PN-ABL-715

INTERNATIONAL RICE RESEARCH INSTITUTE

Program Report for 1990

INTERNATIONAL RICE RESEARCH INSTITUTE

1991

IRRI

INTERNATIONAL RICE RESEARCH INSTITUTE

Los Baños, Laguna, Philippines

P.O.Box 933, 1099 Manila, Philippines

The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of the 13 nonprofit international research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 50 donor countries, international and regional organizations, and private foundations.

IRRI receives support, through the CGIAR, from a number of donors including the Asian Development Bank, the European Economic Community, the Ford Foundation, the International Development Research Centre, the International Fund for Agricultural Development, the OPEC Special Fund, the Rockefeller Foundation, UNDP, the World Bank, and the international aid agencies of the following governments: Australia, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, India, Iran, Italy, Japan, Republic of Korea, Mexico, The Netherlands, New Zealand, Norway, the Philippines, Saudi Arabia, Spain, Sweden, Switzerland, United Kingdom, and United States.

The responsibility for this publication rests with the International Rice Research Institute.

Copyright © International Rice Research Institute 1991

All rights reserved. Except for quotations of short passages for the purpose of criticism and review, no part of this publication may be reproduced, stored in retrieval systems, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior permission of IRRI. This permission will not be unreasonably withheld for use for noncommercial purposes. IRRI does not require payment for the noncommercial use of its published works, and hopes that this copyright declaration will not diminish the bona fide use of its research findings in agricultural research and development.

The designations employed in the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of IRRI concerning the legal status of any country, territory, city, or area, or of its authorities, or the delimitation of its frontiers or boundaries.

The Program Report for 1990 was edited by Meera Kumar, with Gloria Argosino, Teresita Rola, and Theresa Castillo, and graphic design by Patricio Mamon.

International Rice Research Institute
P.O. Box 933, 1099 Manila
Philippines
FAX: (63-2) 817-8470; 818-2087
Telex: (ITT) 45365 RICE PM
(ITT) 40890 RICE PM
(RCA) 22456 IRI PH
(EASTERN) 63786 RICE PN

ISSN 0117-0880

Contents

FOREWORD v

TRUSTEES AND PERSONNEL vi

USING THIS REPORT xiii

ABBREVIATIONS AND ACRONYMS xv

RESEARCH PROGRAMS 1
- Irrigated rice ecosystem 3
- Rainfed lowland rice ecosystem 65
- Upland rice ecosystem 97
- Deepwater and tidal wetlands rice ecosystems 125
- Cross-ecosystems research 143

INTERNATIONAL PROGRAMS 215
- Germplasm conservation and dissemination 217
- Information and knowledge exchange 225
- Networks 229
- Training 253
- Country and regional projects 267

RESEARCH SUPPORT SERVICES 284

PUBLICATIONS AND SEMINARS 288

STAFF CHANGES 301

FINANCES 303

WEATHER SUMMARY 304

KEYWORD INDEX 308

Foreword

Both the problems and the methodologies have changed greatly since research began at IRRI. The driving need in 1960 was to increase the yield potential of rice; in 1970 and 1980, to stabilize yields and improve the ability of farmers to reach yield potentials.

The rice world of the 1990s is even more complex than it was 30 years ago, at IRRI's founding. The further increases in productivity needed to keep up with population growth and rice demand must be linked with imperative concerns about riceland sustainability. That interaction is driving research direction in the 1990s.

For IRRI, this was a year of change, of adaptation to new needs. We took the experience gained over 30 years of rice research and added new insights and new techniques to launch the Institute on the challenging tasks necessary to meet the demands of the next 30 years. The Institute's Work Plan for 1990-1994 was initiated within a new organizational structure: interdisciplinary work is carried out in rice ecosystem-based programs.

This Program Report for 1990 covers work that—in one way or another—contributes to meeting the need for a stable food supply, by people living now and by the 3-4 billion more people who will depend on rice in 2020. Some of the projects are far up the scale of strategic work, some are closer to applied work that national agricultural development programs can adapt to their particular situations.

While IRRI is concentrating on more strategic research issues, all of its research is closely linked to the needs of national agricultural research systems. Much of the work is done in collaboration with advanced laboratories elsewhere and with the rice scientists in national rice research institutions. In applied research, almost all the work is done in interaction with national agricultural research systems.

IRRI's international programs facilitate the interactions of rice scientists and pave the way for the meaningful, productive, timely, and cost-effective rice research needed to resolve current and anticipated barriers to stable and sustainable rice production.

We report IRRI work through this annual Program Report as a permanent record, to account to the Institute's donors, and to make available to rice scientists everywhere current information about the outcomes of IRRI projects.

Klaus Lampe
Director General

Trustees

Chairman
DR. WALTER P. FALCON
Director
Food Research Institute
Stanford University
Stanford, California 94305
USA

Members
DR. JOSE V. ABUEVA*
President
University of the Philippines
Quezon Hall
Diliman, Quezon City
Metro Manila, Philippines

HON. SENEN C. BACANI*
Secretary of Agriculture
Department of Agriculture
Diliman, Quezon City
Metro Manila, Philippines

DR. DIETER F.R. BOMMER
Professor
Sudring 1
D-3405 Rosdorf
Federal Republic of Germany

DR. KAZUTAKE KYUMA
Professor
Laboratory of Soil Science
Faculty of Agriculture
Kyoto University
Kyoto 606, Japan

DR. KLAUS LAMPE*
Director General
International Rice Research Institute
P.O. Box 933
Manila 1099, Philippines

DR. IBRAHIM MANWAN
Director
Central Research Institute for Food Crops
Jalan Merdeka 147
Bogor, Indonesia

DR. JAMES R. McWILLIAM
129 Mugga Way
Red Hill ACT 2603
Australia

DR. LETITIA E. OBENG
P.O. Box 49
Achimota, Ghana
West Africa

DR. RAJENDRA S. PARODA
Deputy Director General
Crop Sciences
Indian Council of Agricultural Research
Krishi Bhavan
Dr. Rajendra Prasad Road
New Delhi 110001
India

DR. HOWARD A. STEPPLER
Emeritus Professor
Department of Plant Science
MacDonald College of McGill University
21,111 Lakeshore Road
Ste. Anne de Bellevue, P.Q.
Canada H9X 1C0

DR. PETCHARAT WANNAPEE
Deputy Director General
Department of Agricultural Extension
Ministry of Agriculture and Cooperatives
2nd Floor, 2143/1 Paholyothin Road
Khet Jatujak, Bangkok 10200
Thailand

PROF. MUHAMMAD YUNUS
Managing Director
Grameen Bank
Mirpur Two, Dhaka 1216
Bangladesh

DR. VO-TONG XUAN
Vice Rector and Center Director
Mekong Delta Farming Systems Research
and Development Center
University of Cantho
Cantho, Haugiang
Vietnam

*Ex officio.

Personnel

Administrative Staff

KLAUS LAMPE, *Ph D, director general*
FERNANDO A. BERNARDO, *Ph D, deputy director general for international programs*
HUBERT G. ZANDSTRA, *Ph D, deputy director general for research programs*
MICHAEL F L. GOON, *MBA, deputy director general for finance and administration* [1]
TIMOTHY L. BERTOTTI, *MBA, director, administration*
EDWARD N SAYEGH, *BBA, director, finance*
ERNEST W. NUNN, *Ph D, director, operations*
DIOSCORO L. UMALI, *Ph D, liaison scientist, China (consultant)*
PEDRO G. BANZON, *LLB, manager security, safety, and shipping*
REBECCA C. PASCUAL, *MS, manager, food and housing services*
ZOSIMO Q. PIZARRO, *LLB, manager, legal office*
ORLANDO G. SANTOS, *MPS, senior farm and grounds superintendent*
JOHN DOWLING, *consultant*
KLAUS WAHL, *consultant* [1]
PHILIP WILLIAMS, *Ph D, consultant*

Scientists Posted to National Agricultural Research Systems

Bangladesh
JERRY L. McINTOSH, *Ph D, research systems specialist and IRRI representative*
NOEL P. MAGOR, *M Agr, agronomist-cropping systems*

Cambodia
HARRY J. NESBITT, *Ph D, agronomist and team leader*
RAM CHET CHAUDHARY, *Ph D, plant breeder*
RICHARD P. LANDO, *Ph D, technology transfer specialist*

Egypt
EDWARD D. SPRATT, *Ph D, project manager*
ANKIREDDY P.K. REDDY, *Ph D, plant pathologist*

India
SUDHAMOY BISWAS, *Ph D, project director*
B.P. GHILDYAL, *Ph D, liaison scientist*

Indonesia/Malaysia/Brunei
CEZAR P. MAMARIL, *Ph D, agronomist and liaison scientist*

Japan
MASAMI HIMEDA, *D Agr, part-time liaison scientist*

Lao PDR
JOHN M. SCHILLER, *Ph D, agronomist and team leader* [4]
SUVIT PUSHPAVESA, *MS, plant breeder* [4]

Madagascar
JAMES R. HOOPPER III, *Ph D, agronomist*
B.B. SHAHI, *Ph D, plant breeder* [1]

Myanmar
ROSENDO K. PALIS, *Ph D, farming systems agronomist*

Thailand
DONALD W. PUCKRIDGE, *Ph D, agronomist and program leader, deepwater and tidal wetland rice ecosystem*

Africa
KRISHNA ALLURI, *Ph D, liaison scientist and INGER regional coordinator*

Latin America
FEDERICO E. CUEVAS-PEREZ, *Ph D, liaison scientist and INGER coordinator*

Agricultural Engineering

Graeme R. Quick, *Ph D, agricultural engineer and head*
Terence Woodhead, *Ph D, physicist* [5]
James S. Townsend, *Ph D, visiting scientist* [1]
N.K. Awadhwal, *Ph D, project engineer* [5]
Anthony J. Ringrose-Voase, *Ph D, consultant* [1]
Salvador C. Labro, *BS, assistant engineer*
Godofredo C. Salazar, *MS, assistant engineer*
Lawrence C. Kramco, *MS, senior research assistant* [9]
Herbert T. Manalugod, *MS, senior research assistant*
Eulito U. Bautista, *MS, research assistant*
Rustico C. Bautista, *BS, research assistant*
Elizabeth P. Bonifacio, *MS, research assistant*
Miguelito S. Diestro, *BS, research assistant*
Nenita B. Fortuno, *BS, research assistant* [1]
Susana G. Maghari, *BS, research assistant* [1]
Alfredo M. Mazaredo, *BS, research assistant* [10]
Bernabe L. Paita, *BS, research assistant* [4]
Estela M. Pasuquin, *BS, research assistant*
Edna A. de San Agustin, *BS, research assistant* [2]
Mary Ethel C. Tenedora, *BS, research assistant* [1,5]
Artemio B. Vasallo, *BS, research assistant*
Nora R. Macariola, *BS, research aide* [5]
Edwin Pilarte, *BS, research aide* [5]
Myra B. Pura, *BS, research aide* [5]
Edgar V. Salire, *BS, research aide* [1,5]

Agronomy, Plant Physiology, and Agroecology

Benito S. Vergara, *Ph D, plant physiologist and acting division head*
Keith T. Ingram, *Ph D, agronomist and deputy division head*
Surajit K. De Datta, *Ph D, principal agronomist and program leader, rainfed lowland rice program*
Donald W. Puckridge, *Ph D, agronomist and program leader, deepwater and tidal wetlands program* [1]
Dennis P. Garrity, *Ph D, agronomist crop ecologist*
Frits W. T. Penning de Vries, *Ph D, agronomist crop modeler* [1]
Keith Moody, *Ph D, agronomist*
Martin J. Kropff, *Ph D, agronomist crop production ecologist* [4]
Minoru Yamauchi, *Ph D, plant physiologist* [4]
Virendra Pal Singh, *Ph D, associate agronomist*
Roland J. Buresh, *Ph D, visiting scientist*
H. D. Catling, *Ph D, visiting scientist*
M.P. Janoria, *Ph D, visiting scientist*
Saroj K. Sanyal, *Ph D, visiting scientist*
Alan K. Watson, *Ph D, visiting scientist* [1]
Mai Van Quyen, *Ph D, visiting scientist* [1]
Michael Dingkuhn, *Ph D, collaborative research scientist* [1]
Heins Friedrich Schmier, *Ph D, collaborative research scientist* [1]
Romeo C. Bruce, *Ph D, consultant* [1]
Wilhelmino T. Herrera, *MS, assistant scientist*
Jose A. Malabuyoc, *MS, assistant scientist*
Romeo M. Visperas, *MS, assistant scientist*
Serafin T. Amarante, *MS, senior research assistant*
Paul C. Bernasor, *MS, senior research assistant*
Alfredo N. Calendacion, *MS, senior research assistant*
Helen Grace S. Centeno, *MS, senior research assistant*
Victoria P. Coronel, *MS, senior research assistant*
Armando S. Erguiza, *MS, senior research assistant* [1]
Anita L. Frio, *MS, senior research assistant* [1]
Romulo E. Furoc, *MS, senior research assistant*
Felipe V. Garcia, *MS, senior research assistant*
Hermenegildo C. Gines, *MS, senior research assistant*
Samuel P. Liboon, *MS, senior research assistant*
Rogelio D. Magbanua, *MS, senior research assistant*
Ofelia S. Namuco, *MS, senior research assistant*
Wilma N. Obcemea, *MS, senior research assistant*
Cecilia H. Reyes, *MS, senior research assistant*
Rogelio L. Rosales, *MS, senior research assistant*
Manuel M. Tamisin, *MS, senior research assistant* [1]
Rolando O. Torres, *MS, senior research assistant*
Elizabeth B. Yambao, *MS, senior research assistant*
Mary Jacqueline C. Alagos, *MS, research assistant*
Jovencio M. Alcantara, *BS, research assistant*
Patricio C. Agustin, Jr., *MS, research assistant*
Francia Felipa D. Baeno, *M Agr, research assistant*
Marilyn S. Cabrera, *BS, research assistant* [1, 4]
Gloria C. Cabuslay, *MS, research assistant*
Jenny C. Calabio, *MS, research assistant* [1]
Ernesto G. Castillo, *MS, research assistant*
Eduardo M. Castin, *BS, research assistant*
Polly Y. Chan, *BS, research assistant*
Rebecca Salome C. Chavez, *MS, research assistant*
Teresita T. Chua, *BS, research assistant*
Josue P. Descalsota, *BS, research assistant*
Maribeth C. Duqueza, *BS, research assistant* [4]
Patricio C. Elliot, *MS, research assistant* [1]
Leopoldo E. Estorninos, Jr., *MS, research assistant*
Dome Harnpichitvitaya, *MS, research assistant* [1]
Joel D. Janiya, *MS, research assistant*
Manoch Kongchum, *MS, research assistant* [1]
Eufrocino V. Lauzeles, *MS, research assistant*
Ma. Rebecca C. Laza, *MS, research assistant*
Rosario T. Lubigan, *MS, research assistant*
Maxima O. Mabbayad, *MS, research assistant*
Aurora M. Mazaredo, *MS, research assistant*
Teodoro R. Migo, *BS, research assistant*
Domingo C. Navarez, *MS, research assistant*
Paquito P. Pablico, *MS, research assistant*
Jaime L. Padilla, *MS, research assistant*
Phannee Panichagon, *BS, research assistant* [1, 4]
George F. Pateña, *MS, research assistant* [1]
Krishda Peassachar, *MS, research assistant* [1, 4]
Joselito G. Real, *BS, research assistant*
Cristoti A. Redulla, *BS, research assistant*
Reynaldo C. Rodriguez, *MS, research assistant*
Soontari Sarsingtong, *BS, research assistant* [4, 5]
Marianne I. Samson, *BS, research assistant*
Acharee Sattarasart, *BS, research assistant* [1]
Somchoke Sinoupakorn, *BS, research assistant* [1]
Joel D. Siopongco, *BS, research assistant*
Conrado M. Siota, *MS, research assistant* [4]
Miliza D. Valde, *BS, research assistant* [1]
Chirawat Vejpas, *MS, research assistant* [1]
Anacorita N. Villegas, *MS, research assistant* [1]
Trainuda Wattuardrock, *BS, research assistant* [1, 5]
Anastacia P. Aclan, *BS, research aide*
Alberto M. Aguilar, *BS, research aide* [1]
Darryl Aragones, *BS, research aide* [1]
Rowena C. Aragones, *BS, research aide*
Visitacion Baquiran, *BS, research aide* [1]
Alberto N. Blanco, *BS, research aide* [1]
Maridelle A. Dizon, *BS, research aide*
Dennis I. Estrella, *BS, research aide* [1]
Ferdinand F. Fajardo, *BS, research aide* [1]
Phoebe B. Gonzales, *BS, research aide* [1]
Edwin M. de Guzman, *BS, research aide* [1]
Prudencio S. Heradura, *BS, research aide* [4]
Elizabeth E. Lapitan, *BS, research aide* [1]
Agustin A. Mercado, Jr., *BS, research aide*
Carmelita J. Moll, *BS, research aide* [1]
Rico R. Pamplona, *BS, research aide* [1]
Zenaida P. Pascual, *BS, research aide*
Rogelio G. Pernito, *BS, research aide* [1]
German O. Turija, *BS, research aide* [1]
Imelda L. Batugal, *MS, editorial assistant* [1]

Entomology

Dale G. Bottrell, *Ph D, entomologist and head* [4]
Kong Luen Heong, *Ph D, entomologist and acting head* [1, 5]
James A. Litsinger, *Ph D, entomologist*
Ramesh C. Saxena, *Ph D, entomologist*
Zeyaur R. Khan, *Ph D, associate entomologist*
A.N.M. Rezaul Karim, *Ph D, visiting scientist* [1]
Filomeno Medrano, *MS, assistant scientist*
Remedios Aguda, *MS, senior research assistant*
Gertrudo Arida, *MS, senior research assistant*
Edralina Baldos-Medina, *MS, senior research assistant*
Jovito Bandong, *MS, senior research assistant* [1]
Alberto Barrion, *MS, senior research assistant*
Cesar Demayo, *MS, senior research assistant* [1]
Patrocinio Fantua, *MS, senior research assistant* [1]
Herminia Rapusas, *MS, senior research assistant*
Angelita Romena, *MS, senior research assistant*
Lourdes Sumo, *BS, senior research assistant*

Vicente Viajante, *MS, senior research assistant*
Ma. Lleva Abenes, *MS, research assistant* [1,6]
Maria Austria, *BS, research assistant*
Ruperto Basilio, *BS, research assistant*
Isaias Domingo, *BS, research assistant*
Lilia Fabellar, *BS, research assistant*
Hilario Justo, Jr., *MS, research assistant*
Amor Lazaro, *BS, research assistant*
Virginia Magalit, *MS, research assistant*
Estelito Palanginan, *BS, research assistant*
Ramier Jacinto Lumcangco, *BS, research assistant*
Nora Peña-Elec, *MS, research assistant*
Elsa Rubia, *MS, research assistant*
Ma. Liberty Almazan, *BS, research aide*
Bernard Canapi, *BS, research aide*
Josie Lynn Catindig, *BS, research aide*
Dominciano Estaño, *BS, research aide*
Edgar Lubetario, *BS, research aide* [1,6]
Madeleine Malayba-Ebore, *BS, research aide* [1]
Macario Parducho, *BS, research aide* [1,6]
Farlyz Villanueva, *BS, research aide*[1]

Plant Breeding, Genetics, and Biochemistry

Gurdev S. Khush, *Ph.D., principal plant breeder and head*
Sant S. Virmani, *Ph.D., plant breeder*
Derk HilleRisLambers, *Ph.D., plant breeder*
Francisco J. Zapata, *Ph.D., tissue culture specialist*
Bienvenido O. Juliano, *Ph.D., chemist*
Dharmawansa Senadhira, *Ph.D., plant breeder*
David J. Mackill, *Ph.D., plant breeder*
Ryoichi Ikeda, *Ph.D., plant breeder*
Lesley Ann Sitch, *Ph.D., associate cytogeneticist*
Darshan S. Brar, *Ph.D., associate plant breeder*
Susan R. McCouch, *Ph.D., associate geneticist* [5]
Michel A. Arraudeau, *MS, visiting plant breeder*
A.L. Carpena, *Ph.D., visiting scientist*
N. Panda, *Ph.D., consultant* [1]
Jun Kyu Park, *Ph.D., visiting scientist*
Gerard Second, *Ph.D., visiting scientist* [1]
B.N. Singh, *Ph.D., visiting scientist*
Rodolfo C. Aquino, *MS, assistant scientist*
Rizal M. Herrera, *BS, assistant scientist*
Jose C. de Jesus, Jr., *MS, assistant scientist*
Enrique L. Navarro, *MS, assistant scientist*
Consuelo M. Perez, *MS, assistant scientist*
Enrique R. Angeles, *MS, senior research assistant*
Normita M. dela Cruz, *MS, senior research assistant*
Regina D. Dalmacio, *MS, senior research assistant*
Antonio A. Evangelista, *BS, senior research assistant*
Ramon A. Oliveros, *MS, senior research assistant*
Adoracion P. Resurreccion, *MS, senior research assistant*
Benito U. Romena, *BS, senior research assistant*
Lina B. Torrizo, *MS, senior research assistant*
Corazon P. Villareal, *MS, senior research assistant*
Ma. Lleva P. Abenes, *BS, research assistant* [1]
Editha M. Abrigo, *BS, research assistant*
Rhodora R. Aldemita, *MS, research assistant*
Manuel S. Alejar, *BS, research assistant*
Alicia V. Alzona, *MS, research assistant* [1]
Modesto M. Amante, *MS, research assistant*
Edward A. Barlaan, *MS, research assistant*
Carlos L. Casal, Jr., *BS, research assistant*
Susan V. Constantino, *BS, research assistant*
Evangeline S. Ella, *MS, research assistant*
Ruth M. Elloran, *BS, research assistant* [1]
Rise R. Gallego, *BS, research assistant*
Marcelino A. Laza, *BS, research assistant* [1]
Milagros T. Lopez, *MS, research assistant*
Norvie L. Manigbas, *BS, research assistant*
Arnold R. Manza, *BS, research assistant* [1]
Teresita V. Mew, *MS, research assistant* [1]
Hermingildo Murakami, *MS, research assistant* [1]
Alvaro M. Pamplona, *BS, research assistant*
Jose P. Roxas, *BS, research assistant*
Alma C. Sanchez, *MS, research assistant*
Nisa Sithibutr, *MS, research assistant* [1]
Rodante E. Tabien, *MS, research assistant* [1]
Rodolfo S. Toledo, *MS, research assistant* [1]
Georgina V. Vergara, *MS, research assistant* [1]
George A. Gusto, Jr., *BS, research aide*
Delta C. de Castro, *BS, research aide* [1]
Rosalie D. Exconde, *BS, research aide*[1]
Glean B. Gregorio, *BS, research aide*
Benildo delos Reyes, *BS, research aide*
Paulino D. Tenorio, Jr., *BS, research aide*
Rizalito R. Yumol, *BS, research aide*

Plant Pathology

Twng-Wah Mew, *Ph.D., plant pathologist and head*
Paul S. Teng, *Ph.D., plant pathologist and IPM coordinator*
J. Michael Bonman, *Ph.D., plant pathologist*
Hiroki Koganezawa, *Ph.D., plant pathologist*
Rebecca Nelson, *Ph.D., associate plant pathologist*
Jean Claude Prot, *Ph.D., visiting scientist*
Jose M. Bandong, *MS, assistant scientist*
Francisco A. Elazegui, *MS, assistant scientist*
Bienvenido A. Estrada, *MS, assistant scientist*
Emmanuel R. Tiongco, *MS, assistant scientist*
Pepito Q. Cabauatan, *MS, senior research assistant*
Rogelio C. Cabunagan, *MS, senior research assistant*
Castana M. Vera Cruz, *MS, senior research assistant*
Teresita Vergel de Dios-Mew, *MS, senior research assistant* [1]
Edna A. Ardales, *MS, research assistant*
Marietta R. Baraoidan, *MS, research assistant*
Emerlito S. Borromeo, *MS, research assistant*
Aurorita C. Calvero, *BS, research assistant*
Silvino B. Calvero, Jr., *BS, research assistant*
Byron L. Candole, *MS, research assistant*
Nestor G. Fabellar, *MS, research assistant*
Zenaida M. Flores, *BS, research assistant*
Evelyn Gergon, *MS, research assistant* [1]
Maria Elizabeth M. Guico, *BS, research assistant*
Danilo M. Matias, *MS, research assistant*
Edward S. Medalla, *BS, research assistant*
Avelita M. Rosales, *MS, research assistant*
Imelda Rizalina S. Soriano, *BS, research assistant*
Filomena C. Sta. Cruz, *MS, research assistant*
Alicia D. Amante-Bordeos, *BS, research aide*
Marichu A. Bernardo, *MS, research aide*
Susan Bondad, *BS, research aide* [1]
Ma. Teresa R. Cerez, *BS, research aide*
Edgardo L. Coloquio, *BS, research aide*
Amaòle Jose P. Magraye, *BS, research aide*
Gilda J. Miranda, *MS, research aide*
Norman P. Oliva, *BS, research aide*
Don Pabale, *research aide* [1]
Ireneo B. Pangga, *BS, research aide*
Robert C. dela Pena, *MS, research aide*
Ma. Leonora M. Yambao, *BS, research aide* [1,6]

Social Sciences

John C. Flinn, *Ph D, agricultural economist and program leader, irrigated rice ecosystem*
Cristina C. David, *Ph D, agricultural economist and acting head*
J. Bart Duff, *MS, agricultural economist* [1]
James Samuel Fujisaka, *Ph D, agricultural anthropologist*
Leonardo A. Gonzales, *Ph D, agricultural economist* [1]
Prabhu L. Pingali, *Ph D, agricultural economist and acting program leader*
Robert E. Huke, *Ph D, visiting scientist* [1]
Eleanor H. Huke, *BFA, visiting scientist* [1]
Yujiro Hayami, *Ph D, visiting scientist* [1]
Keijiro Otsuka, *Ph D, visiting scientist* [1]
Nimal F.C. Ranaweera, *Ph D, visiting scientist* [1]
Violeta Cordova, *MS, assistant scientist*
Abraham Mandac, *MS, assistant scientist*
Thelma Paris, *MS, assistant scientist*
Arlene Baulite, *MS, senior research assistant* [4]
Armando Erguiza, *MS, senior research assistant* [1]
Ricardo Guino, *MS, senior research assistant*
Susan Lagoy-Erguiza, *MS, senior research assistant*
Constancia Maranan, *MS, senior research assistant*
Marilou Martin, *MS, senior research assistant* [1]
Piedad Moya, *MS, senior research assistant*
Florencia Palis, *MS, senior research assistant*
Lourdes Velasco, *MS, senior research assistant*
Luisa Bambo, *BS, research assistant*
Cristina Carpio, *BS, research assistant* [1]
Bettina Dimaranan, *BS, research assistant* [1]
Jonna Estudillo, *MS, research assistant* [1]
Lolita Garcia, *MS, research assistant* [1]
Fe Gascon, *MS, research assistant*
Raymundo Gonzaga, *BS, research assistant*
Alice Laborte, *BS, research assistant* [1]
Esther Marciano, *BS, research assistant*
Vivencio Marciano, *BS, research assistant*
Polycarpio Masicat, *BS, research assistant*
Adelita Palacpac, *BS, research assistant*
Myra Gina Ramos, *BS, research assistant* [1] [2]
Roberta Caridad Valmonte, *BS, research assistant* [1]
Edwin Ardales, *BS, research aide* [1]
Pio Adan Cenas, *BS, research aide* [1]
Grace Coronado, *BS, research aide* [1]
Divah Cecilia Depositario, *BS, research aide* [1]
Joyce Luis, *BS, research aide* [1]
Milagros Obusan, *BS, research aide*
Aida Papag, *BS, research aide*
Ma. Victoria Rodriguez, *BS, research aide* [1]
Sylvia Sardido, *BS, research aide*
Lourdes Noneth Vinas, *BS, research aide* [1]

Soil Microbiology

Iyao Watanabe, *D Agr, soil microbiologist and head*
Jagdish K. Ladha, *Ph D, soil microbiologist*
Pierre A. Roger, *D Pedologie, visiting scientist*
Wilbur B. Ventura, *MS, assistant scientist*
Corazon R. Espinas, *MS, senior research assistant*
Agnes T. Padre, *MS, senior research assistant*
Genalin D. Angelo, *BS, research assistant*
Susan S. Ardales, *MS, research assistant*
Ma. Luisa G. Daroy, *MS, research assistant*
Rosario R. Jimenez, *BS, research assistant*
Grace B. Mascariña, *BS, research assistant*
Reynaldo T. Oliveros, *MS, research assistant*
Benjamin C. Padre, Jr., *research assistant*
Gloria C. Punzalan, *BS, research assistant* [6]
Rolando B. So, *MS, research assistant*
Ma. Theresa L. Tenorio, *BS, research assistant*
Teresita S. Ventura, *BS, research assistant*
Roberto T. Oficial, *BS, research aide* [6]

Soil and Water Sciences

Heinz-Ulrich Neue, *Ph D, soil chemist and head*
Sadiqal I. Bhuiyan, *Ph D, agricultural engineer*
Terence Woodhead, *Ph D, physicist* [5]
Guy Joseth Dyan Kirk, *Ph D, associate soil chemist*
Gaston Amedee, *Ph D, visiting scientist* [4]
Rhoda S. Lantin, *MS, assistant scientist*
Cortina C. Quijano, *MS, assistant scientist*
Domingo F. Tabbal, *MS, assistant scientist*
Marius M. Agua, *MS, senior research assistant*
Manuel M. Alagcan, *MS, senior research assistant* [1]
Ma. Theresa C. Cayton, *MS, senior research assistant* [1]
Rodolfo Y. Reyes, *MS, senior research assistant*
Jocelyn B. Paduna, *BS, research assistant*
Ma. Carmelita R. Alberto, *MS, research assistant*
Nida U. Autor, *MS, research assistant* [1]
Gloria S. Bumanlag, *MS, research assistant* [2]
Romeo J. Cabangon, *BS, research assistant* [2]
Ambrocio R. Castañeda, *BS, research assistant*
Oliver G. Coroza, *MS, research assistant* [1]
Alejandro L. Galang, *BS, research assistant*
Larry C. Guera, *MS, research assistant*
Maximina A. Lantican, *MS, research assistant*
Celeste C. Patena, *BS, research assistant*
Myra Gina P. Ramos, *BS, research assistant* [1] [2]
Josefina L. Solivas, *MS, research assistant*
Roberto S. Soriano, *MS, research assistant*
Rubenito Lampayan, *BS, research aide* [1]
Ma. Beatriz M. Santos, *BS, research aide*

Centralized Research Farm

Orlando G. Santos, *MPS, head*
Juan M. Lapis, *MS, assistant farm superintendent* [1]
Eladio M. Baradas, *MS, officer, grounds development and maintenance*
Lawrence C. Kiamco, *MS, officer, mechanical operations* [9]
Telesforo M. Laude, *MS, officer, labor, irrigation and drainage, seed processing*
Patrocinio C. Pantua, *MS, officer, plant protection and surveillance*
Reynaldo C. Aranda, *BS, senior farm supervisor*
Filomeno O. Lanting, *MS, senior farm supervisor*
Celso C. Salamatin, *BS, senior farm supervisor*
Loreto B. Aclan, *BS, farm supervisor*
Zacarias D. Dacula, *BS, farm supervisor*
Edwin B. Nuevo, *BS, farm supervisor*
Nestor C. Gonzales, *grounds supervisor*
Fabian B. Alcantara, *grounds supervisor*

Seed Health Unit

Twng-Wah Mew, *Ph D, plant pathologist and head*
Silvino D. Merca, *MS, assistant scientist*
Evelyn B. Gergon, *MS, research assistant* [10]
Carlos C. Huelma, *BS, research aide*
Arielo P. Manila, *BS, research aide* [4]

Project Management Services and Biometrics

Kwanchai A. Gomez, *Ph D, head*
V.A. Samaranayake, *Ph D, visiting scientist* [1]
Grace Reyes, *BS, senior research assistant*
Nora Epifania Nano, *BS, senior research assistant* [1]
Ruthie Aguilar, *BS, research assistant* [1]
Violeta Bartolome, *BS, research assistant*
Rowen Calinga, *BS, research assistant* [6]
Victoria Claveria, *BS, research assistant* [1]
Lanie Criseno, *BS, research assistant*
Anabella Fabellar, *BS, research assistant*
Priscilla P. Kennedy, *BS, research assistant* [7]
Dolores Ledesma, *MS, research assistant*
Julie Mojica, *MS, research assistant*
Ester Ulpindo, *BS, research assistant*
Junelya Joyce Arizala, *BS research aide* [6]
Angela Ma. Oliveros, *BS, research aide* [1]
Luralyn Ramos, *BS, research aide* [4,6]

Analytical Service Laboratories

Ruby U. Castro, *MS, manager*
Bernardita E. Mandac, *MS, senior research assistant*
Rene R. Diocares, *BS, research assistant*
Ma. Ederlinda C. Pascual, *BS, research assistant*
Adonna M. Robles, *MS, research aide*

Phytotron

Benito S. Vergara, *Ph D, plant physiologist*
George F. Pateña, *MS, plant growth facilities officer* [1,3]
Bienvenido B. Manimtim, *BS, research assistant*

Pesticide Residue Laboratory

Redentor A.R. Natividad, *BS, research assistant*
Elizabeth F. Acedo, *BS research assistant*

Genetic Resources Center

Te-Tzu Chang, *Ph D, principal geneticist and head*
Duncan A. Vaughan, *Ph D, associate geneticist*
Genoveva C. Loresto, *MS, assistant scientist*
Adelaida P. Alcantara, *BS, research assistant*
Tomas Clemeno, *BS, research assistant*
Flora C. de Guzman, *MS, research assistant*
Amita B. Juliano, *BS, research assistant* [1]
Ma. Elizabeth B. Naredo, *BS, research assistant*
Rizalino C. Portes, *BS, research assistant*
Renato Reaño, *BS, research assistant*
Verena T. Tolentino, *MS, research assistant*
Ma. Socorro R. Almazan, *BS, research aide*
Margarito Obien, *BS, research aide*
Myrna D. Oliva, *BS, research aide*

Information Center

Thomas R. Hargrove, *Ph D, editor and head*
Stephen J. Banta, *Ed D, editor*
M. LaRue Pollard, *Ph D, editor*
William H. Smith, *BS, editor*
George C. Krajesik, *Ph D, software coordinator* [1]
Marinus Cornelis van den Berg, *BS, hardware coordinator and network manager*
Lina M. Vergara, *MS, librarian*
Ramiro C. Cabrera, *BFA, manager*
Gloria S. Argosino, *MA, assistant editor*
Emerita P. Cervantes, *M Ed, assistant editor* [2,3]
Mila M. Ramos, *MLS, assistant librarian*
Milagros C. Zamora, *MS, assistant librarian*
Elma O. Bamilbo, *BS, administrative assistant*
Carmelita S. Austria, *MLS, senior library supervisor*
Editha S. Lantican, *MLS, library supervisor*
Kazuko Morooka, *BA, library supervisor (in Japan)*
Chika Yoshida, *BS, indexer (in Japan)*
Edgardo M. Delfino, *BS, art and illustrations supervisor*
Patricio O. Mamon, *BS, graphics supervisor*
John B. Figarola, *senior illustrator*
Angelito G. Bernardo, *BS senior research assistant*
Victoria L. Cabanilla, *MS, senior research asssistant*
Wenceslao C. Alimagno, *BS, research assistant*
Edgardo M. Mendoza, *BS, research assistant*
Luis L. Porciuncula, *BS, research assistant* [1]
Jose Mikhael A. Ortega, *AB, editorial assistant* [1]
Teresita V. Rola, *BS, editorial assistant*
Heraldina R. Salonga, *BS, database administrator*
Edwin C. Lozada, *BS, senior audiovisual assistant*
Marieta R. Manza, *BS, senior audiovisual assistant*
Antonio C. Tumulak, *BS, systems programmer*
Cristina A. Carpio, *BS, analyst programmer* [20]
Roy Russel M. Romano, *BS, analyst programmer*
Joseph T. Alonzo, *BS, computer programmer* [4,6]

Training Center

Dan R. Minnick, *Ph D, training specialist and head* [2]
Ellis L. Matheny, Jr., *Ph D, acting head* [4]
Gina M. Ordoñez, *MBA, consultant* [4]
Emerita P. Cervantes, *M Ed, senior training assistant* [2,3]
Anita L. Frio, *MS, senior training assistant* [1,2]
Emerito V. Tipa, *MS, senior research assistant*
Orlando N. Magistrado, *MS, senior training assistant*
Ernesto G. Perez, *BS, senior training assistant*
Madeline B. Quiamco, *MS, senior training assistant*
Noemi M. Yapit, *MS, senior training assistant*
Alberto C. Aduna, *BS, training assistant* [1]
Aurora M. Argente, *MS, training assistant*
Jose V. del Carmen, *MS, training assistant* [1]
Joel Rizaldy G. Flor, *AB, training assistant*
Oscar A. Garcia, *BS, training assistant*
Rosela I. Gementiza, *BS, training assistant* [1]
Josefa L. Gonzales, *MS, training assistant*
Rebecca H. Patalen, *M Agr, training assistant*
Salvador I. Yabes, *MS, training assistant*
Fe A. Anido, *BS, research assistant* [6]
Remedios E. Ballesfin, *BS, research assistant*
Ma. Martha L. de Villa, *BS, training aide* [1]
Gina E. Zarzadias, *BS, training aide*

International Programs Management Office

Glenn L. Denning, *Ph D, head*
Julian A. Lapitan, *MS, assistant scientist*
Arsenio R. Samiano, *BS, research assistant* [2]
Elias V. Sandig, *MS, research assistant* [6]
German Turija, *BS, research aide* [2,24]

Rice Farming Systems Program

Virgilio R. Carangal, *Ph D, agronomist and coordinator*
Rolando V. Labios, *MS, senior research assistant* [6]
Antonio C. Morales, *MS, senior research assistant*
Esteban C. Godilano, *MS, research assistant*

Eleuterio T. Rebancos, Jr., *BS, research assistant*[6]
Primitivo L. Tengco, *BS, research assistant*[6]
Efren C. Armada, *BS, research aide*[6]

International Network for Genetic Evaluation of Rice

V. Seshu Durvasula, *Ph D, plant breeder and global coordinator*
Krishna Alluri, *Ph D, liaison scientist and INGER regional coordinator for Africa*
Federico E. Cuevas Perez, *Ph D, liaison scientist and INGER coordinator for Latin America*
Muhammad Akbar, *Ph D, plant breeder*
Sang-Won Ahn, *Ph D, plant pathologist*
Frank J. van Schoubroeck, *MS, consultant*[1]
Victoria C. Lopez, *BS, senior research assistant*
Frisco M. Malabanan, *MS, research assistant*
Imelda F. Malabanan, *BS, research assistant*
Paul Cornelio T. Maturan, *BS, research assistant*
Mario M. Movillon, *MS, research assistant*
Edilberto D. Redoña, *MS, research assistant*
Ma. Concepcion L. Toledo, *BS, research assistant*[6]
Robert C. Ona, *BS, research aide*[6]

---

[1]Left during the year.
[2]On study leave/training.
[3]Joined and left during the year.
[4]Joined during the year.
[5]Cooperative research staff.
[6]On project appointment.
[7]Died during the year.
[8]Transferred from Soil and Water Sciences to Agricultural Engineering.
[9]Transferred from Agricultural Engineering to Centralized Research Farm.
[10]Transferred from Agricultural Engineering to Physical Plant Services.
[11]Transferred from Social Sciences to Agronomy, Plant Physiology, and Agroecology.
[12]Transferred from Agronomy, Plant Physiology, and Agroecology to Training Center.
[13]Transferred from Agronomy, Plant Physiology, and Agroecology to Phytotron.
[14]Transferred from Agronomy, Plant Physiology, and Agroecology to Visitor's Bureau.
[15]Served as acting head, Entomology Division, January-February, July-September, and November-December 1990.
[16]Transferred from Entomology to Plant Breeding, Genetics, and Biochemistry.
[17]Transferred from Plant Breeding, Genetics, and Biochemistry to Human Resources Development.
[18]Transferred from Plant Pathology to Plant Breeding, Genetics, and Biochemistry.
[19]Transferred from Seed Health Unit to Plant Pathology.
[20]Transferred from Social Sciences to Information Center.
[21]Transferred from Soil and Water Sciences to Social Sciences.
[22]Transferred from Soil and Water Sciences to Human Resources Development.
[23]Transferred from Information Center to Training Center.
[24]Transferred from International Program Management Office to Agronomy, Plant Physiology, and Agroecology.
[25]Transferred from Entomology to Centralized Research Farm.

Using this report

This *Program report for 1990* includes capsule summaries of research undertaken by the Institute during the past year, plus discussions of the international programs that interconnect with the research programs. It is similar to the *Annual reports* published 1961-1988 in being the primary, definitive record of progress made by the Institute.

