role in rice production. *In* Proceedings of the Fifth ASEAN Soils Conference Vol. I. Department of Land Development, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

Mamaril, C.P. 1985. International and national cooperation in long-term coordinated schemes of experimentation on fertilizers. Pages 287-295 *in* Potassium in the agricultural systems of the humid tropics. 19th Colloquium of the International Potash Institute, Bern, Switzerland.

Mamaril, C.P. 1985. International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) summary report. Pages 533-535 *in* Wetland soils: characterization, classification, and utilization. International Rice Research Institute, Manila, Philippines.

Mamaril, C.P., and R.R. Villapando. 1984. Increasing the efficiency of nitrogen fertilizer in rice. *In* Extension Bull. 216. ASPAC Food and Fertilizer Development Center, Taipei, Taiwan.

Migo, T.R., and S.K. De Datta. 1984. Chemical control of *Rottboellia exaltata* in upland rice (*Oryza sativa*). Philipp. J. Weed Sci. 11:83-93.

Moody, K. 1983. Weeds in rice-based cropping systems. Pages 1-22 *in* Proceedings of the symposium on weed control in cropping systems. Asian-Pac. Weed Sci. Soc. Conf., Manila, Philippines.

Moody, K. 1984. A literature review of weeds in grain legumes in the Philippines. Philipp. J. Weed Sci. 11:38-55.

Moody, K. 1984. Rice (*Oryza sativa*) weeds in the Philippines: a literature review. Philipp. J. Weed Sci. 11:1-37.

Moody, K., and V.G. Cordova. 1985. Wet-seeded rice. Pages 467-480 *in* Women in rice farming. International Rice Research Institute, Manila, Philippines.

Moody, K., and P.C. Elliot. 1984. The use of ricefield weeds for animal feed. Pages 52-64 *in* Report of the crop-livestock systems research monitoring tour, Philippines and Thailand. International Rice Research Institute, Manila, Philippines.

Moody, K., C.E. Munroe, R.T. Lubigan, and E.C. Paller, Jr. 1984. Major weeds of the Philippines. Science Society of the Philippines, University of the Philippines at Los Baños, College, Laguna, Philippines. 328 p.

Moody, K., and P.P. Pamplona. 1983. Weed control in intercropping. Pages 23-40 *in* Proceedings of the symposium on weed control in cropping systems. Asian-Pac. Weed Sci. Soc. Conf., Manila, Philippines.

Neue, H.U., and C.P. Mamaril. 1985. Zinc, sulfur, and other micronutrients in wetland soils. Pages 307-319 *in* Wetland soils: characterization, classification, and utilization. International Rice Research Institute, Manila, Philippines.

Pamplona, P.P., and K. Moody. 1984. Residual effects of weed control treatments applied to sorghum on mungbean. Philipp. Agric. 67(4):427-432.

Roy, A.C., and S.K. De Datta. 1985. Phosphate sorption isotherms for evaluating phosphorus requirement of wetland rice soils. Plant and Soil 86:185-196.

Sankaran, S., and S.K. De Datta. 1985. Weeds and weed management in upland rice. Adv. Agron. 38:283-337.

Schon, H.G., K. Mengel, and S.K. De Datta. 1985. The importance of initial exchangeable ammonium in the nitrogen nutrition of lowland rice soils. Plant and Soil 86:403-413.

Singh, C.M., K. Moody, and S.C. Cho. 1985. Weed control through interrow cultivation in upland rice. Agric. Mech. Asia, Africa, Latin America 16(3):35-40.

Sharma, P.K., and S.K. De Datta. 1985. A core sampler for puddled soils. Soil Sci. Soc. Am. J. 49:1069-1070.

Sharma, P.K., and S.K. De Datta. 1985. Effects of puddling on soil physical properties and processes. Pages 217-234 *in* Soils physics and rice. International Rice Research Institute, Manila, Philippines.

Sharma, P.K., and S.K. De Datta. 1985. Puddling influence on soil, rice development, and yield. Soil Sci. Soc. Am. J. 49:1451-1457.

Cereal Chemistry

Buttery, R.G., L.C. Ling, and B.O. Juliano. 1985. 2-Acetyl-1-pyrroline and its use for flavoring foods. U.S. Patent No. 4,522,838. 11 Jun. 5 p.

Damarjati, D.S., B.O. Juliano, and B.H. Siwi. 1985. Determination of major physicochemical properties affecting eating quality of Indonesian rice varieties: a multivariate study [abstr.]. Cereal Foods World 30:541.

Juliano, B.O. 1985. Biochemical properties of rice. Pages 175-205 *in* Rice: chemistry and technology, 2d ed. B.O. Juliano, ed. Am Assoc. Cereal Chemists, St. Paul, MN.

Juliano, B.O. 1985. Cooperative tests on cooking properties of milled rice. Cereal Foods World 30:651-656.

Juliano, B.O. 1985. Criteria and tests for rice grain qualities. Pages 443-524 *in* Rice: chemistry and technology, 2d ed. B.O. Juliano, ed. Am. Assoc. Cereal Chemists, St. Paul, MN.

Juliano, B.O. 1985. Factors affecting nutritional value of rice protein [abstr.]. Chem. Austr. 52:311.

Juliano, B.O. 1985. Polysaccharides, proteins and lipids of rice. Pages 59-174 *in* Rice: chemistry and technology, 2d ed. B.O. Juliano, ed. Am. Assoc. Cereal Chemists, St. Paul. MN.

Juliano, B.O. 1985. Production and utilization of rice. Pages 1-16 *in* Rice: chemistry and technology, 2d ed. B.O. Juliano, ed. Am. Assoc. Cereal Chemists, St. Paul, MN.

Juliano, B.O. 1985. Rice. J. Plant Foods 6:129-145.

Juliano, B.O. 1985. Rice bran. Pages 647-687 *in* Rice: chemistry and technology, 2d ed. B.O. Juliano, ed. Am. Assoc. Cereal Chemists, St. Paul, MN.

Juliano, B.O., ed. 1985. Rice: chemistry and technology, 2d ed. Am. Assoc. Cereal Chemists, St. Paul, MN. 774 p.

Juliano, B.O. 1985. Rice hull and rice straw. Pages 689-755 *in* Rice: chemistry and technology, 2d ed. B.O. Juliano, ed. Am. Assoc. Cereal Chemists, St. Paul, MN.

Juliano, B.O. 1985. Rice properties and processing. Food Rev. Int. 1:423-445.

Juliano, B.O., and D.B. Bechtel. 1985. The rice grain and its gross composition. Pages 17-57 *in* Rice: chemistry and technology, 2d ed. B.O. Juliano, ed. Am. Assoc. Cereal Chemists, St. Paul, MN.

Juliano, B.O., M.B. de Mosqueda, A.K. Khandker, R.R. del Rosario, and C.M. Perez. 1985. Some factors affecting the properties of extruded rice noodles and extrusion cooked rice flours [abstr.]. Cereal Foods World 30:540-541.

Juliano, B.O., C.M. Perez, E.P. Alyoshin, V.B. Romanov, M.M. Bean, K.D. Nishita, A.B. Blakeney, L.A. Welsh, L. Delgado L., A.W. El Baya, G. Fossati, N. Kongseree, F.P. Mendes, G. Brilhante, H. Suzuki, M. Tada, and B.D. Webb. 1985. Cooperative test on Amylography of milled rice flour for pasting viscosity and starch gelatinization temperature. Starke 37:40-50.

Juliano, B.O., and J. Sakurai. 1985. Miscellaneous rice products. Pages 569-618 *in* Rice: chemistry and technology, 2d ed. B.O. Juliano, ed. Am. Assoc. Cereal Chemists, St. Paul, MN.

Khush, G.S., and B.O. Juliano. 1985. Breeding for high-yielding rices of excellent cooking and eating qualities. Pages 61-69 *in* Rice grain quality and marketing. International Rice Research Institute, Manila, Philippines.

Roxas, D.B., A.R. Obsioma, R.M. Lapitan, L.S. Castillo, V.G. Momongan, and B.O. Juliano. 1985. The effects of variety of rice and level of nitrogen fertilization on the chemical composition and *in vitro* digestibility of straw. Pages 47-52 *in* The utilization of fibrous agricultural residues as animal feeds. P.T. Doyle, ed. Proc. 4th Ann. Workshop Australian-Asian Fibrous Agric. Residues Res. Network, Khon Kaen, Thailand, 1984. Int. Dev. Prog. Austr. Univ. Coll. Ltd. (IDP), Canberra.

Unnevehr, L.J., B.O. Juliano, and C.M. Perez. 1985. Consumer demand for rice grain quality in Southeast Asia. Pages 15-23 *in* Rice grain quality and marketing. International Rice Research Institute, Manila, Philippines.

Unnevehr, L.J., B.O. Juliano, C.M. Perez, and E.B. Marciano. 1985. Consumer demand for rice grain quality in Thailand, Indonesia, and the Philippines. IRRI Res. Pap. Ser. 116. 20 p.

Communication and Publications

Cabanilla, V.L., and T.R. Hargrove. 1985. Copublication of IRRI materials: a survey of translators and publishers. IRRI Res. Pap. Ser. 108.

Hargrove, T.R., and V.L. Cabanilla. 1985. Changes in rice breeding in 10 Asian countries: 1965-84. Diffusion of genetic materials, breeding objectives, and cytoplasm. IRRI Res. Pap. Ser. 111.