The research reported here follows the ecosystem-based organization that went into effect on 1 January 1990. All research activities are reported under one of the five research programs: Irrigated Rice, Rainfed Lowland Rice, Upland Rice, Deepwater and Tidal Wetlands Rice, and Cross-Ecosystems Research. Other activities are reported under the five international programs: Germplasm Conservation and Dissemination, Information and Knowledge Exchange, Networks, Training, and Country and Regional Projects.

Not all work done by the Institute in 1990 is reported here. The report is limited to activities that had reached a reportable stage involving analysis, interpretation, and conclusions. A few significant interim results are reported because it was felt they would be useful to other rice workers.

The international programs are administered through five entities, which can be contacted for further information:

- Genetic Resources Center (Germplasm Conservation and Dissemination Program)
- Information Center (Information and Knowledge Exchange Program)
- Deputy Director General for International Programs (Networks)
- Training Center (Training Programs)
- International Programs Management Office (Country and Regional Projects)

Information on the research programs can be obtained from the program leaders or the research divisions noted on the table of contents for each program (pp. 3-4, 65, 97, 125, 143-144), following these abbreviations:

- AE = Agricultural Engineering Division
- APA = Agronomy, Physiology, and Agroecology Division
- E = Entomology Division
- PBGB = Plant Breeding, Genetics, and Biochemistry Division
- PP = Plant Pathology Division
- SM = Soil Microbiology Division
- SS = Social Sciences Division
- SWS = Soil and Water Sciences Division

The other abbreviations and acronyms used in this report are listed on the following pages. In addition, we have spelled out all names and terms on first use in each program and have used abbreviations thereafter.

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, and protein content as a percentage of brown rice, at 14% moisture content. 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 formulations (P_2O_5, K_2O, etc.).

Pedigrees are indicated by a slant bar (/) rather than by a multiplication sign (×). For example, (PTB33×IR20)×IR36 is written PTB33/IR30//IR36. Fourth and further crosses are designated /4/, /5/, and so on. Backcrosses are designated by an asterisk (*) and a number indicating the dosage of the recurrent parent. The asterisk and the number are placed adjacent to the crossing symbol, which divides the recurrent and donor parents.

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

In tables, a single asterisk (*) means a 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 program. To use it, bend the book slightly and follow the margin index to the page with the black edge marker.

Abbreviations and acronyms

AC = anther culture, amylose content
ACIAR = Australian Centre for International Agricultural Research
ADB = Asian Development Bank
AE = Agricultural Engineering Division
AG = anastomosis group
AIRAT = African Irrigated Rice Advanced Trial
AIRON = African Irrigated Rice Observational Nursery
AIRPSS = African Irrigated Rice Preliminary Screening Set
ALRESS = African Lowland Rice Evaluation and Screening Set
AMD = Agricultural Mechanization Department
APA = Agronomy, Physiology, and Agroecology Division
AR = absorption ratio
ARA = acetylene-reducing activity
ARBN= African Rice Blast Nursery
ARFSN = Asian Rice Farming Systems Network
ARI = Agricultural Research Institute
AURON = African Upland Rice Observational Nursery
AURPSS = African Upland Rice Preliminary Screening Set

B&I = broadcast and incorporated
BARC = Bangladesh Agricultural Research Council
BARI = Bangladesh Agricultural Research Institute
BEP = break-even point
BGA = blue-green algae
BI = blast
BPH = brown planthopper
BR = bypass ratio
BRRI = Bangladesh Rice Research Institute
BS = best split, brown spot
BSFR = broadcast seeded flooded rice

CA = carbonic anhydrase
CFU = colony-forming units
CIAT = Centro Internacional de Agricultura Tropical
CIDA = Canadian International Development Agency
CMC = critical moisture content
CMS = cytoplasmic male sterile, sterility
CP = cowpea
CRIFC = Central Research Institute for Food Crops
CRURRS = Central Rainfed Upland Rice Research Station

DAH = days after harvest
DAI = days after inoculation
DAP = days after planting
DAS = days after sowing or seeding
DAT = days after treatment
DBPI = days before panicle initiation
DE = days after emergence
DM = dry matter
DMP = dry matter production
DOASL = Department of Agriculture, Sri Lanka
DP = degree of polymerization
DS = dry season
DSR = direct seeded rice, dry seeded rice
DSSAT = Decision Support System for Agrotechnology Transfer
DT = days after transplanting
DW = dry weight
DWP = deepwell pump
DWR = deepwater rice

E = Entomology Division
EC = electrical conductivity
ELISA = enzyme-linked immunosorbent assay
EPA = U.S. Environmental Protection Agency
ESYT = environment-specific yield test

FDD = farm ditch density
FOFIFA = National Center for Applied Research on Rural Development, Madagascar
FR = farm reservoir
FSR = farming systems research

GC = gel consistency
GIS = Geographic Information Systems
GLH = green leafhopper
GM = green manure
GT = gelatinization temperature

HD = high density

IBSNAT = International Benchmark Sites Network for Agrotechnology Transfer
IC = Information Center
ICAR = Indian Council for Agricultural Research
ICLARM = International Center for Living Aquatic Resources Management
IDRC = International Development Research Centre
IDRON = International Deepwater Rice Observational Nursery
IDRYN = International Deepwater Rice Yield Nursery
IFAD = International Fund for Agricultural Development
IFAS = Institute of Food and Agricultural Sciences
IFDC = International Fertilizer Development Center (Muscle Shoals, Alabama)
IFPRI = International Food Policy Research Institute
IIRON = International Irrigated Rice Observational Nursery
IIRYN-E = International Irrigated Rice Yield Nursery-Early
IIRYN-M = International Irrigated Rice Yield Nursery-Medium
IIRYN-VE = International Irrigated Rice Yield Nursery-Very Early
IITA = International Institute of Tropical Agriculture
INGER = International Network for Genetic Evaluation of Rice (formerly IRTP)
INSURF = International Network on Soil Fertility and Sustainable Rice Farming
IPM = integrated pest management
IPMN = Integrated Pest Management Network
IPMO = International Program Management Office
IR = irrigated rice
IRALON = International Rice Acid Lowland Soils Observational Nursery
IRALSN = International Rice Acid Lowland Screening Nursery
IRAUSN = International Rice Acid Upland Screening Nursery
IRBBN = International Rice Bacterial Blight Nursery
IRBN = International Rice Blast Nursery
IRBPHN = International Rice Brown Planthopper Nursery
IRCTN = International Rice Cold Tolerance Nursery
IRDTN = International Rice Drought Tolerance Nursery
IRGC = International Rice Germplasm Center
IRLON = International Rainfed Lowland Rice Observational Nursery
IRLYN = International Rainfed Lowland Rice Yield Nursery
IRLYN-E = International Rainfed Lowland Rice Yield Nursery-Early
IRLYN-M = International Rainfed Lowland Rice Yield Nursery-Medium
IRON = International Rice Observational Nursery
IRRSWYN = International Rainfed Rice Shallow Water Yield Nursery
IRS = internationally recruited staff
IRSBN = International Rice Stem Borer Nursery
IRSTON = International Rice Salinity Tolerance Observational Nursery
IRWBPHN = International Whitebacked Planthopper Nursery
IRYN = International Rice Yield Nursery
IRYN-E = International Rice Yield Nursery-Early
IRYN-VE = International Rice Yield Nursery-Very Early
ITRON = International Tidal Wetland Rice Observational Nursery
IURYN = International Upland Rice Yield Nursery

LEW = leaf epicuticular wax

MARDI = Malaysian Agricultural Research and Development Institute

MAS = Myanmar Agricultural Service
MB = mungbean
MBCR = marginal benefit-cost ration
MBPS = modified bulk pedigree selection
MH = major pedological horizon
MIFS = Myanmar-IRRI Farming Systems
MV = modern variety
MVP = marginal value products
MW = molecular weight
MZ = maize

NARS = national agricultural research system(s)
NCP = non-capsid protein
NGOs = nongovernment organizations
NILS = near-isogenic lines
NIR = near-infrared reflectance
NRS = nationally recruited staff

OM = organic matter
OTMS = Ottawa Texture Measuring System
OYT = observational yield test

PAGE = polyacrylamide gel electrophoresis
PBGB = Plant Breeding, Genetics, and Biochemistry Division
PBH = plowing, broadcasting, harrowing
PBP = payback period
PGM = phosphoglucomutase
PGMS = photosensitive genic male sterile
PMSB = Project Management, Services and Biometrics
PN = peanut
PP = Plant Pathology Division
PR = phosphate rock
PS = pedigree selection
PTR2 = Prosperity Through Rice Phase 2
PU = prilled urea

QE = quantum efficiency
QTL = quantitative trait loci

RFLP = restriction fragment length polymorphism
RLR = rainfed lowland rice
RRTC = Rice Research and Training Center (Egypt)
RSHT = routine seed health testing
RTBV = rice tungro bacilliform virus
RTD = rice tungro disease
RTSV = rice tungro spherical virus
RVDB = Rice Viruses Data Base
RYT = replicated yield trial

SACCAR = Southern Africa Centre for Cooperation in Agricultural Research
SADCC = Southern Africa Development Coordinating Council
SAREC = Swedish Agency for Research Cooperation with Developing Countries
SB = stem borer
SDS-PAGE = sodium dodecyl sulfate polyacrylamide gel electrophoresis
SEM = scanning electron microscopy
SFRIS = San Fabian River Irrigation System
ShB = sheath blight
SHU = Seed Health Unit
SKD = shikimate dehydrogenase
SM = Soil Microbiology Division
SR = siratro
SS = Social Sciences Division
SSB = striped stem borer
SWP = shallow well pump
SWS = Soil and Water Sciences Division

TGMS = thermosensitive genic male sterile
TPR = transplanted rice
TS = transition season
TSA = turnout service area

UAS = urea-ammonium sulfate
UES = urea-elemental sulfur
UPRIIS = Upper Pampanga River Integrated Irrigation System
UR = upland rice
USAID = United States Aid for International Development
USG = urea supergranule
UTRIS = Upper Talavera River Irrigation System

VB = vascular bundles

WARDA = West Africa Rice Development Association
WS = wet season

Xoo = *Xanthomonas oryzae* pv. *oryzae*

YSB = yellow stem borer

Research Programs

Research programs
Irrigated rice ecosystem

SUBPROGRAM I: GERMPLASM IMPROVEMENT 5
- Integrated germplasm improvement 5
  - Yield potential (PBGB) 5
  - Germplasm for direct sowing (PBGB) 7
  - Modified bulk pedigree selection for improving selection efficiency for yield (PBGB) 7
  - Grain quality (PBGB) 8
  - Disease resistance (PBGB) 9
  - Insect resistance (PBGB) 11
  - Elite breeding lines (PBGB) 11
  - IRRI lines named varieties (PBGB) 11
- Tolerance for physical stresses 12
  - Germplasm with tolerance for physical stresses (APA, SWS) 12
  - Korea-IRRI collaborative project on rice cold tolerance (APA, SWS) 12
  - Boro rice (APA, SWS) 12
  - Tolerance for P and Zn deficiency (APA, SWS) 13
  - Improved germplasm for saline-alkaline ricelands (APA, SWS) 14
  - Future plans 14
- Durable resistance to pests 14
  - Resistance to rice tungro disease (PP) 14
  - Durable resistance to bacterial blight (PP) 16
  - Durable resistance to blast (PP) 18
  - Next steps 18
- Hybrid rice 19
  - Search for suitable CMS and restorer lines (PBGB) 19
  - Environment-sensitive male sterility in rice (PBGB) 20
  - Performance of elite rice hybrids (PBGB) 20
  - Physiological analysis of heterosis in grain yield (PBGB) 21
  - Insect/disease resistance of hybrids vs parents (PBGB) 22
  - Guidelines for hybrid rice seed production (PBGB) 22
  - Future research 23

SUBPROGRAM II: CROP, RESOURCE, AND PEST MANAGEMENT 23
- N nutrient efficiency 23
  - Potential of N_2-fixing blue-green algae as biofertilizers in rice soils: effect of inoculation with ammonia-excreting mutant and foreign strains (SM) 23
  - Conclusions 25
  - Simulating nitrogen transformations (APA) 26
  - Conservation of soil N (APA) 27
  - Floodwater chemistry controlling NH_3 volatilization (SWS) 28
- N-cycling 29
  - Genetic enhancement of biofertilizer sources (SM) 29
  - Availability of azolla N to rice (SM) 31
- Water and tillage management 32
  - Water management for diversified cropping in rice irrigation systems (SWS) 32
  - Irrigation infrastructure compatibility between rice and nonrice crops (SWS) 33

On-farm infrastructure adaptation for nonrice crops (SWS) 33
Managing high water table for diversified cropping (SWS) 34
Tillage and water-lifting equipment for increasing riceland productivity (AE) 35
The IRRI twin-furrow plow (AE) 36
Management of direct seeded rice 36
Effect of soil management practices on germination and stand establishment in DSR (APA) 36
Land and water management requirements of direct seeded rice (APA) 37
Differential productivity and profitability (APA) 37
Differential response to water management regimes (APA) 37
Ammonia volatilization as affected by planting method (APA) 38
Nitrogen management and plant type for puddled row-seeded rice (APA) 39
Grain density, seedling quality, and crop establishment (APA) 40
Nitrogen applications timing for control of broadcast seeded flooded rice weeds (APA) 40
Continuous rice cropping experiment (APA) 42
Summary 42
Pest dynamics and management in irrigated rice 42
Larval parasitoids of the rice leaffolder (E) 43
Spatial and temporal dynamics of tungro (E) 44
Biological control of bakanae disease by antagonistic bacteria (E) 44
Distribution and characteristics of soils suppressive to sheath blight (E) 44
Future plans 46
Integrated pest management 46
Strategy for control of chronic insects (E) 46
Engineering pest control 47
Physical (nonchemical) pest control techniques (AE) 47
Improvements in pesticide application technology (AE) 48

SUBPROGRAM III: LIVELIHOOD AND PRODUCTION ENVIRONMENTS 48
Systems productivity 48
Constraints to crop diversification and intensification in Guimba, Nueva Ecija (APA, SS, ARFSN) 48
Evaluation of improved cropping patterns in Guimba, Nueva Ecija (APA, SS, ARFSN) 48
Farmers' vs improved cropping patterns (APA, SS, ARFSN) 49
Effect of planting date on transplanted (irrigated) rice in the wet-dry transition season (APA, SS, ARFSN) 51
Effect of green manure and inorganic N on a following transplanted rice (APA, SS, ARFSN) 51
Sorghum with forage legumes after irrigated rice (APA, SS, ARFSN) 51
Rice - wheat systems 52
Diagnostic surveys of the rice - wheat system in the terai of India (AE, ARFSN, E, SS) 53
Rice-soil structural management for postrice wheat (AE, ARFSN, E, SS) 55
Next steps 57
Global climate change and rice 57
Response of rice to enhanced UV-B radiation (APA, E, PP, SWS) 58
Varietal screening (APA, E, PP, SWS) 59
High temperature effects on rice (APA, E, PP, SWS) 59
Future research 60
Technology-environment interactions 60
Pesticide use and farmer health and productivity (SS) 60
Agrochemical impacts on soil and water invertebrates and N_2-fixing algae (SS) 61
Conclusion 62

Irrigated rice ecosystem

The irrigated rice program has concentrated its resources on the dual problems of yield stagnation and sustaining productivity gains in the irrigated lowlands of Asia. Potentially high-payoff research efforts that could redress the above problems are 1) shifting the yield frontier while maintaining its stability (through germplasm improvement and crop management); 2) increasing the efficiency of input use, especially fertilizers, water, labor, and power; 3) promoting the judicious use of pesticides; 4) understanding the causes of the long-term stagnation or decline in irrigated rice productivity; and 5) quantifying the environmental impacts of intensive rice monoculture (including the effects on health and global climate change).

The irrigated rice program is divided into three subprograms: germplasm improvement; crop and resource management; and production, environment, and livelihood impact. The germplasm improvement subprogram attempts to shift the yield frontier by changing plant architecture and adapting hybrid rice to tropical conditions. The crop and resource management subprogram concentrates on generating technologies that increase input use efficiency. The subprogram on production, environment, and livelihood impact deals with issues related to sustaining productivity and incomes of irrigated rice farmers.

Subprogram I: Germplasm improvement

Integrated germplasm improvement

The main focus of this project is to develop improved germplasm with high yield, superior grain quality, resistance to major diseases and insects, and growth duration of 100-140 d. An equally important objective is to share this germplasm with national programs.

During 1989, 404 crosses were made, 218 F_2 populations grown, 67,132 pedigree nursery rows evaluated, and 800 advanced generation lines evaluated in replicated yield trials (RYTs).

In lowland rice performance trials of the Rice Varietal Improvement Group of the Philippine Seed Board, 35 elite breeding lines were evaluated at 12 sites. About 210 elite breeding lines were evaluated internationally in INGER nurseries. On the basis of 72 seed requests, 3,869 seed packets were supplied to national program scientists. Thus, the improved germplasm was shared with numerous national programs.

Yield potential

Increasing the yield potential of rice is a top priority for IRRI. While various approaches to achieve this objective are being explored, top priority is developing a new plant type. The following characteristics are being emphasized.

Tiller number. Evaluation of several rice cultivars with differences in tillering ability showed that the main shoot produced the largest panicle. The optimum tiller number for obtaining large panicles was five to eight per plant.

Grain characteristics. Studies on grain characteristics have suggested ways of increasing yield potential.

- It may be possible to increase the yield of milled rice by developing varieties with thinner hulls.
- If varieties in which all grains have optimum weight can be developed, yield can be increased by more than 20% even with the same grain number per panicle.
- Within cultivars, the long, wide, and heavy grains produce vigorous seedlings. Heavier grains show highest germination percentage, tallest seedlings with largest leaf area, and highest dry weight.
- High-density grains produce seedlings with a high number of vascular bundles and higher dry weight.

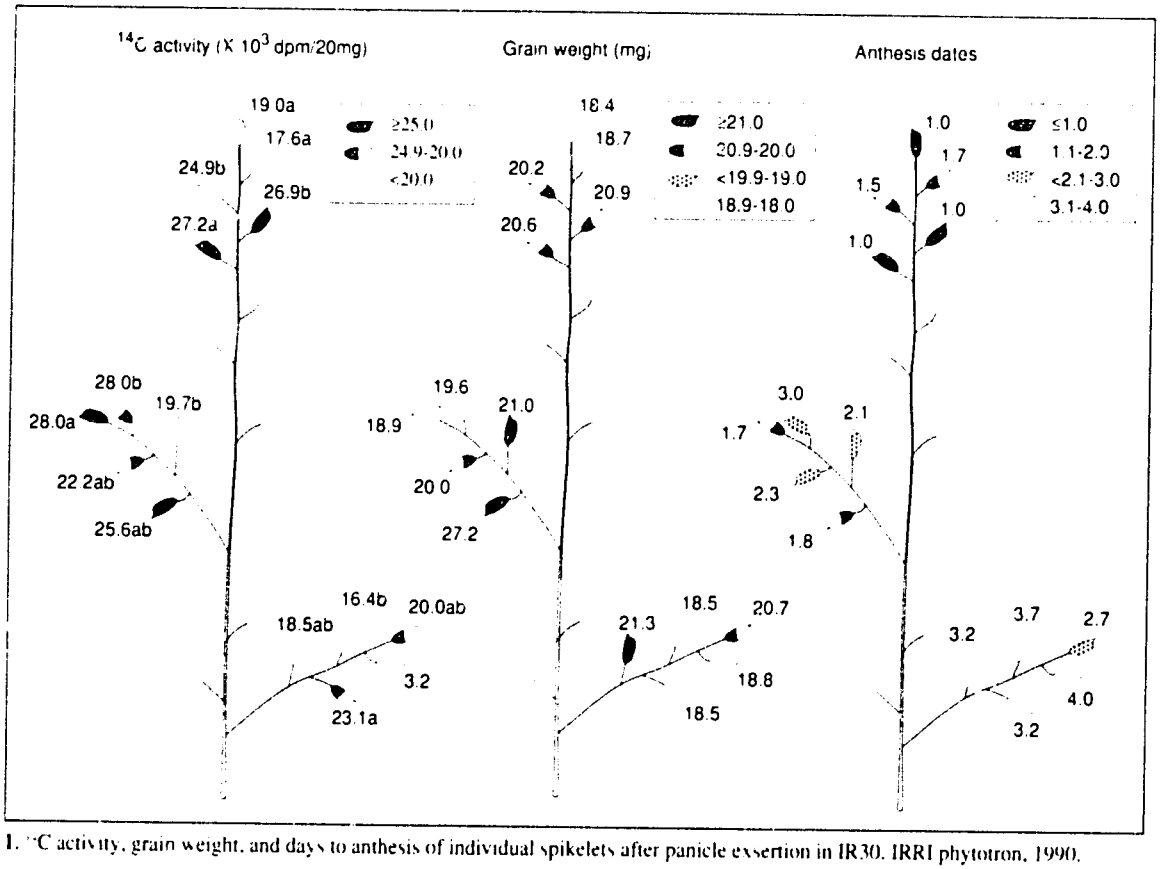
Vascular bundle development. A series of experiments examined the vascular bundles (VB) at different growth stages and the effect of N management on the development of VB and possibly its role in increasing grain yield.

- The cultivars tested showed three patterns of vascular systems in the panicle, but the patterns were not related to spikelet filling and the distribution of high-density and heavy grains.
- Low N level resulted in low peduncle number, small peduncle diameter, and smaller cross-sectional area of the large VB.
- There were more VBs in the peduncle, flag leaf, and leaf sheath of the main culm, but their number and size decreased in later tillers.
- The number of large VBs in the peduncle is highly correlated with peduncle thickness, which, in turn, is correlated with the number of primary and secondary branches on the panicle and the number of spikelets per panicle.

Sink activity. Previous studies have shown the fifth spikelets on the primary branches of the panicle to be high-density grains and the second spikelets to be the lightest.

- Rice spikelets had strong sink activity at early heading stage, but this declined starting 10 d after heading. Spikelets with high density also showed the highest activity using ^{14}C (Fig. 1).

Light and drought stress on individual spikelet filling. Experiments were conducted to investigate



1. ^{14}C activity, grain weight, and days to anthesis of individual spikelets after panicle exsertion in IR30. IRRI phytotron, 1990.

the effect of light stress and water stress on spikelet filling and high-density grain production in different spikelets of a panicle.

- Reduced light intensity during spikelet filling reduced the number of filled spikelets per panicle and also single-grain weight.
- In the top, middle, and lower primary branches, the fifth spikelet was the heaviest and least affected by light.
- Light stress did not reduce the spikelet-filling period. The period of grain growth most sensitive to shading was 7 to 14 d after flowering.
- Plants under low light intensity had very high leaf chlorophyll content, but poor spikelet filling.
- The earlier the water stress was imposed, the fewer the heavy grains and the higher the number of poor grains on a panicle.

Developing the new plant type. To develop the new plant type, 120 crosses were made. F_2 populations from 58 crosses were grown. A pedigree nursery of F_3 lines was grown and plant types with desirable features were selected. Plants with thick and sturdy stems (without unproductive tillers), dark green and erect leaves, large panicles, thick peduncles, and heavy grains were selected. Additional donors with appropriate traits were evaluated and will be used in the hybridization program.

Germplasm for direct sowing

The new plant being developed will be more suitable for direct sowing, which is generally done by broadcasting pregerminated seeds on puddled, drained fields. There are constraints to good stand establishment with broadcast sowing:

- Seeds spread on the soil surface are eaten by birds and rodents; heavy rains after broadcasting wash away the seeds; strong sunlight may desiccate the seeds; if covered with wet soil or sown in standing water, the seeds suffer water anoxia and anchorage problems.
- Because the seeds are placed on the soil surface, the base of the plant where roots start to grow is on top of the soil, making the plants more vulnerable to lodging.
- Poor crop stand results in serious weed problems.

These constraints may be overcome if pregerminated seeds can be dibbled in puddled soil with standing water. A study was undertaken to identify genotypes suitable for dibbling in flooded soil.

The following screening technique was used:

- A pregerminated seed (soaked for 1 d, then incubated for another day) was placed at the bottom of a compartment (1.0 × 1.0 × 2.5 cm deep) with a drainage hole (2-mm diameter) in a 17- × 34-cm seedling tray. The tray has 578 compartments. The design was a randomized complete block with four replications. Each variety had 17 seeds per replication.
- The compartments were filled with soil sieved with mesh 40.
- The tray was submerged and placed firmly on the soil surface in an artificial concrete block (2 × 8 m) in a screenhouse.
- Plant growth was analyzed 2 wk after seeding. Data collected were emergence score (0 = no emergence, 1 = coleoptile emerged on the soil surface, 2 = 1st leaf emerged, 3 = 2d leaf emerged, ...), plant height, and dry weights of seedling (shoot + roots) and seed.

Results of screening *O. sativa* and *O. glaberrima* cultivars. Test varieties of a wide genetic background were obtained from the International Rice Germplasm Center. Plant height, emergence score, and seedling dry weight were the criteria for determining superiority in stand establishment. About 10% of *O. sativa* varieties showed superiority, but none of *O. glaberrima* did (Table 1).

The results demonstrate rice varieties that can be dibbled in flooded soil do exist and can be used as parents for developing genotypes for direct seeding in puddled flooded soil.

Modified bulk pedigree selection for improving selection efficiency for yield

Efficiency and effectiveness of the selection procedure affect the genetic advance made to improve a quantitative trait in a breeding program. We conceptualized the modified bulk pedigree selection (MBPS) procedure, designated earlier as Direct Selection for Yield (Annual report for 1985), to improve selection efficiency. The procedure integrates early generation testing, bulk, single seed descent, and pedigree selection techniques.

The procedure was compared with a conventionally used pedigree selection (PS) on six IR crosses. The crosses were separately handled in F_2 to F_5 from 1987 wet season (WS) to 1989 dry season (DS) by the two selection procedures.

Promising F_5 MBPS-derived and PS-derived lines

Table 1. Screening of *O. sativa* and *O. glaberrima* entries for superiority in crop stand establishment on wet soil.[a]

Screening no.	Species	Varieties tested (no.)	Selected varieties[b] (no.)		
			3 criteria	2 criteria	1 criterion
1	*O. sativa*	41	6	0	6
2	*O. sativa*	45	1	5	2
3	*O. sativa*	44	3	1	2
4	*O. sativa*	105	3	2	1
5[c]	*O. sativa*	201	12	5	8
6	*O. glaberrima*	13	0	0	0

[a]The criteria for superiority to IR50 are seedling dry weight, submergence score, and plant height. When the variety is better in 3, 2, or 1 of the criteria than is IR50, it is classified in the 3, 2, or 1 category. [b]Varieties with poor germination percentage were excluded. [c]Testing reproducibility of screening system. Varieties used in screening 1-4 were retested a different time.

were selected from each cross, and evaluated in F_6 under 2 N fertility levels (N_0 and N_{120}) during 1989 and 1990 DS. Elite MBPS- and PS-derived lines, selected in F_6 from two crosses, were evaluated in 1989 DS and further evaluated for yield in F_7 at similar N levels during 1990 DS. Results indicated that

- Mean yields of long-duration MBPS-derived lines were numerically higher than those of PS-derived lines in all crosses at the two N levels. In several cases (IR54790 and IR54896 at N zero level, and IR54819 and IR54896 at N_{120} level), yield differences were also statistically significant (Table 2).
- Mean yields of short-duration MBPS-derived lines were also numerically higher than those of PS-derived lines in two crosses at both N levels. But in one cross, IR54792, the mean yield of the PS-derived lines was significantly higher at the N_{120} level.

We also compared the genotypic variance among the MBPS-derived F_5 lines (Table 3) and found that MBPS-derived lines had generally higher genotypic variances than PS-derived lines with few exceptions. More MBPS-derived lines yielded significantly higher than the best check (Table 4). Similarly, the yield of the four best MBPS-derived lines was higher than that of the four best PS-derived lines (Table 5). Results indicate that the MBPS procedure is more effective and efficient in selecting for higher yield than is the PS procedure; therefore, MBPS is recommended in breeding for higher yield potential in rice.

Grain quality

In most of the rice-growing countries, a few rice varieties with high palatability are grown. These rices are characterized by intermediate amylose content (AC), intermediate gelatinization temperature (GT), soft gel consistency (GC), and pleasant aroma. They are in demand and command higher prices in the domestic as well as international markets. To date, very few high-yielding varieties with aroma have been developed. Thus, farmers continue to grow tall traditional aromatic rices to meet the demand. The low productivity of such rices is offset by their higher price.

Earlier, we gave priority to incorporation of disease and insect resistance and other adaptation traits into the improved germplasm. Efforts in grain quality improvement were directed to development of

Table 2. Mean yields of short- and long-duration F_6 lines selected in MBPS and PS procedures from 6 crosses.[a] IRRI, 1989-90.

Cross[b]	Yield[c] (t/ha)					
	No N			Optimum N		
	MBPS	PS	Difference	MBPS	PS	Difference
Long-duration lines						
IR54790	3.21	2.94	0.27**	5.80	5.66	0.14
IR54791	2.85	2.70	0.15	5.32	5.19	0.13
IR54819	3.41	3.27	0.14	5.37	4.65	0.72**
IR54853	3.55	3.54	0.01	5.50	5.12	0.38
IR54896	3.53	3.08	0.45**	5.83	5.01	0.81**
IR54942	-	-	-	-	-	-
Short-duration lines						
IR54790	2.83	2.65	0.18	5.09	5.04	0.05
IR54791	1.53	2.70	-0.13	5.50	5.34	0.19
IR54819	2.28	2.27	0.01	4.29	3.99	0.30
IR54853	-	-	-	-	-	-
IR54896	2.07	2.19	0.12	4.44	4.61	0.17
IR54942	1.56	1.54	0.02	2.89	3.75	-0.86**

[a]MBPS = modified bulk pedigree selection, PS = pedigree selection. [b]The underlined entries were evaluated in 1989 dry season (DS); others, in 1990 DS. [c]** = significant at 1% level by *F* test.

Table 3. Genotypic variance and ratios of genotypic variances among MBPS and PS procedures evaluated in F_6. IRRI, 1989-90.

Cross[a]	Genotypic variance at zero N			Genotypic variance at optimum N		
	MBPS	PS	Ratio of s^2g MBPS/ s^2g PS[b]	MBPS	PS	Ratio of s^2g MBPS/ s^2g PS[b]
			Long-duration lines			
IR54790	0.79	0.13	6.08*	1.03	0.20	5.15*
IR54791	0.29	0.17	1.71	0.45	0.13	3.43
IR54819	0.99	0.21	4.71*	0.73	1.88	0.39
IR54853	0.67	0.13	5.15*	0.99	1.32	0.75
IR54896	0.95	0.13	7.13**	2.20	0.50	4.40*
IR54942	-	-	-	-	-	-
			Short-duration lines			
IR54790	0.68	0.65	1.05	0.78	0.44	1.77
IR54791	0.80	0.14	5.71*	0.92	0.27	3.78*
IR54819	0.48	0.94	0.51	1.14	0.53	2.15
IR54853	-	-	-	-	-	-
IR54896	1.05	0.58	1.81	2.28	0.23	9.91**
IR54942	0.75	0.56	1.34	1.08	1.64	0.67

[a]The underlined crosses were evaluated in 1989 DS others in 1990 DS. *, ** = significant at 5% and 1% level, respectively, by *F* test.

germplasm with intermediate AC, intermediate GT, and soft GC. In recent years, the use of aromatic parents has produced high-yielding lines with superior grain quality. Several promising lines with aroma and multiple resistance to diseases and insects are being evaluated in replicated yield trials. IR54950-181-2-1-2-3, a high-yielding aromatic line with intermediate AC, intermediate GT, and soft GC, is being evaluated in Philippine Seed Board trials. It is hoped that within the next 2-3 yr, new high-yielding, aromatic varieties will replace the low yielding ones. This should lead to increased production and lowering of prices of high quality rices and greater access of low-income consumers to more palatable rice.

Table 4. Lines in 2 maturity groups that yielded higher or lower than or equal to check varieties in MBPS and PS procedures. IRRI, 1989-90.

Maturity group	Procedure	Lines (no.) yielding		
		Higher than check[a]	Equal to check[a]	Lower than check[a]
Late	MBPS	3	60	17
	PS	1	46	33
Early	MBPS	1	48	21
	PS	0	52	18

[a]Best check variety is IR66 for early maturing, IR68 for late maturing.

Disease resistance

Incorporation of resistance to major diseases in the elite germplasm has always received priority. Most of the elite breeding lines have multiple resistance to blast (Bl), bacterial blight (BB), and grassy stunt (RGSV) but it has not been possible to incorporate high levels of resistance to tungro (RTD) in the elite germplasm.

Donor for tungro resistance. Several donors with good level of resistance to RTD are divided into

Table 5. Mean yields of the 4 best MBPS and PS derived lines from 2 crosses. IRRI, 1990 DS.

Trial with N level	Mean yield[a] (t/ha)					
	Early maturity group			Late maturity group		
	MBPS	PS	Difference	MBPS	PS	Difference
No N	2.93	2.90	0.03	3.16	2.56	0.60**
N120	5.73	4.86	0.87**	6.54	4.92	1.62*

*, ** = significant at 5% and 1% level, respectively, by *F* test.

three groups. Group I varieties (ARC10343 and Utri Merah [Acc. 16680]) are resistant to infection by rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV); group II varieties (Pankhari 203, PI 184675-2, and ARC11554) are resistant to RTSV infection; and group III varieties (Seratus hari T 36, Tjempo Kijik, and Balimau Putih) show tolerance for RTBV. Most of these varieties are susceptible to green leafhopper (GLH), which vectors the tungro viruses.

Inheritance of resistance to tungro. Using those donors, studies on inheritance of resistance have been initiated. Allelic relationship between resistance genes of different varieties will be studied to identify diverse genes for resistance. Genetic analysis is laborious and time-consuming as it is not possible to determine the reaction of each F_2 plant with certainty. Even in the susceptible varieties, not all the seedlings show susceptible reaction, and in the resistant varieties, some seedlings succumb to disease. Thus, analysis of F_3 lines is necessary to determine the mode of inheritance.

Development of isogenic lines with different genes for tungro resistance. Isogenic lines are useful for identifying races or strains of virus, for studying the mechanism for resistance, and for tagging the resistance genes with restriction fragment length polymorphism (RFLP) markers. Genes for resistance from different donors are therefore being transferred to the genetic background of TN1 and IR22, both of which are highly susceptible to RTD. Three backcrosses have been made using TN1 and IR22 as recurrent parents. Six backcrosses will be necessary for producing isogenic lines.

Breeding for tungro resistance. The backcrossing program using IR1561-228-3-3 as the recurrent parent and Habiganj DW8, Utri Merah, and ARC11554 as donors for resistance was continued. Four backcrosses have been made and F_2 populations from the fourth backcross will be grown in 1991. Improved plant type lines with RTD resistance will be selected and used as parents in the crosses to combine other desirable traits with RTD resistance. Meanwhile, a backcrossing program using IR1561-228-3-3 as the recurrent parent has been initiated to transfer RTD resistance from *O. longistaminata*.

Mutation breeding for tungro resistance. In 1989, some progenies from mutagenized populations of IR24 were evaluated for RTD resistance. These materials had been mutagenized to induce mutations for BB resistance. When about 500 lines were exposed to RTD, a few showed little infection but the rest were severely infected. The leaves of the uninfected lines were tested using the enzyme-linked immunosorbent assay (ELISA) method to determine if those lines had been infected with either RTBV or RTSV or both. The progenies of these lines were inoculated using viruliferous GLH and evaluated for resistance using the ELISA test. Of the three mutant lines, one (YM 53) showed resistance to RTSV infection and two (IM69 AND XM 53) showed tolerance for RTBV. These results indicated that resistance to RTD can be induced through mutagenesis.

To explore the potential of mutation breeding for RTD resistance further, 62 plants of IR22 were treated with 1 mM N-methyl-N-nitrosourea (MNU) at 16-18 h after flowering (HAF). The treated plants had 93.7% fertility and 7,893 M1 seeds were obtained. The M1 seeds had 80.9% germination and 6,383 M1 plants were obtained. A total of 2,642 M2 lines with at least 10 seedlings/line were planted in the field to evaluate for reaction to RTD. Of these, 124 M2 were selected for further evaluation in the M3. Five plants were harvested individually from each of the selected lines. Two seeds from each of the remaining plants of the selected lines were harvested and bulked to produce a bulk population for each line. Thus, in the M3, each family consisted of five sister lines from individual plants and one bulked line. Of the 107 M3 families so evaluated, only one family showed resistance to RTD. All six lines of this family appeared normal; the remaining lines were severely infected. Leaf samples of 10 plants from each of 6 lines of the resistant family were tested using ELISA. The lines are highly tolerant of tungro viruses (Table 6). Fifteen other families appeared to be heterogeneous for resistance or tolerance for tungro in the M3. Tolerant plants from these lines were selected and will be evaluated in M4. The results will be verified in 1991.

Blast resistance. All the pedigree nursery and advanced generation lines were thoroughly screened for Bl resistance in the upland Bl nursery. Races of the fungus virulent on Carreon, UPLRi-5, IR36, IR50, and IR72 were maintained in the Bl nursery. In the pedigree nursery, only the lines with partial resistance were selected for further evaluation. Elite lines were screened for partial resistance using an upland miniplot technique.

Table 6. Results of ELISA test of 10 random samples from each mutant line for tungro.

M3 line no.	Plants infected (no.) with[a]			Infection (%) with[a]	
	B+S	S	H	B	S
398	4	6	0	40	100
399	5	4	1	50	90
400	6	3	1	60	90
401	6	3	1	60	90
402	3	4	3	30	70
397[b]	2	6	2	20	80

[a]B = bacilliform particle, S = spherical particle, H = healthy. Values for the bacilliform particle alone were zero for all entries. [b]Bulk harvested lines

Bacterial blight resistance. Pedigree nursery materials and fixed generation lines grown in the observational and replicated yield trials were evaluated for resistance to BB races 1 and 2. The proportion of materials with resistance to two races increased in 1990, indicating that many lines have either *xa-5* or *Xa-7* for resistance. Several crosses were made to incorporate *xa-13* and *Xa-21* in the elite germplasm.

Insect resistance

The pedigree nursery and advanced generation breeding lines were evaluated for resistance to GLH and the three biotypes of BPH. Only those with resistance were selected for further evaluation.

Breeding lines derived from wide crosses involving *O. australiensis* and *O. latifolia* were evaluated for resistance to BPH; resistant lines will be utilized in the breeding program as new donors.

Elite breeding lines

A total of 800 elite breeding lines were evaluated for grain quality, disease and insect resistance, and tolerance for soil problems such as salinity and alkalinity in RYTs during DS and WS. Several lines were evaluated for yield in N response trials at Bureau of Plant Industry stations in the Philippines. The most promising lines are characterized here:

- IR32809-26-3-3. 130 d duration. Long, slender, and translucent grains with high amylose content (AC) and intermediate gelatinization temperature (GT). Resistance to Bl, BB, GLH, and three biotypes of BPH; field tolerance for tungro.
- IR41985-111-3-2. 105 d duration. Long, slender, and translucent grains with intermediate AC and GT. Resistance to Bl, BB, GLH, three biotypes of BPH; field tolerance for tungro.
- IR50400-72-3-2-6. 130 d duration. Long, slender, and translucent grains with intermediate AC and low GT. Resistance to Bl, BB, GLH, three biotypes of BPH; field tolerance for tungro.
- IR50404-57-2-2-3. 105 d duration. Long, slender, and translucent grains with high AC and low GT. Resistance to Bl, BB, GLH, three biotypes of BPH; field tolerance for tungro.
- IR53936-60-3-2-3-1. 140 d duration. Excellent long, slender, and translucent grains with intermediate AC and GT. Resistance to Bl, BB, GLH, three biotypes of BPH; field tolerance for tungro.
- IR56450-4-2-2. 110 d duration. Long, slender, grains with intermediate AC and GT. Resistance to Bl, BB, GLH, three biotypes of BPH; field tolerance for tungro.
- IR57298-31-2-2. 115 d duration. Long, slender, and translucent grains with intermediate AC and GT. Resistance to Bl, BB, GLH, three biotypes of BPH; field tolerance for tungro.
- IR54950-181-2-1-2-3. 110 d duration. Excellent aromatic, long, slender, and translucent grains with intermediate AC and low GT. Resistance to Bl, GLH, three biotypes of BPH; field tolerance for tungro.

IRRI lines named varieties

In 1990, five IRRI lines from the irrigated breeding program brought to 211 the number of IRRI lines named as varieties worldwide.

- IR18348-36-3-3 was released as IR64 in Tamil Nadu State of India. Earlier this high-yielding variety with excellent grain quality had been released in the Philippines, Indonesia, Vietnam, Cambodia, Bhutan, and Andhra Pradesh, India.
- IR32307-107-3-2-2 was released as IR66 in Cambodia. This early-maturing line had earlier been released as IR66 in the Philippines.
- IR35366-90-3-2-1-2 was released as IR72 in Cambodia. This high-yielding and early-maturing line had been released as IR72 in the Philippines and Indonesia.
- IR31868-64-2-3-3-3 was named OM87-9 in Vietnam. It is an early-maturing and high-yielding line with excellent long, slender, and translucent grains with intermediate AC and GT.
- IR13429-150-3-2-1-2 was released as Kru in Cambodia. This early-maturing line has outyielded all the other early-maturing lines in multilocation trials in Cambodia.