Hargrove, T.R., W.H. Smith, and V.L. Cabanilla. 1985. Overcoming language barriers: autotutorial modules and copublication. Pages 191-200 *in* Education for agriculture. Proceedings of the symposium on education for agriculture. International Rice Research Institute, Manila, Philippines.

Entomology

Barrion, A.A., and R.C. Saxena. 1985. Cytology of *Nilaparvata bakeri* (Muir), a grass-infesting planthopper (Homoptera: Delphacidae). Cytologia 50:577-582.

Cook, A.G., and T.J. Perfect. 1985. Seasonal abundance of macropterous *Nilaparvata lugens* and *Sogatella furcifera* based on presumptive macroptery in fifth-instar nymphs. Ecol. Entomol. 10:249-258.

Cork, A., P.S. Beevor, D.R. Hall, B.F. Nesbitt, G.A. Arida, and O. Mochida. 1985. Components of the female sex pheromone of the yellow stem borer, *Scirpophaga incertulas*. Entomol. Exp. Appl. 37: 149-153.

Heinrichs, E.A., E. Camañag, and A. Romena. 1985. Evaluation of rice cultivars for resistance to *Cnaphalocrocis medinalis* Guenee (Lepidoptera: Pyralidae). J. Econ. Entomol. 78(1): 274-278.

Heinrichs, E.A., F.G. Medrano, and H.R. Rapusas. 1985. Genetic evaluation for insect resistance in rice. International Rice Research Institute, Manila, Philippines. 356 p.

Heinrichs, E.A., and H.R. Rapusas. 1985. Levels of resistance to the whitebacked planthopper, *Sogatella furcifera* (Homoptera: Delphacidae) in rice varieties with the same major resistance. Environ. Entomol. 14:83-86.

Heyde, J.V.D., R.C. Saxena, and H. Schmutterer. 1985. Effects of neem derivatives on growth and fecundity of the rice pest *Nephotettix virescens* (Homoptera: Cicadellidae). Z. PflKrankh. PflSchutz 92(4):346-354.

Hidaka, T., and O. Mochida. 1985. Rice insect pests in the tropics. AICAP Trop. Agric. Ser. 6:58-115.

Khan, Z.R., and R.C. Saxena. 1985. Behavior and biology of *Nephotettix virescens* (Homoptera: Cicadellidae) on tungro virus-infected rice plants: epidemiology implications. Environ. Entomol. 14:297-304.

Khan, Z.R., and R.C. Saxena. 1985. Behavioral and physiological responses of *Sogatella furcifera* (Homoptera: Delphacidae) to selected resistant and susceptible rice cultivars. J. Econ. Entomol. 78:1280-1286.

Khan, Z.R., and R.C. Saxena. 1985. Effect of steam distillate extract of a resistant rice variety on feeding behavior of *Nephotettix virescens* (Homoptera: Cicadellidae). J. Econ. Entomol. 78:562-566.

Khan, Z.R., and R.C. Saxena. 1985. Mode of feeding and growth of *Nephotettix virescens* (Homoptera: Cicadellidae) on selected resistant and susceptible rice varieties. J. Econ. Entomol. 78: 583-587.

Khan, Z.R., and R.C. Saxena. 1985. A selected bibliography of the whitebacked planthopper *Sogatella furcifera* (Horvath) (Homoptera: Delphacidae). Insect Sci. Appl. 6(2):115-134.

Lee, S.C., D.M. Matias, T.W. Mew, J.S. Soriano, and E.A. Heinrichs. 1985: Relationship between planthoppers (*Nilaparvata lugens* and *Sogatella furcifera*) and rice diseases. Korean J. Plant Prot. 24(2):65-70.

Litsinger, J.A. 1985. Integrated pest management for rice in Asia. Pages 489-500 *in* Women in rice farming. International Rice Research Institute, Manila, Philippines.

Medrano, F.G., and E.A. Heinrichs. 1985. *Nilaparvata lugens*. Pages 361-372 *in* Handbook of insect rearing. Vol. I. P. Singh and R.F. Moore, eds. Elsevier Science Publishers B.V., Amsterdam.

Mochida, O. 1985. Buprofezin, one insectistatics, for the brown planthopper control in the tropics based on the data at IRRI. Noyaku 32:46-47.

Perfect, T.J., A.G. Cook, D.E. Padgham, and J.M. Crisostomo. 1985. Interpretation of the flight activity of *Nilaparvata lugens* (Stal) and *Sogatella furcifera* (Horvath) (Hemiptera: Delphacidae) based on comparative trap catches and field marking with rubidium. Bull. Entomol. Res. 75:93-106.

Reissig, W.H., E.A. Heinrichs, J.A. Litsinger, K. Moody, L. Fiedler, T.W. Mew, and A.T. Barrion. 1985. Illustrated guide to integrated pest management in rice in tropical Asia. International Rice Research Institute, Manila, Philippines. 411 p.

Saxena, R.C., and A.A. Barrion. 1985. Biotypes of the brown planthopper *Nilaparvata lugens* (Stal) and strategies in deployment of host plant resistance. Insect Sci. Appl. 6(3):271-289.

Saxena, R.C., and Z.R. Khan. 1985. Effect of neem oil on survival of *Nilaparvata lugens* (Homoptera: Delphacidae) and on grassy stunt and ragged stunt virus transmission. J. Econ. Entomol. 78:647-651.

Saxena, R.C., and Z.R. Khan. 1985. Electronically recorded disturbances in feeding behavior of *Nephotettix virescens* (Homoptera: Cicadellidae) on neem oil-treated rice plants. J. Econ. Entomol. 78(1):222-226.

Saxena, R.C., and S.H. Okech. 1985. Role of plant volatiles in resistance of selected rice varieties to brown planthopper, *Nilaparvata lugens* (Stal) (Homoptera: Delphacidae). J. Chem. Ecol. 11(12):1601-1616.

Shepard, M. 1985. A splitter device for subsampling small insects. J. Plant Prot. Tropics 1(2):111-115.

International Rice Germplasm Center

Chang, T.T. 1984. Evaluation of germplasm rice. Pages 191-198 *in* Crop genetic resources: conservation and utilization. J.H.W. Holden and J.T. Williams, eds. George Allen and Unwin, London.

Chang, T.T. 1984. Rice: germplasm resources, genetic studies and their applications. Proceedings of the Symposium on Genetic Research Trends in the Philippines (Bull. No. 98), pp. 131-138. National Research Council of the Philippines, Taguig, Metro Manila.

Chang, T.T. 1984. The role and experience of an international crop-specific genetic resources center. Pages 35-45 *in* Conservation of crop germplasm an international perspective. CSSA Spec. Publ. 8. Crop Science Society of America, Madison.

Chang, T.T. 1985. Collection of crop germplasm. Iowa State J. Res. 59(4):349-364.

Chang, T.T. 1985. Crop history and genetic conservation: rice a case study. Iowa State J. Res. 59(4):425-455.

Chang, T.T. 1985. Evaluation and documentation of crop germplasm. Iowa State J. Res. 59(4):379-397.

Chang, T.T. 1985. Field collection of rice germplasm and dispersal of upland and javanica rice in SE Asia. East Asian Tertiary/Quaternary Newsl. 2:52.

Chang, T.T. 1985. The genetic resources program of IRRI: present status and challenges. Pages 6-15 *in* Seminar on collection and utilization for genetic resources in rice with particular reference to disease resistance. IRRI-TARC, Japan.

Chang, T.T. 1985. Germplasm enhancement and utilization. Iowa State J. Res. 59(4):399-424.

Chang, T.T. 1985. Preservation of crop germplasm. Iowa State J. Res. 59(4):365-378.

Chang, T.T. 1985. Principles of genetic conservation. Iowa State J. Res. 59(4):325-348.

Chang, T.T., and G.C. Loresto. 1984. The rice remains. Pages 2, 384-385, 390 *in* Prehistoric investigations in northeastern Thailand. C. Higham and A. Kijngam, comp. B.A.R. Int. Ser. 23(ii), Oxford.

Chang, T.T., and G.C. Loresto. 1985. Genetic analysis of rice root systems by the aeroponic technique and applications to rice breeding. Page 116 *in* 5th SABRAO Congress working abstracts, Bangkok, Thailand.

Chang, T.T., C. Zuño, A. M. Romena, and G. C. Loresto. 1985. Semidwarfs in rice germplasm collections and their potentials in rice improvement. Phytobreedon 1(1):1-9.

Denton, L.R. 1985. Problems in field collecting. Plant Genet. Res. Newsl. 62:15-16. FAO/IBPGR, Rome.

International Rice Testing Program

Krishna, T.S., and D.V. Seshu. 1984. Genetics of resistance to brown planthopper in rice and association of certain plant characteristics with resistance. Indian J. Genet. Plant Breed. 44(2):336-342.

Krishna, T.S., D.V. Seshu, and M. B. Kalode. 1984. Inheritance of resistance to whitebacked planthopper in rice. Indian J. Genet. Plant Breed. 44(2):329-335.

Library and Documentation Center

25 years of IRRI theses and dissertations: an abstract bibliography.

International bibliography of rice research. 1984 supplement (25th anniversary issue).

Theses and dissertations on rice available in the library of the International Rice Research Institute. 1985 supplement.

Library list of recent acquisitions. 12 issues, January to December.

Multiple Cropping

Gines, H.C., R.G. Pernito, and R.A. Morris. 1985. The rationale of photoperiod-sensitive rice cultivars in rainfed rice-based cropping systems. Philipp. J. Crop Sci. 10(2):77-80.

International Rice Research Institute. 1985. Farming systems research at IRRI: an overview. Manila, Philippines. 21 p.

Magbanua, R.D., and R.A. Morris. 1985. Agronomic adaptation of two cropping pattern groups in Iloilo Province. Philipp. J. Crop Sci. 10(1):25-35.

Morris, R.A. 1985. A decade of on-farm research in lowland rice-based farming systems: some lessons. Farming Systems Support Project. Networking Pap. 6.

Morris, R.A., D. J. Greenland, and R.E. Huke. 1984. Remote sensing and rice research. Pages 33-54 *in* Application of remote sensing for rice production. A. Deepak and K.R. Rao, eds. A. Deepak Publishing, Virginia, USA.

Morris, R.A., and F.M. Rumbaoa, Jr. 1985. Classification of Philippine rainfall patterns. IRRI Res. Pap. Ser. 109.

Saint Macary, H., E.P. Marqueses, R.O. Torres, and R.A. Morris. 1985. Effect of flooding on growth and nitrogen fixation of two *Sesbania* species. Philipp. J. Crop Sci. 10(1):17-20.

Samson, B.T., R.A. Morris, and M.A. Dizon. 1985. Yields of twenty early and late-planted improved upland rices. Philipp. J. Crop Sci. 10(2):71-75.

Plant Breeding

Inouye, J., D. HilleRisLambers, and S. Chitrakon. 1985. Some morphological and ecological differences between floating and non-floating rice varieties in Thai paddy rice, *Oryza sativa* L. Bull. Inst. Trop. Agric. Kyushu Univ. 8:55-89.

Jena, K.K., and G.S. Khush. 1985. Genome analysis of *Oryza officinalis* complex. Rice Genet. Newsl. 2:4.

Julfiquar, A.W., S.S. Virmani, and A.L. Carpena. 1985. Genetic divergence among some maintainer and restorer lines in relation to hybrid breeding in rice (*Oryza sativa* L.). Theor. Appl. Genet. 70: 671-678.

Kaw, R.N., and G.S. Khush. 1985. Heterosis in traits related to low temperature tolerance in rice. Philipp. J. Crop Sci. 10(2):93-105.

Khush, G.S., and A.L. Librojo. 1985. Naked seed rice (NSR) is allelic to *op* and *lhs*. Rice Genet. Newsl. 2:21.

Khush, G.S., and S.S. Virmani. 1985. Breeding rice for disease resistance. Pages 239-279 *in* Progress in plant breeding. G.E. Russel, ed. Butterworths, London.

Khush, G.S., and S.S. Virmani. 1985. Some plant breeding problems needing biotechnology. Pages 51-63 *in* Biotechnology in international agricultural research. International Rice Research Institute, Manila, Philippines.

Kumar, I., and G.S. Khush. 1985. Effect of amylose content on endosperm appearance of hybrid seeds in rice. Rice Genet. Newsl. 2:67.

Miah, M.A.A., E.D. Earle, and G.S. Khush. 1985. Inheritance of callus formation ability in anther culture of rice, *Oryza sativa* L. Theoret. Appl. Genet. 70:113-226.

Mohanty, H.K., and G.S. Khush. 1985. Diallel analysis of submergence tolerance in rice, *Oryza sativa* L. Theoret. Appl. Genet. 70:467-473.

Virmani, S.S. 1985. Use of male sterility in crop improvement. Pages 161-183 *in* Genetic manipulation for crop improvement. V.L. Chopra, ed. Oxford and India Book House, New Delhi.

Virmani, S.S., and A. Te. 1985. Hybrid rice. Pages 461-465 *in* Women in rice farming. International Rice Research Institute, Manila, Philippines and Gower Publishing Co.

Wu, C.F., and G.S. Khush. 1985. A new dominant gene for resistance to whitebacked planthopper in rice. Crop Sci. 25:505-509.

Yamauchi, M., S. Yoshida, and S.S. Virmani. 1985. Improved leaf development of hybrid rice. Int. Rice Comm. Newsl. 34(1):44-47.

Plant Pathology

Aballa, T.C., and T.W. Mew. 1985. Effects of methods of inoculation and inoculum densities on varietal resistance to bacterial leaf streak disease. Philipp. Phytopath. 21:15. (abstr.)

Aguiero, V.M., and H. Hibino. 1985. Rice tungro virus disease monitoring in Laguna. Philipp. Phytopath. 21:17. (abstr.)

Bajet, N.B., V.M. Aguiero, R.D. Daquioag, and H. Hibino. 1985. Incidence of rice virus diseases in the Philippines. Philipp. Phytopath. 21:5. (abstr.)

Bajet, N.B., R.D. Daquioag, P.Q. Cabauatan, and H. Hibino. 1985. Concentration of rice tungro spherical virus in tungro-infected rice. Philipp. Phytopath. 21:12. (abstr.)

Baloch, K.K., and J.M. Bonman. 1985. Seedling and adult plant resistance of rice varieties to isolates of *Bipolaris oryzae* (Breda de Haan) Shoemaker. Philipp. Phytopath. 21:8-9. (abstr.)

Baraoidan, M.R., C.M. Vera Cruz, and T.W. Mew. 1985. Detection of *Xanthomonas campestris* pv. *oryzae* from seeds of infected rice plants. Philipp. Phytopath. 21:7. (abstr.)

Borromeo, E.S., and T.W. Mew. 1985. A search for primary determinant of brown spot disease of rice. Philipp. Phytopath. 21:1. (abstr.)

Cabauatan, P.Q., and H. Hibino. 1985. Transmission of rice tungro bacilliform and spherical viruses by *Nephotettix virescens* Distant. Philipp. Phytopath. 21:103-109.

Cabauatan, P.Q., H. Hibino, D.B. Lapis, T. Omura, and T. Tsuchizaki. 1985. Rice grassy stunt virus 2; a new strain of rice grassy stunt in the Philippines. IRRI Res. Pap. Ser. 106. 8 p.

Candole, B.L., R.C. de la Peña, S.W. Ahn, and T.W. Mew. 1985. A new evaluation scale for sheath blight of rice. Philipp. Phytopath. 21:15. (abstr.)

Chuke, K.C., and D.B. Lapis. 1985. Pathogenicity of *Sarocladium oryzae* and factors affecting sheath rot development on rice. Philipp. Phytopath. 21(1&2): 28-33.

Daquioag, R.D., P.Q. Cabauatan, and H. Hibino. 1985. IKM-6, a source of resistance to rice tungro spherical virus. Philipp. Phytopath. 21:7. (abstr.)

Fabellar, N.G., and T.W. Mew. 1985. Crown sheath rot of rice. Philipp. Phytopath. 21:16 (abstr.)

Flores, Z.M., and H. Hibino. 1985. Reaction of IR varieties to tungro under different disease pressure. Philipp. Phytopath. 21:7-8. (abstr.)

Flores, Z.M., H. Hibino, and J. Perfect. 1985. Rice grassy stunt and rice ragged stunt virus-carriers in brown planthoppers caught by light trap. Philipp. Phytopath. 21:16-17. (abstr.)

Hibino, H., P.Q. Cabauatan, T. Omura, and T. Tsuchizaki. 1985. Rice grassy stunt virus strain causing tungro-like symptoms in the Philippines. Plant Dis. 69:538-541.

Hibino, H., and P.Q. Cabauatan. 1985. Serological blockage of rice tungro virus complex transmission by *Nephotettix virescens*. Philipp. Phytopath. 21:10-11. (abstr.)

Hibino, H., F. Hongco, and G.Z. Salamat, Jr. 1985. Light trapping of rice virus vectors. Philipp. Phytopath. 21:17. (abstr.)

Hibino, H., T. Usugi, T. Omura, T. Tsuchizaki, K. Shohara, and M. Iwasaki. 1985. Rice grassy stunt virus: a planthopper-borne circular filament. Phytopathology 75:894-899.

Ling, D.H., P. Vidhyasekaran, E.S. Borromeo, F.J. Zapata, and T.W. Mew. 1985. In vitro screening of rice germplasm for resistance to brown spot disease using phytotoxin. Theor. Appl. Genet. 71:133-135.

Mackill, A.O., and J.M. Bonman. 1985. Cross inoculation studies of *Pyricularia oryzae* from rice and other hosts. Philipp. Phytopath. 21:9-10. (abstr.)

Mew, T.W., F.A. Elazegui, and Y.P.S. Rathi. 1985. Cowpea diseases in tropical Asia and control in rice-based cropping systems. Pages 193-197 *in* Cowpea research production and utilization. John Wiley & Sons. Ltd.

Parejarearn, A., and H. Hibino. 1985. Multiplication of rice ragged stunt virus in the brown planthopper vector and its distribution in infected plant. Philipp. Phytopath. 21:11. (abstr.)

Qi, Zhang, and T.W. Mew. 1985. Adult plant resistance of rice cultivars to bacterial blight. Plant Dis. 69(10):896-898.

Reyes, R.C., and T.W. Mew. 1985. A method of inoculation for varietal evaluation to bacterial blight. Philipp. Phytopath. 21:16. (abstr.)

Rosales, A.M., L.L. Hag, T.W. Mew, and F.A. Elazegui. 1985. Mycorrhizae in a rice-based cropping system. Philipp. Phytopath. 21:6-7. (abstr.)

Sta. Cruz, F., and H. Hibino. 1985. Etiology of orange leaf. Philipp. Phytopath. 21:6. (abstr.)