Tolerance for physical stresses

Germplasm with tolerance for physical stresses

Research on rice germplasm tolerance for low temperature, and mineral deficiencies and toxicities associated with soil salinity-alkalinity is undertaken in this project. Prebreeding research for the development of screening methods, varietal screening, and identification of sources of tolerance is conducted and breeding materials are generated at IRRI for use by national agricultural research systems (NARS).

Korea-IRRI collaborative project on rice cold tolerance

Rice cold tolerance screening nursery. This is the 13th year of the Korea-IRRI Collaborative project on rice cold tolerance. Of 1,054 entries subjected to a water temperature gradient of 17 to 24 °C, 21 had a phenotypic acceptability score of 1 or 2 and ≥70% spikelet fertility at the inlet (Table 7). Five of the outstanding entries are IRRI lines; two are from IR25425, from the cross Leng Kwang/IR36.

Cold tolerance screening of bulu rices. Bulu accessions numbering 1,500 were subjected continuously to 17 °C water from tillering to maturity. Most of the entries were tall, with long and awned panicles. In terms of leaf color, most of the bulus were resistant to cold water irrigation. Of the entries screened, 94% had a leaf discoloration score of 2-3.

Screening for cold tolerance at anthesis. The 79 entries in the 1990 International Rice Cold Tolerance Nursery and 9 recommended Korean rice varieties were grown in small pots to maintain only one tiller per hill. The plants were tagged at heading and transferred to the greenhouse with an air temperature of 18 ± 2 °C for 10 d, after which they were returned outside for spikelet filling. The best entries (fertility >70%) were Chucheongbyeo, Oro, Unbongbyeo, Quell-Inia, Tep 62, Jinbu 4, Zhong Hua 3, YR-10, Daecheongbyeo, and Barkat. Ba Ren, K39-96-1-1-1-2, IR39739-7-4-3-1, Vialone Nano, Xintuan Hei Gu, Nagdongbyeo, and Dongjinbyeo showed moderate tolerance (fertility >50%).

Observational yield trial. We grew 16 elite selections from the 1989 cold tolerance screening nursery under continuously flowing cold water (17 °C) and normal irrigation water. The highest yielders at 17 °C were SR14859-6-2, Tella Hamsa, IR18482-PLP1-2B, and IR20897-B-6 (>6.00 t/ha). The yield and yield components of all entries are shown in Table 8. IR20897-B-6, also one of the outstanding lines in the cold tolerance screening nursery, gave the highest yield under normal conditions. The source of its cold tolerance is HR33 from India.

Boro rice

The International Network for Genetic Evaluation of Rice initiated the first meeting to consider the needs

Table 7. Selected entries from the cold water (17 °C) screening nursery.

Entry	Spikelet fertility (%)	Days to heading	Culm length (cm)	Spikelets (no.)	Panicles (no.)	Leaf discoloration score	Panicle exsertion score	Phenotypic acceptability score
Odaebyeo	78	123	52	92	9.3	3	3	2
Suweon 370	74	123	56	137	11.7	2	5	2
Suweon 378	74	113	59	74	11.7	1	3	1
Milyang 107	81	127	61	114	12.7	1	1	2
Jinbu 10	82	113	72	82	10.7	1	1	2
SR12190-HB169-20-1	72	119	66	128	11.7	2	1	1
SR13991-HB295-13	75	118	68	102	11.0	2	1	1
SR14948-HB307-40	90	123	74	124	10.3	2	1	1
SR12234-125-3-1-1-2	75	116	69	124	10.0	1	1	2
HR8338-69-1-2-2	76	113	61	138	10.0	2	3	2
HB8340-64-2-2-3	70	113	54	105	8.7	2	3	2
JKAU(K)450-126-2	77	106	56	112	6.7	4	3	2
IR25425-PLP9-1	85	118	77	192	5.0	2	1	2
IR20913-B-60	83	129	82	143	7.0	5	5	2
IR18482-PLP3-1-2-1-1-1	76	120	81	165	7.7	2	3	2
IR20897-B-6	82	120	82	131	6.7	3	5	2
IR25425-PLP8-1	70	118	85	193	8.7	1	3	2
China 988	94	116	56	102	10.7	4	5	2
Bir-Ze-Goo	95	117	64	126	9.7	4	5	2
Z-Yah-Tsan	86	122	69	90	8.7	4	3	2
IR9202-25-1-3	88	128	18	158	6.3	4	1	2

Table 8. Yield and yield components of entries in the 1990 Observational Yield Trial in Chuncheon, Korea.

Designation	Grain yield (t/ha)		Fertility (%)		Spikelets/panicle		1000-grain weight (g)		Panicles (no./m²)	
	17°C	Normal	17°C	Normal	17°C	Normal	17°C	Normal	17°C	Normal
SR14843-19-3	5.42 a-f	5.44 a-c	84 ab	89 a	56 fg	58 ef	25.3 b	27.2 bc	344 ab	310 a
SR14859-6-2	6.80 a	5.99 ab	85 ab	94 a	60 fg	70 e	22.7 cd	25.8 c-e	328 b-d	307 a
RGA508-11-2-3-3-2	4.10 fg	2.91 e	56 f	93 a	34 g	31 f	22.6 cd	27.4 bc	390 a	312 a
HR7891-B-B-11	5.92 a-e	4.66 b-d	92 a	93 a	80 ef	69 e	21.2 c-e	22.3 f-f	299 b-e	264 bc
IR18482-PLP1-2B	6.19 a-c	5.69 a-c	82 a-c	85 a	155 ab	124 bc	17.9 f	20.8 f	272 c-e	240 b-d
IR20897-B-6	6.10 a-d	6.55 a	80 b-d	88 a	98 de	88 c-e	25.2 b	29.3 ab	264 de	224 d-f
B3619C-TB-8-1-4	5.34 a-f	5.42 a-c	72 de	74 ab	168 a	166 a	20.4 de	23.6 e-h	190 f	227 ef
HP5247-PLP1-1-2	5.60 a-e	4.65 b-d	66 ef	56 c	123 cd	88 c-e	19.2 ef	26.0 cd	254 e	235 c-e
IR25425-PLP8-1	5.91 a-e	4.73 b-d	80 b-d	86 a	114 cd	81 de	21.0 c-e	21.8 g-f	262 e	259 b-d
Oro	4.67 d-g	4.54 b-d	76 b-e	86 a	66 f	82 de	29.2 a	30.2 a	267 de	195 f
RP1681-1701-4204	4.60 e-g	3.65 de	47 g	43 c	132 bc	111 b-d	23.0 bc	25.8 c-e	280 c-e	267 bc
Tella Hamsa	6.38 ab	4.28 c-e	73 c-e	54 c	114 cd	89 c-e	21.8 cd	23.6 e-g	302 b-e	259 b-d
Yun Geng 9	3.53 g	3.61 de	60 f	60 bc	124 cd	132 b	20.6 c-e	21.4 hf	248 e	222 d-f
Sangpungbyeo	4.76 c-g	4.93 b-d	80 b-d	75 ab	79 ef	76 de	22.2 cd	21.6 g-f	334 a-c	312 a
Pungangbyeo	5.21 b-f	5.01 b-d	70 de	81 a	114 cd	114 b-d	22.7 cd	24.2 d-f	283 b-e	246 b-d
Odnebyeo	5.80 a-e	5.79 a-c	90 a	87 a	77 ef	90 c-e	25.5 b	25.7 c-e	291 b-e	275 ab

of boro rice, a winter irrigated rice crop with a high productivity potential. The informal network formed has generated not only interest among the scientists but also exchange of ideas and site testing of breeding materials. Ample possibilities for increasing the boro rice area exist provided suitable varieties and matching cultural practices are developed. The objective of the network is to develop varieties with tolerance for low temperature during seedling and vegetative phases. Screening of varieties and elite breeding lines in boro areas began this year and IRRI supplied 20 lines for these tests. In the eastern and northeastern Himalayan areas of India, boro rice is grown in about 2.5 million ha; the highest area of 550,000 ha is in West Bengal. The present modern varieties are susceptible to low temperature at early vegetative stage during the period November to February. Low temperature sometimes kills the plants or prolongs growth duration. As a result of a prolonged growth period, varieties normally flower in April-May, the summer months, and are often affected by drought and very high temperatures at the reproductive phase. Short-duration varieties maturing the latest in mid-April while maintaining higher yield potential will require less inputs, particularly irrigation water.

Tolerance for P and Zn deficiency

Adaptability of varieties to alkaline soils depends primarily on their efficiency in P and Zn uptake. Therefore, efficient varieties have to be identified for breeding purposes. In 1990, 32 modern rices grown at 2 P levels (0 and 25 kg/ha) on a P-deficient Aeric Tropaquept (pH 4.4, 2.1 mg available P/kg) gave average yields of 3.1 t/ha in DS and 1.7 t/ha in WS. None of the rices responded to added P. IR68 produced 5 t/ha in DS while 5 other lines yielded about 4 t/ha (Table 9).

In a Zn-deficient Typic Tropaquept (pH 7.2, 0.18 ppm available Zn) in Bay, Laguna, the performance of 16 varieties was tested during 1990 DS and WS under 2 Zn levels (0 and with ZnO dip). There was no significant response to Zn treatment (Table 10).

Soil problems do not occur singly. Deficiencies of both P and Zn are common problems in soils, regardless of pH. Performance trials conducted during the past 6 yr show that varieties IR68 and IR70 have remarkable efficiency for both P and Zn. These rices may be used instead of or with minimal amendments under moderate soil stresses.

Table 9. Yield of some rices grown at 2 P levels in a P-deficient farmer's field, 1990.

Variety	Yield (t/ha) at		
	P0	25 kg P/ha in dry season	Mean
IR68	5.03 a	4.97 a	5.00 a
IR28222-9-2-2-2-2	4.37 ab	4.49 ab	4.43 ab
IR37873-16-2-3-3-3-1	4.29 ab	4.04 ab	4.16 ab
IR32453-20-3-2-2	3.76 b	4.47 ab	4.12 b
IR55366-28-3-1-2-2	3.96 b	4.17 ab	4.07 b
IR74	3.91 b	4.09 ab	4.00 ab

Table 10. Grain yield of selected varieties on a Zn-deficient soil with and without ZnO dip.

Variety	Yield (t/ha)		
	Without Zn	With Zn	Mean
IR74	2.11 ef	2.36 cd	2.24 fg
IR72	2.50 c-f	2.51 cd	2.51 d-g
IR70	3.14 ab	2.97 a-c	3.05 a-c
IR68	3.16 ab	3.47 a	3.32 a
IR66	2.47 c-f	2.66 cd	2.57 d-g
IR60	2.63 b-e	2.49 cd	2.56 d-g
IR58	1.45 g	1.71 e	1.58 i
IR56	2.17 ef	2.22 de	2.19 gh
IR54	2.70 b-e	2.91 a-c	2.81 b-d
IR52	1.93 fg	1.75 e	1.84 hi
IR42	2.93 a-c	3.31 ab	3.12 ab
IR33059-26-2-2	3.38 a	3.37 ab	3.38 a
IR44530-41-1-2	2.62 b-e	2.82 b-d	2.72 b-e
IR26	2.85 a-d	2.86 bc	2.86 b-d
IR21567-9-2-2	2.70 b-e	2.57 cd	2.64 c-i
IR9764-45-2	2.30 d-f	2.45 cd	2.38 e-g

Improved germplasm for saline-alkaline ricelands

Forty-five advanced bulk populations and lines were developed at IRRI for selection on saline-alkaline ricelands of India (Karnal, Gudha, and Mudlana) and Pakistan (Sadhoke, Pindi Bhattian, and Rakh Dera Chal). Though a wide range of salt-tolerant traditional varieties were used to generate these materials, only the crosses with Nona Bokra and Pokkali produced advanced bulks and lines with high adaptability. These included somaclonal variants of Pokkali. NARS breeders selected best lines for further tests.

Future plans

Varieties with tolerance for low temperature at various growth stages will continue to be sought to identify donors. Efforts to further increase the yield of boro rice will be expanded and strengthened, and exchange of knowledge and germplasm promoted.

Research on P and Zn efficiency will be directed toward identifying high-yielding types and determining the genetic components of these two traits. Breeding materials for use by NARS will continue to be generated. Because of the similarity of this research to that for the tidal wetlands ecosystem, it will either be linked with or transferred to the tidal wetlands breeding program.

Durable resistance to pests

The project aims to characterize and utilize not only individual host plant resistance but also the resistance mechanisms operating at the level of population that would be compatible with the concept and process of integrated pest management (IPM). The population dynamics of pathogen races and adaptation of insect populations in relation to the types and levels of host resistance, and other factors affecting durability of resistance in irrigated rice varieties are studied.

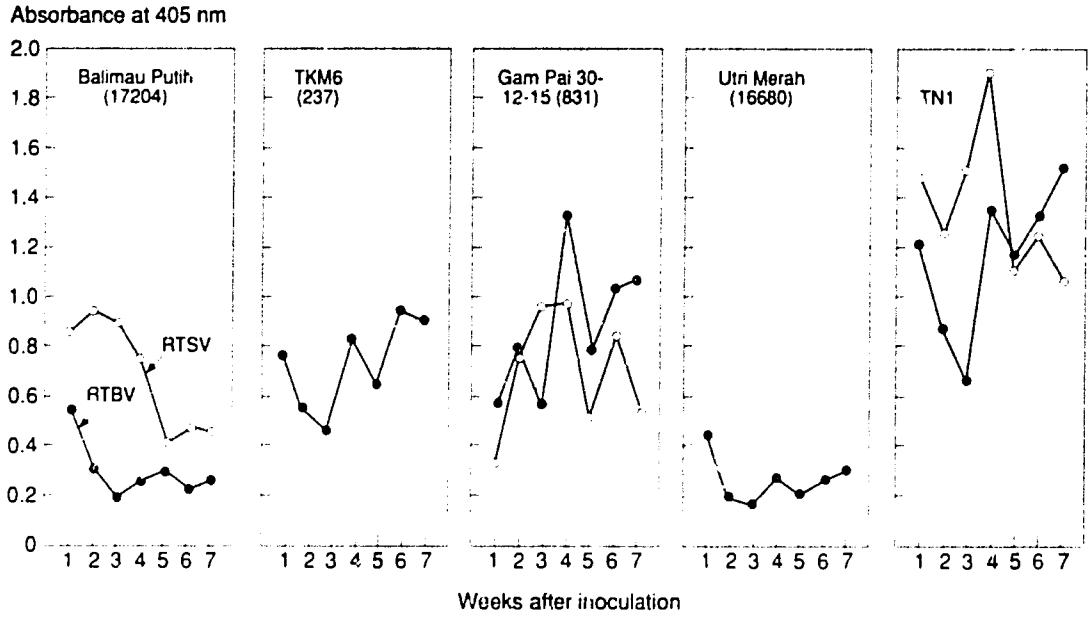
Resistance to rice tungro disease

Virus concentration in varieties resistant to or tolerant of rice tungro viruses. Relative amounts of RTBV and RTSV in infected rice plants of different varieties were examined by ELISA to clarify the relationship between virus concentration in plants and resistance or tolerance.

We selected several rice varieties resistant to or tolerant of tungro—Balimau Putih (Acc. no. 17204), tolerant; Utri Merah (Acc. no. 16680), resistant to RTSV and tolerant; TKM6 (Acc. no. 237), resistant to RTSV; and Gam Pai 30-12-15 (Acc. no. 831), resistant to the vector. Seven-day-old seedlings of the different varieties were planted singly in clay pots, enclosed in mylar cages, and inoculated by 5 viruliferous GLH/plant at 21 d after sowing (DAS). One week after inoculation 3-cm leaf samples were collected from all expanded leaves, weighed, homogenized in 0.1 M phosphate buffer containing 0.14 M NaCl and 0.05% Tween 20 (PBS-T) at 10× dilution, and subjected to ELISA. Four wells, 2 each for RTBV and RTSV were used for each of the 54 samples per variety. Virus concentration in extracts was indicated by absorbance at 405 nm. Samples with absorbance greater than four times the absorbance (means from four wells) of the uninoculated control were considered infected.

In another study, relative amounts of RTBV and RTSV in different parts of doubly or singly infected plants of the test varieties were detected by ELISA at 1 to 4 wk after inoculation. Random samples of 18 plants per variety were uprooted weekly, soils removed, and roots, leaf sheath or culm, and leaf blade separated. A sample—about 4 cm long—from these parts was collected, weighed, and homogenized in PBS-T at 10 × dilution.

Although the virus concentration values estimated from ELISA fluctuated, the RTBV concentrations in Balimau Putih and Utri Merah were consistently lower than those in TKM6 and Gam Pai 30-12-15 (Fig. 2).



2. Relative amounts of rice tungro bacilliform (RTBV) and rice tungro spherical viruses (RTSV) in doubly infected plants of Balimau Putih, Gam Pai 30-12-15, and TN1, and in RTBV-infected plants of TKM6 and Utri Merah at different weeks after inoculation as detected by ELISA.

Except in Utri Merah, rice tungro viruses were detected in roots, leaf sheath or culm, and leaf blade of the test varieties. Virus concentration was highest in the leaf blade (Table 11). In Utri Merah, low concentration of RTBV was detected only in leaf blades. In Balimau Putih, RTBV was detected on the roots in the first week after inoculation but none at later stages. On the other hand, RTSV was continu-

Table 11. Relative amounts of RTBV and RTSV in different parts of doubly infected Balimau Putih, Gam Pai 30-12-15, and TN1 plants and in RTBV-infected TKM6 and Utri Merah plants at 1 to 4 wk after inoculation as detected by ELISA.

Variety	Plant part[a]	Relative amounts[b]							
		1 wk		2 wk		3 wk		4 wk	
		RTBV	RTSV	RTBV	RTSV	RTBV	RTSV	RTBV	RTSV
TN1	R	.31	.46	.15	.58	.12	.32	.11	.33
	LS/C	.96	.94	.53	1.28	1.17	.63	.79	.43
	LB	1.11	1.63	.68	1.67	1.55	1.10	1.02	.53
TKM6	R	.19	0	.13	0	.17	0	0	0
	LS/C	.57	0	.19	0	.35	0	.30	0
	LB	.68	0	.38	0	.76	0	.53	0
Utri Merah[c]	LB	.15	0	.11	0	.20	0	.14	0
Balimau Putih	R	.25	.43	0	.44	0	.20	0	.14
	LS/C	.10	.19	.05	.32	.05	.15	0	.12
	LB	.19	.61	.18	.76	.19	.35	.14	.24
Gam Pai 30-12-15	R	0	.47	.22	.35	.17	.15	0	.18
	LS/C	.37	.38	.21	.39	.47	.33	.25	.05
	LB	.57	.46	.46	.96	1.02	.43	.47	.20

[a]R = roots, LS/C = leaf sheath or culm, LB = leaf blade. [b]Absorbance at 405 nm. [c]Virus was detected only in the leaf blade

ously detected. RTBV concentration in the leaf sheath or culm decreased gradually, and in the 4th week after inoculation was detected only in the leaf blade.

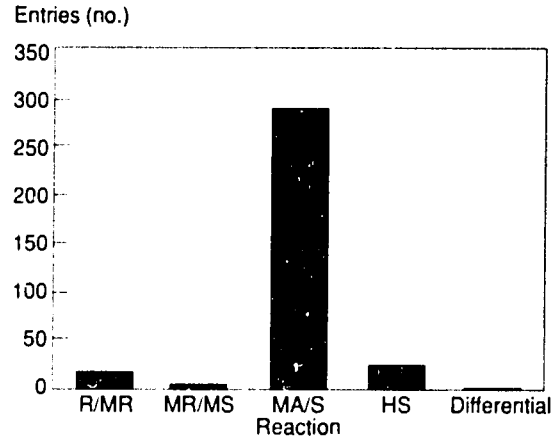
RTD symptoms are induced mainly by RTBV. Utri Merah and Balimau Putih do not show visible symptoms, even if infected. In susceptible varieties, RTBV concentration is high. The low concentration of RTBV in these varieties throughout their growth stage can be the evidence of tolerance.

DURABLE RESISTANCE TO BACTERIAL BLIGHT

Assessment of host diversity in a traditional agroecosystem in the Philippines. Host resistance is still the most effective and economical means of controlling rice BB. However, resistance in cultivars can be overcome by virulent races of the pathogen. To enhance resistance to existing cultivars, germplasm accessions were assessed for new or broad-spectrum resistance. This study sought to identify new resistance genes in conserved germplasm with the use of tester strains identified by DNA typing. The information on pathogen diversity assisted us in determining host diversity and will allow us to design improved methods of disease management.

Host diversity was assessed using 361 traditional cultivars from Banaue, Ifugao. Race 5 of *Xanthomonas oryzae* pv. *oryzae* (Xoo) is endemic in the region and is virulent on most of the cultivars. The experiment was conducted in screenhouse plots. Three single hills per cultivar were sown and systematically arranged according to accession number in 20- × 20-cm distance in the plot. Rice plants at late maximum tillering stage were inoculated with strains PXO80, PXO112, and PXO154, representing different RFLP types using pJEL101 analysis from among isolates of race 5.

Different reactions were obtained from the 361 traditional cultivars and even within cultivars. About 321 entries were moderately (MS) to highly susceptible (HS) to the three RFLP types, 21 were resistant (R) to moderately resistant (MR) or MS, and two accessions showed differential reactions (Fig. 3). Entries showing resistance to moderate resistance and differential reactions were further tested using 16 RFLP types identified by pJEL101, pTnX1, and Psd analyses from race 5. In the screenhouse, each tiller from a single hill per cultivar was inoculated with multiple strains representing 16 RFLP types. Three to five tillers from separate hills were inoculated with each RFLP type. Thirteen accessions were R to MR to all 16 RFLP types, 5 were MR to all 16 RFLP types, 5 were MR to MS, 8 were MS to S, and 2 showed differential reactions to some isolates. Seven showed mixtures of R and S genotypes.



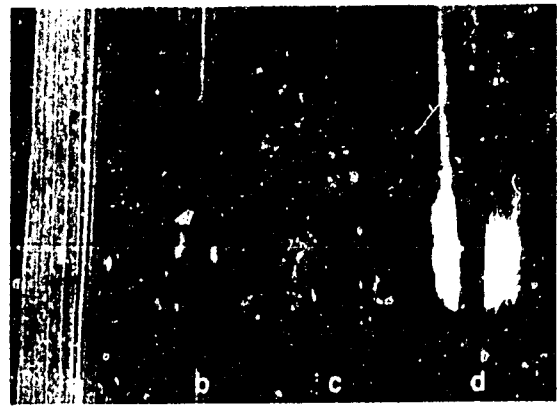
3. Frequency of reactions of 361 traditional cultivars to RFLP types from race 5 of *Xanthomonas oryzae* pv. *oryzae* in Banaue, Philippines. R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, HS = highly susceptible.

Further tests were done on Acc. 8106, which shows differential reaction to the isolates. Fifteen progenies each from six parental plants showing differential reactions to RFLP types 22 (PXO80, PXO112), 23 (PXO154), and 24 (PXO144) by pJEL101 and types D (PXO80, PXO112) and D-1 (PXO154, PXO144) by pTnX1 analysis were tested in the greenhouse to confirm the reactions. Single hills were planted in pots and inoculated with the four isolates at late maximum tillering stage. Lesion length and percent diseased leaf area were measured at 14 and 21 d after inoculation. Five parental plants showed R reaction to PXO80 and PXO112 and S reaction to PXO154 and PXO144 (Table 12). These results confirmed the differential reaction of Acc. 8106 to the isolates and the heterogeneity of different lines from the same accession as shown by susceptibility of 15 progenies from one parental plant (no. 6) to the four RFLP types. Heterogeneity was also indicated by diverse appearance of seeds from the original accession; however, the progenies showing differential and nondifferential reactions showed no distinct morphological difference. It seems that this accession carries resistance gene(s) possibly unidentified and different from those of the set of differential cultivars used to define Xoo races. Likewise, the tester strains identified by DNA typing using

Table 12. Reaction of selected lines from Acc. 8106 ("Ifugao Rice") to selected strains of *Xanthomonas oryzae* pv. *oryzae*.

Parental plant no. (code)	Progeny tested (no.)	Mean lesion length[a] (cm)			
		PXO80 (D/22)[b]	PXO112 (D-1/22)	PXO154 (E/23)	PXO144 (E/24)
1	15	7.3 (R)	7.1 (R)	30.6 (S)	23.5 (S)
2	15	9.6 (R)	6.8 (R)	30.7 (S)	25.3 (S)
3	15	7.7 (R)	6.1 (R)	30.8 (R)	24.0 (S)
4	15	9.1 (R)	8.7 (R)	29.4 (S)	23.9 (S)
5	4	6.1 (R)	7.3 (R)	31.1 (S)	26.1 (S)
6[c]	15	23.4 (S)	19.6 (S)	29.3 (S)	23.3 (S)

[a]Mean of lesion length (cm) of 15 progenies, 3-8 leaves per isolate per progeny. [b]RFLP type D as defined by pTnX1 and type 22 by pJEL101 analysis. [c]Genetic heterogeneity within Acc. 8106 indicated by heterogeneous reaction to Xoo, diverse appearance of seeds, and RFLPs detected for 2 out of 25 probes tested using a single restriction enzyme.



4 Four lesion types of bacterial blight on rice inoculated with incompatible Xoo races. a) Asymptomatic type, b) restricted chlorotic lesion with greenish yellow color, c) necrotic dark brown lesion, and d) typical chlorotic yellow lesion.

pJEL101, pTnX1, and PstI analyses revealed diversity among and within traditional cultivars in Ifugao Province and thus, appear to be useful in identifying unrecognized resistance genes present in conserved germplasm.

Infection types of near-isogenic lines for *Xanthomonas oryzae* pv. *oryzae* (Xoo) races. Infection types represent complex genetic interactions between the host varieties and pathogen races. In rice BB, infection types describe the incompatible response of a rice variety possessing specific resistance genes to infection caused by Xoo races with specified virulence. In this project, our objectives were to 1) define the infection types of rice near-isogenic lines (NILS) with the different genes for BB resistance to incompatible races; and 2) assess if infection types of a specific variety-race interaction are influenced by temperature, inoculum density, and levels of exogenous N. This study in the IRRI phytotron and greenhouse used the pin-prick method of inoculation. The infection types with the pin-prick inoculation were not distinguishable from those with the clipping method of inoculation.

Among the 48 line-race combinations, 3 major types of lesions were observed. The typical BB lesion with initial water-soaking then turning to straw yellow was observed in the compatible combinations of variety and race. This kind of lesion would continue to elongate and, in the course of lesion expansion and elongation, might become yellow with wavy margin. Necrotic, chlorotic, and asymptomatic types of lesion were produced by incompatible combinations (Fig. 4).

The necrotic type appeared initially as round to irregular spots, or a dark brown strip. Lesions of this type sometimes showed dark red color or a mixture of dark brown with yellow, making this type easily distinguishable from others. The chlorotic type was a more restricted greenish yellow to a very small greenish lesion. The typical yellow lesion might be either round or irregular-shaped, or rectangular. The asymptomatic type showed only a tiny spot in the court of infection.

NILs carrying the *Xa-3* gene when infected with races 2, 3, and 4 or 5 showed necrotic lesions (Fig. 5). NILs with *Xa-4* and *xa-5* infected with incompatible races such as 1 and 5 for *Xa-4*, and 1, 2, 3, and 5 for *xa-5* showed typical chlorotic yellow lesions (Fig. 6). NILs with *Xa-10* showed no symptom when infected with an incompatible race, such as races 2 and 5.

5. Necrotic dark brown infection type produced on line with Ka-3 at 21 d after inoculation with incompatible races 2 (c,e), 3 (a), and 4 (b,d).

6. Typical chlorotic yellow infection type produced on lines with *Xa-4* and *xa-5* inoculated with incompatible Xoo races.

Lesion size varied as inoculation time was prolonged, but the infection types varied with plant age. Lines with *Xa-3* and *Xa-4* showed typical susceptible lesions when infected 35 DAS. The distinct infection necrotic and chlorotic types on lines with *Xa-3* and *Xa-4*, respectively, shown at later growth stages (65 or 85 d) were perhaps related to the type of resistance these genes conferred. The infection type on NILs with *xa-5* and *Xa-7* infected with incompatible races was less variable than that on lines with *Xa-4* and *Xa-3*, and became asymptomatic after heading.

High temperature, inoculum density, and level of exogenous N enhanced lesion development and shortened the incubation period. The infection types were generally not affected by these factors but the time of their expression varied.

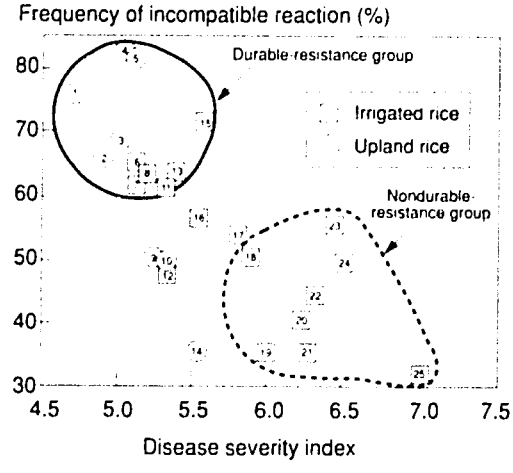
Durable resistance to blast

Common features of cultivars with durable blast resistance in multilocation tests. Except in a retrospective way, it is not possible to predict the durability of Bl resistance in the breeding line in question. Many rice cultivars, however, are known to possess durable Bl resistance under Bl-prone irrigated ecosystems. We studied the reactions of rice cultivars with or without durable resistance in the International Rice Blast Nursery (IRBN). The frequency of incompatible reaction—0-3 in *Standard evaluation system for rice* (SES)—and disease severity index (DSI)—the average score of compatible reaction (4-9 in SES) for a cultivar in 1975-88 IRBN trials of 25 cultivars, 17 irrigated rice, and 8 upland rice—were assessed.

Most of the durably resistant cultivars in the IRBN test showed low DSI value, mostly near 5.0, while the DSIs of all the known susceptible cultivar are higher than 6.0 (Fig. 7). The frequency of incom patible reactions of durably resistant cultivars i higher than 60%. These results suggest that th combination of broadly effective qualitative resis tance controlled by major gene(s) and high level o partial resistance would enhance the durability o host resistance to rice Bl. Some intermediate grou of cultivars such as IR20 and IAC47 have bee grown in a large area for long periods; however, the gradually became susceptible. It can be conclude that DSI and frequency of incompatible reaction ar good indicators of potentially durable resistance t rice Bl.

Next steps

Varieties known to be resistant to RTD will be re-evaluated to identify donor sources. The reasons fo low concentration of RTBV in Utri Merah and Bali-mau Putih will be studied to characterize tolerance mechanisms. Several methods for screening RTD resistance will be critically compared. Resistance t BB and ShB of improved germplasm as well as local varieties in the Philippines and other countries will be assessed and characterized. Race distribution and virulence pattern of the BB pathogen in areas of improved varieties will be monitored. The expression of chitinasis and glucanases in selected cultivars



7. Reactions to leaf blast of rice cultivars with and without durable resistance in the International Rice Blast Nursery, 1975-88. 1 = Moroberekan, 2 = Dourado Precoce, 3 = OS6, 4 = IRAT104, 5 = IRAT13, 6 = IR36, 7 = Taebaeg, 8 = Baegyang, 9 = IAC47, 10 = Partao, 11 = IR42, 12 = Milyang 42, 13 = Chupung, 14 = Denorado, 15 = Samgang, 16 = Milyang 30, 17 = IR20, 18 = IR50, 19 = Milyang 23, 20 = Yushin, 21 = IR8, 22 = CICA4, 23 = Yeongpung, 24 = IR24, 25 = Nopung.

in relation to expression of their resistance to ShB will be studied.

Resistance of irrigated rice cultivars with low DSI in IRBN test will be studied and varietal effect on the fitness of virulent BI isolates will be monitored.

Hybrid rice

The aim of this project is to develop hybrid rice technology to increase the yield potential of rice in the tropics and subtropics. As reported last year, a major constraint to developing commercially usable heterotic rice hybrids has been the dearth of suitable cytoplasmic male sterile (CMS) lines (characterized by complete pollen sterility, stability over environments, adaptability to the target areas, good outcrossing potential, and high general combining ability). During the year, we continued our search for suitable CMS lines. We identified heterotic hybrids derived from the available CMS lines and developed guidelines for hybrid seed production.

Search for suitable CMS and restorer lines

IRRI-bred CMS lines IR58025 A and IR62829 A, developed during 1989, were evaluated for pollen sterility and spikelet fertility in the Philippines, Republic of Korea, India, Egypt, and Vietnam. Both lines were nearly stable for male sterility. Seed set on bagged panicles was usually 0-0.4%, except at the high-altitude location of Banaue, Philippines, where seed set was 2.2% in IR62829 A. We produced bulk quantities of seeds of both lines at IRRI and supplied them to India, Indonesia, Malaysia, Philippines, Vietnam, Republic of Korea, and Egypt.

The new CMS line IR64608 A, developed by converting a Mexican rice cultivar, C8CU80-8MCU-SMINA-3CU-INA-2CU-6 in cms-WA cytoplasm, showed complete pollen sterility in tests at IRRI and in Korea and Egypt. We are studying its reaction to biotic and abiotic stresses and its outcrossing potential. The wide hybridization program at IRRI also developed a CMS line possessing *O. perennis* (IRRI Acc. 10483) cytoplasm and nuclear genotype of the popular rice cultivar IR64. It appears to be stable for pollen sterility and has been designated tentatively as IR64 A. Since rice cultivar IR64 is a known restorer for cms-WA cytosterility system, its conversion into a CMS line indicates that the *O. perennis* CMS source is genetically diverse from cms-WA.

To develop new CMS lines, we continued the search for maintainers of available CMS lines by testerossing these with elite lines and varieties of different origins. The frequency of maintainer lines was high among elite lines originating in Japan, Korea, and the Ivory Coast (using japonica rices) and in India, Pakistan, Indonesia, and Sri Lanka (using indica rices) (Table 13). Elite lines from IRRI continued to show low frequency of maintainer lines. Maintainer frequency was higher for CMS line possessing cms-ARC cytoplasm than CMS lines possessing cms-WA cytoplasm. CMS lines V20 A, IR58025 A, and IR62829 A, which possess the same cytoplasm but different nuclear genotype, showed differences in maintainer frequency (Table 14). Thus, the genetic background of the CMS lines influenced their maintaining ability.

To develop suitable CMS lines to breed aromatic F_1 rice hybrids, we made 44 testerosses to identify maintainers. Five maintainer lines—IR42685-C8-192-2-3-3, IR52813-C4-216-1-1, IR54718-C1-257-2-2-1-2, IR54718-C2-77-3-2-2, IR54718-C3-152-1-3-3—were identified for CMS line IR58025 A (a derivative of Basmati 370 crosses) and used in the conversion program. Similarly, three maintainer lines—IR43450-SKN-516-2-3-2-2, IR49722-179-3-

Table 13. Frequency of maintainers among elite lines and varieties of different origins in a testcross nursery. IRRI, 1990.

Origin	Lines tested (no.)	Maintainer frequency	
		no.	%
IRRI	550	11	2.0
Bangladesh	22	-	0.0
China	4	-	0.0
Taiwan, China	16	1	6.2
CIAT	7	1	14.3
Colombia	5	-	0.0
Egypt[a]	3	-	0.0
India[a]	94	14	14.9
Indonesia[a]	10	1	10.0
Ivory Coast	7	2	28.6
IITA	1	-	0.0
Iran	1	-	0.0
Japan[a]	2	2	100.0
Korea[a]	9	4	44.4
Nepal	1	-	0.0
Pakistan	5	1	20.0
Philippines[a]	10	-	0.0
Sri Lanka	21	2	9.5
Thailand[a]	3	-	0.0
Vietnam	4	-	0.0
Total	775	39	

[a]IRRI does collaborative research on hybrid rice with this country.

Table 14. Maintainer frequency of different CMS lines among lines originating at IRRI and NARS,[a] 1990 wet season.

CMS line	Cytoplasm	Lines tested (no.)	Origin	Maintainers	
				No.	%
IR54755 A	cms-ARC	16	IRRI	0	0.0
		25	NARS	8	32.0
V20 A	cms-WA	22	IRRI	0	0.0
		41	NARS	7	17.1
IR58025 A	cms-WA	53	IRRI	5	9.4
		80	NARS	7	8.7
IR62829 A	cms-WA	172	IRRI	3	1.7
		9	NARS	0	0

[a]National agricultural research systems.

2-1, IR48552-1-3-3-2—were identified among the elite lines developed for rainfed lowland conditions. We are also transferring the cms-WA cytoplasm in selected lines from crosses involving parents possessing wide compatibility genes. Some of the wide compatible cultivars (viz., Moroberekan, Palawan) are tropical japonicas.

The frequency of restorer lines among elite lines developed for irrigated and rainfed lowland condition was 65-75%. Therefore, there is no dearth of suitable restorers for developing rice hybrids.

Environment-sensitive male sterility in rice

In recent years, genic male sterility in rice, sensitive to variations in daylength and temperature, has been identified in China and Japan. In China, photoperiod-sensitive genic male sterile (PGMS) lines showed complete pollen sterility when daylength was longer than 14 h and partial fertility when daylength was less than 13 h 45 min. Japanese scientists developed a thermosensitive genic male sterile (TGMS) line—H89-1 (Norin PL 12)—which showed complete pollen sterility at a temperature regime of 31/24 °C and partial to complete fertility at lower temperatures (28/21 °C and 25/18 °C). Both PGMS and TGMS lines can be multiplied by selfing under appropriate environmental conditions and do not require maintainer lines for multiplication; hence, hybrids can be developed by using only two lines: PGMS or TGMS and a pollen parent. Furthermore, the pollen parent of the commercial hybrid does not have to be a restorer. Using the PGMS system, Chinese scientists have already developed some rice hybrids, which are in on-farm testing.

In the IRRI-Japan Shuttle Research Project initiated during the year, we introduced the TGMS mutant H89-1 or Norin PL 12 for evaluation and utilization in the tropics. The mutant was grown in the IRRI phytotron at 3 temperature regimes and at 2 locations: Los Baños (15 m altitude) and Banaue (950 m) in the Philippines. In the phytotron, the mutant was completely male sterile at 31/24 °C but partially fertile at 28/21 °C, 24/18 °C, or 26/15 °C (Table 15). These results conform to those reported from Japan. Since the mutant is in the genetic background of the japonica rice cultivar Reimei, we are transferring this ms gene into a number of elite indica and indica-japonica derivative lines for utilization in hybrid rice breeding programs in the tropics and subtropics.

Because PGMS lines developed in China are not available to rice scientists in other countries, we tried to induce such mutations at IRRI. We treated seeds of selected rice cultivars with gamma rays (25 kr) at the Philippine Atomic Energy Agency in Manila. A number of ms plants showing complete pollen sterility were selected in M_2 and multiplied into several plants by vegetative propagation. From maximum tillering stage onwards, clones of each ms plant were subjected daily to different daylengths (10 and 14 h) using the screenhouse dark room facilities of Agronomy, Plant Physiology, and Agroecology Division at IRRI. Pollen and spikelet fertility of individual tillers of each clone were monitored. Clones of some ms plants of three genotypes showed differential behavior for pollen and spikelet fertility (Table 16). These ms mutants appear to be photoperiod-sensitive. Further studies are in progress to confirm these findings.

Performance of elite rice hybrids

During 1990, we tested a number of elite rice hybrids in RYTs at IRRI, Philippines; India; Vietnam; Re-

Table 15. Spikelet fertility reaction of TGMS mutant Norin PL 12 under different temperature regimes in the Philippines.

Location	Spikelet fertility (%)		
	31/24 °C	28/21 °C	24/18 °C
Phytotron, IRRI	0	27.3	10.4
Field			
Los Baños[a]	0		
Banaue[b]			41.4

[a]Temperature during panicle initiation (PI) to flowering (FI) was 31/21 °C. [b]Temperature during PI to FI was 26/15 °C.

Table 16. Pollen and spikelet fertility of some male sterile mutants of rice grown under 2 daylengths, IRRI, Oct-Dec 1990.