Torres, C.Q., and J.M. Bonman. 1985. Effect of plant age on components of rice blast resistance. Philipp. Phytopath. 21:10. (abstr.)

Vera Cruz, C.M., and T.W. Mew. 1985. Analysis of virulence of the rice bacterial blight pathogen. Philipp. Phytopath. 21:9. (abstr.)

Vidhyasekaran, P., M. Alvenda, and T.W. Mew. 1985. Phytotoxic polysaccharides produced by virulent and avirulent strains of *Xanthomonas campestris* pv. *oryzae*. Philipp. Phytopath. 21:11-12. (abstr.)

Yoshimura, A., T. Omura, T.W. Mew, and G.S. Khush. 1985. Genetic behavior of resistance to bacterial blight in differential rice cultivars in the Philippines. Bull. Inst. Trop. Agric. Kyushu Univ. 8:1-54.

Plant Physiology

Chauhan, J.S., B.S. Vergara, and F.S.S. Lopez. 1985. Rice ratooning. IRRI Res. Pap. Ser. 102. 19 p.

Fujita, K., V.P. Coronel, and S. Yoshida. 1984. Grain filling characteristics of rice varieties (*Oryza sativa* L.) differing in grain size under controlled environmental conditions. Soil Sci. Plant Nutr. 30(3):445-454.

Fujita, K., and S. Yoshida. 1984. Partitioning of photosynthates between growing panicle and vegetative parts before anthesis. Soil Sci. Plant Nutr. 30(4):509-518.

Fujita, K., and S. Yoshida. 1984. Partitioning of photosynthates between panicle and vegetative organs of rice under different planting densities. Soil Sci. Plant Nutr. 30(4):519-525.

Kwak, T.S., B.S. Vergara, J.S. Nanda, and W.R. Coffman. 1984. Inheritance of seedling cold tolerance in rice. SABRAO J. 16(2):83-86.

Lopez, F.S.S., J.S. Chauhan, and B.S. Vergara. 1985. Effect of light intensity before and after main crop cuttings on ratooning ability of rice (*Oryza sativa* L.). Philipp. J. Crop Sci. 10 (Suppl. 1):S16.

Ponnuthurai, S., S.S. Virmani, and B.S. Vergara. 1984. Comparative studies on the growth and grain yield of some F_1 rice (*Oryza sativa* L.). Philipp. J. Crop Sci. 10(1):21-23.

Vergara, B.S. 1985. Growth and development of the deep water rice plant. IRRI Res. Pap. Ser. 103. 38 p.

Vergara, B.S. 1985. *Oryza sativa*. Pages 435-441 *in* Handbook of flowering, vol. 3. A.H. Halevy, ed. CRC Press, Florida.

Vergara, B.S., and R.M. Visperas. 1984. Adaptability and use of indica varieties in high latitude areas. Pages 39-54 *in* Potential productivity and yield constraints of rice in East Asia. Proceedings of international crop science symposium, Fukuoka, Japan. Oct 1984.

Rice Farming Systems Program

Calub, A.D., and R.M. Mendoza. 1985. Leucaena as livestock feed. Pages 137-149 *in* Report of the crop-livestock systems research monitoring tour, Philippines and Thailand. International Rice Research Institute, Manila, Philippines.

Soil Chemistry/Physics

Akbar, M., and F.N. Ponnamperuma. 1985. Salt-tolerant rice varieties. Page 6 *in* Executive report on workshop on the conversion of mangrove areas for paddy cultivation. SEARCA, Los Baños, Laguna. Philippines.

Cayton, M.T.C. 1985. Boron toxicity in rice. IRRI Res. Pap. Ser. 113. 10 p.

Cayton, M.T.C., E.D. Reyes, and H.U. Neue. 1985. Effect of zinc fertilization on the mineral nutrition of rices differing in tolerance to zinc deficiency. Plant and Soil 87:319-327.

De San Agustin, E.M., and T. Woodhead. 1985. Toposequence agrohydrology for upland rice and legumes. Paper presented at the Saturday Seminar, 5 Oct, International Rice Research Institute, Manila, Philippines. 34 p. (mimeo.)

Dexter, A.R., and T. Woodhead. 1985. Soil mechanics in relation to tillage, implements, and root penetration in lowland soils. Pages 261-281 *in* Soil physics and rice. International Rice Research Institute, Manila, Philippines.

Li Jin Pei. 1985. Amelioration of an acid sulfate soil in the Philippines. I. The effect of organic and inorganic matter amendments on rice growth and yield in an acid sulfate soil. Philipp. J. Crop Sci. 10(1):37-42.

Neue, H.U. 1985. Organic matter dynamics in wetland soil. Pages 109-122 *in* Wetland soils: characterization, classification, and utilization. International Rice Research Institute, Manila, Philippines.

Neue, H.U., and C.P. Mamaril. 1985. Zinc, sulfur, and other micronutrients in wetland soils. Pages 307-320 *in* Wetland soils: characterization, classification, and utilization. International Rice Research Institute, Manila, Philippines.

Neue, H.U., and V.P. Singh. 1985. Management of wetland rice and fishponds on problem soils in the tropics. Pages 352-366 *in* International seminar on ecology and management of problem soils in Asia, 8-11 Nov 1983.

Ponnamperuma, F.N. 1985. Chemical kinetics of wetland rice soils relative to soil fertility. Pages 71-89 *in* Wetland soils: characterization, classification, and utilization. International Rice Research Institute, Manila, Philippines.

Ponnamperuma, F.N. 1985. Use of mangal lands in the Philippines for wetland rice production. Pages 7-8 *in* Executive report on workshop on the conversion of mangrove areas for paddy cultivation. SEARCA, Los Baños, Laguna, Philippines.

Singh, N.T., G.C. Aggarwal, and T. Woodhead. 1985. Physical aspects of the root and seed environment in lowland soils. Pages 367-382 *in* Soil physics and rice. International Rice Research Institute, Manila, Philippines.

Van Mensvoort, M.E., R.S. Lantin, and R. Brinkman. 1985. Toxicities of wetland soils. Pages 123-138 *in* Wetland soils: characterization, classification, and utilization. International Rice Research Institute, Manila, Laguna, Philippines.

Woodhead, T. 1984. Soil mechanical problems in a tropical rainfed rice - maize cropping system. Pages 165-167 *in* International workshop on soils. Australian Centre for International Agricultural Research, Townsville, Queensland, Australia.

Soil Microbiology

Gowda, T.K.S., and I. Watanabe. 1985. Hydrogen-supported N_2 fixation of *Pseudomonas* sp. and *Azospirillum lipoferum* under free living conditions and in association with rice seedlings. Can. J. Microbiol. 31:317-321.

Grant, I.F., P.A. Roger, and I. Watanabe. 1985. Effect of grazer regulation and algal inoculation on photodependent nitrogen fixation in a wetland rice field. Biol. Fert. Soils 1:61-72.

Ito, O., and I. Watanabe. 1985. Availability to rice plants of nitrogen fixed by azolla. Soil Sci. Plant Nutr. 31(1):91-104.

Ladha, J.K., I. Watanabe, and P.A. Roger. 1985. Biological nitrogen fixation in wetland rice. Pages 481-487 *in* Women in rice farming. Gower Publishing Co. and International Rice Research Institute, Manila, Philippines.

Roger, P. 1985. Blue-green algae in rice fields, their ecology and their use as inoculant. Pages 99-117 *in* Proceedings of a consultants meeting, FAO/IAEA Joint Project, Vienna, 11-15 Oct 1982 (IAEA-TECDOC 325).

Watanabe, I. 1985. Limiting factors in increasing N_2-fixation in rice fields. Pages 436-464 *in* Biological nitrogen fixation in Africa. Proceedings of the 1st conference of the African Association for Biological Nitrogen Fixation, 23-27 Jul 1984. Nairobi Rhizobium Mireen.

Watanabe, I. 1985. Nitrogen fixation associated with wetland rice plant. Pages 185-195 *in* Proceedings of the international symposium on nitrogen and the environment, 7-12 Jan 1984. R.A. Malik, S.H.M. Naqui, and M.I.H. Aleem, eds. Published by NIAB, Faisalabad, Pakistan.

Watanabe, I., and T.K.S. Gowda. 1985. Stimulating effect of hydrogen on N_2 fixation in association with field-grown wetland rice. Can. J. Microbiol. 31:503-507.

Watanabe, I., and T.K.S. Gowda. 1985. Variation in the incidence of H_2-oxidizing chemolithotropic bacteria in rice grown under different cultivation conditions. Plant and Soil 85:97-105.

Watanabe, I., and P.A. Roger. 1985. Ecology of flooded rice fields. Pages 229-243 *in* Wetland soils: characterization, classification, and utilization. International Rice Research Institute, Manila, Philippines.

Watanabe, I., and P.A. Roger. 1985. Use of ^{15}N in the study of biological nitrogen fixation in paddy soils at the International Rice Research Institute. Pages 81-98 *in* Proceedings of a consultants meeting, FAO/IAEA Joint Project, Vienna, 11-15 Oct 1982 (IAEA-TECDOC 325).

Tissue Culture

Ling, D.H., P. Vidhyaseharan, E.S. Borromeo, F.J. Zapata, and T.W. Mew. 1985. In vitro screening of rice germplasm for resistance to brown spot disease using phytotoxin. Theor. Appl. Genet. 71:133-135.

Zapata, F.J. 1985. Rice anther culture at IRRI. II. Pages 85-95 *in* Proceedings of the intercenter seminar on international agricultural research centers (IARCs) and biotechnology. International Rice Research Institute, Manila, Philippines.

Training and Technology Transfer

Denning, G.L. 1985. Integrating agricultural extension programs with farming systems research. Pages 113-135 *in* M.M. Cernea, J.K. Coulter, and J.F.A. Russel, eds. Research-extension-farmer: a two-way continuum for agricultural development. The World Bank, Washington, D.C., USA.

Dilag Jr., R., R.M. Aseron, D.P. Callo, Jr., F.C. Tagalog, and G.L. Denning. 1985. Annual report of the inter-agency rice-based cropping systems pre-production evaluation program, 1984-85. International Rice Research Institute, Manila, Philippines.

Magistrado, O.N. 1985. Preparation and use of slides for extension and teaching. Extension Update, Vol. 3, 1985. University of the Philippines at Los Baños, Laguna, Philippines.

Minnick, D.R. 1985. Computers in education: the revolution. Pages 185-190 *in* Education for agriculture. International Rice Research Institute, Manila, Philippines.

Water Management

Moya, T.B. 1985. An evaluation of water distribution within tertiary areas of the Philippines' Lower Talavera River irrigation system. Pages 28-46 *in* Irrigation management research from Southeast Asia. T. Wickham, ed. Agricultural Development Council.

Moya, T.B., and H. Murray-Rust. 1985. Water management issues for deep tubewell irrigation. Philipp. Agric. Eng. J. 16(4):14-19.

Sattar, M.A., and S.I. Bhuiyan. 1985. Water utilization in a selected tubewell project in Bangladesh. Bangladesh J. Agric. 1(1):23-33.

Tapay, N.E., and A.C. Early. 1985. Structure and effectiveness of Philippine irrigation organization. Water Manage. Rev. 1(1):12-13.

SEMINARS

The seminars held at IRRI during 1985 are grouped as Thursday seminars, Saturday seminars, and special seminars. The Saturday seminars report ongoing IRRI research. Unless otherwise stated, the speakers were staff members.

Thursday seminars

IRRI: looking ahead. Dr. M.S. Swaminathan.

Current and future wheat breeding for quality. Prof. W. Bushuk, professor, Department of Plant Science, University of Manitoba, Canada.

Use of Ti-mediated transformation to study tissue-specific and light-regulated expression of monocot and dicot genes. Dr. Nam-Hai Chua, Laboratory of Plant Molecular Biology, Rockefeller University, USA.

New directions for Irrigation Water Management research. Dr. H. Murray-Rust.

Rice production in the Caribbean. Prof. F. Cuevas, professor, Instituto Superior de Agricultura, Dominican Republic.

Malthus, Marx, Meadows, and me. Dr. R.L. Zimdahl, visiting scientist, Agronomy Department.

Department of Statistics: past, present, and future. Dr. K.A. Gomez.

The cereal chemistry program of IRRI in perspective. Dr. B.O. Juliano.

What about the soil organic matter content on the IRRI farm in the year 2500? Dr. H.U. Neue.

The IRRI copublication program. Dr. T. R. Hargrove.

Rice improvement: past, present, and future. Dr. G.S. Khush.

Operationalizing the university extension function: by contribution, selling response, or participative response. Dr. R. Cuyno, director of extension, University of the Philippines at Los Baños, College, Laguna.

Small creatures do big jobs. Dr. I. Watanabe.

A semi-continuous stirred tank reactor (SCTR) with cell sedimentation process for ethanol production using a thermotolerant flocculating yeast fusant. Dr. L.M. Joson, program coordinator, Microbiological Research Program, NIST, Manila.

IRRI's plant pathology research progress and prospects. Dr. T.W. Mew.

Agricultural engineering at IRRI: a retrospection. Dr. C.W. Bockhop.

IRRI Plant Physiology Department: contributions to higher crop productivity. Dr. B. S. Vergara.

Rice insect management: a quarter century of progress in the development of control tactics. Dr. E.A. Heinrichs.

The rainfed rice environments: technology generation or adaptation? Dr. D.P. Garrity.

Human exposure to herbicides. Dr. T. Lavy, professor, Crops and Soils Department, University of Arkansas, USA.

Genetic, epidemiologic, specificity, and histological aspects of hypersensitivity, partial and mature plant resistance in barley against barley leaf rust, *Puccinia hordei*. Dr. E.J. Parlevliet, head, Institute of Plant Breeding, Wageningen, The Netherlands.

Philippine potato research. Dr. P.A. Batugal, coordinating scientist of SATTRAD, Philippine Council for Agriculture and Resources Research and Development, Los Baños, Laguna.

Tailoring for high yield potential in rice. Dr. B. Venkateswarlu, senior research fellow, Plant Physiology Department.

Rice blast: genetic studies and breeding for resistance. Dr. D.J. Mackill.

IRRI's 25th anniversary symposia: message for the future. Dr. M.S. Swaminathan.

Water and nitrogen relations of legume crops. Dr. P.J. Gregory, Department of Soil Science, University of Reading, U.K.

Rice straw utilization for animal feeds. Dr. L.T. Trung, assistant professor, Dairy Training and Research Institute, University of the Philippines at Los Baños, College, Laguna.

Irrigation and rice production. Dr. D. J. Greenland and Dr. H. Murray-Rust.

Pollen analysis: past, present, and prospects in the Philippine setting. Dr. P.C. Payawal, assistant professor and head, Institute of Biological Sciences, University of the Philippines at Los Baños, College, Laguna.

Cooperative IFDC/IRRI research on nitrogen fertilizers. Dr. R.J. Buresh, soil scientist, IFDC, Agronomy Department.

Bio-gas production, utilization, and benefits. Dr. Y.H. Joo, special research fellow, Agricultural Engineering Department.

Wisdom and illusions about organic matter: current and future research of the GTZ special project on organic matter. Dr. H.U. Neue.

How to become your own editor. Dr. L.R. Bostian, visiting editor, Communication and Publications Department.

Composition and agronomic significance of blue-green algae. Dr. P.A. Roger, visiting scientist, Soil Microbiology Department.

Overview of NIBAM Program. Dr. W.G. Padolina, deputy executive director, National Institute of Biotechnology and Applied Microbiology, University of the Philippines at Los Baños, College, Laguna.

Yield stability and modern rice technology. Dr. J.C. Flinn.

Science and technology education in the Republic of the Philippines. Dr. E. Q. Javier, director-general, National Science and Technology Authority, Taguig, Metro Manila.

Biocontrol of bacterial wilt in important food crops. Dr. R.B. Aspiras, assistant professor, Institute of Biological Sciences, University of the Philippines at Los Baños, College, Laguna.

Microcomputers at IRRI: today and tomorrow. Dr. E.H. Tryon, visiting scientist, Entomology Department.

Development of a rice dryer for the Philippines. Dr. R.E. Stickney.

Audiotutorials and the training process. Dr. B.R. Tripathi, visiting scientist, Training and Technology Transfer Department.

Fertilizer injectors and beyond. Dr. A.U. Khan.

Water availability and use of crops in arid regions. Dr. P.J. Gregory, Department of Soil Science, University of Reading, U.K.

Progress and prospects in plant pathology. Dr. T.W. Mew.

The Multiple Cropping Department, its past and future. Dr. R.A. Morris.

Saturday seminars

Simulation modeling of agricultural mechanization policy decisions in Thailand. Dr. T. Pongsrikul, postdoctoral fellow, Agricultural Economics Department.

Impact of modern varieties on fertilizer use in Asia. Ms. V. Cordova.

Adoption and productivity of improved upland rice in Zamboanga del Sur, Philippines. Mr. C. Tautho, research fellow, Agricultural Economics Department.

Design parameters affecting the performance of the IRRI designed axial-flow pump. Mr. M. Aban.

Cropping systems research in two environments: potentials and problems. Dr. R.A. Morris.

The influence of bio-physical variables on the adoption of modern rices in the Cagayan Valley. Mr. Jae Ho Kim, research fellow, Multiple Cropping Department.

Field conservation and the value of rice germplasm. Mr. I.R. Denton, special research fellow; Ms. C. Zuño, research assistant, and Dr. T.T. Chang, geneticist, International Rice Germplasm Center.

The impact of mechanization on labor use in the Philippines, West Java, and South Sulawesi. Mr. A. Markanday, research fellow, Agricultural Engineering Department.

Comparison of land preparation equipment used on small rice farms in the Philippines. Mr. E. Calilung.

Taxonomic and biological studies on pyralid moths on azolla (Lepidoptera). Dr. Y. Yoshiyasu, postdoctoral fellow, Entomology Department.

Rice root response to water stress in rainfed lowland. Dr. C. Thangaraj, postdoctoral fellow, Agronomy Department.

Growth development of selected upland and lowland varieties grown in aeroponic culture. Ms. C. Zuño, Ms. G. Loresto, Mr. M. Obien, Ms. J. Godilano, and Dr. T.T. Chang.

Factors governing susceptibility and resistance of rice varieties to the whitebacked planthopper *Sogatella furcifera* (Horvath). Dr. Z.R. Khan, postdoctoral fellow, and Dr. R.C. Saxena, associate entomologist, Entomology Department.

Genetics of cold tolerance in rice. Dr. R.N. Kaw, senior research fellow, and Dr. G.S. Khush, plant breeder, Plant Breeding Department.

Breeding for salinity tolerance in rice. Dr. M. Akbar.