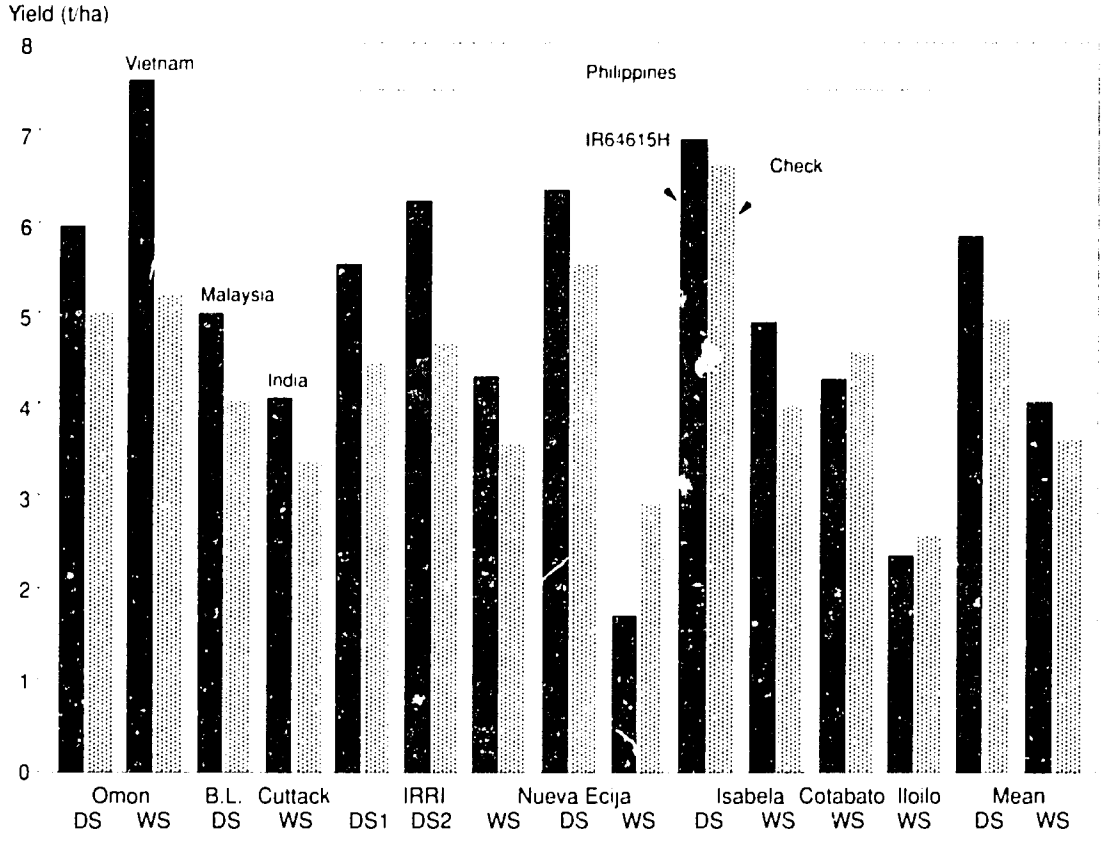
Genotype	Plants (no.)	Pollen fertility (%)		Spikelet fertility (%)	
		10 h	14 h	10 h	14 h
IR62829 B	29	3.0	63.6	0.0	8.4
IR54752 B	18	1.6	53.1	0.0	4.7
	19	21.0	0.0	5.0	0.0
IR32464-20-1-3-2	10	0	4.7	0.0	3.6
	26	30	0.0	11.4	0.0

public of Korea; and Egypt. Partial results indicate the yield superiority of the hybrid IR64615H over the inbred checks at certain locations in Vietnam, Philippines, Malaysia, and India (Fig. 8). At other locations, some other IRRI-bred hybrids—IR64618H, IR64616H, IR64611H—performed better. IRRI entomologists and pathologists reported IR64615H to be resistant to BPH, GLH, and moderately resistant to striped stem borers (SSB) and yellow stem borers (YSB).

PHYSIOLOGICAL ANALYSIS OF HETEROSIS IN GRAIN YIELD

F_1 hybrid IR58025 A/IR54742-22-19-3R showed close to the estimated maximum yield potential for WS in the tropics (Table 17). The panicle weight of the F_1 hybrid was 8.8 t/ha. Because the 2 values came from different sample materials, the yield of 8.0 t/ha was considered reliable. We are reevaluating this hybrid in 1991 DS to reconfirm these findings.

The high grain yield of the F_1 hybrid was attributed to both high total dry matter production (DMP) and harvest index. The relationship between grain yield and DMP (Table 18) indicated that DMP between heading and 15 d thereafter is most important for achieving high grain yield. A significant correlation between relative growth rate and relative leaf growth rate was observed at 30 to 16 d before heading (r = 0.978**) and between 15 d after heading and maturity (r = 0.785**). These results indicate that high leaf area development is important at the early growth stage and slow senescence at the late growth stage.



8. Yield of hybrid rice IR64615H compared with that of check varieties in replicated trials at various locations in Vietnam, Malaysia, India, and the Philippines during 1990 dry (DS) and wet season (WS).

Insect/disease resistance of hybrids vs parents

IRRI entomologists and pathologists evaluated the resistance of a number of F_1 rice hybrids and parental lines under artificial infestation or inoculation for BPH, GLH, and BB. Results (Table 19) showed that hybrids were resistant if parents were resistant; if one parent was susceptible, the hybrids were either resistant or susceptible, depending on whether the gene imparting resistance was dominant or recessive. If both parents were susceptible, then the F_1 hybrids were also susceptible.

A comparison of five CMS lines with their maintainer lines for reaction to BPH, GLH, YSB, SSB, and BB (race PXO61) showed identical reaction to indicate that male sterility-inducing cytoplasm did not confer any susceptibility to these biotic stresses.

Guidelines for hybrid rice seed production

Experiments conducted during 1990 to develop guidelines for hybrid rice seed production indicated the following:

- At IRRI, hybrid rice seed production plots flowering from late February to early March 1990 gave higher seed yields than plots flowering during other times of the year (Fig. 9). During this period the sky was clear, radiation was 11.2-17.8 MJ/m², max-min temperature 29/22.5 °C, relative humidity 50-60%, and wind velocity during blooming hours was 3-4 m/s.
- Among various cultural practices (GA_3 application, flag leaf clipping, and supplementary pollination) used to produce hybrid seeds, GA_3 application was the most effective to increase seed yield (Fig. 10).
- Seed discoloration, a problem in hybrid rice production in the tropics, was higher at Los Baños (Laguna) and Maligaya (Nueva Ecija) than in San Mateo (Cagayan) in the Philippines. Thus, a suit-

Table 17. Grain yield of F_1 rice hybrids, their parental lines, and check variety IR72, 1990 WS.

Variety or line	Grain yield[a] (t/ha)
Experiment 1	
IR62829 B	2.8 b
IR62829 A/IR9761-19-1R	5.8 a
IR9761-19-1R	6.0 a
IR46830 B	0.2 c
IR46830 A/IR9761-19-1R	4.5 ab
IR72	4.6 ab
Experiment 2	
IR58025 B	(Damaged by rats)
IR58025 A/IR9761-19-1 R	5.4 b
IR9761-19-1 R	4.7 b
IR58025 A/IR54742-22-19-3 R	8.0 a
IR54742-22-19-3 R	5.4 b
IR72	4.0 b
Experiment 3	
IR58025 B	4.5 bcd
IR58025 A/IR29723-143-3-2-1 R	5.8 a
IR29723-143-3-2-1 R	5.7 ab
IR62829 B	3.7 d
IR62829 A/IR29723-143-3-2-1 R	4.4 cd
IR72	5.0 abc

[a]Within an experiment, values having a common letter are not statistically different at the 5% level

Table 18. Correlation between grain yield and dry matter production in 3 field experiments, 1990 WS.

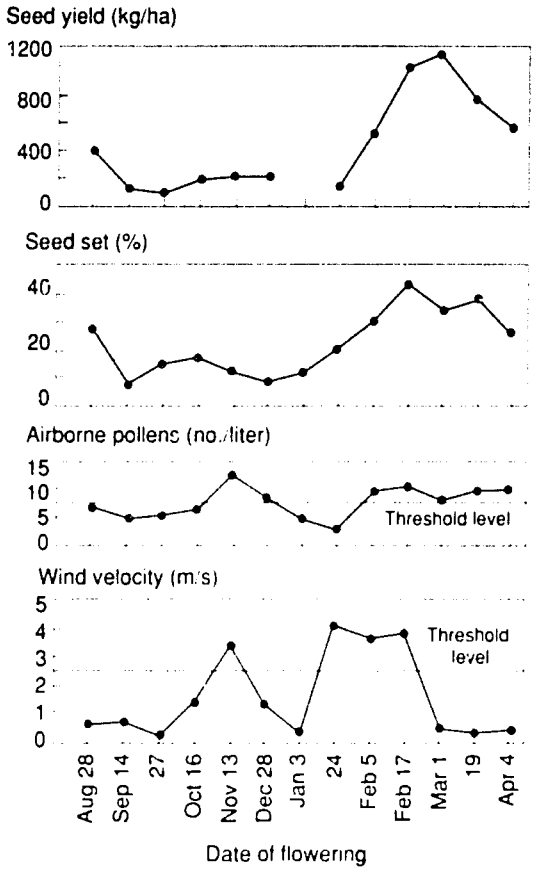
Character	Correlation coefficient[a]	
	A	B
Shoot dry weight		
14 d after seeding	–0.321 ns	–0.214 ns
30 d before heading (DBH)	0.589*	0.616*
16 DBH	0.421 ns	0.438 ns
Heading	0.635**	0.665**
15 d after heading (DAH)	0.765**	0.861**
Maturity	0.671**	0.754**
Shoot dry weight increase		
30 DBH - 16 DBH	–0.305 ns	–0.307 ns
Heading - 15 DAH	0.519*	0.625**
15 DAH - maturity	0.396 ns	0.422 ns
Panicle-to-shoot dry weight ratio	0.572*	0.038 ns

[a]A = includes all values for the correlaton analysis. B = excludes IR46830 B of Experiment 1 for the analysis.

Table 19. Parents and hybrids exhibiting specific reaction to brown planthopper biotype 2, green leafhopper, and bacterial blight. IRRI, 1990.

Parent reaction[a]	Hybrids (no.) showing specific reaction		
	Susceptible	Moderately resistant	Resistant
	Brown planthopper		
R/R	0	0	8
R/S	0	1	3
S/R	7	5	0
S/S	7	0	0
	Green leafhopper		
R/R	0	4	6
R/S	0	1	4
S/R	2	3	5
S/S	6	0	0
	Bacterial blight race PXO61		
R/R	0	0	5
R/S	0	0	4
S/R	0	0	3
S/S	3	0	0

[a]R = resistant, S = susceptible.



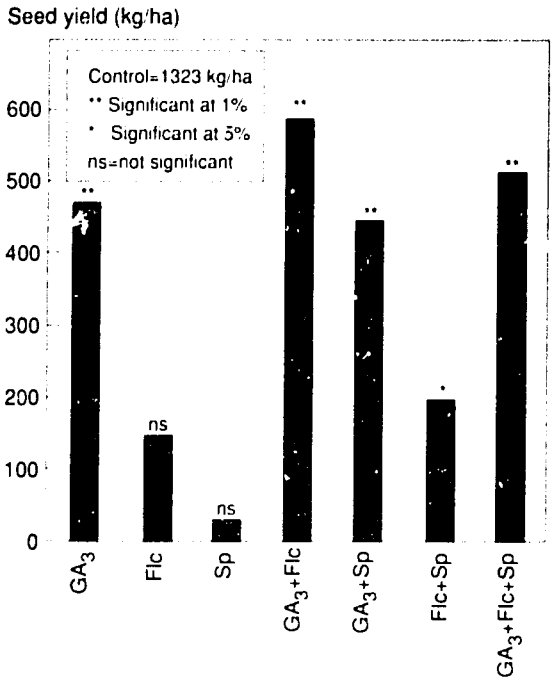
9. Relationships among wind velocity, number of airborne pollens per liter, seed set, and seed yield as affected by time of flowering of CMS line IR62829 A.

able location would have to be selected to produce clean hybrid rice seeds.

- The extent of synchronization of flowering of male and female parents in seed production plots affected seed yield considerably.
- The vertical movement of rice pollen grains, recorded during 1990 WS in ricefields in full bloom at IRRI, showed maximum pollen load (19.2 airborne pollen per liter) at panicle level. This drastically decreased to 0.4 to 2.3 pollen per liter of air at 1.5 to 2.0 m height above the panicle. Therefore, a 2.5-m-tall barrier can provide isolation in seed production plots.

FUTURE RESEARCH

We will continue the search for commercially usable CMS lines possessing diverse cytoplasmic and/or nuclear genetic backgrounds. The role of roots in manifestation of heterosis for yield will be studied. The heterotic rice hybrids will be tested in additional



10. Main effect of the components of hybrid seed production practices on seed yield of IR62829 A, 1990 DS.

locations in NARS. To obtain enhanced level of heterosis, suitable parental lines among improved tropical japonicas would be developed. Guidelines for hybrid seed production technology developed so far would be compiled in the form of a seed growers' primer on hybrid rice seed production. Cost of hybrid rice seed production would be determined. A training course on hybrid rice seed production will be organized at IRRI. Steps will be taken to organize a hybrid rice research consortium/task force involving IRRI and interested NARS to expedite the development and use of hybrid rice technology in the interested NARS.

Subprogram II: Crop, resource, and pest management

N nutrient efficiency

POTENTIAL OF N_2-FIXING BLUE-GREEN ALGAE AS BIOFERTILIZERS IN RICE SOILS: EFFECT OF INOCULATION WITH AMMONIA-EXCRETING MUTANT AND FOREIGN STRAINS

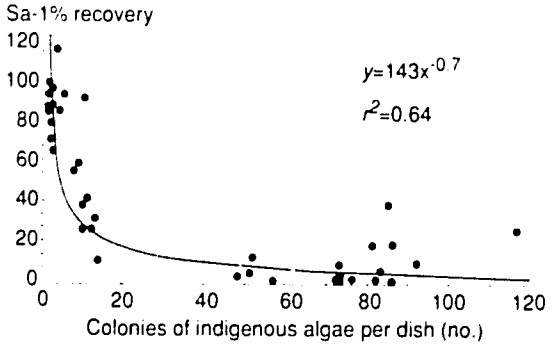
Nitrogen accumulated in N_2-fixing blue-green algae (BGA) growing in ricefields is usually released during the decomposition of the algal biomass, but

that release may occur too late during the crop cycle for optimum use by the plant. Continuous excretion of part of the fixed N, as it occurs in symbiotic BGA, would ensure better utilization by the plant.

Spontaneous mutants of free-living N_2-fixing *Anabaena variabilis* Kutz (ATCC 29413) that excrete a significant part of their fixed N_2 as NH_4^+ have been isolated by scientists at Institute of Food and Agricultural Sciences (IFAS) (University of Florida). Pot experiments with rice and the most effective N_2-fixing and NH_4^+-excreting strain (SA-1) have shown that under gnotobiotic conditions (rice+SA-1 grown on artificial medium) SA-1 could supply enough N to the plant to support its growth in a N-free medium. We have studied, in collaboration with IFAS, the possibility of establishing SA-1 in various soils. The experiments also assessed the effect of fertilizers on indigenous and inoculated BGA productivity, and the ratio between P applied and N accumulation.

Plating the combinations of various soil dilutions with the strain SA-1 and four media showed that SA-1 colonies could be easily identified through their morphology. Counts decreased when the quantity of soil plated increased; we found a strong negative correlation between the percentage of SA-1 colonies recovered on a petri dish and the number of colonies other than SA-1 growing on the dish (Fig. 11), which demonstrates that SA-1 is not a competitive strain.

Inoculation trials were conducted in trays containing about 4 cm of soil. The first experiment with a ricefield soil with low P content studied the effect of P (0 and 15 kg/ha) and N (0 and 30 kg/ha) on the establishment of SA-1 and a mixture of 200 strains of IRRI's BGA collection inoculated at 6.7 kg dry wt of fresh algae/ha, and on the growth of indigenous strains in noninoculated trays. Visual and microscopic examinations, and counts plating showed that, despite the high level of inoculation, SA-1 did not establish. SA-1 fresh inoculum might have been consumed by grazers at early stages of the experiment. In trays where N fertilizer was applied, inoculation had no effect on grazers because unicellular green algae developed immediately and provided feed to the ostracods, which were then sustained by the indigenous BGA developing because of P fertilization.



11. Competition between indigenous soil strains and SA-1 on petri dishes.

Measurements of N accumulated in algae and upper soil layer showed a statistically significant effect of inoculation in trays where a mixture of strains was applied but not in trays inoculated with SA-1 (Table 20). On the average, N accumulation was about 25 kg/ha in 47 d in trays inoculated with a mixture of strains and 17 kg/ha in the noninoculated controls. Most of the difference was due to N accumulated on the soil surface. Algal productivity and N accumulation were mostly related to P fertilization. N accumulation averaged 30 kg/ha in P-fertilized trays and 12 kg/ha in trays with no P. In the trays where P was applied, N accumulation in inoculated trays was 4 to 9 kg/ha higher than in the noninoculated trays, where 28 kg/ha accumulated. The difference was not significant and, even if significant, would not justify inoculation in economic terms.

The second experiment studied the effect of P, N, and the quantity of inoculum (7, 13, and 34 kg ash-free dry wt of fresh algae per ha) on the establishment of SA-1 in a low-P soil, with increased grazer control. Despite the high levels of inoculum and efficient grazer control, SA-1 did not establish. Blooms of indigenous algae developed in all the trays where P was applied. SA-1 counts rapidly decreased during the experiment, but the strain persisted more in trays with poor algal growth, as shown by a significant (p:0.05) negative correlation between SA-1 counts and 1) floating algal biomass, and 2) total N accumulated. This confirmed the lack of competitiveness of the strain.

Blooms of indigenous algae developed in most microplots, causing an average N accumulation of about 20 kg/ha in 6 wk in microplots where 15 kg P/ha or 6 kg N/ha was applied. A low N accumulation at the soil surface as compared with the previous experiment was probably due to strong control of grazers. Large populations of grazers reduce algal growth, but some grazing activity is needed to re-

Table 20. Effect of inoculation and fertilizers on N accumulation in algae and the upper soil layer.[a]

Treatments[b]			N accumulated in floating algae (kg/ha)		N accumulated on soil surface (kg/ha)		Total accumulated (kg/ha)	
			Mean	SD[a]	Mean	SD	Mean	SD
SA-1	–N	–P	0.0	0.0	12.0	6.5	12.0	6.5
None	–N	–P	0.1	0.3	6.8	3.9	6.8	3.9
Inoc.	–N	–P	2.3	0.8	14.3	2.7	16.6	2.3
SA-1	–N	+P	21.0	3.1	11.0	5.2	32.1	6.6
None	–N	+P	15.1	4.2	13.1	1.1	28.2	4.7
Inoc.	–N	+P	17.6	5.7	19.0	5.7	36.6	7.2
SA-1	+N	–P	0.2	0.3	9.1	1.7	9.3	1.9
None	+N	–P	0.4	0.1	10.3	4.6	10.8	4.6
Inoc.	+N	–P	3.2	0.7	16.2	11.2	19.3	11.1
SA-1	+N	+P	13.7	5.6	15.6	7.3	29.2	6.8
None	+N	+P	14.4	7.3	9.5	4.7	23.9	6.8
Inoc.	+N	+P	15.1	10.0	12.1	3.0	27.3	9.5
Factors								
SA-1			8.7	b	11.9	ab	20.7	ab
None			7.5	b	9.9	b	17.4	b
Inoc.			9.5	a	15.4	a	24.9	a
	–N	–P	0.8	c	11.0	ns	11.8	b[c]
	–N	+P	17.9	a	14.4	-	32.3	a
	+N	–P	1.3	b	11.9	-	13.1	b
	+N	+P	14.4	a	12.4	-	26.8	a
	–N		9.4	ns	12.7	ns	22.0	ns
	+N		7.8	ns	312.1	-	20.0	-
		–P	1.0	b	11.5	ns	12.5	b
		+P	16.1	a	13.4	-	29.5	a

[a]SD (standard deviation) indicated as the interaction between the 3 factors was not significant. [b]Inoc. = inoculated with a mixture of 200 strains of the IRRI Culture Collection. [c]Significant at p = 0.09 only

cycle nutrients accumulated in the algal biomass and to avoid the overcrowding of algae.

The third experiment compared SA-1 inoculation (13 kg dry wt of fresh BGA/ha) in four soils (pH 5.0-7.4, 0.088-0.227% total N, 92-762 ppm total P) receiving 15 kg P/ha where grazers were controlled. SA-1 decreased from 2.5-5.0 × 10^5 cm^{-2} soil 1 d after inoculation to less than 10^3 cm^{-2} after 1 mo. Counts of indigenous N_2-fixing BGA increased by 9 to 50 times (average 20) depending on the soil. Algal biomass was highest in soils with pH close to neutrality and a high total P content (Pila: 316 kg ash-free dry wt/ha; Maahas: 231 kg/ha). Biomass (expressed in kg N/ha) was significantly lower in the acidic soil of Pangil (84 kg/ha) and the P-deficient soil of Pangasinan (101 kg/ha) (Table 21). Inoculation with SA-1 had no effect on the biomass of floating algae (kg dry wt/ha and kg N/ha) and its composition (%N, %P). Highest N accumulation recorded in a single plot was 37 kg/ha in 30 d.

Conclusions

Strains excreting NH_4^+ do not seem suitable for field inoculation because of very low competitiveness and susceptibility to grazing, which does not allow their establishment in situ. Data also confirm previous observations at IRRI that foreign strains of BGA inoculated in rice soil usually do not establish. Most ricefields have a rich natural algal flora and it seems likely that indigenous strains will usually outgrow populations derived from laboratory isolates unless a simultaneous change in the environment gives inoculated strains a competitive advantage.

Data show that inoculation of foreign strains of BGA has limited potential, and that P application together with grazer control is usually sufficient to allow the development of blooms of indigenous algae leading to the accumulation of 4.5-40 kg N/ha in 3-4 wk (Fig. 12). Such values provide an estimate of the potential contribution of BGA under optimized conditions.

Table 21. Nitrogen accumulation at 30 d after seeding in 5 soils.

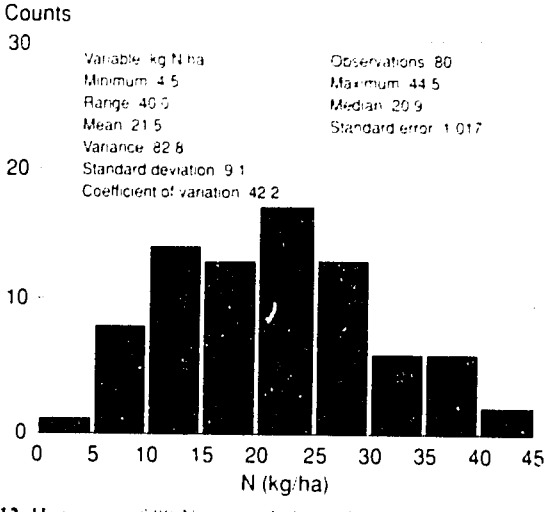
Treatment		N accumulation (kg/ha)						
		In algae		In 1st cm of soil		Total		N/P
Soil	Inoculation	Mean	SD	Mean	SD	Mean	SD	
Maahas	+	12.9	5.3	13.1	2.1	26.0	6.4	1.7
Maahas	–	16.4	11.4	9.7	7.2	26.2	8.1	1.7
Pangasinan	+	3.1	0.7	10.0	4.4	13.1	3.9	0.9
Pangasinan	–	7.8	1.7	2.1	2.1	9.9	2.3	0.7
Pangil	+	4.6	1.1	5.3	3.0	9.9	4.1	0.7
Pangil	–	4.5	2.4	7.3	1.3	11.8	3.3	0.8
Pila	+	10.9	4.8	9.4	1.7	20.3	3.4	1.4
Pila	–	16.1	6.7	7.1	3.9	23.2	4.5	1.5
Maahas	all	14.6 a		11.4 a		26.1 a		1.7 a
Pangasinan	all	5.5 b		6.0 b		11.5 b		0.8 b
Pangil	all	4.5 b		6.3 b		10.8 b		0.7 b
Pila	all	13.5 a		8.3 ab		21.8 a		1.5 a
All soils	+	7.9 a		9.5 a		17.3 a		1.2 a
All soils	–	11.2 a		6.6 b		17.8 a		1.2 a

The promotion of photodependent N_2-fixation in wetland soils most often requires P application. The N/P ratios recorded in the experiments ranged from 0.3 to 3.0 and averaged 1.4 (Fig. 13), while the average ratio of farmer's price of P to N in Asian countries was 2.79 for 1982-86. This indicates that the cost of P is an important factor to be considered in agronomic practices that aim to promote photodependent BNF in ricefields.

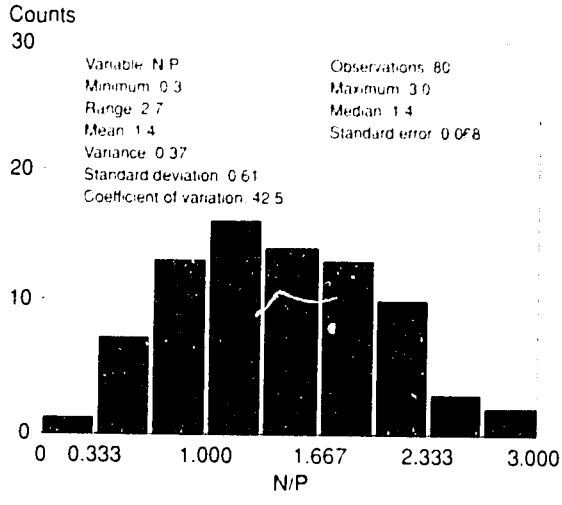
Simulating nitrogen transformations

Our understanding of N fertilizer in rice-based cropping systems could be enhanced with computer simulation models that can predict the effects of weather, soil properties, and crop management on N dynamics and crop growth processes. One such simulation model is CERES-RICE, developed by the International Benchmark Sites Network for Agrotechnology Transfer, Michigan State University, and IFDC. The CERES-RICE model incorporates water balance, soil N, plant N, and crop growth components to simulate rice growth and yield in response to water and N. It was validated with data from previous collaborative IRRI-IFDC field research in the Philippines.

Since many processes in floodwater can occur rapidly, the floodwater N transformations are simulated using an hourly time step. Input data for run-



12. Histogram of 80 N accumulation values (algal biomasss + upper soil) obtained in 3 greenhouse experiments.



13. Histogram of 80 N-to-P values obtained in 3 greenhouse experiments.

ning the model include daily solar radiation, daily maximum and minimum air temperature, daily rainfall, soil organic C, initial soil water content, initial soil bulk density, initial soil ammonium-N, rate of N fertilizer, depth of daily irrigation, and cation exchange capacity of the surface soil layer. Relatively less available information such as diffusion coefficients, windspeed, and floodwater pH, temperature, ammoniacal N, and oxygen are not required as model inputs.

The model simulates the rapid disappearance of floodwater urea and the buildup of floodwater ammoniacal N following broadcast application of urea to flooded soil (Fig. 14). It successfully simulates the field observation that midday floodwater ammoniacal N after either incorporation, or broadcasting of urea on clay soils seldom exceeds 8% of the applied urea N. Urea hydrolysis is simulated in the floodwater, oxidized soil layer, and reduced soil layer. The prediction of urea hydrolysis and subsequent ammonia loss is particularly influenced by the urea hydrolysis rate in floodwater relative to the hydrolysis rate in the soil, and by the depth and distribution of urea when incorporated in the soil.

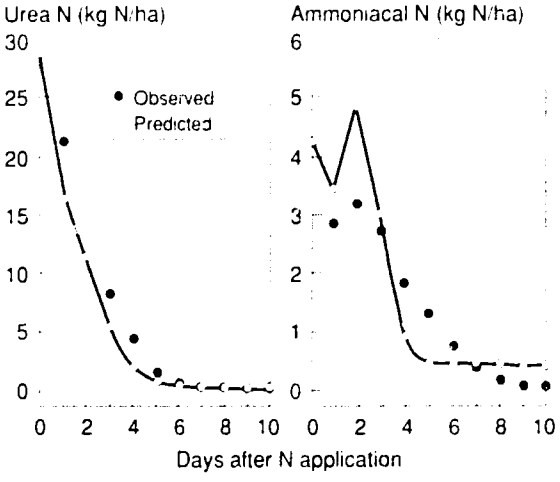
Predicted gaseous N losses from urea were compared with total gaseous losses, estimated by the ^{15}N balance technique for transplanted irrigated lowland rice in eight experiments at three sites. In all cases, the model predicted appreciable loss of added urea N by ammonia volatilization but negligible loss of N by nitrification-denitrification, which is consistent with field measurements. The model closely simulates the magnitude of ammonia loss from delayed split applications in which urea was broadcast into standing floodwater (Fig. 15). Ammonia loss tended to be overestimated for early split applications in which at least part of the urea was basally incorporated, frequently without standing water. Accurate simulation of ammonia loss from basal incorporated urea requires greater understanding of the distribution of urea in the soil and floodwater following incorporation, and knowledge of ammonia loss from saturated, puddled soil without standing water.

After the N components of the CERES-RICE model are validated, the model will be used to predict rice yield gains associated with various management practices that reduce N loss, and to identify fertilizer management options for farmers.

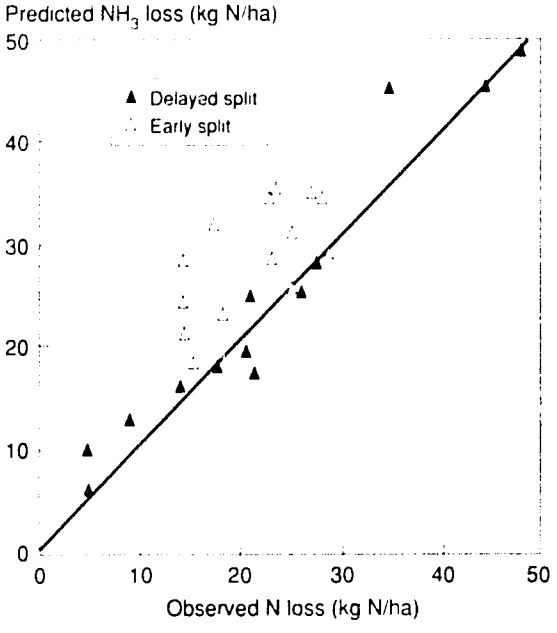
Conservation of soil N

Tropical lowland rice soils typically undergo alternate saturation and drying. Field research conducted in the Philippines examined the effect of plant growth during the dry-wet transition period before WS rice on soil nitrate dynamics and rice yield.

Following harvest of lowland rice on 31 January, nitrate in the top 60-cm soil layer increased from about 15 kg N/ha on 27 Feb to over 50 kg N/ha on 24 April. In the absence of plant growth (weed-free fallow), soil nitrate decreased by 34 kg N/ha from 24 April to 2 July during the dry-wet transition period



14. Observed and predicted N transformations in floodwater.



15. Predicted ammonium loss from delayed split applications of urea to standing floodwater.

and the subsequent puddling of the soil for rice production. The decrease in nitrate was presumably due to N losses by denitrification and leaching. *Sesbania rostrata*, a waterlogging-tolerant, N_2-fixing green manure, and weeds assimilated soil nitrate, thereby reducing losses of soil N.

Prerice treatment strongly influenced WS rice yield. Yield without applied N fertilizer was 2.3 t/ha following weed-free fallow; it increased by 0.6 t/ha following weedy fallow and by 1.3 t/ha following sesbania. At least part of the increase appears due to conservation of native soil N. Nitrate N taken up by plants before soil wetting and flooding is recycled in the plant residues incorporated during land preparation for rice. Mineralization of these residues provides N for the rice.

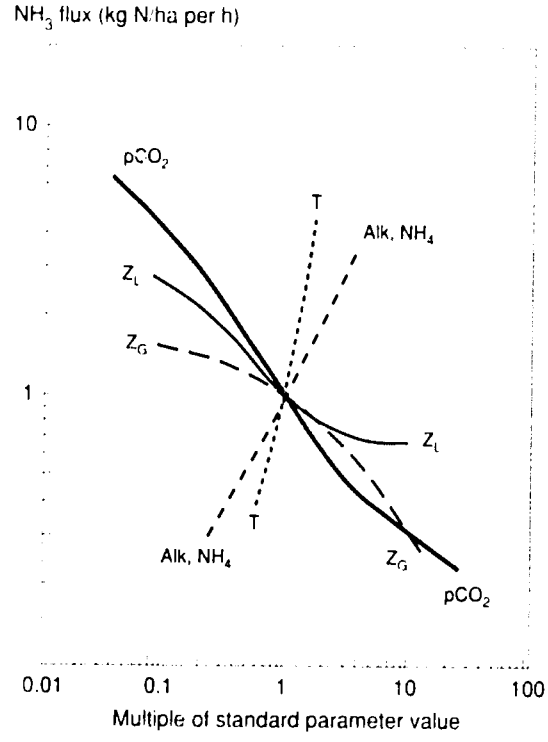
Research findings suggest that cropping intensity and soil management during the dry-wet transition period can influence losses of soil N and N fertilizer requirements of rice. Research is continuing to identify crop, water, and soil management practices to effectively utilize native soil fertility and reduce emissions of nitrous oxide, a greenhouse gas formed during nitrification-denitrification.

Floodwater chemistry controlling NH_3 volatilization

To better understand how agronomic practices may be manipulated to improve N fertilizer efficiency, we developed a detailed computer model of ricefield floodwater chemistry as it affects NH_3 volatilization. Dissolved CO_2 is an important determinant of floodwater pH (and hence NH_3 volatilization) because its concentration may be very high (the underlying soil being a source of CO_2) and very dynamic (photosynthetic algae remove CO_2 in photosynthesis and add it in respiration). Also, CO_2 loss tends to make the solution more alkaline, whereas NH_3 loss makes it more acidic. In developing a model, therefore, it is necessary to consider the simultaneous transport of both NH_3 and CO_2 through the floodwater, their coupling through acid-base reactions, and the transport and reaction of acids and bases that move in response to the consequent pH changes.

In the model, the air-water interface is pictured as two still films—one in the air and one in the water—separating the two bulk fluids which are well-mixed by turbulence. In the transfer of each gas across the interface, there are three potentially rate-limiting processes: diffusion across the still air film, diffusion across the still water film, and chemical reactions in the water. The still film thicknesses range from a few microns to a few tenths of a millimeter, and vary with factors such as wind velocity, surface roughness (especially plant cover), temperature, incident radiation, albedo, and water turbidity. The model allows for each of the potentially rate-limiting processes. Equilibrium between ammoniacal and carbonate species in the water is rapid, but the CO_2 hydration-dehydration reactions are slow and their rates must be allowed for.

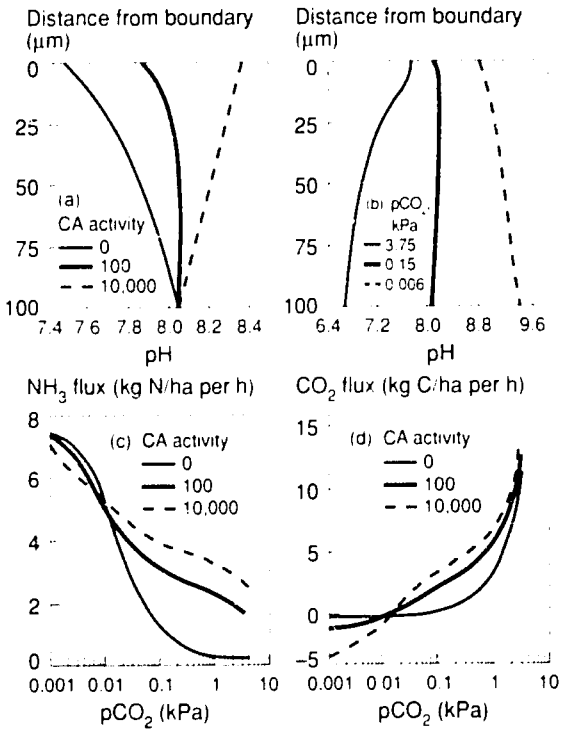
The model predicts how the gas fluxes and reactant concentration profiles in the water film vary with five input parameters: the thicknesses of the still layers, and the concentrations of alkalinity, ammoniacal species, and carbonate species in the floodwater. Figure 16 shows how the predicted NH_3 flux changes as the parameter values are changed around realistic average values. Clearly, all the parameters have significant effects. The importance of floodwater CO_2 pressure is well known, but the



16. Effect of varying model parameter values on predicted NH_3 fluxes from floodwater into the atmosphere. The standard parameter values are Z_L (thickness of still-air film) = 100 µm, Z_G (thickness of still-water film) = 100 µm, NH_3 ([ammoniacal species]) = 2 mM, Alk ([alkalinity]) = 3 mM, pCO_2 (CO_2 pressure) = 0.003 atm, T (temperature) = 25°C. CO_2 hydration-dehydration is uncatalyzed.

effect of floodwater temperature, diurnal changes in which can be as much as 15 K, is less well studied.

The extent of the pH gradients across the still-water film are shown in Figure 17a,b. When the equilibrium between CO_2 species is uncatalyzed, acidification resulting from NH_3 loss dominates alkalinization resulting from CO_2 loss, and the pH at the air-water boundary is considerably lower than that in the bulk water (Fig. 17a, CA activity = 0). But in the natural environment, it is likely that CO_2 hydration-dehydration is catalyzed by the enzyme carbonic anhydrase (CA). In these circumstances, alkalinization from CO_2 loss would dominate, and the air-water boundary pH may be considerably greater than that in the bulk, as Figure 17a shows. The importance of this effect obviously varies as the CO_2 pressure varies (Fig. 17b). Figure 17c shows the resultant large increases in NH_3 loss. During intense algal activity, the floodwater CO_2 pressure may fall below the atmospheric value, causing the water to absorb CO_2 from the atmosphere (i.e., negative CO_2 flux, Fig. 17d). This would tend to acidify the water surface. But at low CO_2 pressure, floodwater pH is high, and the rate of acidity diffusion neutralizing pH changes in the water is also high (Fig. 18). Thus, the effect of CA activity at low CO_2 pressure is small.



17. Predicted pH profiles a) at different carbonic anhydrase (CA) activities with CO_2 pressure = 0.003 atm, and b) at different CO_2 pressures with CA activity = 1000; and effects of CA activity on (c) NH_3 fluxes and (d) CO_2 fluxes at different CO_2 pressures. The other parameter values are as the standards in Figure 16. The CA activity units are arbitrary.

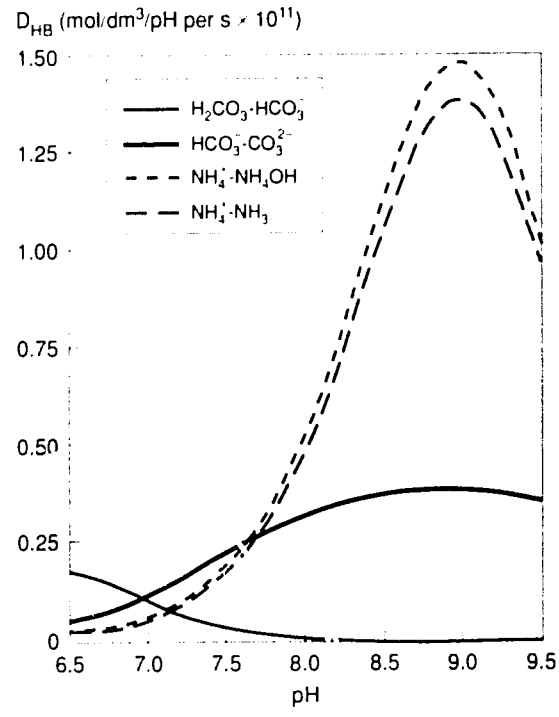
The large effect of CA raises the interesting possibility of artificially inhibiting CA as a means of reducing NH_3 losses. CA inhibition would effectively enhance the suppression of NH_3 volatilization brought about by CO_2 released in organic matter decomposition. More work is needed to judge the agronomic feasibility of this approach.

The model does not account for all components of the ricefield atmosphere-floodwater-soil system. Missing components include movement of the reactants between the floodwater and soil, CO_2 production in the soil, and CO_2 uptake by algae. Further work is being done to incorporate these components.

N-cycling

Genetic enhancement of biofertilizer sources

In this project, reducing dependence on chemical fertilizer by using farm-grown sources is an ultimate



18. Contribution of different acid-base pairs to acidity diffusion in the floodwater. The diffusion coefficient of pair HB (D_{HB}) relates the flux of HB (F_{HB}) to the pH gradient: $F_{HB} = D_{HB}dph/dz$. The net acidity flux is the sum of the individual fluxes.

goal. An immediate concern is the improvement of biofertilizer germplasm.

Agronomic traits of azolla can be improved by sexual hybridization, selection of F_1, and mutation. To achieve this objective, genetic, morphological, and physiological characters of strains in IRRI's large collection should be recorded. The data base of these characters will be useful for national programs. Following the discovery of positive heterosis in sexual hybrids, hybridization work has been expanded.

Hybridization of azolla. That sexual hybridization of azolla is a promising way of improving azolla is evidenced by better growth and higher N_2-fixation of hybrids of *A. microphylla* (female) with *A. filiculoides* compared with that of the parents. Hybridization work was, therefore, expanded in collaboration with the University of the Philippines at Los Baños (UPLB). Because sporulation or sexual organ formation is essential for hybridization, and sporulation is more active in cooler regions, azolla plants were grown in Baguio, northern Luzon, the Philippines. Putative hybrids were identified by zymograms (electrophoretic pattern of isozymes). Crosses of *A. filiculoides* (female) with *A. microphylla* (male), and other combination were made (Table 22).

By zymograms of shikimate dehydrogenase (SKD) and phosphoglucomutase (PGM) and morphological characters (number of leaf trichome cells), eight strains were identified to be hybrids between *A. filiculoides* and *A. microphylla*. Among them, strains 8007-8012 showed unique characteristics. At early stage of sporophyte development, symbiotic algae either entered the leaf cavity or got lost (8011). Although N_2-fixing activities were as active as those of *A. filiculoides* at 22 °C, growth was poor even in the presence of combined N. At 33 °C, these strains died, while parents azolla and 8006 grew. Strain 8015 produced male and female sporocarps. It was concluded that unlike the *A. microphylla* (female) and *A. filiculoides* combination, positive heterosis was not found in the opposite combination.

Zymograms of some putative hybrid strains obtained at UPLB were examined. Among them, only Acc. no. 2024 (2001 * 4001) was confirmed to be hybrid and formed fertile female and male organs. These results confirm that proper combination of parents is needed to improve azolla by sexual hybridization.

Chemotaxonomy of azolla. In collaboration with W. Zimmerman, Washington State University, chemotaxonomy of azolla, particularly Section Azolla (primarily New World Azolla), was made. There are 11 alleles in SKD electrophoresis and 33 enzyme types were found. Frequencies of these bands are shown in Table 23. Progenies after sexual propagation are not included. Frequencies of bands in *A. filiculoides* are different from those of the three other species. *A. microphylla* may be separated from *A. caroliniana-mexicana* by the absence or low frequency of H, I, J, K bands. The SKD zymogram confirmed previous work, showing distinct differences between *A. filiculoides* and other azolla species. Most of *A. filiculoides* accessions (87%) had DI bands, and only some of Latin America *A. filiculoides* shared bands found in *A. caroliniana-mexicana*. SKD alleles analysis also supports the idea that *A. caroliniana*, *A. mexicana*, and *A. microphylla* or

Table 22. Characteristics of azolla hybrids.

Acc. no.	Species	Cross	Anabaena[a]	Leaf trichome cells	Band pattern	
					SKD[b]	PGM[c]
1001	F1	Parent	+	Single cell	DI	DEF
4061	MI	Parent	+	Double cells	ACDE	ABC
3522	CA	Parent	+	Double cells	AK	EGI
8003-4	FI	1001 x 4061	–	Single>double	ACDI	
8006	FI	1001 x 4061	+	Single cell	ADI	
8007,9,10	FI	1001 x 4061	+(O)	Double>single	ADEI	ABCDEF
8007,11	FI	1001 x 4061	–(O)	Double>single	ADEI	ABCDEF
8012,18	CA	3522 x 4061	+	Double	AC	ABCEGM
8013,14,15,16	CA	3522 x 4061	+	Double	AEK	ABCEGM
8017	CA	3522 x 4061	+	Double	ADEK	ABCEGM

[a]+(O) = Anabaena were present outside the leaf cavities at early stage of F. development, but were inside leaf cavities later. –(O) = Anabaena were outside leaf cavities, and eventually disappeared. [b]SKD = shikimate dehydrogenase. [c]PGM = phosphoglucomutase.

Table 23. SKD bands frequency in zymograms of the Azolla section of the genus *Azolla*.

Species[a]	Enzyme types (no.)	SKD bands frequency (%)										
		A	B	C	D	E	F	G	H	I	J	K
Aca	20	85	10	40	30	40	5	40	15	10	10	25
Amex	9	78	11	33	44	0	20	22	11	0	22	
Amic	12	83	33	58	42	33	17	20	8	8	0	0
Afil	5	20	0	20	40	0	0	60	0	60	0	20
All	33	73	18	36	42	30	9	30	12	21	6	18

[a]Aca = *Azolla caroliniana*, Amex = *A. mexicana*, Amic = *A. microphylla*, Afil = *A. filiculoides*.

A. caroliniana and *A. mexicana* should be included in one species. Monoclonal antibody C16 against Anabaena cells reacted with Anabaena from most of *A. filiculoides* tested and with a small group of *A. caroliniana*, which had G band in SKD zymogram.

Progenies of 4018 (ABC) type segregated into AC and AB types, and those of 4061 (ACDE type) into ACE, ACD, and DE types. No segregation was observed in SKD alleles in the progenies of *A. filiculoides* (DI type). SKD zymograms also identified misclassification of some azolla, like #1538, which is unlikely to be *A. filiculoides*.

SKD alleles analysis of *A. pinnata* and PGM alleles of Latin America *A. filiculoides* is going on. To make data bases and establish means of identifying species and strains of azolla, chemotaxonomic studies will be continued until we can get fingerprinting of the collection.

Availability of azolla N to rice

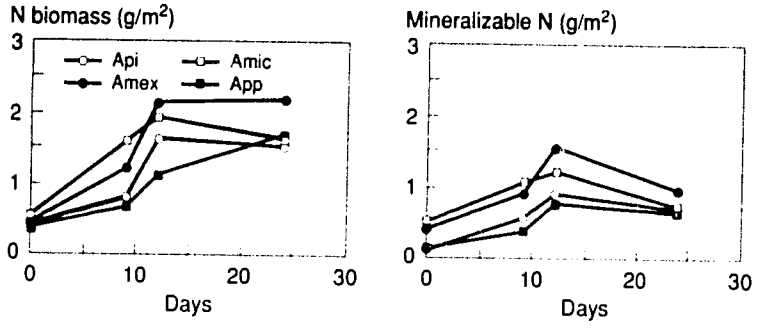
The primary goal is to reduce dependence on chemical N fertilizer by using farm-grown sources. Basic knowledge of the use of organic fertilizer is an immediate concern. Nitrogen of azolla, a green manure crop from wetland rice, becomes available to rice after mineralization. A survey of field-grown azolla in the Philippines showed a large variation in N content (2-6% on dry weight basis).

The effect of azolla species and their chemical composition on mineralization of N in azolla was studied. As P-enriched azolla strains of *A. pinnata* var. *imbricata* #5, *A. mexicana* #2026, *A. microphylla* #4018, *A. pinnata* var. *pinnata* #7001 grew in the field, their P contents decreased. From 12 to 24 d after inoculation, P deficiency became severe, N contents decreased while lignin and fiber contents increased. *A. pinnata* var. *pinnata* had lower N content than other species. Plants with different N content were incubated for 4 wk in the laboratory under flooded condition to examine N mineralization. As N contents decreased, %N mineralized decreased. Correlation coefficients of %N mineralized at 2 wk incubation with N, lignin, and fiber contents (Table 24) show that N mineralization was proportional to N content, and negatively correlated with lignin and fiber contents. *A. pinnata* var. *imbricata* had lower mineralization at the same level of N content than other species. Mineralizable N peaked at 12 d after inoculation, when azolla started to become P deficient. After that, total N increase was not accompanied by increase in mineralizable N, for N became less mineralizable because of P deficiency and high plant population (Fig. 19). These results show that N in azolla deficient in P and, hence, low in N, or in *A. pinnata* var. *pinnata* with consistently low N content has low mineralization ratios, and probably low fertilizer efficiency.

To examine fertilizer efficiency, N uptake of rice, and N balance in various azolla species with different N content, field experiments were conducted in 1987 and 1988 WS, using azolla with low and high

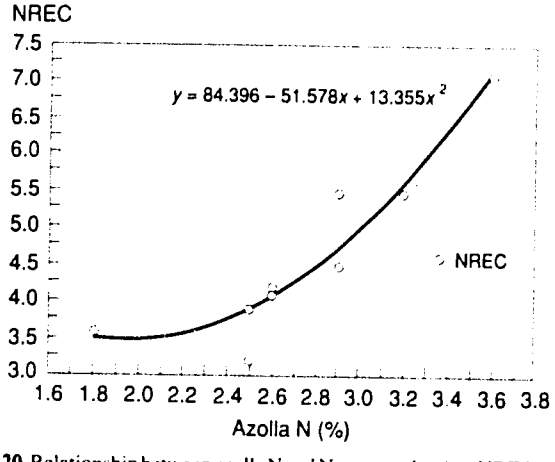
Table 24. Correlation coefficients among mineralization ratios at 2 wk incubation and contents of N, fiber, and lignin of azolla.

	Mineralization ratio	N %	Fiber %	Lignin %
Mineralization ratio		5.5	–0.66	–0.62
N %	0.95		–0.61	–0.27
Fiber %	–0.69	–0.64		0.85
Lignin %	–0.3	–0.16	0.54	



19. N biomass and its mineralization for 4 wk (Sep 1986). Api = *Azolla pinnata* var. *imbricata*, Amex = *A. mexicana*, Amic = *A. microphylla*, App = *A. pinnata* var. *pinnata*.

N contents. In one experiment, recoveries of azolla ^{15}N in two consecutive rice crops were studied in field microplots (1987 WS). *A. microphylla* gave the highest N contents, and *A. pinnata* var. *pinnata* with 1.8% N gave less than 50% for 8 wk. Field experiments showed that azolla N was effective in increasing rice grain yield despite the wide range of N contents (Table 24). Linear correlation coefficient between N content and N recovery by rice (the difference method) was 0.89 (Fig. 20). To get rice grain yield increase comparable to those from urea N uptake, azolla must have at least 3.2% N. Similar to laboratory incubation data, mineralization of N from *A. pinnata* var. *pinnata* was slow in the field, resulting in slow rice growth. The ^{15}N recoveries by rice were proportional to azolla N content ($R = 0.73$, 1987 data); it was higher from azolla high in N content than from the same azolla species low in N. Recoveries by the second rice of ^{15}N remaining in soil after the first rice were higher from urea than from azolla; no difference among azolla sources was found in



20. Relationship between azolla N and N recovery by rice (NREC), 1988 field experiment.

these recoveries. It was concluded that despite wide variation in N contents of various species, azolla is an effective N fertilizer to wetland rice, but fertilizer efficiency was primarily determined by azolla N content.

In these experiments, higher N fertilizer recoveries were calculated with the N difference method than with the labeled N fertilizer method. To reduce the difference in total N uptake in rice between fertilized plants and nonfertilized ones, a concrete plot (1.5 × 1.5 m with bottom at 30 cm) was divided into two, and N fertilizers were applied in one-half of the plot. *A. microphylla* with high N (3.7%) and low N (3.1%), *A. pinnata* var. *pinnata* (2.6%), and urea were applied before rice was transplanted. Grain yield and N uptake in high N *A. microphylla*-treated plots were higher than in urea-treated plots. *A. pinnata* var. *pinnata* gave the lowest yield and N uptake (Table 25). Difference in growth due to N contents of azolla was greater at early rice growth stage than at harvest. Difference in N recoveries by rice by the non-isotope and isotope methods was small in *A. pinnata* var. *pinnata* plots, suggesting that ^{15}N in available N from slowly decomposing azolla was less diluted by unlabeled soil N than was that in fast-decomposing. Because this research has clarified the relationship between azolla N content and fertilizer efficiency in wetland rice, this activity will be terminated.

Water and tillage management

Water management for diversified cropping in rice irrigation systems

In the Philippines, as in many other Asian countries, irrigation systems were developed mostly for rice - rice cropping systems. The scarcity of water supply

Table 25. Effect of azolla and urea on rice yields, N uptake, and N recovery to rice, field experiment, 1988 WS.

N source		N (%)	Rice yields (t/ha)		Applied N (kg/ha)	N absorbed (kg/ha)	Recovery (difference) (%)
Species[a]	N content		Grain	Straw			
Control			3.2	2.6	0	56	
Urea			4.0	2.9	45	82	56
Amic	High	3.2	4.1	3.1	46	81	55
Amic	Low	2.49	3.7	3.0	44	73	39
Api	High	2.94	3.9	3.2	47	70	45
Api	Low	2.49	3.7	3.1	47	63	32
App	High	2.57	3.8	2.9	47	75	42
App	Low	1.80	3.6	2.6	48	73	36
Amex	High	2.93	3.8	3.2	49	76	41
Amex	Low	2.58	3.8	3.2	49	75	41
Amic hybrid		3.58	4.2	3.3	45	88	71
SE			0.1	0.4		13	20

[a]Amic = *Azolla microphylla*, Api = *A. pinnata* var. *imbricata*, App = *A. pinnata* var. *pinnata*, Amex = *A. mexicana*.

in DS has, however, consistently caused low cropping intensities in these systems, and tail section areas of most irrigation systems are deprived of DS crops. In recent years, there has been increasing concern as to how the low levels of land utilization and low incomes from rice production could be improved. Growing diversified crops in DS, which require less water than rice, may provide a practical solution to these problems. Is the rice irrigation system infrastructure capable of meeting the irrigation needs of nonrice crops? Can irrigation water be adequately controlled at the farm for growing nonrice crops? How should irrigation water be managed to provide farmers the flexibility of crop choice, and to improve water use efficiency and land productivity? These questions and issues constituted the central theme of a collaborative research with the International Irrigation Management Institute (IIMI). Research was conducted during 1988-90 in Bangladesh, Indonesia, and the Philippines, in partnership with concerned NARS.

Irrigation infrastructure compatibility between rice and nonrice crops

In general, water control and distribution facilities at the main system level of rice irrigation systems are sufficiently flexible to support the irrigation needs of nonrice crops in DS. Rice irrigation systems are amenable to establishment of rotational irrigation supply schedules suitable for both rice and nonrice crops in DS.

We found that adequate supply of irrigation water was a necessary, but not sufficient, condition for farmers' shift from rice to nonrice crops in DS. In areas where the soil was not very heavy and drainage was satisfactory, economic incentive was the main driving force for this shift. When such incentive existed, farmers invested money to develop on-farm groundwater to supplement canal supplies for nonrice crops, especially in areas that are at the far ends of irrigation canals. Groundwater users achieved significantly higher incomes from their farms in DS than did nonusers. In general, farmers with access to adequate supply of water can best exercise their cropping options. Fluctuating and low prices of nonrice crops often force small farmers to switch back to rice after growing nonrice crops for one or more seasons because rice culture provides a more stable income.

On-farm infrastructure adaptation for nonrice crops

The study was conducted in two selected irrigation systems in Central Luzon, Philippines, namely: the Upper Talavera River Irrigation System (UTRIS) and the San Fabian River Irrigation System (SFRIS). The farmers in both systems have a long history of growing irrigated nonrice crops, mostly onion in UTRIS and tobacco in SFRIS, during DS. The study area consisted of three turnout service areas (TSA) in each of three land use categories: areas growing mixed rice and nonrice crops, areas planted entirely to nonrice crops, and areas planted entirely to rice.

For growing nonrice crops on rice paddies during DS, certain structural adaptations dependent on the crop were required. To grow onion in UTRIS, farm-

ers divided and reshaped their original rice plots, which were larger than 500 m^2, into 2 or more subplots. About 80% of the plot area was effectively used for growing onion and the remainder was used as buffer and for the construction of additional ditches along the plot or subplot perimeter to intercept seepage from adjacent farm ditches—rice or onion plots—and to facilitate irrigation water application and the removal of excess water. In contrast, the SFRIS farmers who grew tobacco after rice maintained the original size and shape of rice plots, and no additional or-farm water control structures were used.

Within the TSA, additional internal and supplementary farm ditches were required in DS to convey water from the main supply canal and the main farm ditch to the farms. In UTRIS, the average farm ditch density (FDD) during DS increased about 3.5 times in lands used for mixed rice and nonrice crops, or only for nonrice crops compared to the FDD in areas where only rice was grown in WS or DS. In SFRIS, only about 30% more farm ditches were used for irrigating the nonrice crop in DS. These additional farm ditches were seasonal and were erased during WS when the area was used for rice cultivation. There was no change in the FDD between WS and DS in the land planted entirely to rice.

The land area used for the construction of temporary farm ditches in DS was 315 m^2/ha (or about 3.5% of the TSA) in UTRIS, but only 60 m^2/ha (or about 0.6%) in SFRIS. The difference is due to the water application methods for onion and tobacco.

It can thus be inferred that the main farm ditch and the essential water control structures such as turnouts, division boxes, and check drops (where necessary), which were provided and maintained for rice, are suitable for adequately supporting the basic irrigation requirements of diversified cropping in DS. On-farm ditches and other water control facilities needed for growing nonrice crops in DS must be handled by farmers according to their specific needs.

Managing high water table for diversified cropping

In parts of rice irrigation systems, especially in topographically flat tailend areas, the subsurface water table may remain very close to the ground even in DS because of continuous percolation and seepage from unlined canals and irrigated ricefields. However, nonrice crops can be satisfactorily grown only if the water table is effectively lowered. With proper regulation, the water table can be used as the source of irrigation for the crop root zone by the capillary rise phenomenon as in subirrigation systems. The prospect of water table lowering and regulation to introduce flexibility of crop choice was investigated in a farmer's field within the service area (TO: MC-14) of the Lower Talavera River Irrigation System, Nueva Ecija, in 1990 DS. The field, which was adjacent to an unlined irrigation canal and surrounded by irrigated ricefields on three sides, had a flat topography with a slope of about 0.25% perpendicularly away from the canal. The farm had silty clay loam soil and had been planted to rice in both seasons.

The water table control was established by use of drainage-cum-interceptor channels in 20- × 10-m plots with the following specifications in a randomized complete block experimental design (RCBD) with four replications:

T1. Drainage-cum-interceptor channel, 50 cm deep, constructed around the perimeter of each plot.

T2. Two drainage-cum-interceptor channels, 30 cm deep, constructed at the two sides of each plot.

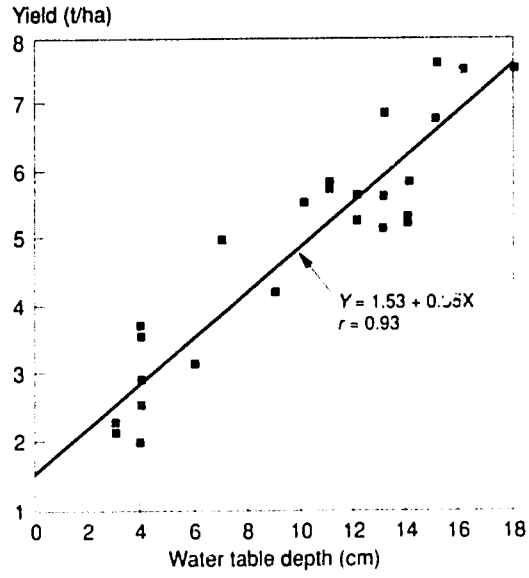
T3. T2 plus one channel in the middle of the plot.

T4. No special water table control up to the end of the vegetative phase and then same as T3, except that the channels were 20 cm deep.

T5. No special water table control throughout the season.

Each channel had a nearly rectangular cross-section and was 30 cm wide, constructed by use of a country plow and shaped manually after completion of land preparation. These channels were connected to the existing drainage ditches of the rice irrigation system. Hybrid yellow maize (variety: SMC 305) was grown on rows with 160-40-40 kg NPK/ha. No irrigation water was applied for any of the treatment areas. Irrigated rice was grown on three sides of the maize plots.

The average water table depths during the vegetative phase of the crop were 15, 13, 12, 5, and 5 cm for T1, T2, T3, T4, and T5, respectively. In each plot, the water table depth was higher in the middle than at the sides, and the average plant height at the vegetative phase was highest in the middle and gradually reduced toward the sides. This indicated that water interception role of the treatments was effective and that plants at the sides suffered more from lack of aeration due to shallower water tables.



21. Correlation between water table depth and yield for maize grown in Lower Talavera River Irrigation System area, Philippines, 1990 DS.

For each cm lowering of the water table, there was a yield increase of 0.35 t/ha (Fig. 21). Treatment T1 was superior to the others in all respects: lowering of water table, plant height, rooting depth, and crop yield. T2, T3, T4, and T5 (control) had similar effects on the above variables. There was no sign of water stress in any crop plot, indicating that the subirrigation phenomenon worked adequately for supply of water to the root zone.

T1 yielded a gross margin that was about 45% higher than that of T2 or T3 and more than twice that of T4 or T5. T1 water table control produced 26% higher gross margin than that from irrigated rice grown in adjacent areas on the same farm (Table 26). The results indicate the possibility of growing non-rice crops in DS on high water table areas by use of temporary drainage-cum-interceptor ditches and of achieving higher economic returns than that possible from rice.

Tillage and water-lifting equipment for increasing riceland productivity

Hydrotillers for wetland preparation. For the past 2 yr, the IRRI Hydrotiller, a floating power tiller for wetland preparation, has seen increasing acceptance by manufacturers (9 in the Philippines, 1 in Indonesia, 2 in Vietnam, and 1 in India). The original machine (1-m working width and 7.5 kW engine size) has proven itself capable of puddling, leveling, weed control, and green manure incorporation. In well-managed fields, two passes are sufficient for irrigated conditions. For very small parcels, terraces, or areas of tall levees, and for research trial plots, there has been a need for a smaller hydrotiller of lighter weight that can be carried by just two people. Two smaller hydrotillers (mini and micro hydrotillers) were accordingly designed and developed. They use similar power train, with V-belt drive through final chain and sprockets to the rotor, as on the regular hydrotiller. However, the density of residues or green manure that can be incorporated is less.

Both designs puddle the soil in a similar fashion as the 1-m hydrotiller does on wetlands and waterlogged areas. They have dual and adjustable pontoons that leave no trails, thereby saving additional leveling costs and other operations.

The mini and micro hydrotillers have these features and specifications:

	Mini	*Micro*
Working width (cm)	80	60
Weight without engine (kg)	51	48
Length (cm)	150	145
Height (cm)	85	75
Recommended power, hp	5.0	3.5

(Purchaser advised to select engine with half-speed drive shaft, e.g. 1800 rpm camshaft drive.)

Average field capacity for 8-h day:

First pass (single pass)	1.28 ha	0.9 ha
Second pass (single pass)	1.69 ha	

Table 26. Costs and returns from maize under different levels of water table control as compared to rice, LTRIS, Nueva Ecija, Philippines, 1990 DS.

Treatment	Yield (t/ha)	Channel construction ($/ha)	Total value of output ($/ha)	Total cost of production ($/ha)	Gross margin ($/ha)
T1	7.3	40.8	1488	499	948
T2	5.5	16.3	1106	446	644
T3	5.6	24.5	1126	449	653
T4	3.5	1.6	712	391	320
T5	3.3	-	672	385	287
Rice	6.2	-	1256	501	755

Field evaluation of IRRI Hydrotiller designs. An estimated 3,000 regular Hydrotillers are currently at work in the Philippines. Design improvements continue and one of the recommendations is that manufacturers install the more recently available engines with half-speed drive shafts for cheaper and yet more durable belt-drive configurations.

To make more precise recommendations, we assessed actual power demand using an on-board dynamometer and data reduction equipment at different puddling speeds and blade angles of the cagewheels. The following are our findings:

1. The optimum axle speed was 243 rpm.
2. At lower axle speeds, less power input was required but puddling results were less satisfactory, and multiple passes were required.
3. Higher axle speed required higher horsepower, which was wasteful and did not meet optimum puddling quality criteria.
4. The normal maximum power requirement under ideal soil conditions at 243 rpm was 5.06 kW for the 1-m Hydrotiller;
5. Power requirement was affected by cagewheel blade angle, in which "flatter" approach angles (<25°) produced more effective puddling but required higher input power. Optimal angle is considered to be 15° backward from the radial configuration.

The IRRI twin-furrow plow

Land preparation with the traditional carabao-plow is time-consuming and laborious—it takes more than 65 km of walking behind the draft animal to plow a hectare.

We built several prototypes, the key feature of which is the thin share, moldboard shape, and attention to depth control, to keep the draft effort within reasonable limits and the capacity of a single carabao.

Field tests were conducted in several locations to evaluate the plow on different soil types and conditions: on clay to clay-loam soils, with short to long stubble, and in weedy fields. Results showed that one of the prototypes performs well: it is lightweight and easy to operate, and produces more uniform depth and plowing finish. The average draft requirement is 67.9 kg, which is about 18% higher than for the traditional single-furrow plow.

Twin-furrow plow specifications. The twin-furrow plow is an animal-drawn moldboard plow consisting of two 3-mm-thick stainless steel bottoms. The moldboard shape has been modified for low draft and the two moldboards are mounted on a common beam. A 30-cm tandem spacing was sufficient for good trash clearance. Other specifications for the plow are

All-up weight of plow	10 kg
Average draft requirement (typical conditions)	67.9 kg
Width of cut	32 cm
Depth of cut	8-10 cm
Capacity	Twice the capacity of the traditional plow and within the comfortable range of a single average carabao
Specific draft	0.27 kg/cm^2

Management of direct seeded rice

Direct seeded rice (DSR) continues to expand in area and importance in South and Southeast Asia, where farmers are mostly concerned about lowering the cost of rice production through labor-saving technology in a falling rice price scenario. The additional knowledge we gained in 1990 may help resolve some problems in this production system.

Effect of soil management practices on germination and stand establishment in DSR

A series of greenhouse and phytotron experiments was conducted to evaluate some of the production practices that affect germination and stand establishment of direct seeded flooded rice.

Varietal screening. Twenty seeds each of indica and japonica varieties—10 seeds/box—were sown in Maahas clay soil (Andaqueptic Haplaquoll). The soil was maintained at saturation. There were distinct varietal differences in the germination percentage of IR5, IR42, IR47, IR54, IR64, and IR74, which had at least 95% germination prior to straw incorporation. With straw incorporation, however, germination dropped to 32% in some varieties.

Water and straw management. Greenhouse and phytotron studies were carried out using a japonica variety Donjin Byeo and indica rice IR42 on the main plots, with and without rice straw as subplots,

at water depths of saturation, and 2, 4, and 6 cm as sub-subplots. Phytotron studies were carried out at 21/26 °C night/day temperature. Seedling establishment rate, highest under saturated conditions, decreased progressively up to 6-cm water depth. Shoot weight, dry matter, and chlorophyll content decreased with increased water depth.

Straw incorporation into different soils. IR42 and Donjin Byeo were grown on three soils: Maahas clay, a saline soil, and a red uncultivated soil from Caliraya, Philippines. Water depths were maintained at 4 to 6 cm throughout the experiment. Table 27 shows dissolved oxygen levels as affected by straw incorporation. Dissolved oxygen content and shoot weight were inversely correlated with water depth.

Land and water management requirements of direct seeded rice

In 1989-90 DS, we conducted a study in the Upper Pampanga River Integrated Irrigation System (UPRIIS), the premier irrigation facility in the rice bowl of the Philippines, to determine the differential hydrologic and land management requirements associated with the shift from transplanted rice (TPR) to DSR, and farmers' reasons for that shift. The survey involved 141 farmers from three areas: area dominated by DSR, area dominated by TPR, and area with a nearly equal mixture of the two. A field experiment in the Central Luzon State University experimental farm, which is part of UPRIIS, sought to establish a comparative performance profile of DSR and TPR under various water regimes.

Table 27. Change in dissolved oxygen (O_2) concentrations of the standing water during seedling growth.

Treatment		O_2 (ppm) after sowing		
Straw	Water level	1 wk	2 wk	3 wk
		Japonica Donjin Byeo		
With	Saturation	5.0	6.5	6.2
	2.0	3.1	5.9	5.7
	4.0	2.9	5.1	5.4
	6.0	2.4	5.2	4.6
Without	Saturation	5.1	6.4	6.1
	2.0	3.0	5.8	5.5
	4.0	2.5	5.5	5.3
	6.0	2.3	5.0	5.0
		Indica IR42		
With	Saturation	5.3	6.5	6.2
	2.0	3.5	5.9	5.6
	4.0	3.0	5.6	4.8
	6.0	2.6	4.9	4.3
Without	Saturation	4.4	6.7	6.4
	2.0	3.4	6.3	5.9
	4.0	3.2	5.7	5.1
	6.0	2.6	5.2	4.6

Ninety-three percent of farmers considered the capacity of the land to control water as the most essential prerequisite to successful direct seeded rice culture. All farmers considered submergence from excess water at the crop establishment period—when the seeds are sown or when plants are still very young—as the most acute problem to guard against in shifting from TPR to DSR. About 80% used additional drainage channels within the farm plots to drain excess water quickly. Undulating and unleveled lands were considered unsuitable for DSR because such lands trap water and prevent the germination of seeds sown. About 95% of the farmers practiced for DSR an additional land leveling operation beyond the normal for TPR. They also gave DSR extra supervision in the first 15 d after seeding to ensure a subsaturated soil condition for better rooting and to protect the seedlings from submergence in excess water and from rats and birds. After that period, water management practices were practically the same for DSR and TPR areas.

All farmers cultivating DSR believed yields were higher than those of TPR in conditions of water shortage.

Differential productivity and profitability

Farmers used higher levels of chemical fertilizer for DSR than for TPR. DSR farms yielded an average 5.4 t/ha, or 0.3 t/ha higher than the average TPR yield. Labor for each hectare averaged 1.8 man-d for DSR and 25 man-d for TPR. On the average a farmer practicing DSR culture achieved an extra net return of $110/ha. About 55% of that gain was from savings in labor cost for transplanting; the remainder was mostly from the yield difference.

Differential response to water management regimes

A completely randomized, split-plot experiment with 4 replications was conducted with DSR and TPR in main plots, and 4 water regimes in subplots 10 × 5 m in size. The water management regimes, maintained from crop establishment to the terminal drainage before harvest, were continuous standing water 5-7 cm deep (W1); saturated soil, which required 2-cm water applied every other day (W2); water regime between saturation and field capacity, which re-

quired 2-cm water at 4-d intervals (W3); and reirrigation with 5-cm water when cracks appeared in the soil, which required water application at 7-d intervals (W4). Land preparation was the standard puddling practice, which used 275 mm water. The soil in the crop root zone was silty clay loam. IR72 rice variety was grown in all plots with 120-60-60 kg NPK/ha and standard crop protection measures. TPR plots used 31-d-old seedlings.

For all water regimes combined, DSR produced a significantly higher yield than TPR, but for individual water regimes the differences were not statistically significant. DSR produced 1.2 t/ha (or 29% higher yield) under moderate water-short conditions of regime W3. The yield difference narrowed down to 530 kg/ha (or 17%) in the severely water-short condition of W4. With continuous standing water or saturated conditions, DSR and TPR yields did not significantly differ.

Water regime W4 used more water than did W3, because in W4, cracks developed in the soil before each irrigation application, and thus average percolation loss was higher. We conclude that the intermittent irrigation practice must prevent soil cracking. Both DSR and TPR used about equal amounts of water under water regime W1. In W2, DSR had a water-saving of 18% and TPR 14% compared with W1 (Table 28). Greater savings could be achieved in W2 if water was applied at 1-d intervals to keep the soil saturated.

Ammonia volatilization as affected by planting method

Because of labor shortage, direct seeding is more likely to be widely practiced. However, weeding is difficult in DSR; hence, IRRI engineers developed a drum seeder to mechanize direct seeding as well as to provide rows for the mechanical weeder to pass through.

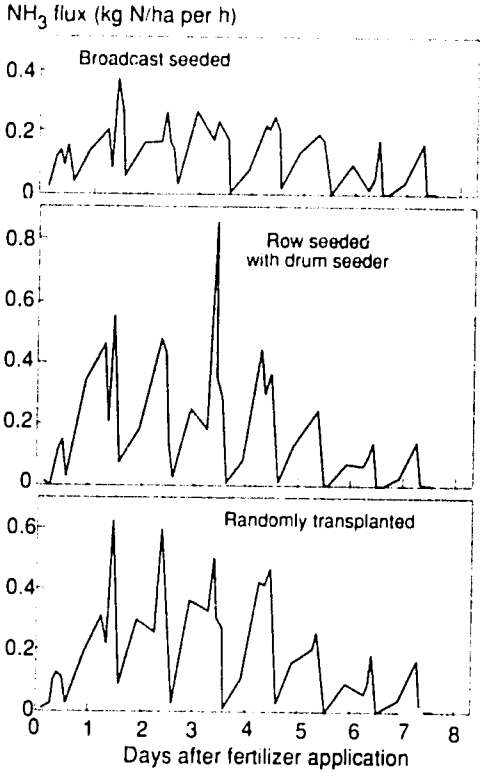
A field experiment in Victoria, Laguna, compared the ammonia (NH_3) volatilization loss from broadcast seeded flooded rice (BSFR), rice row seeded with drum seeder, and randomly TPR. The mass balance micrometeorological technique was used to measure NH_3 volatilization loss. BSFR hinders wind passage because of its scattered architecture. This explains the lower NH_3 volatilization loss in BSFR than in TPR when N fertilizer was applied 21 DAS in BSFR and 11 d after transplanting (DT) in TPR.

Table 28. Total water[a] required in the experimental plots for direct seeded and transplanted methods of rice cultivation, 1989-90 DS.

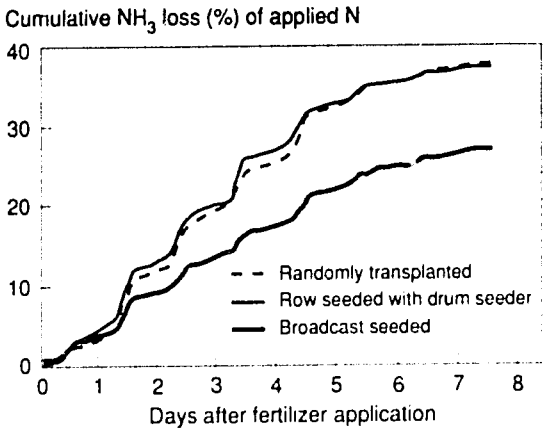
Water regime	Water requirement[b] (mm)			
	Direct seeded	Transplanted	Difference	Mean
W1	1303 a	1255 a	48**	1279 a
W2	1068 b	1042 b	26 ns	1055 b
W3	713 d	725 d	−12 ns	719 d
W4	993 c	1015 c	−22 ns	1004 c
Mean	1019	1009	10	1014

[a]Includes 275 mm water used in land preparation. [b]In a column, means followed by a common letter are not significantly different at the 1% level of LSD. ** = significantly different at 1% level by LSD, ns = not significant.

Fluxes of NH_3 from BSFR was 0.4 kg/ha per h 2 d after fertilizer application and remained between 0.2 and 0.3 kg/ha per h up to 7 d (Fig. 22). With randomly TPR, NH_3 flux of about 0.6 kg/ha per h was measured 2 d after N fertilizer application and remained high up to 4 d. With BSFR, highest NH_3 flux was 0.8 kg/ha per h, 3 d after fertilizer application (0.5-0.6 kg/ha per h on the first 2 d).



22. Ammonia fluxes from urea applied to broadcast seeded, drum seeded, and random planted IR72 in circular plots. Victoria, Laguna, Philippines, 1990 DS.



23. Cumulative NH_3 loss from urea applied to broadcast seeded, drum seeded, and random planted IR72 in circular plots. Victoria, Laguna, Philippines, 1990 DS.

Cumulative NH_3 losses from row-seeded rice and TPR (38%) were similar and higher than that from BSFR (27%) (Fig. 23). Grain yields of randomly TPR and BSFR IR72 were also higher than that of row-seeded rice with N fertilizer topdressed at 21 DAS or 11 DT (Table 29). However, with 2/3 basal and incorporated + 1/3 at 7 d before panicle initiation, all planting methods gave similar grain yields, which were superior to those with N topdressed at 21 DAS or 11 DT.

Results suggest that randomly TPR plays a role similar to that of BSFR rice in reducing N loss through NH_3 volatilization. BSFR has the added advantage of labor savings.

Nitrogen management and plant type for puddled row-seeded rice

A field experiment during 1990 DS followed up our initial findings that multiple split applications of 150 kg N/ha for DSR gave substantially higher grain yields than the same amount of N applied basally. A total of 150 kg N/ha was variously applied in 2, 4, and 6 splits to a high-tillering cultivar, IR58, and a relatively low-tillering line, IR25588-7-3-1, direct seeded in rows at the rate of 100 kg seeds/ha.

Grain yield was highest when one-half of N was applied basally and the other half split into three applications at later stages of growth (Table 30). The yield advantage from multiple split applications—more than 1 t/ha over all basal or 2 split applications of N—was due mainly to more spikelets per panicle and higher percentage of filled spikelets.

Comparison of 75-0-0-40-25-10 with 25-25-25-40-25-10, which differed in N management during the vegetative stages but not during the reproductive stages, indicates that splitting of 75 kg N/ha during the vegetative stages did not result in grain yield increase over the same amount applied basally. Comparison of 75-0-0-40-25-10 and 75-0-0-25-40-10 indicated that an alternative split N management during the reproductive phase did not have a significant effect on grain yield.

As in the previous experiment, low-tillering IR25588-7-3-1 gave higher grain yield than IR58. IR58 grain yield was more dependent on panicles/m^2, while spikelets per panicle were more important in IR25588-7-3-1 (Table 30). In low-tillering cultivars, grain yield is largely from early tillers—mostly primary and some secondary—which produce relatively larger and heavier panicles. But in high-tillering cultivars, a large number of secondary and tertiary tillers with small panicles contribute to grain yield. Results show that low-tillering cultivars and multiple split applications of N would be more appropriate for flooded, row-seeded rice.

Table 29. Grain yield of IR72 as affected by planting method. Victoria, Laguna, Philippines, 1990 DS.

N (kg/ha) timing[a]				Grain yield (t/ha)			
B&I	21 DAS or 11 DT	7 DBPI	API	Broadcast seeded flooded rice	Rice row seeded with drum seeder	Randomly transplanted rice	Transplanted rice
0	0	0	0	4.4	4.3	5.3	4.7
-	53	-	27	7.2	6.1	7.2	7.0
53	-	27	-	8.0	8.2	7.9	7.9
LSD (0.05)					0.6		
-	53[b]	-	27	7.6	6.9	7.4	

[a]B&I = basal and incorporated in saturated soil, DAS = days after seeding, DT = days after transplanting, DBPI = days before panicle initiation, API = after panicle initiation [b]In circular plot.

Table 30. Main effects of N management and variety on grain yield and yield components. IRRI, 1990 DS.

N management (kg N/ha) at different DAS[a]	Grain yield (t/ha)	Spikelets/ m^2 (x 10^3)	Panicles/m^2	Spikelets/ panicle	Filled spikelets (%)	1000-grain wt (g)
None	2.4 e	15.9 c	371 b	44 d	89 a	23.4 ab
150-0-0-0-0-0	5.2 bcd	31.3 b	533 a	59 c	87 ab	24.1 a
50-0-0-100-0-0	5.4 bcd	36.2 ab	560 a	66 abc	77 c	22.6 bc
75-0-0-75-0-0	4.9 d	39.4 a	564 a	71 ab	79 c	22.1 c
100-0-0-50-0-0	5.2 cd	36.8 ab	564 a	65 bc	80 c	23.0 bc
75-0-0-40-25-10	6.0 ab	37.0 ab	514 a	73 a	79 c	22.9 bc
75-0-0-25-40-10	6.3 a	37.0 ab	509 a	73 a	85 b	23.1 b
25-25-25-40-25-10	5.7 abc	35.7 ab	520 a	70 ab	84 b	22.5 bc
SE	0.3	2.8	31.2	3.2	1.8	0.4
CV (%)	13.1	16.8	12.1	10.2	4.5	3.4
Variety						
IR25588-7-3-1	5.4**	33.5	464	71**	81	23.4**
IR58	4.9	33.9	570**	59	84*	22.5
LSD	0.4	ns	45	5	2.4	0.4
CV (%)	12.0	13.6	12.6	10.6	5.7	2.4

[a]Basal - 14-28-42-56 DAS - heading.

Grain density, seedling quality, and crop establishment

In DSR, seed quality is very important since seedling selection is not possible. Studies were made on the importance of high-density (HD) grains or quality grains on DSR crop establishment.

Ten rice cultivars with known HD grain index were grouped into HD grains (specific gravity of 1.20 and above) and low-density (LD) grains (specific gravity 1.05 to less than 1.20).

- HD grains generally had higher germination percentage and fewer abnormal seedlings than LD grains.
- The electrical conductivity (EC) of seed leachate in LD grains was 60% higher than in HD grains. The low membrane integrity of LD grains might be responsible for the poor vigor and more abnormal seedlings developed.
- Average seed weight was higher in HD grains. Leaf area, leaf weight, mean relative growth rate, and amount of carbohydrate utilization by the seedling were higher in HD than in LD grains in all cultivars.
- Under field conditions, seedlings from HD grains showed better plant growth.
- By using HD grains, seedling growth can be increased by 25 to 50% at a reduced seeding rate. The practice can increase the chances for better crop establishment.