Cytoplasmic male sterility and fertility restoration in rice. Dr. K. Govinda Raj, postdoctoral fellow; Ms. R.D. Dalmacio, senior research assistant; Mr. C. Casal, research aide; and Dr. S. S. Virmani, plant breeder, Plant Breeding Department.

Nitrogen fixation associated with the rice plant. Dr. J.K. Ladha.

Standardization of acetylene-reduction activity measurement of photodependent nitrogen-fixing microorganisms in wetland rice fields (with emphasis on blue-green algae). Ms. R.R. Jimenez, research assistant, Dr. P.A. Roger, visiting scientist, and Dr. I. Watanabe, soil microbiologist, Soil Microbiology Department.

Soil physical edaphology research in lowland rice-based cropping systems. Dr. P.K. Sharma, postdoctoral fellow, Agronomy Department.

Phosphorus availability in soils and azolla growth. Ms. C. Ramirez.

Proper use of the analytical service laboratories. Ms. B.E. Mandac.

Growth of azolla under rice canopy. Mr. T. Kroeck, research fellow, Soil Microbiology Department.

The use of azolla for weed suppression in transplanted rice. Mr. J.D. Janiya.

Factors affecting elongation of deep water rice under submergence. Dr. A.R. Gomosta, research fellow, Plant Physiology Department.

Influence of cultivars and agronomic management on the yield of soybean in rice-based farming systems in the Philippines. Mr. E. A. Barlaan.

The effect of ratoon rice on rice insect pest and natural enemy populations. Mr. C.G. dela Cruz.

Biological control of rice insect pests. Mr. G. Arida.

Sulfur studies in some Philippine wetland rice soils. Ms I.C. Reyes.

Potassium nutrition of rice in saline soil. Ms. N. Uy.

Chemical induction of flowering in mango. Dr. R.C. Barba, Institute of Plant Breeding, University of the Philippines at Los Baños, College, Laguna.

Screening for moisture-stress tolerance for improved milling quality. Ms. M.G. Ibabao, Ms. C.M. Perez, Dr. B.O. Juliano, and Dr. G.S. Khush.

Isolation of fractions biocidal to brown planthopper from IR26 rice plants. Ms. M.R. Momongan, Dr. B.O. Juliano, Ms. B.P. Rueda, and Dr. R.C. Saxena.

Grain yield losses caused by rice insects. Mr. V. Viajante, Mr. G.B. Aquino, and Dr. E.A. Heinrichs.

The role of the basic mineral nutrient ratios on the growth of rice in saline soils. Ms. N. Uy.

Toposequence agrohydrology for upland rice and legumes. Ms. E. de San Agustin and Dr. T. Woodhead.

Water allocation and distribution requirements for viable operation of a deep tubewell irrigation system. Mr. T.B. Moya and Dr. D. H. Murray-Rust.

Water allocation options in droughty seasons: the recent experience from a large irrigation system. Mr. W.C. dela Vina and Dr. S.I. Bhuiyan.

Farm-level effects of irrigation system design and operation problems. Mr. D.F. Tabbal, Dr. S.I. Bhuiyan, and Dr. D.H. Murray-Rust.

Effects of rice straw decomposition of *Trichoderma* species on inoculum of sheath blight pathogen. Ms. A. Rosales.

Resistance studies to the rice tungro viruses. Mr. E.R. Tiongco and Dr. H.R. Hibino.

Pathogenic variation in the rice blast fungus *Pyricularia oryzae*. Ms. T. Vergel de Dios, research assistant; Mr. J.M. Bandong, assistant scientist; Mr. M.M. Khin, former research scholar; Dr. E.J. Lee, former visiting scientist; and Dr. J.M. Bonman, associate plant pathologist, Plant Pathology Department.

Quarantine certification of rice seeds at IRRI. Mr. D.M. Matias, Mr. C.C. Huelma, Mr. S.D. Merca, and Dr. T.W. Mew.

Sink size, quality grain, and yield potentials in rice. Dr. B. Venkateswarlu, senior research fellow; Dr. B.S. Vergara, plant physiologist; and Mr. J.K. Ahn, research fellow, Plant Physiology Department.

Deep placement fertilization at later growth stage of rice under the tropical environment. Mr. F.T. Parao, Ms. V. Coronel, and Dr. S. Akita.

Rice research and production in the Democratic People's Republic of Korea. Dr. M.S. Swaminathan, Dr B.S. Vergara, and Dr. G.S. Khush.

Special seminars

Activities at TARC, Okinawa. Dr. T. Gotoh and Mr. H. Araki, Tropical Agriculture Research Center, Okinawa Branch, Japan.

Water relations of sugarcane. Dr. K.T. Ingram, associate agronomist, Hawaiian Sugar Planters' Association, AIEA, Hawaii.

Statistical tables and diagrams: help or hindrance? Dr. D.J. Finney, visiting scientist, Statistics Department.

Pollen and fungus: feeding thrips an ecological perspective. Dr. T.N. Ananthakrishnan, director, Entomology Research Institute, Loyola College, Madras, India.

Rice and flooding tolerance: preliminary work and plans for future tissue culture experiments. Dr. J. McComb, senior lecturer, Biology School of Environmental and Life Sciences, Murdoch University, Western Australia.

Somatic cell culture and salt tolerance in rice. Dr. D.S. Brar, senior research fellow, Tissue Culture Facility.

Is there a future for plant chemicals in crop protection? Prof. L.M. Schoonhoven, Agricultural University, Wageningen, The Netherlands.

IITA hybrid maize for the tropics. Dr. S.K. Kim, IITA maize breeder, Ibadan, Nigeria.

Development of a molecular genetic system for understanding the pathogenicity and host specificity of the rice blast fungus *Pyricularia oryzae*. Dr. B. Valent, research scientist, E.I. Du Pont de Nemours and Company, Inc., Central Research and Development Department, Experimental Station, Wilmington, Delaware, USA.

Symbiont in the brown planthopper. Dr. M. Sugiura, Applied Microbiology, National Institute of Agro-Biological Resources, Japan.

Persistence of organochlorine pesticides under subtropical conditions. Dr. H.C. Agarwal, Department of Zoology, University of Delhi, Delhi, India.

Rural unemployment problem. Prof. R. Sinha, International Exchange Department, Tokyo, Japan.

A statistical analysis of body measurements of Filipino women. Dr. A.I. Gironella, associate professor of statistics, Institute of Mathematical Sciences and Physics, College of Arts and Sciences, University of the Philippines at Los Baños, College, Laguna.

CIRAD What is it? Dr. J. Servant, soil scientist, INRA, France.

Interspecific hybridization in *Medicago*. Dr. T. McCoy, Rockefeller Foundation, New York, USA.

Indian industries' role in increasing fertilizer use efficiency, particularly use of urea supergranules. Mr. V. Kumar, chief, Agricultural Services, IFFCO, New Delhi, India.

Pathotoxin and tissue culture: tools for selection of disease-resistant plants in vitro. Dr. P. Vidhyasekaran, visiting scientist, Plant Pathology Department.

Environmental management research in Japan. Dr. K. Muraoka, chief, Hydrospheric Environment Management Section, National Institute for Environment Studies, Tsukuba, Japan.

Nitrogen research in northwest Syria. Dr. K. Harmsen, head, Program, Agro-Economic Division, International Fertilizer Development Center, Muscle Shoals, Alabama, USA.

Applications of remote sensing and satellite imagery in rice production and water management. Dr. J. Hill and Mr. S. Leibowitz, Remote Sensing Laboratory, Louisiana State University, USA.

Fertilizer and soil nitrogen: improving the economic sustainability of MV rice. Dr. J. Smith, visiting scientist, Agricultural Economics Department.

Analysis of bibliographical data relating to the international bibliography of rice research. Ms. K. Morooka, IRRI-Japan Library Office.

Sociolinguistics in the communication process and its implications for language teaching. Dr. T.J. Kral, regional English teaching officer for ASEAN, United States Information Service.

The potential for adapting high technology in no-tillage to Asian requirements. Dr. C.J. Baker, director, Agricultural Machinery Research Center, Massey University, Palmerston North, New Zealand.

Fertilizer scenery in India and role of fertilizer industries in increasing agricultural production. Mr. S. Ekambaram, joint manager (agronomy and extension), Southern Petrochemical Industries Corporation, Ltd., Madras, India.

Some problems of rice production in the Philippines. Dr. R. Dumont, professor, Institute of Agronomy, Paris, France.

Plant breeding for straw ruminant feeding quality characteristics. Dr. B.S. Capper, Animal Feed Section, Tropical Development and Research Institute, London.

Nondegree training at IRRI a time scan. Dr. D.R. Minnick.

Plant breeding for the nineties: problems and opportunities. Dr. P.R. Day, Plant Breeding Institute, Cambridge, England.

BOSTID research grants program. Dr. M. Greene, deputy director, Board on Science and Technology for International Development, National Academy of Sciences, USA.