Nitrogen applications timing for control of broadcast seeded flooded rice weeds

During their early growth stages, rice crops and weeds compete for N but because weeds usually grow faster than the rice crop, they absorb greater quantities of available N. To maximize N use efficiency and minimize weed growth, the present approach is to take out weeds and apply N fertilizer. Withholding N application until after the weeds have flowered or when N uptake of weed has virtually slowed down is also a promising technique. Delayed N fertilizer application is effective in BSFR where initial rice plant population is normally high and early N application for tillering purposes may not be needed. Also, weeds flower much earlier than do most rice cultivars. The rice crop could use the N applied during late crop growth stage, for example, at the onset of panicle initiation (F_0) for panicle development and spikelet filling.

Experiments at IRRI in 1990 DS and WS examined the effect of rates and timing of N application on weed competitiveness, N uptake, and grain yield of BSFR. In DS, all of N at 60 or 120 kg/ha was either broadcast and incorporated (B&I) before seeding or topdressed 5 d before panicle initiation (DBPI) on unweeded fields. This treatment was compared with a 120 kg N/ha standard split treatment applied 2/3 B&I + 1/3 at 5 DBPI in weeded fields. Treatments

Table 31. Weed density, panicle density, N uptake, and grain yield of unweeded broadcast seeded flooded IR72 as affected by rate and timing of N application.[a] IRRI, 1990 DS.

N rate (kg/ha) and timing[b]	Weed density[c] (no./m²)	Panicle density (no./m²)	N uptake[d] (%)	Grain yield (t/ha)
No fertilizer N	64 b	416 c	0.81 c	2.3 d
60, B&I	82 b	590 ab	0.86 c	3.4 c
60, 5 DBPI	50 ab	622 ab	1.09 b	4.4 ab
120, B&I	94 b	562 b	0.80 c	3.7 bc
120, 5 DBPI	47 ab	690 a	1.36 a	4.8 a
120, 2/3 B&I + 1/3 at 5 DBPI[e]	8 a	611 ab	1.08 b	4.9 a

[a]Av of 4 replications. [b]B&I = broadcast and incorporated, DBPI = days before panicle initiation. [c]Sampled at harvest. [d]Sampled 70 d after seeding. [e]Standard treatment, weeded.

were laid out in a randomized complete block design with four replications.

In WS, a strip block design with four replications was used with weeding regime (weeded and unweeded) as the vertical factor and N rate (0, 20, 40, 60 kg/ha applied full dose at 5 DBPI, and 60 N at standard 2/3 B&I +1/3 at 5 DBPI) as the horizontal factor.

Tillage level (one plowing + two rototillings), plot size (3 × 5 m), cultivar (IR72), seeding rate (100 kg/ha), N fertilizer (urea), and dominant weeds (*Scirpus maritimus*, *Fimbristylis miliacea*, and *Echinochloa glabrescens*) were common to both experiments. Earthen dikes 30 cm wide separated each treatment. Preplanting N was broadcast into drained, puddled soil and was incorporated during land leveling. On the following day, pregerminated rice seeds, soaked in tap water for about 18 h and incubated in moist gunny bag for around 48 h, were broadcast onto plots. Weeding was done with pretilachlor/fenclorim at 0.3 kg ai/ha applied with a hydraulic knapsack sprayer 3 DAS. Young rice seedlings were protected from golden snails *Pomacea canaliculata* by keeping the plots water saturated during the first 25 DAS. The biological parameters reported here are those consistently responsive to the treatments.

Although natural weed infestation was only moderate, N treatment effects were still evident (Table 31). Weed growth in plots with N B&I or topdressed at 5 DBPI, irrespective of N rate, was less than or comparable with that of the standard N split. N application significantly increased panicle density though the timing of N application did not. N uptake of plants that received 120 kg/ha at 5 DBPI was significantly higher than that of plants in other treatments (Table 31). Standard split of N and the 60 N applied at 5 DBPI gave similar N uptake, which was significantly higher than that with zero N and B&I treatments.

Grain yield significantly increased with timing but not with rate. Doubling N rate within the same application timing did not further increase grain yield. However, yield significantly increased when N application was delayed within the same N rate.

Weed growth did not vary with N rate (Table 32); however, the difference in weed biomass between the weeded and unweeded plots at the same N rate was highly significant, suggesting that weed control was effective. Although the weeds were already somewhere between 10 and 20 d of flowering, and were as stunted and yellowish as the crop at 5 DBPI, they resumed growth and attained full height as did the crop.

The higher the N rate, the higher was N uptake in both weeding regimes. The difference in N uptake between rates was more distinct under unweeded conditions.

Table 32. Weed biomass, N uptake, and grain yield of broadcast seeded flooded IR72 as affected by weeding and rate of N applied at 5 DBPI.[a] IRRI, 1990 WS.

N rate (kg/ha)	Weed biomass[b] (g/m²)			N uptake[c] (%)			Grain yield (t/ha)		
	Weeded	Unweeded	Difference	Weeded	Unweeded	Difference	Weeded	Unweeded	Difference
No fertilizer N	5 a	164 a	−159**	0.82 c	0.70 d	0.12*	2.9 c	2.2 b	0.7*
20	13 a	146 a	−133**	0.88 bc	0.82 c	0.06 ns	3.3 bc	2.7 ab	0.6 ns
40	1 a	132 a	−131**	0.93 b	0.96 b	−0.03 ns	3.8 ab	3.0 a	0.8*
60	4 a	140 a	−136**	1.05 a	1.06 a	−0.01 ns	4.1 a	3.1 a	1.0**
40 B&I + 20 at 5 DBPI[d]	13 a	118 a	−105**	0.84 bc	0.83 c	0.01 ns	3.2 c	2.6 ab	0.6 ns

[a]Av of 4 replications. [b]At harvest. [c]At 70 DAS. [d]Standard 2/3 + 1/3 split.

Grain yield markedly varied with N rate in the weeded plots. But when the weeds were not removed, N rate had no effect on yield.

Results indicate that applying N fertilizer shortly before PI of the rice crop can considerably reduce the N needed by the crop. However, the weeds were apparently still in their active nutrient uptake stage when N was applied in IR72 at around 5 DBPI (50 DAS), hence, the poor weed control. Delaying further the prepanicle initiation N application by planting late-maturing cultivars should improve weed control.

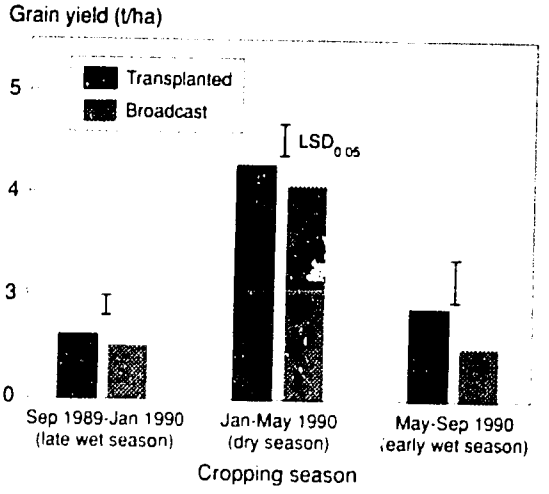
Continuous rice cropping experiment

The continuous rice cropping experiment initiated in 1962 continued up to 1990. It presented an opportunity to evaluate some of the improved IRRI early-maturing varieties and genetic lines, and tested the capacity of the soil to withstand continuous one-crop cultivation under good management. There were some changes in varieties or lines used, but the four levels of N and two crop establishment methods remained the same as in previous years.

A 1-ha field, Blocks B5-8, of the IRRI farm was divided into 4 equal blocks corresponding to 4 replications. Each replication consists of 4 blocks, in which 4 N levels (0, 50, 100, and 150 kg N/ha) in the DS and (0, 30, 60, and 90 kg N/ha) during the early and late WS are assigned. Each block of N level is subdivided into six plots where test varieties or lines are assigned. Each subplot is further subdivided into 2 plots measuring 4 by 12 m for each crop establishment method: transplanted and broadcast seeded.

Nine- to 11-d-old dapog seedlings are used for the transplanted plots. Pregerminated seeds are broadcast seeded at the rate of 80-100 kg seeds/ha. Two-thirds of the recommended N, 13 kg P/ha, and 25 kg K/ha are applied basally and incorporated during the final harrowing. One-third of the recommended N is topdressed 5-7 DBPI. Weed control, insect control, and other cultural practices were at optimum levels. A total of 7 to 10 d is allotted as turnaround time for 3 crops grown during the year.

As in the Jan-May crop of previous years, grain yields were always higher in DS than in WS (Fig. 24) because of favorable climate, sufficient solar radiation, and lower pest incidence. Low yields in early WS (May-Sep crop) were caused primarily by lodging; those in the late WS (Sep-Jan) were due to the high incidence of rat and bird damage and high spikelet sterility.



24. Average yields of transplanted and broadcast seeded rice under 3 cropping seasons in continuous rice cropping experiment. IRRI, 1989-90.

Numerically, TPR yields were higher than those of broadcast seeded rice, but the differences were not significant. In places where labor supply is limited and expensive, broadcast seeding offers an advantage over the more laborious and expensive transplanting.

Summary

This project focused on critical knowledge gaps in different production systems for irrigated rice. Issues such as weed control continued to receive high priority while attention also focused on germination behavior in puddled soil, comparing broadcast seeding with random transplanting for reduced N losses, and improving N management practices through a greater number of fertilizer application splits. Future research will evaluate physiological parameters for higher yield potential with crop, nutrient, water, and pest management dynamics using breeding lines tailored for high yields.

Pest dynamics and management in irrigated rice

Pests are serious constraints to yield in irrigated rice. For the development of sustainable management strategies that will reduce yield losses, knowledge of the pests' dynamics is necessary.

Larval parasitoids of the rice leaffolder

In most cases, rice leaffolder (LF) populations are kept under natural control. Of more than 130 species of parasitoids known to attack rice LF in Asia, the larval parasitoids are most important. In Victoria, Laguna, Philippines, 17 species were found while in Zaragoza, Nueva Ecija, 10 were recorded in 1989 WS. Among them, two braconids, *Cardiochiles philippinensis* and *Macrocentrus philippinensis*, were predominant.

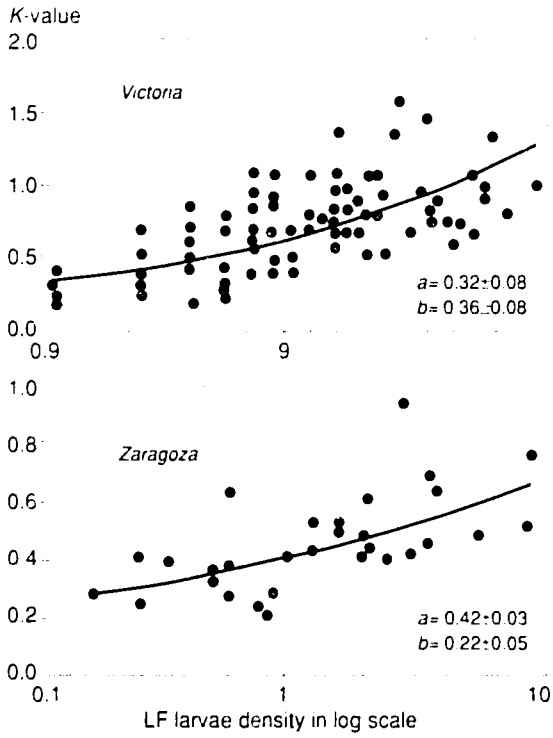
Field samples of 20 hills from 1 m^2 were taken at regular intervals. Mortality due to larval parasitization was expressed as K-value (a measure of killing power) by the function, $K = \log (N/S)$, where N is total larvae collected and S the unparasitized larvae. The relationship between K and larval density fitted well the density dependence model

$$K = aN^b$$

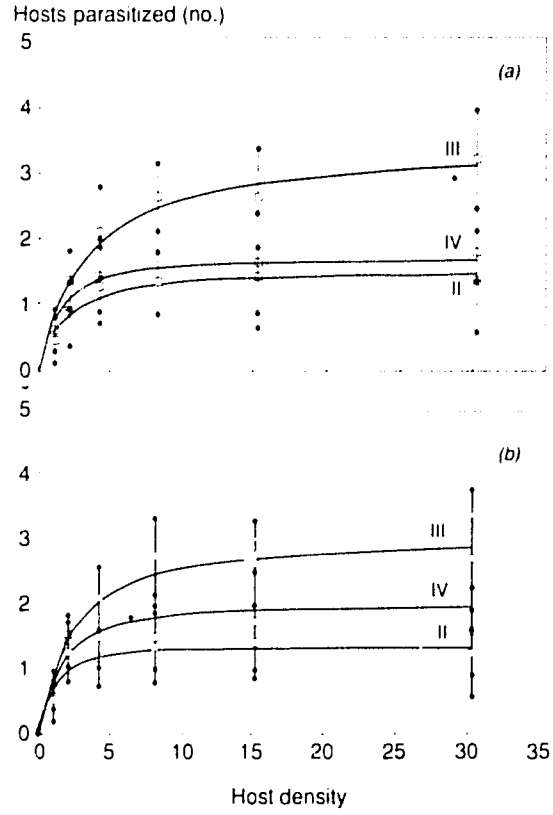
where a and b are constants. The parameter b determines the degree of density dependence. Parasitization is directly density dependent, and slopes were $0<b<1$ (Fig. 25). This implies that larval parasitoids cause dampening of the exponential growth of the LF populations and play an extremely important role in regulating the pests' abundance.

Functional responses of two braconid parasitoids of rice leaffolder larvae. Parasitization rates are affected by host densities and age, parasitoid age, the test arena used, and environmental conditions. The parasitoid's response to host density is often termed *functional response*. Using standard conditions and varying only the character for investigations, comparisons of the searching behavior were made using *C. philippinensis* and *M. philippinensis*.

Test arena sizes did not affect the searching behavior of the two parasitoids. Both the F-test and the nonparametric rank-sums test were not significant. Both parasitoids attacked the third-instar larvae efficiently (Fig. 26). Differences were due primarily to different satiation levels: parasitoids of ages 3 and 4 d were most efficient. In paired comparisons of all cases, the searching behavior of the two parasitoids did not significantly differ.



25. Plots of K value against log density of LF larvae in Victoria, Laguna, and Zaragoza, Nueva Ecija, Philippines. The solid line is the best fit curve of Bellows' model: $K=aN^b$.



26. Functional responses of 2 larval parasitoids of *Cnaphalocrocis medinalis*: *Cardiochiles philippinensis* (a) and *Macrocentrus philippinensis* (b) attacking 3 larval instars (II, III, IV). Means (□) are presented with SEs at 95% confidence.

Spatial and temporal dynamics of tungro

We are using a geographical information system and a historical data base from the Department of Agriculture to plot the occurrence of tungro (RTD) in the Philippines. Sultan Kudarat Province in Region 12, where the disease is known to be endemic, was used as a pilot site for technique development.

A total of 354 (65%) RTD observations were recorded from 1983 to 1986 in 31 barangays in 6 municipalities. The major cultivars planted were IR36, IR46, IR56, IR60, IR62, IR64 including a locally named Index 22. A number of local and unknown cultivars were included. RTD incidence was observed during the entire period but was lower during the 1983-84 DS and 1984 WS croppings. In most cases, relatively high numbers of GLH were collected per 10 sweeps in major cultivars like IR36 and IR64, which also recorded high RTD infection. More RTD observations were made during the vegetative phase than during the reproductive phase. Few infected plants were observed in the ratooned crop.

Biological control of bakanae disease by antagonistic bacteria

Bakanae or root rot of rice has gained economic importance because of the commercial cultivation of susceptible varieties. The pathogen *Fusarium moniliforme* is seedborne and soilborne. Under favorable conditions, infected plants have the capacity to produce numerous conidia that subsequently infect proximate healthy plants. The disease can be controlled by chemical seed treatment and use of resistant cultivars. Breeding for resistance is top priority among all national rice improvement programs. Efforts will have to be made to understand the races or strains of *F. moniliforme*. There are economic and technical constraints in the use of fungicides. As bakanae is transmitted primarily through seedborne inoculum, seed treatment with antagonistic bacteria as an integral part of disease management appears feasible.

Out of 441 isolates, 113 inhibited mycelial growth in *F. moniliforme*. The bacteria inhibited the conidial germination of the pathogen. The pH of aerated liquid cultures of antagonistic bacteria changed after 1 and 7 d of incubation (Table 33).

In an experiment to determine the interactions of 20 *Fusarium* isolates and 17 isolates of antagonistic bacteria, 3 isolates were effective against 5 isolates of *Fusarium* whereas the others were isolate specific (Table 34). When the two isolates of bacteria from Nueva Ecija were tested against *Fusarium* isolates from different locations, these were effective only against *Fusarium* isolates from Nueva Ecija, Laguna, and Leyte (Table 35). Bacterial isolates In-b-714 and In-b-715 were effective against 2 of 12 *Fusarium* isolates from Laguna.

Distribution and characteristics of soils suppressive to sheath blight

Soils from ricefields of IRRI, Cavite, Albay, Camarines Sur, Legaspi, Laguna, and six other locations in the Philippines were air-dried, powdered, and sieved through a 2-mm sieve. The method of Ko and Ho (1983) was followed in determining the suppressiveness of the soils.

Isolates of bacteria from healthy plants (lowland, source 4) and rhizosphere of healthy plants (source 8) afforded higher sheath blight (ShB) protection (maximum 75.9 and 76%, respectively) than those

Table 33. Effect of 1-d and 7-d-old liquid cultures of antagonistic bacteria on conidial germination of *Fusarium moniliforme* and on pH of aerated liquid cultures.

Bacterial isolates	Conidial germination (%)		pH of liquid cultures	
	1 d	7 d	1 d	7 d
In-b-714	0	0	6.6	7.7
In-b-784	1.7	0	6.7	7.3
In-b-178	7.3	0	6.8	7.8
In-b-722	8.3	2.7	6.6	7.6
In-b-715	9.3	4.4	6.6	7.7
In-b-150	10.0	0	6.4	7.5
In-b-17	22.3	0	6.6	8.2
In-b-33	57.3	0.17	6.6	8.2
In-b-520	23.3	1.4	6.6	7.6
In-b-442	11.0	0.9	6.7	7.7
Check	90	90	6.1	6.1

Table 34. Bakanae incidence in relation to isolates of *Fusarium*[a] and isolates of antagonistic bacteria applied as seed treatment.

Isolates of bacteria	Bakanae incidence (%)				
	F-2	F-13	F-27	F-22	F-19
In-b-521	1.7 a	4.0 a	12.7 ab	5.0 ab	2.7 a
In-b-442	3.0 a	4.7 a	8.3 a	3.7 a	3.0 a
In-b-527	4.7 a	6.3 a	8.7 a	1.3 a	2.0 a
In-b-715	18.0 b	18.0 abc	29.7 c	16.7 bcd	18.0 b
In-b-33	24.3 bc	32.0 cde	64.0 fg	51.3 fgh	50.0 de
In-b-520	25.3 bc	25.0 b-e	36.7 cd	19.3 cd	28.0 dc
In-b-714	33.7 cde	19.7 a-d	24.3 bc	10.0 abc	23.3 b
In-b-178	31.7 cde	35.3 de	60.7 efg	52.3 h	49.3 de
In-b-837	27.0 bcd	14.7 ab	30.0 c	26.7 de	22.7 b
Check	30.7 cd	31.7 cde	58.7 ef	40.0 fgh	26.7 bc

[a]*Fusarium* isolates: F-2 from Cavite, F-13 from Leyte, F-27 from Nueva Ecija, F-22 from Laguna, and F-19 from Bicol.

Table 35. Bakanae incidence in IR58 infected with *Fusarium* isolates and bacterized with antagonistic bacteria isolated from rice plants in Nueva Ecija.

Fusarium isolates	Bakanae incidence (%)		
	In-b-714	In-b-715	Check
F-2 (Cavite)	33.67	18.00*	30.67
F-19 (Bicol)	23.33	18.00	26.67
F-13 (Leyte)	19.67*	18.00*	31.67
F-14 (Laguna)	23.33	23.00	32.00
F-21 (Bicol)	17.33	12.33	21.67
F-22 (Laguna)	10.00**	16.67**	40.00
F-27 (Nueva Ecija)	24.33**	29.67**	58.67

*LSD (0.05) = 10.87 **LSD (0.01) = 14.41

from other sources (Table 36). Regression and correlation analysis between inhibition zone and percent ShB protection confirmed that isolates from healthy plants grown in the lowlands gave higher biological control of ShB.

In a survey to determine the distribution of suppressive soils, 45% of the 104 soil samples collected from various localities in the Philippines were suppressive to *R. solani* (Table 37). The results showed that suppressive soils are widely distributed in the Philippines. The linear growth of *R. solani* on the suppressive soil was about 50% or less of that in conducive soils (Table 38). About 32.3% of the 65

Table 36. Sheath blight protection afforded by 10 promising isolates from different sources.[a] IRRI.

Rank of isolates	Protection[b] (%)								
	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7	Source 8	Source 9
1	42.92**	64.75**	69.23**	75.90**	69.57**	64.63**	73.31**	76.07**	50.35**
2	38.48**	43.37**	58.07**	49.14**	68.22**	61.89**	70.02**	56.77**	47.65**
3	36.98**	39.94**	36.85**	39.59**	40.07**	60.36**	53.28**	51.91**	42.26**
4	34.29**	36.97**	30.49**	38.73**	38.20**	57.11**	43.89**	43.43**	41.01**
5	27.65**	36.97**	22.04**	37.39**	36.97**	46.74**	42.69**	41.47**	39.21*
6	23.91**	34.78**	19.07**	35.94**	36.63**	43.78**	42.36**	41.47**	35.77*
7	19.76**	33.78**	12.93**	35.76**	32.47**	43.33**	38.18**	37.98**	34.98*
8	16.15*	31.36**	0.77ns	34.65**	27.15**	43.08**	34.01**	37.75**	29.04ns
9	16.01*	30.82**	0.00ns	33.15*	25.12**	41.83**	31.88**	37.64**	29.41ns
10	14.70*	30.26*		30.21*	24.58**	39.93**	30.75**	37.39**	29.06ns
LSD (0.01)	19.18	15.48	11.38	33.60	10.93	10.37	17.09	10.67	40.93
LSD (0.05)	14.47	11.60	8.43	25.37	8.18	7.80	12.83	8.05	30.89

[a]Source 1 = paddy water (43 isolates), source 2 = infected plant lowland (24 isolates), source 3 = infected plant upland (15 isolates), source 4 = healthy plant lowland (45 isolates), source 5 = healthy plant upland (22 isolates), source 6 = sclerotia lowland (29 isolates), source 7 = sclerotia upland (27 isolates), source 8 = rhizosphere soil of healthy plant (44 isolates), source 9 = rhizosphere soil of infected plant (44 isolates). [b]Significant at the 1% (**) and 5% (*) levels by LSD; ns = not significant.

Table 37. Distribution of soils suppressive of and conducive to *Rhizoctonia solani* in the Philippines.

Location	Total (no.)	Suppressive (no.)	Conducive (no.)
IRRI	65	21	44
Cavite	8	5	3
Albay	6	6	0
Camarines Sur	6	5	1
Legaspi City	2	2	0
Laguna	3	1	2
Victoria	3	2	1
Pagsanjan	1	1	0
Santa Cruz	1	0	1
Camarines Norte	1	0	1
Bay	1	0	1
Calauan	1	0	1
Masiit	1	0	1
Total no.	99	43	56

Table 38. Total bacterial population and mycelial length of *Rhizoctonia solani* in suppressive and conducive soils.

Soil origin	Soil type[a]	Bacterial population (CFU x 10^8/g soil)	Mycelial length (mm/d)
26	S	75.00	2.97 a
N8	S	6.40	7.10 abc
36	S	8.60	6.13 ab
33	S	280.00	6.50 abc
06	S	25.00	5.77 ab
18	C	1200.00	21.03 def
28	C	267.00	22.27 def
23	C	74.00	20.77 de
31	C	0.12	13.93 d
01	C	64.00	64.33 e

[a]S = suppressive soil, C = conducive soil.

soil samples at IRRI were suppressive to *R. solani*. At Camarines Sur, five of six samples were suppressive to *R. solani*. When compared with conducive soils at the same inoculum density in pot experiments, suppressive soil was suppressive to rice ShB. Suppressiveness could be nullified by sterilization and restored by reinfestation with 20% suppressive soils.

Future plans

Predators, parasitoids, and antagonists are important natural resources in irrigated rice ecosystems as they keep pest species well below injury levels. A study of the ecological and management factors that can enhance their roles will lead to the design of effective and sustainable pest management strategies. Research in this area will be pursued with particular attention to natural enemy dynamics, movements, and the effects of cultivation practices on natural balance.

Ecological studies of insect vectors of rice virus diseases will provide better understanding of the distribution, spread, and epidemics of RTD. The potentials of antagonistic bacteria for biological control of rice diseases will be further investigated. The distribution of nematodes and their effects on rice yields will also be studied.

Integrated pest management

Strategy for control of chronic insects

Insect-resistant rices are targeted against epidemic pests such as planthoppers and leafhoppers that vector virus diseases. Chronic stem borer (SB) and defoliator pests are managed by corrective action when their populations reach economic threshold levels. In spite of decades of experience using insecticides in rice, farmers find it difficult to master chemical control technology. Reasons range from failure to diagnose pest incidence, choice of inappropriate chemicals, and underdosage. Crop cuts over three seasons—1989 WS, 1990 DS, and 1990 WS—in Zaragoza, Nueva Ecija, compared the yield from 15 farmer-managed, insecticide-protected and untreated plots in the same bunded fields. The farmers' plots were sprayed an average of 1.9 ± 1.2 times per crop (range 0-4 times) and averaged 4.2 t/ha which is no different from the yield in 100-m^2 untreated check plots within the same bunded field. Yield loss from insect pest damage was calculated as 7% or 0.3 t/ha per crop, averaged over the 3 cropping seasons. Farmers were unable to prevent this yield loss using insecticides.

A new strategy is emerging based on crop management practices designed to increase crop tolerance through either preventive or corrective measures. Determining an appropriate maturity class and seeding rate are preventive actions whereas application of supplemental fertilizer when an economic threshold is reached is a corrective action. Additional fertilizer to an attacked crop may give timely energy to outgrow insect damage. Research is needed to determine a suitable blend of crop husbandry practices by location and season.

In Zaragoza, we tested medium-duration (IR74) and very early short-duration (IR58) rices at varying seeding rates. From earlier work it was hypothesized that varieties of longer duration would be able to compensate for insect damage. It was also hypothesized that a higher seeding rate (9 vs 3 seedlings/hill)

practiced by farmers in the area would strengthen crop tolerance because of greater tiller number. Insect pest densities were monitored and yields were compared of plots treated with either insecticide or 20 kg N/ha when the economic threshold level was reached. Yield loss was measured as the difference between plots protected by a blanket insecticide regime and an untreated check. IR74 was planted 2 wk ahead of IR58 to harvest both varieties under the same environmental conditions.

The crop was heavily damaged by whorl maggot (RWM) *Hydrellia philippina*, which produced 40% damaged leaves in IR58 and 29% in IR74. Green hairy caterpillar *Rivula atimeta* defoliated 8-14% of leaves concurrently with RWM. Other insect pests were at low levels. SB deadhearts were less than 1% and whiteheads reached only 2%. Leaffolder damaged at most 6% of leaves.

Yield loss was 0.8 t/ha in IR58 (5.1 vs 4.3 t/ha) and an insignificant 0.2 t/ha in IR74 (5.2 vs 5.0 t/ha), indicating greater tolerance of IR74 for vegetative phase insect damage. Seedling density had no effect on yield. The yields averaged 4.8 and 4.7 t/ha, respectively, for 3 and 9 seedlings/hill.

Triazophos, sprayed once when the economic threshold of 1 RWM egg was reached, produced no yield response in IR58 and was unnecessary in IR74. RWM is difficult to control with insecticide, particularly in the rainy season. Applying N in response to RWM threshold did not benefit IR58 and caused IR74 to lodge. Vegetative phase insect damage in WS could be tolerated by simply growing a medium-duration variety. These results need to be verified.

Long-duration plants have more time to outgrow SB damage; on the other hand, they are susceptible for a longer time. Deadhearts from YSB were over three times as high (22 vs 7%) in a 130-d variety (IR70) than in a 110-d variety (IR72). The vegetative phase is prolonged in long-duration cultivars, and stem elongation occurs over a longer period. In a 110-d cultivar, the crop was most susceptible 1-3 wk after transplanting (WT), whereas in the 130-d cultivar the period was extended 2 more weeks. Whiteheads (11 vs 14%) were caused by infestation at 8-9 WT in the 110-d cultivar and 13-14 WT in the 130-d cultivar.

The rice plant is most susceptible to SB during tiller elongation and panicle exsertion. The silica in the tissues of the tillers becomes concentrated when the plant is not elongating and provides protection against first-instar SB larvae trying to tunnel their way into the plant. A longer period for penetration means greater vulnerability to natural enemies. During tiller or panicle elongation, silica density decreases and more larvae are able to penetrate successfully. For the same reason, tall cultivars are more susceptible to SB than are short-statured types. Deepwater rice, which elongates over the greatest period, is the most susceptible to SB. An ideal growth duration for irrigated plant types is between 110 and 130 d to allow optimal compensation and shortest exposure to SB.

Engineering pest control

Pest control research along two lines has been undertaken to improve profitability of sustainable rice farming systems.

Physical (nonchemical) pest control techniques

Passive rodent barriers. Electric fencing has been and continues to be the principal means of controlling rodents around IRRI trial areas. Despite a substantial work force, however, effectiveness is not high. Hence, Agricultural Engineering Division staff are in the process of developing low-cost, low-labor designs for controlling damage. Passive barrier designs are being evaluated, based on initial work using a rodent enclosure. The shape and height of barriers were evaluated to determine what type of passive barrier would keep rodents out of rice without requiring human intervention, poison-baiting, or electrification. Rodent behavior at night was also studied with red light illumination (which caused the least distraction) and the use of video recordings. It was concluded that the structural integrity of fences must be of extremely high standard; otherwise, rodents will find ways through or over since they are extremely adept at jumping and climbing, and chicken wire facilitates their movement.

Field experiments on effectiveness of passive barriers. Four passive rat barrier configurations were compared with a nonfenced treatment during 1990 WS at IRRI Field F2. Preliminary analysis of the proportion of damaged hills on 511 rice hills adjacent to the treatment plots showed > 80% damage alongside fenced plots and 37% alongside nonfenced plots.

Evidence suggests that rats preferred the aromatic rice (841) inside the plots—95-100% damaged—compared with 37% in nonaromatic IR74 adjacent to the plots.

There was no variation in the performance of the four rat barriers. Testing will continue during the Experimental Farm's "closed season" when rat pressure is expected to be high.

"Active Barrier" rodent exclusion system. This system employs a passive fence made of plastic in conjunction with mousetraps spaced at regular intervals. The field test installation commenced late in 1990 WS at IRRI Field 4 and initial indications are that the system is promising. Tests continue on the impact on rodents in the vicinity and on crop protection inside the "Active Barrier" design.

Improvements in pesticide application technology

The objectives of this work are to reduce operator hazard, improve manual sprayer designs, reduce pesticide usage, and improve target efficiency.

General concepts for improved safety in the use of knapsack sprayers were drafted; this includes a number of specific features concerning sprayer components, including an Australian-design "spray management valve" to improve pressure control and mixing, and to eliminate dribble.

Subprogram III: Livelihood and production environments

Systems productivity

Constraints to crop diversification and intensification in Guimba, Nueva Ecija

The relationship between gross value of rice produced and the value of farm implements, labor, draft power, and agrochemicals was examined under three water regimes: deep well pump (DWP), shallow well pump (SWP), and rainfed.

Based on mean marginal value products (MVPs), which measure increase in output generated by increase in input, the following conclusions emerged: 1) all groups of farms overinvested in implements; 2) although labor could be profitably increased on DWP farms, rainfed and SWP farms have driven the MVP of labor below the wage rate; 3) investment in land preparation can be profitably increased in the three areas, assuming no technical constraints; and 4) DWP farms used agrochemicals at less than profit-maximizing levels while SWP and rainfed farms applied these at above economic levels (Table 39).

Physical and environmental factors dominated farmer-perceived constraints to diversification and intensification of rice production. DWP farms considered typhoons and resulting floods, and insect pests as major WS constraints: nearly one-third reported that pests reduced yields by almost 25%. For DS, 50% reported golden snails and 15% mentioned drought (associated with DWPs and electric power interruptions) as problems. Estimated rice yield reductions from those factors ranged from 15 to 31%. Drought reportedly affected 88% of rainfed farms (but only 43% of SWP farms) and reduced rainfed yields by up to 75%. Fourteen percent of SWP farms considered drought a DS constraint, indicating that SWPs may not be delivering enough water in some years.

New cropping patterns can require higher total investments than farmer patterns and low production levels often do not generate surpluses needed to finance improved technologies. Credit availability was higher among farmers under DWP and SWP areas where over 80% of the farmers borrowed from a cooperative, relatives, friends, and private moneylenders. Only about one-third of rainfed farmers borrowed for production purposes. Farmers partly finance production from previous crop incomes and off-farm and nonfarm income. Cash was used for land preparation and transplanting, while fertilizers, insecticides, and herbicides were distributed according to amounts requested.

Evaluation of improved cropping patterns in Guimba, Nueva Ecija

The performance of partially irrigated and rainfed rice-based farming and the impact on farm household income were determined (Table 40). Income

Table 39. Marginal value product (MVP) of factors under 3 water regimes. Guimba, Nueva Ecija, Philippines, 1987-89.

Factor	MVP		
	Deep well pump	Shallow well pump	Rainfed
Capital	0.02	−0.15	0.08
Labor	2.89	0.73	−4.06
Draft power	3.74	3.72	8.13
Agrochemicals	1.76	−0.15	−1.26

Table 40. Sources of farm household income by water regime. Guimba, Nueva Ecija, Philippines, 1989.

Source of income	Deep well pump		Shallow well pump		Rainfed	
	Farmers (%)	Income (₱/yr)	Farmers (%)	Income (₱/yr)	Farmers (%)	Income (₱/yr)
Crops[a]						
Rice (1st crop)	100	8,791	100	5,189	81	6,190
Rice (2d crop)	77	8,819	42	7,832	-	-
Other crops	10	−1,364	20	15,890	16	1,821
Other farms[b]						
Plowing/harrowing	15	5,400	0	0	6	125
Transplanting	60	648	0	0	12	675
Harvesting	50	762	0	0	12	612
Minithresher operator	15	14,611	0	0	0	0
Milking carabao	5	1,200	0	0	6	300
Fishing	10	390	0	0	0	0
Nonfarm						
Tricycle driving	15	5,953	28	3,900	12	12,400
Buy and sell	10	4,515	14	1,680	12	6,580
Sari-sari store	10	4,970	14	21,000	6	128
Household helper	15	20,400	0	0	6	2,880
Carpentry	15	1,210	0	0	29	1,612
Factory worker	5	17,723	0	0	18	10,342
Others	0	0	14	0	12	2,093
Dressmaking	0	0	0	0	12	4,500
Government service	0	0	0	0	12	19,945
Sound system operator	0	0	14	37,000	12	19,945

[a]On farms owned by the wage earners. [b]Farms owned by persons other than the worker or wage earner.

from rice farming was highest for DWP farms and lowest for rainfed. Twenty percent of SWP and 16% of rainfed farms substantially increased incomes by growing DS subsidiary crops.

Transplanting and harvesting were the most common sources of income earned from other farms. Less than one-third engaged in nonfarm income-generating activities. About 15% of DWP, SWP, and rainfed households were part-time farmers and derived a larger proportion of household income from nonagricultural rather than agricultural sources.

In DWP areas, production increased from 9.3 to 12.3 t/ha. Net returns increased by 15% for TPR - TPR as a result of change in variety (to IR64) and a 6% increase in material inputs. Returns to labor and power and to material costs increased by 51 and 41%, respectively. An improved TPR - wet seeded rice pattern similarly increased production to 10.4 t/ha, representing net returns of 51% with a 10% increase in total variable costs.

In the rainfed area, dry seeded rice - fallow gave the highest increase (38%) in net returns over farmers' TPR - fallow. Improvements involved an 11% increase in labor and power costs and a 39% increase in material costs. Although labor and power costs are only marginally higher than farmers' practices, the required increase in material inputs may be too much for rainfed farmers. Dry seeded rice also required that land preparation be completed under dry conditions, which is difficult under local conditions.

An improved TPR - fallow pattern increased production by 20% (0.7 t/ha per yr) with a net gain of more than ₱2000/ha from a 9% increase in total variable cost. This pattern increased returns to labor and power costs by 15% and to material costs by 16%, and provided a net gain 30% higher than farmers' practice. A sesbania + TPR - fallow pattern increased total production by 0.9 t/ha but gave slightly less net gain than the experimental TPR - fallow because of increased labor and power costs (23%) and material costs (39%).

Farmers' vs improved cropping patterns

Farmers' and improved cropping patterns were studied in both higher (*turod*) and lower (*lungog*) landforms. Treatments were laid out in a RCBD with four replications. Cropping patterns were tested in WS - transition season (TS) - DS

1. TPR - TPR - mungbean
2. TPR - ratoon rice - TPR
3. TPR - *Sesbania rostrata* - TPR
4. TPR - *Aeschynomene afraspera* - TPR
5. TPR - fallow - TPR

For rice, 80 kg N/ha was applied, with half applied basally and the rest 5-7 DBPI. For rice after green manure (GM), inorganic N applied 5 DBPI was the difference between the recommended 80 kg N/ha and accumulated N of GM. The rice ratoon was fertilized with 30 kg N/ha. No fertilizer was applied to mungbean (MB). Insects and weeds were controlled as the need arose.

Results. Although agronomic characteristics (plant height, number of panicles, number of spikelets, percent filled grain, 1,000-grain weight, and grain-straw ratio) were recorded, results are summarized here only in terms of yield. Landform produced no significant difference in IR72 yield during WS (4.2 t/ha in *turod* and 4.4 t/ha in *lungog*). Yields during TS were reduced by about 40% in the *turod* and 39% in the *lungog* compared with those in WS because of harsh weather during early development stages; however, there was no significant difference due to landform. Grain yield of ratooned IR72 was 0.5 t/ha in *turod* and 0.6 t/ha in *lungog*.

Dry matter yield of *S. rostrata* was 50% less in *lungog* (1.6 t/ha) than in *turod* (3.6 t/ha) because of early waterlogging. Although *A. afraspera* was not affected by waterlogging, it consistently produced less dry matter than *S. rostrata* in both landforms (1.5 t/ha in *turod* and 1.4 t/ha in *lungog*). Accumulated N yield of *S. rostrata* was 81 kg/ha in *turod* (equivalent to the recommended N) whereas *A. afraspera* produced only 43 kg N/ha. In *lungog*, both GM crops produced less than half the recommended N.

For late DS, rice yield averaged 4.1 t/ha in *turod* and 4.3 t/ha in *lungog* (not a significant difference). Rice after *S. rostrata* in *turod* produced 4.3 t/ha with no inorganic N added. This is slightly higher than in plots that received 80 kg N/ha. In *lungog*, plots with GM produced slightly better rice yields than those with only inorganic fertilizer.

MB produced significantly higher yield (1.1 t/ha) in *turod* than in *lungog* (0.6 t/ha). Except for plant density and grain weight, all plant characteristics were significantly better in *turod*. Poor MB performance in *lungog* was due to waterlogging during early crop stages.

Costs and returns analysis of the designed cropping patterns were compared with farmers' rice - fallow - rice. Rice - rice - MB generated the highest rates of return to total variable costs in both landforms (Table 41). The high yields obtained from WS rice and late DS MB contributed largely to the mean marginal benefit-cost ratio (MBCR), which was also the highest among the patterns. The MBCR of this pattern in *turod* is 4.2 (i.e., for every ₱1.00 increase

Table 41. Cost and returns of cropping patterns in 2 landforms in a partially irrigated environment. Guimba, Nueva Ecija, Philippines, CY 1989-90.

Cropping pattern[a]	Yield (t/ha)			Return (₱/ha)			
	1st	2d	3d	Total variable cost[b]	Gross	Return above variable cost[c]	MBCR[d]
Turod							
Rice - rice - MB	4.4	2.5	1.1	29,883	52,515	22,632	4.2
Rice - ratoon - rice	4.2	0.5	4.0	28,385	41,995	13,610	2.0
Rice - GM/SR - rice	4.2	-	4.4	27,200	40,926	13,726	3.7
Rice - GM/AA - rice	4.0	-	4.1	26,640	38,775	12,135	3.2
Rice - fallow - rice	4.1	-	4.0	26,476	38,245	11,769	-
Lungog							
Rice - rice - MB	4.4	2.7	0.6	28,776	47,791	19,015	3.6
Rice - ratoon - rice	4.5	0.6	4.2	28,996	44,627	15,631	1.9
Rice - GM/SR - rice	4.1	-	4.4	27,821	40,596	12,775	0.5
Rice - GM/AA - rice	4.5	-	4.5	28,037	42,688	14,651	1.9
Rice - fallow - rice	4.4	-	4.0	26,612	40,005	13,392	-

[a]MB = mungbean, GM = green manure, SR = *S. rostrata*, AA = *A. afraspera*. [b]Includes labor, power, material, and irrigation costs. [c]Gross return – total variable cost (TVC).

$$^{d}\text{MBCR} = \frac{\text{(gross return of potential pattern} - \text{gross return of prevalent pattern)}}{\text{(TVC of potential pattern} - \text{TVC of prevalent pattern)}}$$

in variable cost above the farmer's rice - fallow - rice pattern, ₱4,20 was returned).

The average MBCR of patterns with GM was 3.5, the next highest among the patterns tested, but MBCRs were very low in *lungog* where GM growth was suppressed by waterlogging.

Effect of planting date on transplanted (irrigated) rice in the wet-dry transition season

Nine planting dates at 15-d intervals from 15 Oct 1989 to 15 Feb 1990 were compared to evaluate the yield potential of IR72. The experiment used a RCBD with four replications. In a 3- × 6-m plot, 21-d-old seedlings were transplanted 3-4 seedlings/hill at 15- × 15-cm spacing. NPK at 45-30-30 kg/ha and 20 kg $ZnSO_4$/ha were applied basally; another 45 kg N/ha was topdressed 5-7 DBPI. Complete weed and insect control were applied.

Early planting (15-30 October) resulted in significantly lower grain yields than later planting dates (Table 42). These were associated with significantly lower numbers of panicles, spikelets per panicle, and filled grains percentage. Highest yields (over 6 t/ha) were obtained from the 30 December to 30 January planting dates. Declining yields for 15 February were due to water stress (less water from pumps).

Lower minimum temperatures in December to late February may have affected the two early planting dates, resulting in significantly lower number of spikelets per panicle and filled grains percentage. High wind velocity and lower solar radiation from October to late January may have contributed to significantly lower grain yield of the early planting dates.

Effect of green manure and inorganic N on a following transplanted rice

The experiment featured a split-plot RCBD with four replications. Treatments (GM as main plot and kg N/ha as subplot) were 1) weedy fallow and no N, 2) *S. rostrata* and 50 kg N, 3) *A. afraspera* and 100 kg N, and 4) 150 kg N. GM was incorporated at 66 d after emergence (DE). One-third of the N, 30 kg each of P and K, and 20 kg $ZnSO_4$/ha were applied basally. The remaining N was topdressed 5-7 DBPI. The fallow treatment received the same amount of P, K, and $ZnSO_4$. IR72 seedlings were transplanted 1 wk after GM was incorporated.

S. rostrata produced 1.6 t dry matter (DM)/ha, equivalent to 38 kg accumulated N/ha. *A. afraspera* produced only 0.9 t DM/ha, equivalent to 24 kg N/ha. The photosensitivity of GM resulted in low biomass production; consequently, their effect on rice yield over the fallow treatment at no N was negligible. The average main effect of GM across N levels, however, was significantly higher IR72 yields over the fallow treatment. The effect of the inorganic N was pronounced: higher levels (100 and 150 kg N/ha) produced significantly higher yields than did 50 kg N/ha.

Sorghum with forage legumes after irrigated rice

Intercropped sorghum and forage crops in a partially irrigated environment were evaluated at IRRI. The

Table 42. Effect of transplanting date on yield and agronomic characteristics of IR72, Guimba, Nueva Ecija, Philippines, 1989-90 wet-dry transition season.

Date of planting	Grain yield (t/ha)	Plant height (cm)	Panicles (no./m²)	Spikelets (no./panicle)	Filled grains/panicle	Grain-straw ratio	1000-grain wt (g)
15 Oct	3.0 e	60 f	377 e	62 b	69 e	0.75 c	22.4
30 Oct	3.3 e	62 ef	438 d	60 b	72 e	0.77 c	22.8
15 Nov	4.9 d	65 de	460 d	69 a	79 d	0.79 c	22.7
30 Nov	5.2 cd	66 d	496 bc	70 a	80 cd	0.80 bc	22.5
15 Dec	5.5 c	69 bc	501 bc	69 a	81 cd	0.91 ab	22.8
30 Dec	6.2 b	71 ab	524 ab	71 a	82 bc	0.92 a	22.8
15 Jan	6.9 a	74 a	560 a	70 a	87 a	1.00 a	22.6
30 Jan	6.5 ab	72 a	537 ab	70 a	84 b	0.98 a	22.8
15 Feb	5.3 cd	66 cd	499 bc	69 a	80 cd	0.79 c	22.6
Difference between treatment means	**	**	**	**	**	**	ns
CV (%)	6.4	2.8	7.3	4.9	2.3	9.0	1.3

experiment, laid out in RCBD with three replications, followed TPR with minimum tillage. Grain crop *Sorghum bicolor* was intercropped with 3 forage legumes (*Clitoria ternatea*, *Desmanthus virgatus*, and *Stylosanthes guianensis*) in a 1:1 row proportion. Monocrops of each crop were included as check plots. Supplemental irrigation was provided three times.

Fodder was first harvested 60 DAS for clitoria and desmanthus and at 90 d for stylo, and subsequently every 4 wk. After harvest, sorghum was ratooned 10 cm aboveground, regrown throughout DS, and harvested for fodder. The last regrowth of forage legumes and of weeds were cut at ground level, weighed, chopped, and incorporated in situ as GM before land preparation for the following rice crop.

IR74 was the test cultivar. Inorganic N was applied to all plots at 60-30-30 kg NPK/ha.

Sorghum grain yields of 1.9-2.6 t/ha were not significantly affected by forage legume intercrops. Sorghum with desmanthus and stylo intercrops produced a higher grain yield than the monocrop, but with clitoria, yield was reduced by 6% (Table 43). Fodder DM yield of sorghum was not significantly affected by forage legume intercrops; however, yield with desmanthus was the highest (26% higher than in the monocrop). In terms of the ratoon fodder DM yield, the sorghum monocrop outyielded all intercrop combinations.

Clitoria produced 2.1 t of intercrop total herbage DM/ha, but this did not significantly differ from that of stylo and desmanthus, both of which yielded 1.3 t/ha. Monocrop total herbage DM yields of clitoria (4.2 t/ha), stylo (2.6 t/ha), and desmanthus (4.8 t/ha) were significantly higher than those of the intercrops. Reductions were 74, 50, and 49% for intercropped desmanthus, stylo, and clitoria, respectively.

Combined total DM yield of sorghum + forage legumes was highest with sorghum + desmanthus (7.4 t/ha). All intercrops produced significantly higher DM yield than the respective monocrops.

The last forage harvest plus weeds were incorporated as GM for the next rice crop. Desmanthus and stylo monocrops produced the highest DM from GM: 2.2 and 1.4 t/ha. Weeds in fallow plots produced the highest DM from among the treatments. Rice grain yield after intercropping did not differ significantly among treatments: 2.7-3.6 t/ha. Grain yield was highest in the desmanthus monocrop plot. Fallow plots with 30 kg N/ha produced the lowest grain yield of 2.7 t/ha.

Rice - wheat systems

Research to improve the productivity and sustainability of tropical and subtropical rice - wheat systems must be directed to the pertinent constraining factors.

Table 43. Grain and fodder dry matter (DM) yields of sorghum and forage legumes and rice grain yield as affected by green manure in a food + forage legumes intercropping experiment in a partially irrigated environment, IRRI, 1990.

Treatment	Sorghum (t/ha)			Legume DM yield (t/ha)	Total forage & DM yield (t/ha)	Total DM (t/ha) from incorporated green manure		Rice grain yield (t/ha)
	Grain	Fodder DM						
		Main crop	Ratoon crop			Forage legumes	Weeds	
Sorghum	2.0	3.2	1.9	-	5.1 bc	-	1.1 a	2.8
Desmanthus	-	-	-	4.8 c	4.8 bc	2.2 c	2.0 a	3.6
Sorghum + desmanthus	2.6	4.3	7.9	1.3 a	7.4 d	0.9 a	0.9 a	3.1
Clitoria	-	-	-	4.2 c	4.2 d	0.7 a	2.2 a	3.3
Sorghum + clitoria	1.9	2.6	1.6	2.1 ab	6.3 cd	0.4 a	0.6 a	2.8
Stylo	-	-	-	2.6 b	2.6 a	1.3 b	2.7 ab	3.0
Stylo	-	-	-	2.6 b	2.6 a	1.3 b	2.7 ab	3.0
Sorghum + stylo	2.1	3.3	1.7	1.3 a	6.2 cd	0.8 a	1.2 a	3.2
Fallow (30 N)	-	-	-	-	-	-	6.0 c	2.7
Fallow (60 N)	-	-	-	-	-	-	4.4 bc	3.0
Fallow (90 N)	-	-	-	-	-	-	5.8 bc	3.5
Mean	2.2	3.3	1.8	2.7	5.2	1.6	2.7	3.1
CV (%)	26	20	31	23	16	25	42	14
F-test	ns	ns	ns	**	**	**	**	ns

One constraint generally recognized by rice - wheat researchers and farmers is delayed and suboptimal wheat establishment in previously puddled rice soil. The *1989 Program report* described strategic studies of the postrice soil—structural, temperature, and moisture conditions that promote effective wheat emergence. Research in 1990 investigated the rates of wheat emergence, growth, and yield that resulted from tillage procedures and soil amendments that create the desired soil-structural conditions, and from seeding technologies that aim to exploit them effectively.

Diagnostic surveys of the rice - wheat system in the terai of India

Rice season survey. A diagnostic survey around GB Pant University in Uttar Pradesh, India, in the 1990 wet (rice) and dry (wheat) seasons examined farmer practices and perceptions. Rice and rice - wheat problems were identified and prioritized, and research needs were suggested.

Results. About 30% of small farmers and 70% of larger farmers owned tractors. Many nonowners hired tractors for land preparation and wheat harvest. Lands were irrigated by tubewell, gravity flow from rivers, pumping stations, and artesian wells; and 20% of small and 44% of large farmers had more than one source of water.

Small farmers applied 132 kg N/ha, large farmers applied 160 kg N/ha, and most applied 12-22 kg P/ha, and Zn. Use of butachlor and some hand weeding were widespread, and unsafe application of various pesticides was observed. Rice nurseries were sown from early May to the end of June, transplanting was 30 DAS, and harvest was in mid-October. Reported rice yields were 5.5 (small farmers) to 6.0 (large) t/ha (Table 44).

Problems and needed research. Problems in the rice crop or those exacerbated by the rice - wheat system were identified and prioritized (Table 45), using a simple model. SB and inefficient pesticide use had insignificant effects on yield and were, therefore, not considered as research issues. Weeds were not included as a research problem because farmers effectively controlled them and the rice - wheat system did not appear to increase rice weeds.

Nutrient depletion. Numbers of large animals per farm decreased with mechanization, resulting in a decrease in farmyard manure (FYM). Except for farmers located near forests, small farmers used 50-75% of their FYM for fuel; large farmers used 25-50%. Overall, proportions of FYM used as fuel increased because of increased demand and lack of alternatives. Planted trees, daincha (*Sesbania* sp.), and biogas converters provided limited alternatives.

FYM was applied to fields where rice - wheat yields declined and sugarcane was planted after FYM application. Some farmers applied press mud from the sugar mills to their fields. Where rice - wheat was grown without sugarcane, FYM was applied more to rice than to wheat.

Data from 16 yr of long-term trials show that rice—but not wheat—yields declined significantly over time but other data indicate that wheat yields in

Table 44. Rice crop production, small and large farmers (n = 36).

	Small farmers		Large farmers	
	Percent	Quantity	Percent	Quantity
Labor inputs				
Animal land preparation (d/ha)	-	2.18	-	2.02
Tractor land preparation ($/ha)	-	7.44	-	8.58
Transplanting: family labor (d/ha)	12.14	4.04	-	-
contract ($/ha)	1.61	7.20	2.30	7.06
Hand weeding (d/ha)	40.49	3.64	35.62	3.64
($/ha)	-	-	-	3.86
Harvest and threshing ($/ha)	-	6.53	-	6.90
Material inputs				
Seed (kg/ha)	-	4.45	-	3.24
Fertilizer N (kg/ha)	100	132	100	160
P (kg/ha)	75	12	94	22
K (kg/ha)	15	14	56	32
Yield (t/ha)		0.89		0.97

Table 45. Scoring and ranking of identified rice and rice - wheat system problems.

Problem	Score[a]					
	Frequency of problem (% of yr)	Yield loss	Proportion of farms reporting	Large vs small	Aggregate score	Rank
Nutrient depletion	3	1	3	2	9	I
Rats	3	1	2	2	8	I
Brown planthopper	2	1	2	2	7	II
Inefficient fertilizer use	3	1	2	1	7	II
Bacterial blight	1	2	1	2	6	II
Delayed rice transplanting	2	1	1	1	5	III
Yellow stem borer	3	0	3	2	0	
Inefficient pesticide use	3	0	2	2	0	
Sheath blight[b]	1	?	?	?	?	?
Waterlogging[b]	2	?	?	2	?	?
Nematodes[b]	3	?	3	2	?	?

[a]Criteria for scoring

Score	Years	Yield	Farms	Size
0	0-10%	0-5%	0-55%	
1	10-40%	5-15%	5-15%	Large
2	40-80%	15-50%	15-50%	Both large and small
3	>80%	>50%	>50%	Small

[b]Could not be scored because of insufficient data

experimental plots in Nepal declined by 50% in 10 yr. Researchers thought that rice yield declines were due to increases in soil pH (7.1 to 7.8), soil-borne pathogens, declines in OM and degraded soil-physical properties. Overall, the data suggest that the rice - wheat system is not sustainable.

Work to further understand the problem included collating data related to yield declines and monitoring farmers' fields (i.e., land use and management, livestock and FYM production, yields, OM, macro- and micronutrients, root depth, plow pan, and pests) over the long term. Research to address the problem would examine 1) nutrient cycling from deeper soil layers through testing of dry seeding, reduced tillage, GM, and deeper plowing; 2) ways to increase OM or OM use efficiency; and 3) improved inorganic fertilizer management. Work on improved OM management would examine GM, linkages with agroforestry research, crop-residue management, FYM management (storage, combining with P and micronutrients), and use of cane mill residues.

Brown planthopper. Farmers applied insecticides for BPH, SB, and ricebugs, the most serious pests. In addition, some farmers weeded and applied raw cow dung for SB. Yield loss to BPH was due to susceptible cultivars combined with high N use, normal planting dates for medium-duration cultivars, waterlogging, and resurgence from wrong insecticide use or underdosage. Research is needed for development of resistant varieties, improved forecasting, and study of natural enemy dynamics.

Inefficient N use. Some researchers thought that farmer use of N was inefficient for these reasons: many farmers did not apply a basal N, sometimes last N applications were late, some rice was transplanted late, and some farmers applied excessive N. Unknown factors may have reduced responses to nutrients. Suggested research includes a comparison of farmers' and researchers' methods in farmers' fields, monitoring of N losses, and review of work on planting date × N, N × water management, and balanced NPK use.

Bacterial blight. ShB was becoming serious and is a disease of sugarcane and wheat. False smut may be a serious problem in the future. To control BB, farmers drained fields, reduced N, and sprayed bac-

teriocide. BB losses were caused by waterlogging, excessive N use, susceptible varieties, and normal planting dates. Research should focus on tolerant or resistant varieties.

Late transplanting. Some late rice transplanting was due to labor shortages, use of land for seedbeds or short-duration crops, lack of irrigation or rainfall, lack of power, and seedbed-sensitive cultivars. Late transplanting may lead to reduced rice yield, late wheat planting, increased SB (due to an additional pest cycle), and reduced fertilizer efficiency. The group recommended a review of results of seeding date × yield trials, work on dry seeding and testing of varieties for dry seeding, and monitoring of farmers' fields.

Research should determine if farmers who now apply more inputs to get the same yields are at a yield plateau or are suffering from land degradation. Monitoring of fields and farmers should examine physical measures (yields, OM, macro- and micronutrients, soil compaction, pest incidence and damage; farmer survey data (fertilizer and FYM use, crop sequences, residue management, tree fuel use, cane mill residue use, pest control, water management, transplanting dates, and crop management in general); and secondary data.

Wheat season survey. The wheat season survey in February 1990 described the site, farmers' crop rotations and land types, water management, rice and wheat crop management, system interactions, recommendation domains, trends, problems and possible solutions, and follow-up research. The following near-term problems were discussed:

- Wheat yields were reduced by late planting due to late harvest of rice and other crops such as sugarcane, and long turnaround time.
- Waterlogging and excess moisture constituted a problem in lower lying, heavier, poorer drained soils where rice - wheat was continuous.
- The weed *Phalaris minor* was a major problem where rice - wheat was grown continuously. Farmers used herbicides and hand weeded but with limited success.
- N use was inefficient.

Longer term problems included the following:

- Nutrient deficiencies, farmers' residue management practices, and decreased FYM applications to fields. Research should focus on residue management, organic fertilizers, legumes and GM in rotations, different sources of P, K, and NPK mixes, soil testing and calibration, nutrient requirements of the rice - wheat system, FYM management, and agroforestry to decrease use of FYM as fuel.
- Pests, diseases, and weeds. Research could examine zero tillage, rice - wheat vs rice - wheat - sugarcane, nematodes and soilborne pathogens, weed problems in farmers' fields, alternative methods of rice crop establishment, and water management for wheat after rice.

Rice-soil structural management for postrice wheat

Emergence and growth of postrice wheat were investigated in field trials to determine the benefit from 5.0 t gypsum/ha applied to the rice-phase field water (known to increase postrice soil aggregation and emergence of MB), and from four combinations of postrice tillage and wheat seeding, each applied at three soil-moisture states. The preceding irrigated rice was grown in rows spaced alternately at 7 and 28 cm. The 28-cm spacing allowed easy access of postrice implements that tilled the soil and seeded the wheat without impediment from rice roots and stubbles. The four tillage and seeding combinations were between-stubbles rototillage followed by (1b) wheat (UPLW-3) seeding using a prototype slit seeder that seeded two rows 10-cm apart within the 28-cm interstubbles space (TTS); between-stubbles rototillage 1b manual seeding (TTM); no tillage 1b slit-seeder seeding (TOS); farmers' practice of plowing the whole plot (including stubbles), broadcasting seeds, and harrowing (PBH).

Contrasts of seed zone soil moisture (simulating rainfed conditions) were achieved by deliberate delay of tillage and seeding following rice harvest on 28 Nov 1989. The respective delays and moisture contents (g/g for plots) without gypsum were 7 d, 0.47 g/g; 15 d, 0.34 g/g; 18 d, 0.29 g/g. With gypsum, seed zones were 0.03 g/g wetter; and tilled seed zones were about 0.03 g/g drier than the nontilled at seeding.

Rain at 19 d after rice harvest (DAH) confounded interpretations of seed zone strength and wheat emergence for seeding at 15 and 18 DAH. From 26 DAH (when, in the absence of rain, emergence comparisons would have been completed), all treatments received 160 mm irrigation (season's rainfall was 55 mm). For the first seeding into wet soil, emergence percentages were higher with gypsum.

Among tillage and seeding methods, the percentage was lowest (28%) for PBH because plowing under wet conditions induced large clods. The prototype slit seeder achieved 72 ± 5% emergence in gypsum-treated soil rototilled between stubbles, and 85 ± 5% in nontilled gypsum-treated soil. However, there was some unevenness in seed delivery into wet soil and hence in plant spacing along rows. Conditions were suitable for mechanized seeding 7-14 DAH, and too dry after 14 DAS, but emergence measurements were confounded by rain at 19 DAH.

Seed rate for T1M and PBH was 120 kg/ha; for the prototype slit seeder, severe mechanical vibration caused a seed rate (200 kg/ha) substantially higher than the intended 120 kg/ha. Comparisons of seedling population densities must therefore be made separately from those of percentage emergence: from the first sowing, PBH achieved 1.4 million plants/ha (Mp/ha), T1M 2.9 Mp/ha, and the seeder 4.1 Mp/ha (acceptably high for farm practice) whether into tilled or nontilled soil. Population densities from the second and third sowings were appreciably higher because of rain, and correspondingly indicated the benefits from postseeding seed zone irrigation.

Irrigation commenced at 26 DAH. Soil dried between irrigations, and soil resistance to cone penetration (and to root extension) consequently increased. Immediately prior to scheduled irrigation, soil resistance late in the growing season achieved values in excess of 3.0 MPa at 15-50 cm depth and probably prevented root extension; for all seeding dates, roots reached 85 ± 5 cm maximum depth at 60 DAS. Root-length density was enhanced by tillage in the 0-10 cm depth.

Growth and yield of wheat depend on tillering, culm population density at harvest (CPH), fertile grains per culm, and mean grain mass. The CPH depends on the population density of culms at maximum tillering (CPM) and hence on the emerged seedling density (PPE), which is responsive to the tillage and seeding methods investigated here.

At maximum tillering, there were 5-8 million culms/ha (Mc/ha) for seeding delay 1, and 5-11 Mc/ha for delays 2 and 3. CPM responded to rainfall and interplant competition: thus at delay 1, CPM was 7.8 Mc/ha for PBH (notwithstanding only 1.4 Mp/ha at emergence) and 5.6 Mc/ha for other seeding and tillage methods, which had PPE of 2.9-4.1 Mp/ha. This is consistent with stronger competition among closely adjacent plants (1 cm separation) along seeded rows. For delays 2 and 3, PBH achieved CPM of 10.4 Mc/ha.

Interplant competition also affected the survival of culms to harvest. Figure 27 shows the relation of CPH to PPE for each tillage and seeding method and averaged over seeding delays and gypsum treatments. Provided PPE > 2 Mp/ha, CPH was essentially constant, at 5 Mc/ha for PBH and 4 Mc/ha for other methods. The ratios CPH/PPE and CPH/CPM (the latter quantifying culm survival after maximum tillering) are shown in Figures 28, 29, and are represented by the equations:

$$CPH/PPE = 0.25 + 3.0/PPE, \quad r^2 = 0.83^{***} \quad n = 120$$

$$CPH/CPM = 0.18 + 2.8/CPM, \quad r^2 = 0.51^{***} \quad n = 120$$

Grain yield (GY, in t/ha) was higher from tilled than from nontilled soil, but differences were slight: PBH and T1M each produced 2.3 t/ha; T1S, 2.1 t/ha; and T0S, 2.0 t/ha. Yield was not affected by seeding delay or gypsum. GY/CPH (grain yield per harvested culm) reveals an inverse dependence on CPH (in Mc/ha), with distinct relations for tilled and nontilled soil and for data aggregated across seeding delays and gypsum treatments. The yield advantage from tillage (for CPH < 6 Mc/ha) was associated with more grains per spike. We list the respective relations:

Tilled soil: $GY/CPH = 0.97 - 0.102\ (CPH)$
$r^2 = 0.53^{***}$, n = 90

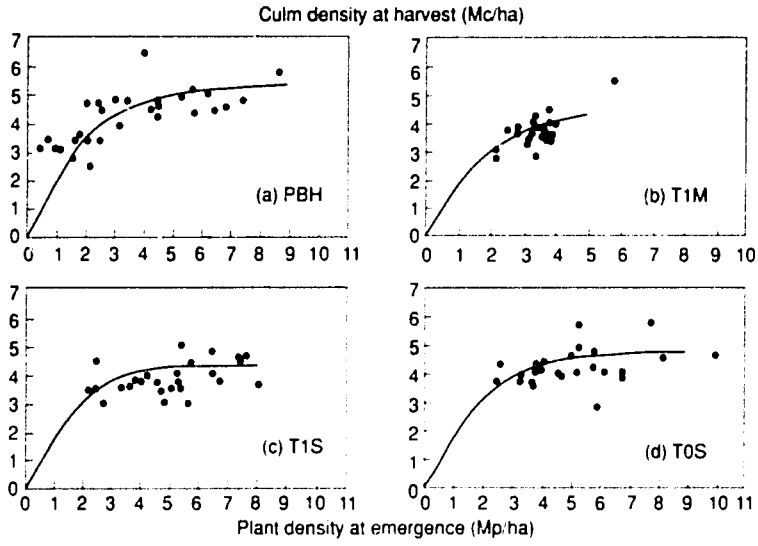
Nontilled soil: $GY/CPH = 0.76 - 0.067\ (CPH)$
$r^2 = 0.35^{***}$, n = 30

which, respectively, translates into these relations:

Tilled soil: $GY = 0.97\ (CPH) - 0.102\ (CPH)^2$

Nontilled soil: $GY = 0.76\ (CPH) - 0.067\ (CPH)^2$

These equations imply a maximum GY of 2.30 t/ha from CPH of 4.7 Mc/ha in tilled soil, and of 2.18 t/ha from 5.7 Mc/ha in the nontilled. Correspondingly, GY ≥ 2.0 t/ha can be achieved using 3.0-6.4 Mc/ha in tilled soil, and 4.0-7.4 Mc/ha in nontilled. In tropical conditions (14°N), irrigated wheat can generally yield 2.0 t/ha from >4.0 Mc/ha at harvest, which corresponds (Fig. 27,28) to a requirement that emerged population (PPE) also should exceed 4.0 Mp/ha. This minimum population is high compared with those recommended for semitropical environments; it reflects the shortness and high temperature of the tropical wheat-growing season, and the corresponding need for dense populations to intercept efficiently the season's solar irradiance.



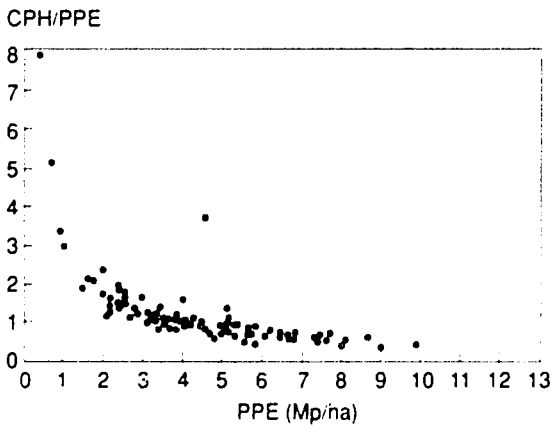
27. Wheat-culm density at harvest in relation to plant density at emergence for each of 4 tillage and seeding methods and combined over 3 seeding delays and with or without gypsum. a) Plow, broadcast, harrow (PBH), b) between-stubbles rototillage; manual seeding (T1M), c) between-stubbles rototillage, prototype seeder (T1S), d) no tillage, prototype seeder (T0S). IRRI, 1990 DS.

NEXT STEPS

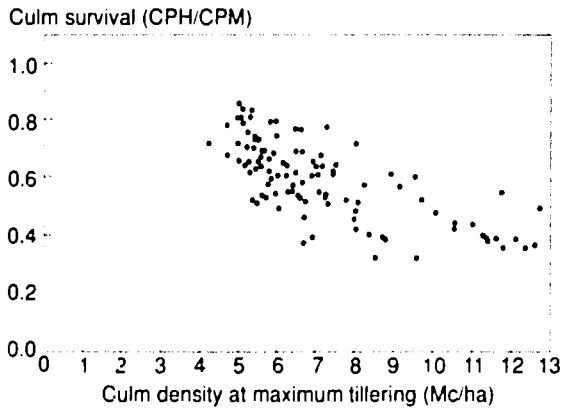
During 1991, coordinated research into rice - wheat systems will be undertaken by eminent national system groups in collaboration with CIMMYT and IRRI at key locations in Bangladesh, India, Nepal, and Pakistan. Diagnostic farm-constraint surveys for both rice and wheat seasons will be conducted at locations not yet surveyed, and key features of the biological and physical constraints to the productivity, profitability, and sustainability of the rice - wheat system will be addressed. Findings will be shared through the consortium mechanism.

Global climate change and rice

Although it has been clearly established that atmospheric CO_2 concentrations are rising and that the stratospheric ozone layer has been partly degraded, how these anthropogenic factors will cause global climatic changes is still unknown. Nonetheless, we



28. The ratio CPH/PPE of wheat-culm population density at harvest to plant-population density at emergence in relation to the density of emergence. Aggregated for various seeding delays, tillage and seeding methods, and with or without gypsum. IRRI 1990 DS.



29. Wheat-culm survival ratio (defined as culm-population density at harvest/population density at maximum tillering, CPH/CPM) in relation to the density at maximum tillering. Aggregated for various seeding delays, tillage and seeding methods, and with or without gypsum. IRRI, 1990 DS.

have begun research to allow rice farmers to maintain food production should the threatened global climate changes occur.

In October 1990, we initiated a joint 5-yr project funded by the U.S. Environmental Protection Agency (EPA) with its Environmental Resources Laboratory in Corvallis, Oregon (ERL-C). This $1 million/yr project will emphasize the effects of possible climate change on rice production, but it will also address the question of how rice cultivation may affect global climate.

Response of rice to enhanced UV-B radiation

Ambient ultraviolet-B (UV-B) flux in the tropics, the major rice-growing area, is among the highest on the earth's surface because the stratospheric ozone layer is naturally thinner and because solar angles are higher near the equator than at higher latitudes. With the depletion of stratospheric ozone caused by chlorofluorocarbons, increased UV-B flux may adversely affect rice productivity. Therefore, phytotron research 1) assessed physiological and biochemical responses to enhanced UV-B for a few selected cultivars, and 2) screened rice germplasm from diverse ecosystems for their morphological and physiological responses to UV-B radiation.

Physiological and biochemical responses. Rice seedlings were grown in pots and subjected to UV-B radiation treatments beginning at 10 DAS, using a split-plot design with three replications. Main plots were radiation treatments imposed with Q Panel UV 313 sunlamps filtered with either cellulose acetate for the UV-B treatment or with mylar film for the control treatment. Plants were irradiated for 6 h daily for 4 wk. Subplots were rice cultivars IR30, IR45, IR64, and IR74; the changes are summarized in Table 46.

Chlorophyll content. The 4-wk UV-B treatment significantly increased total chlorophyll content of fresh leaves of IR30 and IR64, but did not significantly affect that of IR45 or IR74. Previous studies showed that IR30 and IR64 were more tolerant of UV-B than are IR45 and IR74. The chlorophyll a/b ratio was not significantly affected by UV-B; thus, UV-B affected both chlorophylls equally.

Flavonoid content. UV-B treatment increased the flavonoid content of leaves in all cultivars. Flavonoid production is a common response of plants exposed to UV-B. Flavonoids absorb UV-B radiation; hence greater flavonoid content may shield inner tissues from direct damage from UV-B.

Root oxidizing activity. Root metabolic activity, as measured by oxidation of alpha-naphthylamine,

Table 46. Physiological and biochemical responses of 4 rice cultivars to 4 wk of enhanced UV-B irradiation. IRRI phytotron, 1990.

Variable	Change[a] (%)			
	IR30	IR64	IR45	IR74
Chlorophyll (mg g fresh wt)				
Total	15.86*	15.18*	2.47	9.02
Ratio chlorophyll a and b	0.03	−4.15	1.34	−3.17
Flavonoid (absorbance at 280 nm)	34.53**	35.17**	16.50*	25.57**
Root oxidizing activity (mg/h per g dry wt)	−15.26*	−12.12*	−16.22*	−13.55*
Stomatal aperture (score)	−13.16*	−8.11*	−16.67*	−22.22**
Stomata frequency (no./mm²)				
Adaxial	−22.70**	−6.53	−20.72**	−23.61**
Abaxial	−18.18**	−5.34	−18.50**	−21.71**
Ion leakage from leaves (mS/12 h)	49.7**	6.3	28.3**	33.0**
Total ion content in leaves (mS)	−19.2*	−6.4	−19.3*	−15.9*
Soluble protein (mg/g)	−30.01**	−11.93*	−15.76**	−26.75**
Total nucleic acid (µg/g)	−6.59	−5.55	−15.66*	−11.73*
Silica (mg/g)	4.0	−7.3	9.8	17.6
(mg/cm²)	−3.1	−6.1	15.8	28.1
Leaf area (cm²)	−1.9	−4.5	−21.5	−14.9
Leaf length (cm)	−4.0	−8.8	−10.7	−9.7
Leaf width (cm)	2.1	4.6	12.2	−6.1

[a]Change (%) = [(UV-B − control)/control] 100

was significantly reduced by UV-B treatment, even in tolerant cultivars (Table 46). Apparently, UV-B damage to shoots was transmitted to the root system, which is shielded from direct UV-B radiation. Indirect root damage by UV-B may reduce root growth and mineral uptake.

Stomatal aperture. UV-B treatment decreased stomatal aperture on the abaxial surface of penultimate fully expanded leaves (Table 46). In general, stomatal aperture was reduced more in UV-B-sensitive than in tolerant cultivars. Although the mechanism of UV-B impact on stomatal aperture is not certain, it appears that UV-B causes the collapse of guard or bulliform cells. As stomatal aperture is related to CO_2 exchange, there may be an interaction between UV-B and increased CO_2 effects on rice.

Stomatal distribution. The number of stomata per unit area on both leaf surfaces was significantly reduced by UV-B treatment in all cultivars except IR64. The effect was greater for the adaxial (upper) than the abaxial surface (Table 46). UV-B appeared to inhibit formation and development of stomata in rice seedlings and may cause interactions with rice responses to changes in CO_2 level.

Ion balance. UV-B treatment significantly increased ion leakage from leaves in all cultivars except IR64 (Table 46). This result suggests that UV-B damages leaf membrane systems. From observations through time, it appears that such damage to the membrane system is cumulative (data not shown). UV-B treatment significantly reduced total ion content of leaf tissues in all cultivars except IR64 (Table 46). This result suggests that UV-B diminishes ion uptake or transport, and agrees with the observation that UV-B reduced root oxidizing activity.

Soluble protein and nucleic acids. UV-B treatment significantly reduced soluble protein content in leaves of all cultivars and reduced nucleic acid content of UV-B-susceptible cultivars. It is possible that nucleic acids of different cultivars had different stabilities when irradiated with UV-B, whereas the stability of soluble proteins did not differ among cultivars. A better explanation of the difference may be related to their differences in absorption spectra and thus differences in the ability of flavonoids to protect the molecules.

Epicuticular wax. Scanning electron micrograph observations of leaf surfaces suggested that UV-B treatment increased wax content, but intraspecific differences were not clearly delineated (data not shown).

Silica. UV-B treatment increased total leaf silica content in sensitive but not in tolerant cultivars. As leaf area, length, and width decreased in sensitive cultivars, UV-B gave an even greater increase in leaf silica content.

Summary. Cultivars differ in sensitivity to UV-B, which is definitely detrimental to rice. In general, biochemical and physiological variables were more sensitive to UV-B than were growth variables reported earlier. In particular, chlorophyll, flavonoid, and nucleic acid contents discriminated well between UV-B-tolerant and -susceptible cultivars. It is more convenient to measure growth variables to assess UV-B response, but that requires longer exposure periods.

Varietal screening

Thirty rice varieties were screened at seedling stage for their morphological and physiological responses to enhanced UV-B radiation with 9 h irradiation daily for 2 wk.

Significant differences were observed in plant height, root length, leaf area, leaf dry weight, leaf sheath, root, and total shoot to root ratio, and specific leaf weight. Correlations were significant among shoot dry weight and plant height or leaf area. Shoot dry weight and leaf area had the greatest range of sensitivity to UV-B; thus, these variables are possible indices for identifying UV-B-tolerant varieties. To eliminate differences, varieties were compared under UV-B-free conditions, by using the ratio of UV-B to control values of the different variables. The most UV-B tolerant varieties were OS4 and Fujisaka 5. The most UV-B sensitive varieties were IR45 and IR74 with 23 and 21% reduction in shoot dry weight by UV-B treatment, respectively.

High temperature effects on rice

Field research at IRRI characterized the effect of high temperatures on rice growth, development, and productivity. Data from the field experiment will be used to calibrate a crop simulation model.

To impose temperature differentials, we used a split-plot design with three planting dates as main plots (15 Jan, 8 Feb, and 4 Mar). Within planting dates, treatments were with or without open-topped

chambers about 1.50 m high, having clear plastic walls to give an additional temperature variation and four cultivars (IR20, IR46, IR52, and N22) having diverse tolerance for abiotic stresses in factorial combination. At a given developmental stage, canopy temperatures as measured by infrared thermometer were about 1 °C greater for successively later planting dates. On clear days, canopy temperatures were about 1 °C greater inside than outside the open-topped chambers.

There were significant cultivar × planting date × chamber interactions for most harvest variables (Table 47). Only the data for panicle weight at harvest are given here. Later planting date (higher temperature) decreased yields of all cultivars. Effects of chamber treatments were not consistent, probably because chambers affected pest attack in addition to increasing temperatures. For the latest planting, N22, the cultivar considered to be most tolerant of high temperature, had panicle weight of 0.86 g in the first planting compared to 0.60 for IR20 (susceptible to water deficit), 0.45 for IR52 (susceptible to water deficit and high temperature), and 0.43 for IR46 (tolerant of water deficit). Although N22 was most tolerant of high temperature on a relative basis, it had low overall panicle weight. On the basis of yield potential, IR20 and IR46 were the most tolerant of high temperature.

Future research

Future research on UV-B effects will emphasize germplasm screening in the phytotron and effects on yield. Research on high temperature effects will investigate the physiological bases for high temperature tolerance and the interactions between increased CO_2 and temperature. A multidisciplinary approach will be used to investigate the effects of UV-B radiation on rice disease and pests, the effects of increased CO_2 and temperature on rice yields and rice pests, modeling of plant responses to climate changes, and emission of climate-changing gases from rice soils.

Table 47. Panicle weight of 4 rice genotypes in response to high temperatures induced by late planting and open-topped chambers. IRRI, 1990 DS.

Cultivar	15 Jan	8 Feb	4 Mar
	Without chamber		
N22	176 c	164 d	159 b
IR20	370 b	379 a	244 a
IR52	404 b	229 c	182 b
IR46	553 a	334 b	233 a
	With chamber		
N22	173 d	147 c	142 b
IR20	445 b	315 a	242 a
IR52	370 c	231 b	163 b
IR46	501 a	346 a	219 a

Technology-environment interactions

Pesticide use and farmer health and productivity

Concerns about the effects of pesticide use on human health and the environment have been expressed for more than a decade, but few studies have systematically quantified the effects. The multidisciplinary study initiated in January 1989 examined on a sample of farms in Laguna and Lucban the impact of pesticide use in rice production.

Thirty-two farm households in Laguna have been monitored for 3 yr. All farm inputs and practices have been recorded, particularly pest management practices and methods of handling pesticides. Twenty-two randomly selected pesticide applicators who worked in the area were added to the sample to make a total of 56 farmers representing the group exposed to pesticides. A group consisting of 40 farmers from Lucban who have never used pesticides was the control group.

Extensive and intensive sampling of biotic and abiotic variables such as soil, paddy water, well water, groundwater, algae, zooplanktons, aquatic insects, fish, frogs, rice plant, and rice grains were conducted on the 32 Laguna farms and 40 Lucban farms. Detailed medical assessments such as physical examination, laboratory tests—CBC, blood chemistry, ECG, X-ray, and cholinesterase test—were done on the 56 Laguna farmers and pesticide applicators and 40 Lucban farmers to measure the acute and chronic effects of pesticide use.

Acute health effects, which predominate over the environmental effects of pesticide use were manifested in the cholinesterase levels, while chronic effects were manifested in the cardiovascular, hematologic, and neurologic systems. In the first and second monitoring periods, 56 and 61% of the farmers, respectively, suffered a depression in their cholinesterase levels. Fifty-four percent in the exposed group had cardiovascular abnormalities compared

with 7% of the control group. Compared with 25% in the exposed group, only 5% in the control group had lower than normal hemoglobin levels. Three polyneuropathy cases were found in the exposed group and none in the control despite the fact that there were more drinkers in the control group. These three farmers had normal blood sugar levels (Table 48).

A cost function model quantified the impact of pesticides on farm productivity and on human health. When health effects are explicitly included in the model, the net impact of pesticides on farm income is negative.

We also simulated the effects of different governmental policies on pesticide use and human health. The model predicted that a tax on pesticide purchases would lead to reduced use and improved health. With a tax higher than 50%, the effects on improved health would more than offset reduced yield.

This implies a need to reassess return on research investment. When health effects are not considered, the rate of return on general rice research is overestimated, and the rate of return on research that reduces pesticide use underestimated.

Agrochemical impacts on soil and water invertebrates and N_2-fixing algae

Research has shown that, at the levels of inorganic fertilizer applied in ricefields, most N absorbed by the plant originates from the soil. Soil N is released by the turnover of a microbial biomass that represents only a few percent of total soil N. Crop residues, algae, and aquatic plants contribute nutrients—including biologically fixed N_2—that allow the replenishment of the microbial biomass. The recycling of nutrients accumulating in algae and aquatic plants is ensured by zooplankton and their translocation into the deeper soil by the soil fauna, mainly aquatic oligochaetes. Soil and water invertebrates are therefore key components of the ricefield fertility and it is important to understand how factors of crop intensification, especially agrochemical use, affect their ecology.

Table 48. Physical examination and laboratory results of the 56 exposed (Laguna) and the 40 unexposed (Lucban) farmers.