Finances

Summary of financial support to IRRI core and to special and collaborative projects received in 1985.[a]

Source	US$ (thousand)			
	Core		Special and Collaborative Projects	Total
	Unrestricted	Restricted		
Details of sources of support from grants				
United States Agency for International Development	**7,419**		1,599	9,018
Japanese Government	—	3,384	427	3,811
International Bank for Reconstruction and Development	2,500	—	—	2,500
Canadian International Development Agency	1,199	—	1,233	2,432
United Nations Development Programme	—	1,570	352	1,922
European Economic Community		**1,172**	—	1,172
Overseas Development Administration, United Kingdom	933		—	933
Federal Republic of Germany	459	150	75	684
International Development Research Centre, Canada	—	215	359	574
Australian Government	571	—	—	571
Government of Italy	145	—	319	464
Asian Development Bank	—	—	421	421
Government of Sweden	349	—	—	349
Government of the Netherlands	—	92	232	324
Government of Saudi Arabia	**300**	—	—	300
International Fund for Agricultural Development	—	300	—	300
Government of India	**250**	—	25	275
Government of the Philippines	**90**	—	113	203
Ford Foundation	150	—	48	198
Government of Denmark	172	—	—	172
Government of Belgium	**80**	—	80	160
Office of Rural Development, Korea	—	—	132	132
Government of Mexico	**132**	—	—	132
Government of Norway	102	—	—	102
Government of China	100	—	—	100
Government of the Islamic Republic of Iran	—	—	58	58
Swiss Development Corporation	—	206	55	261
Rockefeller Foundation	—	**000**	50	50
Government of Spain	**25**	—	—	25
Government of New Zealand	13	—	—	13
Miscellaneous research grants	—	—	86	86
Funds reimbursed under collaborative research program				
Resources Management International, Indonesia	—	—	89	89
International Food Policy Research Institute	—	—	84	84
International Institute of Tropical Agriculture	—	—	76	76
International Centre of Insect Physiology and Ecology	—	**69**	—	69
International Fertilizer Development Center	—	—	43	43
International Board for Plant Genetic Resources	—	—	42	42
Food and Agriculture Organization of the United Nations	—	—	8	8
United Nations Environmental Programme	—	—	4	4
Total	14,989	7,158	6,010	28,157

[a]Receipts are accounted for on a cash basis. Amounts shown in boldface differ from 1985 pledges from grantors in that they may reflect 1984 pledges received in 1985, or may not reflect the full amount of 1985 pledges, which are anticipated to be received in 1986. The Governments of France (through the research organizations ORSTOM and IRAT) and the Netherlands provided IRRI the services of three resident scientists; the value of their services cannot be quantified.

Staff changes

January

Dr. M. Akbar, National Coordinator (Rice), PARC, joined IRRI as plant breeder with the International Rice Testing Program.

Dr. T. T. Chang, geneticist and head of the International Rice Germplasm Center, was appointed principal geneticist, effective 1 Jan.

Dr. S. H. M. Zaman, former director general of Bangladesh Rice Research Institute, joined IRRI as liaison scientist for Africa.

Dr. Lloyd T. Bostian, professor, Department of Journalism, University of Wisconsin-Madison, joined IRRI as visiting editor with the Communication and Publications Department.

Dr. Foster F. Cady, Benchmark Soil Project, East-West Center, Hawaii, joined IRRI as consultant to help analyze rice-weather data and organize the handling of the data in collaboration with Dr. L. R. Oldeman.

Mr. Noel P. Magor, former agricultural program consultant, HEED, Bangladesh, joined IRRI as associate agronomist with the IRRI BRRI Collaborative Project in Bangladesh.

Mr. Frank Shideler, former senior editor of CIP, joined IRRI as contract editor with the Communication and Publications Department.

Dr. Sang-Won Ahn completed a 1-yr assignment as visiting associate scientist from CIAT with the Plant Pathology Department.

February

Dr. Sang-Won Ahn, plant pathologist, was appointed visiting associate plant pathologist.

March

Dr. Robert E. Huke, Dartmouth College, left after completing his assignment as short-term visiting scientist.

Dr. T. Ogawa left after completing his assignment as visiting plant breeder.

Dr. L. R. Oldeman, World Meteorological Organization, left after completing his assignment as visiting scientist with the joint IRRI-WMO studies on rice-weather relationships in the Multiple Cropping Department.

Mr. Ian Montagnes of the University of Toronto Press arrived to begin a 2-yr assignment as visiting editor with the Communication and Publications Department.

Mr. Frank Shideler, former senior editor, CIP, left after completing his work as contract editor with the Communication and Publications Department.

Dr. Foster F. Cady, University of Hawaii, left after completing his consultancy assignment with the Multiple Cropping Department.

Dr. J. Ritchie Cowan, retired IRRI liaison scientist for Indonesia and Malaysia, arrived to begin another 6-mo consultancy assignment with the Director General's Office.

Mr. Makoto Ariyoshi resigned as agricultural engineer.

Dr. Amanda Te, former IRRI research associate, left after completing a 1-yr assignment as visiting associate agricultural economist.

April

Dr. Jennie Dey, FAO, left after completing consultancy work on the role of women in rice farming systems.

Dr. Ian F. Grant of Boyce Thompson Institute for Plant Research, Cornell University, left after completing his assignment as visiting associate soil microbiologist.

May

Dr. T. Ogawa, TARC staff, joined IRRI as plant breeder.

Dr. Jean C. Glaszmann, IRAT, arrived to begin a 3-yr assignment as visiting associate scientist with the Plant Breeding Department under the IRRI-IRAT Memorandum of Agreement.

Dr. G. L. Denning, visiting associate field specialist, returned after completing his Ph D.

Dr. Robert L. Zimdahl, Colorado State University, left after completing a 1-yr assignment as visiting scientist with the Agronomy Department.

Dr. H. D. Catling resigned as IRRI entomologist, IRRI Cooperative Project in Thailand.

June

Mr. Federico V. Ramos, farm superintendent and head, Experimental Farm Department, retired upon reaching age 65.

Dr. Anwar A. Khan, New York State Agricultural Experiment Station, Cornell University, arrived to begin a 1-yr assignment.

Dr. Laurian J. Unnevehr, former research associate, left after completing a 1-1 2-yr assignment as visiting associate agricultural economist.

July

Dr. Felix N. Ponnamperuma, principal soil chemist and head of the Soil Chemistry Department, retired upon reaching age 65.

Dr. Joyotee Smith, former research associate, left after completing her assignment as visiting associate agricultural economist.

Dr. Dennis M. Wood, visiting scientist with the International Rice Testing Program, resigned to join ISNAR.

August

Dr. E. A. Heinrichs, entomologist and head, Entomology Department, resigned.

Dr. Genshichi Wada, TARC research coordinator, joined IRRI as plant physiologist.

Dr. S. I. Bhuiyan, agricultural engineer and head, Water Management Department, returned after completing a 1-yr sabbatic leave at Rutgers University, Department of Agricultural Economics and Marketing.

Dr. Keith T. Ingram, former associate agronomist of the Hawaiian Sugar Planters' Association, joined IRRI as associate agronomist.

Dr. J. Ritchie Cowan, retired IRRI liaison scientist for Indonesia and Malaysia, left after completing his assignment as consultant for the outreach programs and the 25th Anniversary symposium.

Dr. Leo Dale Haws, rice production training specialist with IRRI's Rice Research and Training Project in Egypt, resigned.

September

Dr. David J. Finney of the University of Edinburgh left after completing his assignment as consultant in the Statistics Department.

Dr. Billy J. Cochran, agricultural engineer with IRRI's Cooperative Projects with the Ministry of Agriculture and Cooperatives, Thailand, left upon completion of the project.

Dr. Venkat R. Reddy, agricultural engineer, IRRI-DITPROD Industrial Extension Project, Jakarta, Indonesia, resigned.

October

Mr. R. Vaidyanathan, manager, Purchase and Supplies Division, ICRISAT, arrived to begin a 6-mo consultancy assignment with Administration on purchasing and supplies management.

Dr. B. Merle Shepard, entomologist, was appointed head of the Entomology Department, effective 16 Oct.

November

Dr. M. A. Choudhary of Massey University arrived to begin a 6-mo sabbatic leave with the Agricultural Engineering Department.

Dr. Gelia T. Castillo, UPLB professor, began a 1-yr assignment as visiting scientist with the Agricultural Economics Department.

December

Dr. Lloyd R. Bostian of the University of Wisconsin-Madison left after completing a 1-yr assignment as visiting editor with the Communication and Publications Department.

Ms. Yoshiko Yamamoto, Cornell University, left after completing a consultancy assignment, assisting in the preparation of the exhibits of the rice museum and collecting lowland artifacts to complement the Ifugao artifacts collected by Dr. Harold Conklin.

Mr. C. Thomas Brackney, rice production specialist on the IRRI-BRRI Project, resigned.

Dr. Pedro B. Escuro, plant breeder, IRRI-Burma Cooperative Project, resigned.

Mr. Malcolm M. Hammond, IRRI team leader/agricultural engineer on the IRRI-Burma Cooperative Project, resigned.

Mr. Salvador Labro, mechanization specialist, returned to the Agricultural Engineering Department after completing a 1-yr assignment with the IRRI-Egypt Rice Research and Training Project.

Dr. Kaung Zan, visiting scientist with the IRTP, left after completing his assignment.

Weather summary

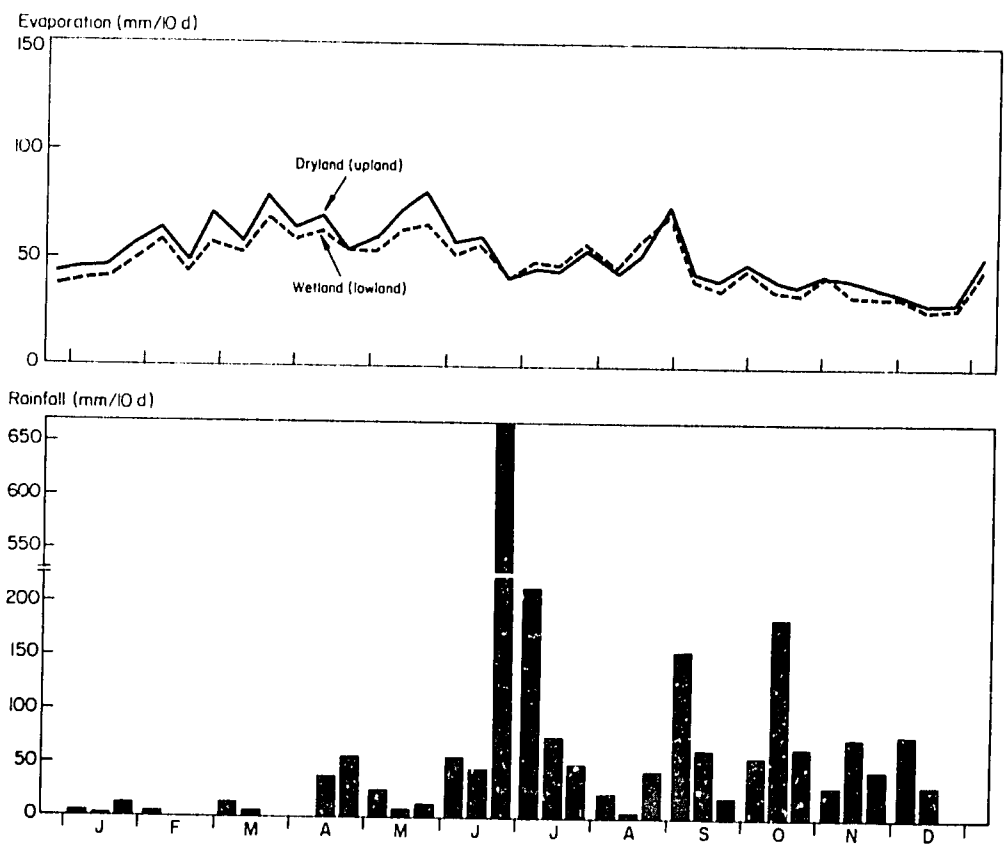
The 1985 annual rainfall totals were 2,144 mm for the dryland (upland) site and 2,125 mm for the wetland (lowland) site (Table 1). The wet season lasted from June to December. August rainfall was abnormally low: 67 mm (Fig. 1). June was exceptionally wet, with 754 mm rainfall at the dryland site and 680 mm at the wetland. IRRI annual rainfall total for 1985 was 153 mm above the 68-yr normal for Los Baños.

Annual solar radiation for both sites was 445 mWh/cm^2 per d. Solar radiation was highest in May, with 565 mWh/cm^2 per d at the dryland site and 557 mWh/cm^2 per d at the wetland, and 8.0 h of bright sunshine (Fig. 2). Solar radiation was lowest in December, with 332 mWh/cm^2 per d at the dryland site and 321 mWh/cm^2 per d at the wetland, and 4.7 h of bright sunshine.

Maximum, minimum, and mean temperatures are in Figure 3. Maximum temperature averages were lowest in January (29.2 °C at the dryland site and 27.8 °C at the wetland) and highest in May (33.8 °C dryland and 32.1 °C wetland). The warmest temperature (36.2° C) was registered on 28 May at the dryland site. Minimum temperature averages were lowest in January (21.3 °C dryland and 20.7 °C wetland) and highest in August (24.5 °C dryland and 24.4 °C wetland). The coldest temperature (16.5 °C) was registered on 11 January at the dryland site.

Monthly means for vapor pressure deficit were consistently higher throughout the year at the dryland site (Fig. 4).

Windspeed measured at 2 m aboveground was highest at the dryland site in June (2.5 m/s) and at

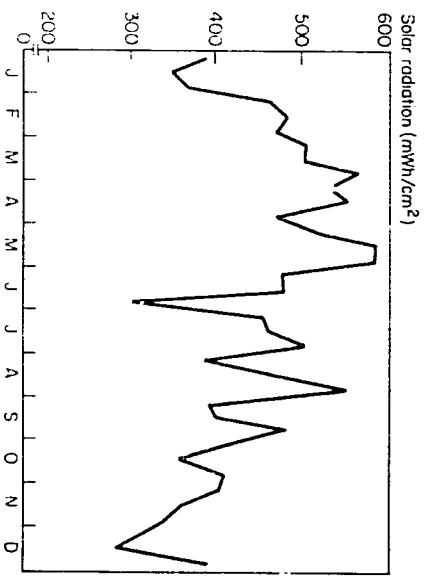


1. Rainfall and evaporation by 10-d period, IRRI, 1985.

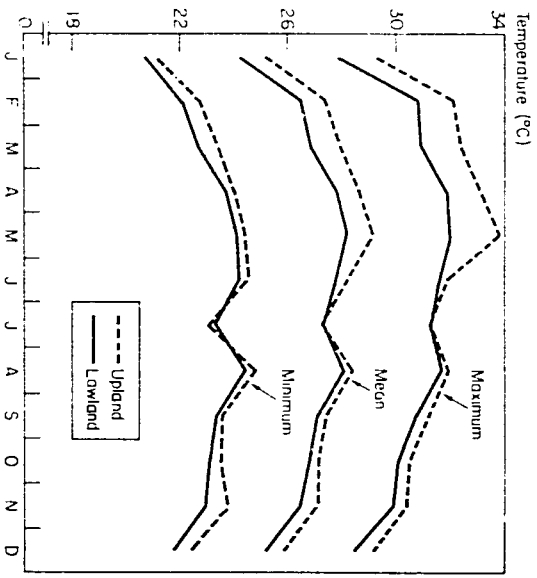
Table 1. Monthly weather data at IRRI dryland and wetland sites, Los Baños (14°13'N, 121°15'E), Laguna, Philippines, 1985.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Dryland site													
Rainfall (mm/mo)	9	5	31	94	40	754	340	67	238	307	151	108	2144
Total radiation (mWh/cm² per d)	365	470	530	515	565	418	472	468	420	388	369	332	445
Maximum temperature (°C)	29.2	32.0	32.4	33.2	33.8	31.8	31.3	31.8	31.2	30.5	30.3	29.2	31.4
Minimum temperature (°C)	21.3	22.6	23.2	23.8	24.3	24.3	23.0	24.5	23.5	23.4	23.7	22.4	23.3
Windspeed (m/s)	1.9	1.9	1.9	1.5	1.7	2.5	1.4	2.1	1.4	1.4	1.5	1.6	1.7
Total evaporation (mm/mo)	134	169	202	185	209	157	145	168	132	121	111	111	1843
Wetland site													
Rainfall (mm/mo)	13	6	30	87	54	680	391	61	239	336	139	90	2126
Total radiation (mWh/cm² per d)	365	500	555	545	557	417	472	461	415	386	349	321	445
Maximum temperature (°C)	27.8	30.8	30.8	31.9	32.1	31.6	31.2	31.8	30.8	30.3	29.9	28.4	30.6
Minimum temperature (°C)	20.7	22.0	22.6	23.5	24.0	24.0	23.1	24.4	23.2	23.1	22.9	21.6	22.9
Windspeed (m/s)	1.5	1.8	1.8	1.2	1.1	1.8	1.2	1.7	1.3	1.2	1.3	1.5	1.4
Wind direction[a]	NE	NE	ENE	NE	NE	VRBL	VRBL	SE	VRBL	SE	VRBL	VRBL	NE
Bright sunshine (m/d)	5.0	8.0	8.2	7.4	8.0	4.9	6.1	5.7	4.5	5.1	4.6	4.7	6.6
Total evaporation (mm/mo)	117	148	177	174	178	147	150	164	121	111	96	100	1680

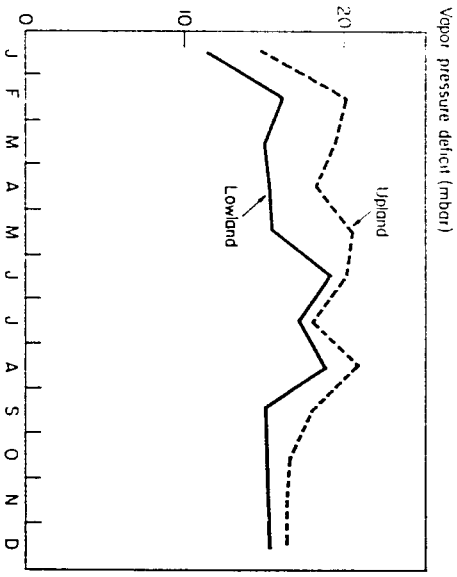
[a]VRBL = variable.



2. Solar radiation level by 10-d period. IRRI, 1985.



3. Average monthly temperature. IRRI, 1985.



4. Midday vapor pressure deficit. IRRI, 1985.

the wetland site in February, March, and June (1.8 m/s). Wind was variable in most of the months.

Evaporation from the Class A pan was higher at the dryland site (Fig. 1). The highest monthly evaporation (209 mm in May) dropped to 111 mm in November and December at the dryland site. The highest evaporation at the wetland site was 178 mm in May; the lowest was 96 mm in November.

Of 17 tropical disturbances that passed through the Philippine area of responsibility, 2 typhoons in June affected the immediate Los Baños area (Typhoon Kuring, 20-24 Jun; Typhoon Daling, 25-29 Jun).