Item	Exposed (%)	Unexposed (%)	Z-test
Physical examination			
Cardiovascular system	54	7	*
Polyneuropathy	5	0	*
Hyporeflexia	25	15	ns
Eye	55	80	*
Lungs	19	ns	
Skin	15	20	ns
Laboratory			
Low hemoglobin	25	5	*
Abnormal ECG	41	40	ns
Positive albumin	16	18	ns
Cholinesterase (baseline below normal)	5	2	ns
Average health cost (pesos)	611	323	* (t-test)

An experiment with 65 plots (16 m^2 each, 5 replications) was used to study the combined effects of N fertilizer and widely used pesticides—carbofuran and butachlor—on major populations of aquatic and soil invertebrates, and on N_2-fixing BGA. We used one unplanted unfertilized plot as control and 12 selected combinations of 5 N treatments and 4 pesticide levels:

- no N, 55 and 110 kg N/ha broadcast split, 55 kg N/ha deep placed, and azolla incorporated before transplanting;
- one application of carbofuran at 0.1 kg active ingredient (ai)/ha, 2 applications of 0.3 kg each, 3 applications of 0.5 kg each, and 5 applications of 0.5 kg each. The 3 treatments with 2 and 5 carbofuran applications also received 0.375 kg ai butachlor/ha.

Invertebrates recorded are listed in Table 49. The dynamics of their populations followed a similar pattern in most plots (Fig. 30) with a peak of chironomid and mosquito larvae at 12 DT and of ostracods, the most abundant organisms, at 40 DT. Populations of ostracods, and chironomid and mosquito larvae were much more abundant in the plots receiving the largest quantity of agrochemicals than in fallow plots.

The comparison of treatments with different levels of N fertilizer or pesticide showed a marked effect of N fertilizer on algivorous aquatic arthropods (ostracods and chironomid and mosquito larvae, (Fig. 31) but no significant effect of pesticides. Neither N fertilizer nor pesticides significantly affected the populations of copepods and cladocerans, which developed late in the crop cycle.

Pesticide application inhibited the development of aquatic oligochaete populations. A clear negative correlation between BGA growth and the level of applied fertilizer was observed. Deep placement

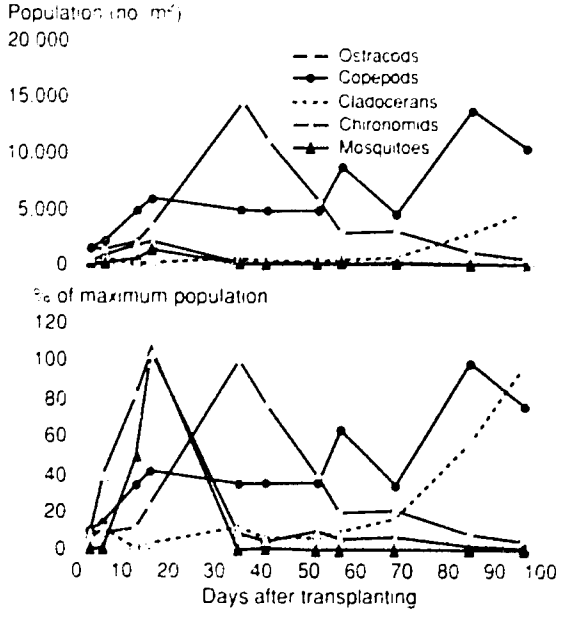
Table 49. Effect of N fertilizer and carbofuran on aquatic invertebrates and N_2-fixing BGA populations.[a] IRRI, 1990 DS.

Organisms	Rice fallow vs planted	N fertilizer		Carbofuran		
		Deep placement	Increasing level	At 4 levels 110 N	At 2 levels 55 N	With 2 levels azolla
Ostracods	-	0	+++	0	0	-
Copepods	0	0	0	0	0	0
Cladocerans	-	+	0	-	0	-
Chironomid larvae	-	---	+++	0	0	0
Mosquito larvae	+	---	+++	0	0	0
Aquatic oligochaetes	nd	nd	++	---	nd	nd
Snails	nd	nd	0	nd	0	nd
N_2-fixing BGA	---	+++	---	+++	+	0
Dissolved O_2 (0-20 d)	---	---	+++	0	0	0

[a] 0 = no effect; + or - = not very marked, possibly incidental, positive or negative effect; +++ or --- = clear positive or negative effect; nd = no data

markedly decreased the inhibitory effect of N fertilizer on BGA growth (Fig. 32). Some stimulating effect of pesticide application was observed on BGA abundance and on photosynthetic activity in the floodwater.

This experiment, conducted at rates of agrochemicals currently used in farmers' fields, shows a stimulatory effect of N fertilizer on algivorous aquatic arthropods associated with increased primary productivity in floodwater. Pesticides had no marked effect on these organisms at the crop cycle level.



30. Dynamics of zooplankton populations during a crop cycle. IRRI farm, 1990 DS. Average of 13 treatments with 5 replications

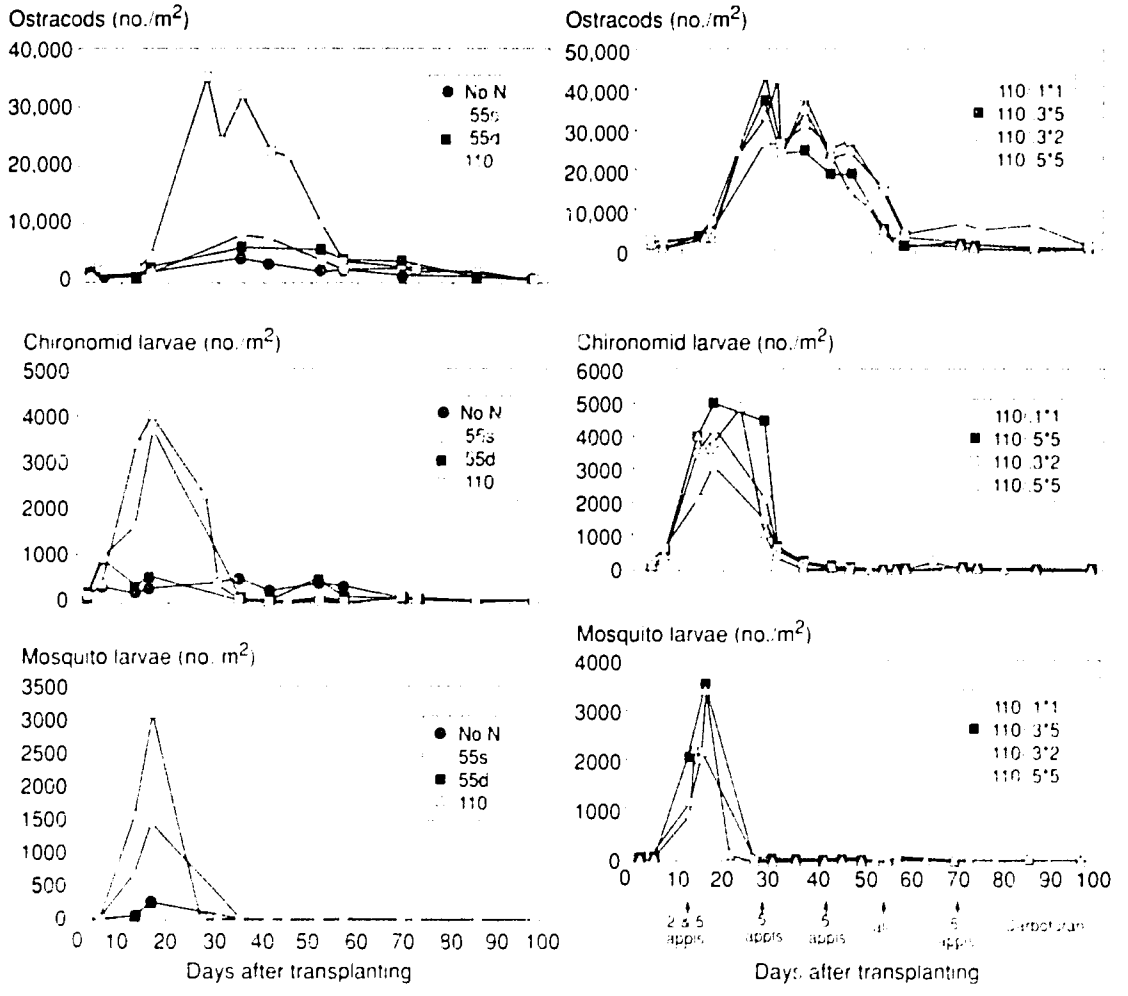
Among tested invertebrates, only aquatic oligochaetes were significantly inhibited by pesticide application. This indicates that pesticide use might reduce the translocation into deeper soil of recycled nutrients accumulating at the soil/water interface, and thus reduce their availability to rice plants.

Broadcasting N inhibited the growth of N_2-fixing BGA and favored the growth of eukaryotic algae. But agrochemical use did not markedly reduce primary production in floodwater. By favoring algivorous aquatic arthropods, it also favored nutrient recycling.

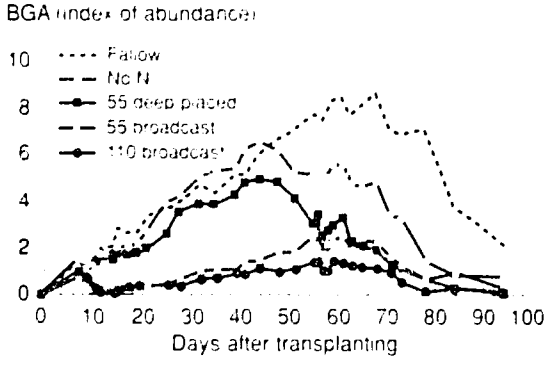
Conclusion

The common theme that emerges through this report is the increasing complexity of the environment for sustaining productivity growth in irrigated rice. This increased complexity is particularly manifested in the need to improve the management and efficiency of use of scarce resources utilized in rice production. A significant shift in the yield frontier and more efficient input utilization could lead to a more rational exploitation of the agricultural resource base.

Prospects for shifting the yield frontier through changes in plant architecture are high within the 7- to 10-yr horizon. Hybrid rices for tropical conditions should be available within the next 5 yr. With both technologies, yield increments of 25% could be expected. Input efficiency gains can be expected through better fertilizer placement and incorporation, integrated pest management, the switch from transplanting to direct seeding, and more judicious water use. The increase in productivity and incomes



31. Dynamics of zooplankton populations in a plot receiving various levels of N fertilizer and pesticides, IRRI farm, 1990 DS. 55s = 55 kg N/ha split broadcast, 55d = 55 kg N/ha deep placed, 110 = 110 kg N/ha split broadcast, 1*1 = one application of 0.1 kg ai carbofuran/ha, 3*5 = 3 applications of 0.5 kg ai carbofuran/ha each, etc. appls. = applications



32. Dynamics of N-fixing BGA populations during a crop cycle under five N fertilizer managements, IRRI farm, 1990 DS. N in kg/ha. Index of abundance: 0 = nil, 10 = full coverage of the floodwater

from these efficiency-increasing technologies are highly sensitive to the farmer's skills and efficiency in utilizing them. Adoption of these technologies would require a closer interface between the research and extension system and between national and international research efforts.

Research programs
Rainfed lowland rice ecosystem

SUBPROGRAM I: SUSTAINABLE RESOURCE MANAGEMENT 66
- Determinants of low productivity in the rainfed lowlands 66
  - Rapid characterization of rainfed lowlands (SS) 66
  - Future directions 68
  - A method for extrapolating rainfed cropping systems by land type (APA) 68
- Crop establishment 69
  - Beusani (APA, AE) 70
  - Root growth (APA) 72
  - Weed dynamics in rainfed lowland ricefields in Northeast Thailand (APA) 72
  - Future research 73
- Technologies for crop intensification 73
  - The farm reservoir optimization model (SWS) 73
  - Land characterization for designing intensified cropping systems (APA) 76
  - Next-step activities 77
- Legume/BNF in rice-based cropping system 77
  - Relative contribution of stem and root nodule in nitrogen fixation of *S. rostrata* (SM) 77
  - Intercropping sesbania green manure with mungbean at different row ratios under rainfed condition (APA) 79
  - Postrice food forage production systems (APA) 80
  - Concluding discussion and future research 82
- Integrated nutrient management 82
  - Measurement of ammonia volatilization following incorporation of urea, *Sesbania rostrata*, and *Aeschynomene afraspera* in flooded transplanted IR72 (APA) 82
  - Management of urea fertilizer (APA) 83
  - Dissolution of phosphate rock and partially acidulated phosphate rock fertilizers in acidic lowland rice soils (APA) 85
  - Sulfur in flooded soil (APA) 87
  - Future research 88

SUBPROGRAM II: GERMPLASM IMPROVEMENT 89
- Physiology, genetics, and screening methods (PBGB) 89
  - Photoperiod sensitivity (PBGB) 89
  - Drought resistance (APA, PBGB) 90
  - Future research 92
- Breeding and evaluation 92
  - Evaluation of advanced breeding lines (APA, PBGB) 93
  - Field plot techniques for rainfed lowland rice (PMSB) 93
  - Varietal adaptation to drought- and submergence-prone rainfed lowland conditions (APA, PBGB) 94
  - Future plans for rainfed lowland rice program 96

Previous Page Blank

Rainfed lowland rice ecosystem

Considerable increases in rice production in recent years have come from the rainfed lowland area. In many countries in South and Southeast Asia, rainfed lowland rice is a priority area for rice production. India's eighth five-year plan has designated rainfed rice areas, which cover most of northeast India, as priority areas. Relative to other ecosystems, the proportion of rainfed lowland areas will increase with shrinkage in some ecologies and less expansion of irrigated rice areas. Hence, there is an urgent need to develop better technologies for rainfed lowland rice.

In 1990, seven research projects focused on priority areas of activities. A decision was made to consolidate two projects in subprogram II into one unified, clearly delineated project. Consolidation took place in January 1991.

Funding from ADB will augment core funds and help in implementing IRRI's strategy of decentralizing research efforts and solving problems of the ecosystems concerned by drawing on the respective strengths of the members. In 1990, eight key sites were chosen in six countries for the rainfed lowland rice consortium. Selection of sites was based on specific constraints that they represented within the rainfed lowland rice ecosystem.

From 1991 through 1994 and perhaps beyond, greater efforts are contemplated for eight key sites and, if necessary, for additional satellite sites.

Subprogram I: Sustainable resource management

Determinants of low productivity in the rainfed lowlands

Rapid characterization of rainfed lowlands

Rapid surveys of the rainfed environments in the Philippines, Thailand, East India, Cambodia, and Nepal were conducted to develop a quantitative understanding of the agroecology of the rainfed lowlands of Asia and the constraints to sustained productivity growth. Land use, technology, input, and other economic data were collected, and detailed farmer resource assessment and technical knowledge information was obtained. General findings from the survey are summarized below.

Resource-poor farmers possess sound technical knowledge pertaining to

- the risks, problems, and potentials corresponding to landforms, soil types, and hydrologies as they vary by local landscape,
- rice varieties adapted to such ecosystems,
- corresponding management strategies.

Characterizations of landscape position, soil type, hydrology, flood and drought risk, suitable land uses and problems were detailed and closely matched to hydrological conditions. Farmers differentiated between upland and lowland, and then divided lowland rice areas into upper, middle, and lower terraces, and into subcategories reflecting variations over local landscapes (Table 1). In East India, for instance, differences in water table depth between upper and lower terraces were 0.2 to 0.8 m in the wet season (WS) and 0.5 to 2.0 m in the dry season (DS).

Table 1. Some farmer categories for lower, middle, and upper rainfed lowland terraces or environments.

Lower	Middle	Upper
	Cambodia	
sre-kraum (lower rice) trapeang (rice pond) chumrau (high bunded)	kandal (middle plain)	sre leu (upper rice)
	Southern Laos and NE Thailand[a]	
din lum (lower) kan (intermediate) don (upper)	tommada (normal) pon (upper)	non (highest)
	The Terai of Nepal	
khala (lower) jadahaniya (quality rice) itahawa (water all season) samtal (difficult to drain)	madhaym (middle) parsahawa (easy to drain) osahaniya (easy to drain)	danda (upper)

[a]People of NE Thailand and Laos speak the same language, Isai

In the unfavorable rainfed lowlands, upper fields were associated with high drought risk, low productivity, and the use of shorter duration, more drought-tolerant rice cultivars. Farmers described lower fields as poorly drained and prone to flooding, but productive if not flood damaged. Lower terraces were normally planted to long-duration, more submergence-tolerant, photoperiod-sensitive traditional rice cultivars and then fallowed. In the favorable rainfed environments, modern high-yielding irrigated varieties dominate traditional varieties in terms of yield and income. It is only in the drought- and submergence-prone environments that traditional varieties are dominant and continue to be preferred.

Generally, there is consistency across locations within a country and across countries in terms of the levels of purchased inputs and labor used for rainfed rice cultivation and rice yields (Table 2). Less than

Table 2. Input use for rainfed lowland rice production in Southeast Asia.

	Chemical fertilizer N (kg/ha)	Manure (kg/ha)	Labor						Rice yield (t/ha)
			Land preparation	Trans-planting	Weeding	Harvesting	Post-harvest	Total	
Philippines									
Upper paddy	57.00	-	12.25	16.75	27.00	15.70	11.40	83.00	2.4
Lower paddy	56.00	-	11.00	15.00	27.00	15.70	11.40	80.00	3.1
Thailand									
South									
Upper paddy	-	-	-	-	-	-	-	-	-
Lower paddy	23.10	-	1.90	18.75	10.44	30.19	-	61.28	1.9
Central									
Upper paddy	20.00	-	2.60	37.50	18.75	28.12	-	86.97	1.9
Lower paddy	-	-	0.90	18.75	-	14.06	12	45.71	2.4
Northeast									
Upper paddy	17.50	1187.50	13.50	54.50	16.10	56.56	8.25	148.91	1.3
Lower paddy	-	1100.00	7.1	28.25	6.63	27.13	7.37	76.98	1.7
Cambodia									
Upper paddy	35.00	2300	14.00	50.00	19.00	37.00	17.00	137.00	1.6
Lower paddy	22.00	2600	13.00	50.00	27.00	41.00	19.00	150.00	1.8
India									
Faizabad									
Paddy	40.3	3000						116	1.4
Bahraich									
Paddy	27.8	4500						83	1.6

30 kg of N is supplied through chemical fertilizer; the amount is lower in the less favorable rainfed areas. There is some augmentation of nutrient supplies through the addition of farmyard manure (FYM), especially in Northeast Thailand, Cambodia, and East India. Nutrients are usually applied to the upper terraces, with lower terraces benefiting from the runoff. Yields are generally similar across the unfavorable rainfed lowlands; upper terrace yields range from 1.3 to 1.9 t/ha, while lower terrace yields range from 1.6 to 2.4 t/ha. Yields in the favorable rainfed lowlands of the Philippines, where modern variety use is widespread, are substantially higher—about 2.4 t/ha for the upper terraces and 3.1 t/ha for the lower terraces.

Future directions

Participation of farmers in on-farm research is essential to efforts seeking sustainable productivity in the rainfed lowlands, given the dynamic complexity of the agroecosystem and the poverty of most of its farmers. Research in each area should include the collection of traditional cultivars, farmer interviews about crop management, and monitoring of production in different environments. The best combinations of cultivar, environment, and management can then be tested in farmers' fields. Pureline selections may be appropriate in some cases.

Research addressing short- to medium-term soil-related problems focus on

- further study of farmer management, use, and knowledge concerning organic and inorganic fertilizers, leading to the development of appropriate research for improved farmer management and use;
- building upon past use of *Chromolaena odorata*, on-farm systems testing of green manure (GM) suited to excess water (e.g., *Sesbania rostrata* and *Aeschynomene afraspera*) or to water scarcity (*Indigofera tinctoria*) in the postrice DS;
- working with farmers to test ways to raise FYM use efficiency (e.g., management, storage, application timing, combining with inorganic fertilizers and more fuel-efficient stoves);
- complementing and improving the sustainability of farmers' use of FYM, on-farm systems testing of multipurpose trees for fodder, fuel, and fertilizer, and systems for their use by local farmers;
- testing improved animal-drawn tillage implements, direct seeding and dapog seedbeds (seedbed sown without soil on concrete, plastic, or banana leaves) to address the difficulties associated with compacted sandy soil conditions. Generally, taller traditional varieties (TVs) were grown on lower and middle terraces while traditional and improved or specialty rices were grown on the riskier, drought-prone upper terraces.

For the short term, pests and diseases affecting the rice crop must be positively identified, and yield losses and the efficacy of farmer management methods need to be assessed. For weeds, competitive rice plant types, hand weeders, herbicides, row direct seeded rice for upper terraces and ways to reduce weed seed in FYM need to be tested. For the medium to long term, country- and agroecosystem-relevant integrated pest management (IPM) programs are needed. Programs would consider farmers' current low-input strategies and their use of other paddy organisms (e.g., fish and frogs).

Perhaps less than 20% of the rainfed rice area grows plants other than single rice crop per year. Technically, double cropping of rice in the favorable rainfed lowland areas is possible with early-maturing varieties. However, the real potential for increasing cropping intensities lies with nonrice crop production. Among the supply side constraints to crop intensification in the rainfed lowlands, the following deserve special attention: 1) better crop establishment practices for the prerice and postrice crops, 2) better qualitative understanding of the competition for labor between crop and noncrop activities during the nonrice growing season.

A method for extrapolating rainfed cropping systems by land type

Identification of the extrapolation domains for new technology is a crucial stage in the agricultural development process, but it has received little attention. Hence, there is an urgent need for simplified methods that can assist researchers and extensionists to specify relevant extrapolation domains. A major issue is how to assemble and display spatial information in ways that are both practical and convenient for extension specialists to use in guiding farm-level decisionmaking.

We initiated a project to evolve a set of practical procedures to merge the available geographic and crop technology information, and make it available to extension specialists in a practical and convenient format.

The project focused on a set of five municipalities in Cagayan, Philippines: Solana, Tuguegarao, Amulong, Enrile, and Iguig. A set of recent 1:25,000 scale topographic maps was used as the principal base maps. The areas occupied by ricelands were determined from recent Department of Agriculture soil maps, which also supplied area coverage of the soil types (series) with information on surface texture, drainage class, and slope class. The irrigated areas were distinguished from the rainfed by the irrigation map of the National Irrigation Administration, Solana office. Landforms were identified from the map of Bruce and Morris (1981).

Data and mapping unit boundaries from the thematic maps were transferred onto the topographic base maps. The mapping scales (the map-to-ground-distance ratio) varied. Therefore, the map entities (points, lines) from the respective maps were transferred, using a mechanical pantograph. The result was a composite map containing administrative units, soil types, landform units, and land use units (irrigated and rainfed ricelands).

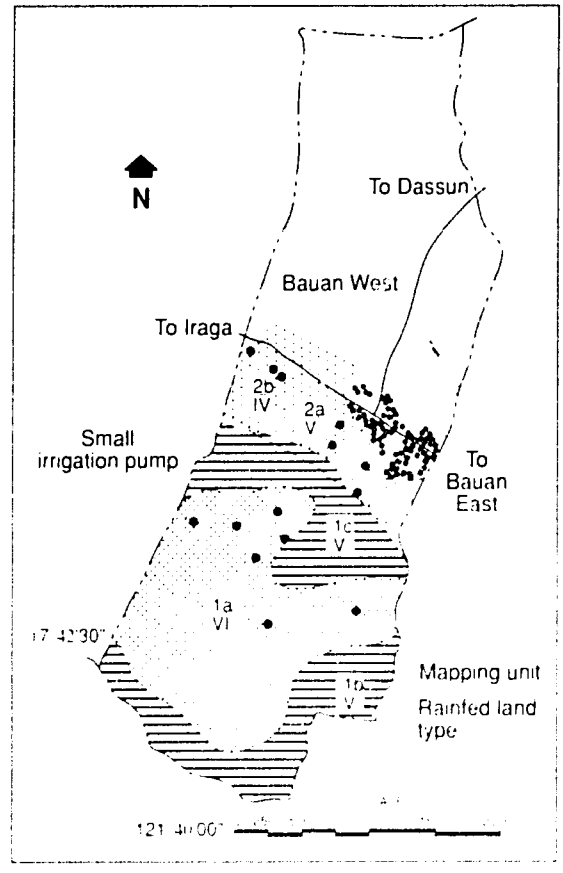
A set of six rainfed land types were defined by correlating the landform, soils, hydrology, and crop adaptation information from 12 research sites in the study area. They were designated on the basis of overall hydrological conditions, and were arranged as follows:

I. Favorable rainfed
II. Submergence-prone
III. Drought-prone
IV. Drought- and submergence-prone
V. Submergence- and drought-prone
VI. Waterlogged, severely submergence-prone

The nature of the drought and submergence threat, length of hydrological year, soils, and representative locations for each rainfed land type were specified. The current cropping patterns were determined for each land type and a set of suggested cropping patterns was specified.

Figure 1 shows the barangay map for Bauan West, Solana. It contains five mapping units corresponding to two rainfed land types. The nonrice portions of the barangay are unshaded. Most of the nonrice cropland in the five municipalities was planted to maize.

The rice geographic data base had 20 attributes, entered in separate columns. The section for Bauan West, corresponding to the map in Figure 1, is shown in Table 3.



1 Rainfed land type map of barangay Bauan West, Solana, Cagayan, Philippines

The final product of the project was a series of field manuals composed for extension specialists. For each barangay, maps of the rainfed land types and the geographic data base were printed on facing pages. The text included instructions on how to use the information for various purposes, including advice to farmers on the directions in which cropping patterns can be intensified.

The ultimate success of the geographic information system will depend on its institutionalization within the extension system, and the continual improvement of the quality and quantity of its contents. This effort will require a coordinator responsible for data base maintenance and development, and microcomputers dedicated to this task at the provincial and regional levels.

Crop establishment

The first problem faced by farmers of rainfed lowland rice is the establishment of a good crop stand

Table 3. Rice geographic data base for barangay Bauan West, Solana, Cagayan, Philippines.

	Bauan West (856 ha total land area)				
Mapping unit	1a	1b	1c	2a	2b
Culture type	RFE	RFE	RFE	RFE	RFE
Rainfed land type	VI	V	V	V	IV
Rice area (ha)	225.6	85.6	76.3	11.9	81.9
Landform	AT	AT	AT	AT	AT
Soil type	192	192	192	903	903
Soil texture	F	F	F	M	M
Soil drainage	P	P	P	P	P
Slope class	A	A	A	A	A
pH	8.3	8.3	8.3	6.2	6.2
OM (%)	2.3	2.3	2.3	1.6	1.6
P	28.7	28.7	28.7	29.3	29.3
K	420	420	420	500	500
Soil fertility	VH	VH	VH	H	H
Fertilizer recommendation (kg NPK/ha)	55-20-0	55-20-0	55-20-0	70-20-0	70-20-0
Variety	LV	LV	LV	LV	LV
Yield (t/ha)	2.0	2.0	2.0	2.0	2.0
Present cropping pattern	F- TPR - F	F- TPR - F	F - TPR - F	F - TPR - F	F - TPR - F
Suggested cropping pattern	TPR(LV) or DSR(LV) - F	WSS (Sesb) - TPR (IC)	WSS (Sesb) - TPR (IC)	WSS (Sesb) - TPR (IC)	Mg (rp) - TPR (IC) - F
Remarks	10 small water irrigation pumps in the barangay				

[a]Mapping unit refers to Fig. 1. Culture type: RFE = rainfed, IRR = irrigated. Landform type: AT = alluvial terrace. Rainfed land type: IV = drought- and submergence-prone, V = submergence- and drought-prone, VI = waterlogged, severely submergence-prone. Soil type: 192 = Bigaa clay, 901 = Quingua silty clay loam, 903 = Tagulod clay loam. Soil texture: F = fine, M = medium. Drainage: P = poor, W = well. Slope class: A = 0.0 to 1.0%, flat or level land. pH: Soil acidity index = >7.5 alkaline, 6.5-7.5 neutral, <6.5 acidic. OM = organic matter content. P = available phosphorus (P_2O_5) level (ppm). K = exchangeable potassium (K_2O, ppm). Soil fertility level: H = high, VH = very high. Variety dominant: LV = local variety, photoperiod sensitive; MV = modern variety. Present cropping pattern: TPR = transplanted rice, F = fallow. Suggested cropping pattern: DSR = direct seeded rice; WSS = wet seeded sesbania green manure; IC = improved rice cultivar, intermediate height, medium maturity; Mg(rp) = mungbean ridge planting).

without which they cannot justify use of inputs needed for increasing productivity. Results of research on a system of dry seeded rice (DSR) management in eastern India, on the effect of establishment method on root growth and on weed ecology in rainfed lowland rice are reported in this section.

Beusani

Farmers of rainfed lowland rice in eastern India follow a unique crop establishment practice called beusani (also biyasi, bidahani). The farmers dry seed rice before the onset of monsoon rains, then plow the fields 30-50 d after seedlings have emerged (DE) when there is standing water in the field. After plowing through the seedlings, farmers ladder or plank the field and redistribute seedlings to fill gaps. Yields of beusani rice tend to be very low.

Experiment 1. Field experiments were conducted with IR64 in 1989 DS and IR72 in 1990 DS to evaluate the effects of different beusani operations on rice, weeds, and soils. We used a split-plot design with five replications. Main plot treatments were 3 establishment methods: 1) broadcast DSR (BDSR); 2) row-seeded DSR with 25 cm between rows on dry soil (RDSR); and 3) transplanted rice (TPR) at 25- × 25-cm hill spacing in puddled soil. To synchronize maturity of all main plot treatments, DSR was established 7 d after sowing the seedbed for TPR, and 20-d-old seedlings were used for TPR. Subplot treatments employed 4 crop management practices: 1) no additional treatment (control), 2) wet plowing through seedlings at 45 DE (plow), 3) P plus laddering (beusani), and 4) chemical plus hand weeding (weeded). Before puddling plots for TPR, the DSR plots were sprinkler-irrigated to germinate seeds. After puddling for TPR, all plots were flood-irrigated.

Although RDSR had greater root length density than BDSR or TPR 4 d after plow and beusani treatments (Table 4), there were no significant ef-

Table 4. Root length density of IR72 at 4 d after beusani. IRRI, 1990 dry season (DS).

Establishment method[a]	Root length density[b] (km/m³)			
	0-5 cm	5-10 cm	10-20 cm	20-40 cm
Row seeded DSR	48.4 a	16.4 a	5.51 a	0.995
Broadcast DSR	28.3 b	10.4 b	3.10 b	0.680
TPR	24.3 b	11.2 b	3.84 b	0.868

[a]DSR = dry seeded rice. TPR = transplanted rice. [b]In a column, means followed by a common letter are not significantly different at the 5% level by LSD.

fects on root length at any soil layer 16 d later. Nor did crop establishment or management treatments have significant effects on soil penetration resistance. Apparently, as long as the clay soil of the experimental area is kept flooded, soil penetration resistance and root growth are independent of establishment and tillage.

Establishment method had no significant effect on IR64 yield in 1989, but the weeded treatments yielded more (1.75 t/ha) than all other management practices ($P<0.05$). In 1990, a significant interaction between establishment and management treatments resulted from uniformly high yields in all TPR treatments and all weeded treatments (Table 5).

Experiment 2. Low yields of beusani rice may be partly attributed to poor soil fertility and minimal use of fertilizers by farmers. As rapid onset of monsoons precludes opportunities for a prerice green manure (GM) crop, a field experiment was conducted at IRRI to evaluate the potential for intercropping GM with DSR. Four establishment and GM treatments were tested: 1) beusani: broadcast DSR with plowing, cross plowing, and planking at 38 d after sowing (DAS); 2) GM: paired row DSR (7 and 33 cm between rice rows) and *Aeschynomene afraspera* grown as GM in the 33-cm interrows until incorporation at 38 DAS; 3) urea: paired row DSR with weed incorporation at 38 DAS; and 4) trampling: paired row DSR with weed incorporation and additional trampling by foot to apply pressure to the soil similar to GM incorporation. For all treatments except GM, 30 kg urea N/ha was incorporated before sowing and 20 kg urea N/ha was incorporated during beusani or weeding at 38 DAS.

Initial plant population was greater than 250 seedlings/m² for all treatments (Table 6), usually more than adequate for rice. But however great the seedling population, beusani plots still had large gaps. At harvest, there were greater numbers of tillers in the GM treatment than in all other treatments. In this experiment GM incorporation and trampling reduced water infiltration compared to that in the beusani and urea treatments. This result differs from what was reported by scientists in eastern India. This may indicate that we were not adequately simulating beusani operations as performed by farmers. The high yield in the GM treatment indicates good potential for this practice in areas where beusani is practiced. Grain yields were also higher in the GM and trampling treatments than in the beusani and urea treatments (Table 6), suggesting that excessive water infiltration reduced yields.

Diagnostic survey. To better understand the rationale for beusani and to establish needs for future research, we conducted a diagnostic survey in Orissa, India, during July 1990. We found that farmers prefer TPR, but practice beusani when there is inadequate water control or constraints of time or labor availability during critical periods for TPR. Farmers practice DSR with beusani because it is the fastest method of planting the largest area.

Table 5. Grain yield of IR72 in response to crop establishment and management treatments. IRRI, 1990 DS.

Management practice	Grain yield[a] (t/ha)		
	Direct, dry seeded		Transplanted
	Row	Broadcast	
Control	0.56 b	0.67 b	3.11 a
Plowed	1.03 b	1.05 b	2.60 a
Beusani	1.26 b	1.01 b	2.59 a
Weeded	2.68 b	2.73 a	2.48 a

[a]Means followed by a common letter are not significantly different at the 5% level by LSD.

Table 6. Effects of rice establishment, nutrition, and post-emergence tillage on stand density, water infiltration rate, and grain yield. IRRI, 1990 wet season (WS).[a]

Treatment	Seedling density, 14 DAS (no./m²)	Tillers at harvest (no./m²)	Water infiltration 38 DAS (mm/d)	Grain yield (t/ha)
Paired row, GM[b]	302	428	7	3.7
Paired row, urea	278	345	13	2.6
Paired row, urea and trampling	260	345	7	2.9
Broadcast, beusani	283	343	19	2.1
Pooled standard error of mean	22	15	2	.14

[a]DAS = days after seeding. [b]Green manure.

The results suggest that research is needed to make more efficient use of resources in DSR. Additional characterization of the farming system is needed including surveys to establish baselines, to measure changes in DSR and TPR yields and areas over time, and to relate DSR and TPR to hydrology and weed population dynamics. In declining priority, research must focus on: 1) reducing labor requirement for weed control in DSR, e.g., by improving local farm implements; 2) improving crop stands with DSR; 3) reducing soil compaction in DSR; and 4) improving cultivars for DSR.

Root growth

In cooperation with the University of Arkansas, field experiments were conducted at IRRI to investigate the effects of crop establishment method on rice root systems using a minirhizotron system to observe roots. A split-plot design with five replications was used. Main plot treatments were wet sowing and transplanting, both with 20- × 20-cm hill spacing. Both establishment methods were done on the same day in a puddled continuously well-watered field. Subplot treatments were four cultivars: Binato, IR20, IR46, and IR72. After harvest, all plots were ratooned and observations continued.

Total root length (TRL) was significantly affected by establishment method and cultivar, but there were no significant interactions between the two factors. Seasonal patterns of root growth and development showed that wet seeded rice (WSR) had greater root length than TPR from culm elongation onward (Fig. 2). This result explains previous observations that WSR was more drought resistant than TPR. The fact that TRL decreased from panicle initiation until after panicle emergence may help to explain observations that rice is most susceptible to yield reduction by water deficit during panicle emergence.

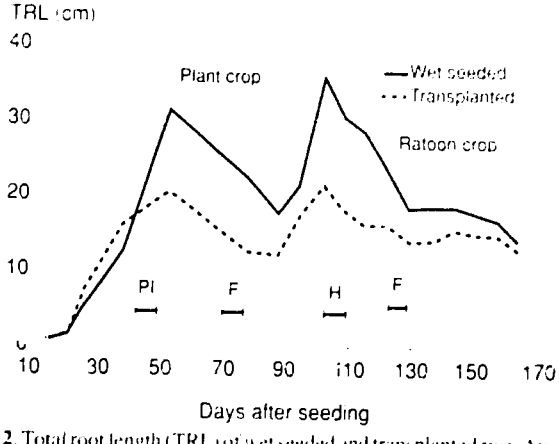
Among cultivars, Binato showed the greatest TRL from panicle initiation of the main crop until panicle emergence of the ratoon crop (Fig. 3). Although TRL of 4 cultivars followed a similar pattern, TRL of Binato and IR46 declined at a faster rate after panicle initiation and increased faster in the ratoon crop than did that of IR20 and IR72.

Weed dynamics in rainfed lowland ricefields in Northeast Thailand

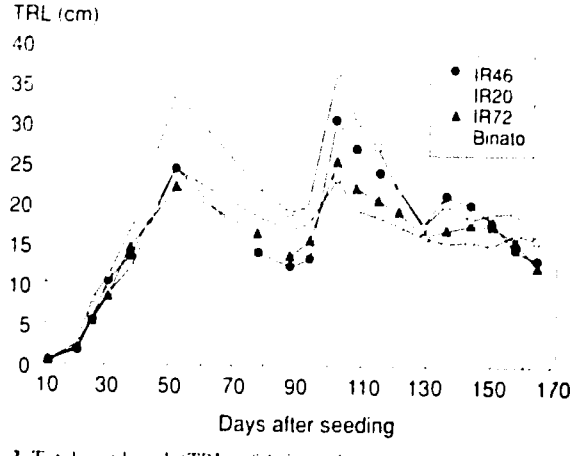
Without floodwater control in rainfed lowland rice, weeds often make land preparation time-consuming and difficult. As a result, rice stand establishment is suboptimal. Understanding weed dynamics and weed succession will help in developing appropriate strategies for integrated weed management.

Weeds were surveyed in 15 lowland ricefields in Ban Khu Khat, Ban Nonyai, and Ubonratchathani Rice Research Center (URRC) during the 1990 WS. The fields covered five hydrological transects and three landscape positions (upper, middle, and lower). Weeds were sampled 3 times: immediately before transplanting, and 1 and 2 mo after transplanting.

Before transplanting, the dominant weeds in upper fields of Ban Khu Khat were grasses such as *Paspalum distichum* and *Cynodon dactylon*, followed by broadleaf weeds such as *Hedyotis tetrangularis* and *H. diffusa*, and some sedges such as *Cyperus pulcherrimus* and *Fimbristylis aestivalis*. In middle fields,



2. Total root length (TRL) of wet seeded and transplanted rice. Av of 4 cultivars. PI = panicle initiation, F = flowering, H = harvest.



3. Total root length (TRL) of 4 rice cultivars.

P. distichum dominated, but in the south transect broadleaf weeds such as *H. tetrangularis* were observed. In lower fields, the major weeds were *P. distichum*, *Digitaria longiflora*, and *H. diffusa*.

Upper fields of Ban Nonyai, which has more fertile soils than Ban Khu Khat, were dominated by grasses such as *D. elongata*. Middle fields had more broadleaf weeds such as *Glinus oppositifolius* and *Coldenia procumbens*.

The URRC study site had the greatest weed density, with upper fields dominated by *Hyptis suaveolens*, middle fields by *Eragrostis* spp., and lower fields by grasses such as *D. longiflora*.

Future research

We will continue research on DSR methods used by rainfed lowland rice farmers in drought-prone areas—including follow-up research on beusani and new research on gogo rancah practiced in Indonesia—and wet seeding methods for more favorable areas. Continued research on weed ecology will evaluate the relationships among weed succession, and establishment method for different landscape positions. Finally, we will initiate research in collaboration with the germplasm improvement project to identify plant traits needed for different crop establishment methods.

Technologies for crop intensification

Cropping intensification in rainfed lowland rice farms usually requires improvement in the availability of water in a drought-prone environment or drainage improvements in submergence-prone areas in order to extend the crop growing season. In many situations, even some marginal improvements in the water status can present opportunities for an additional crop and increased farmer income. Rainwater collected in on-farm reservoirs is an economically viable means to alleviate drought problems in rainfed lowland rice farms. Since the amount of available water in the reservoir as well as other resources of the farmer to grow a second crop after rice are limited, allocation of resources is critical for generation of high incomes. The main objectives of the research reported here were to 1) develop a decision tree model for farmers with on-farm reservoirs to optimize economic returns, and 2) characterize the research sites in eastern India for designing intensified cropping systems.

The farm reservoir optimization model

The farm reservoir optimization model consists of three submodels: 1) water supply reliability submodel, 2) reservoir operation simulation submodel, and 3) crop-area allocation submodel (Fig. 4). Initially, seasonal water supply is estimated based on a desired probability, which is then allocated to different crops using submodel 3. Based on this allocation, reservoir operation is simulated using submodel 2, considering rainfall effectivity. Seasonal water supply is then adjusted and reallocated using submodel 3 to achieve the minimum water deficit or surplus status. Water supply reliability, which describes the chance of attaining an estimated seasonal water supply and expected return, are computed as follows:

$$RL = V0/W + ((W - V0)/W)*P$$

$$ER = RL*(TR) + (1-RL)*((-TC+TR)/2)$$

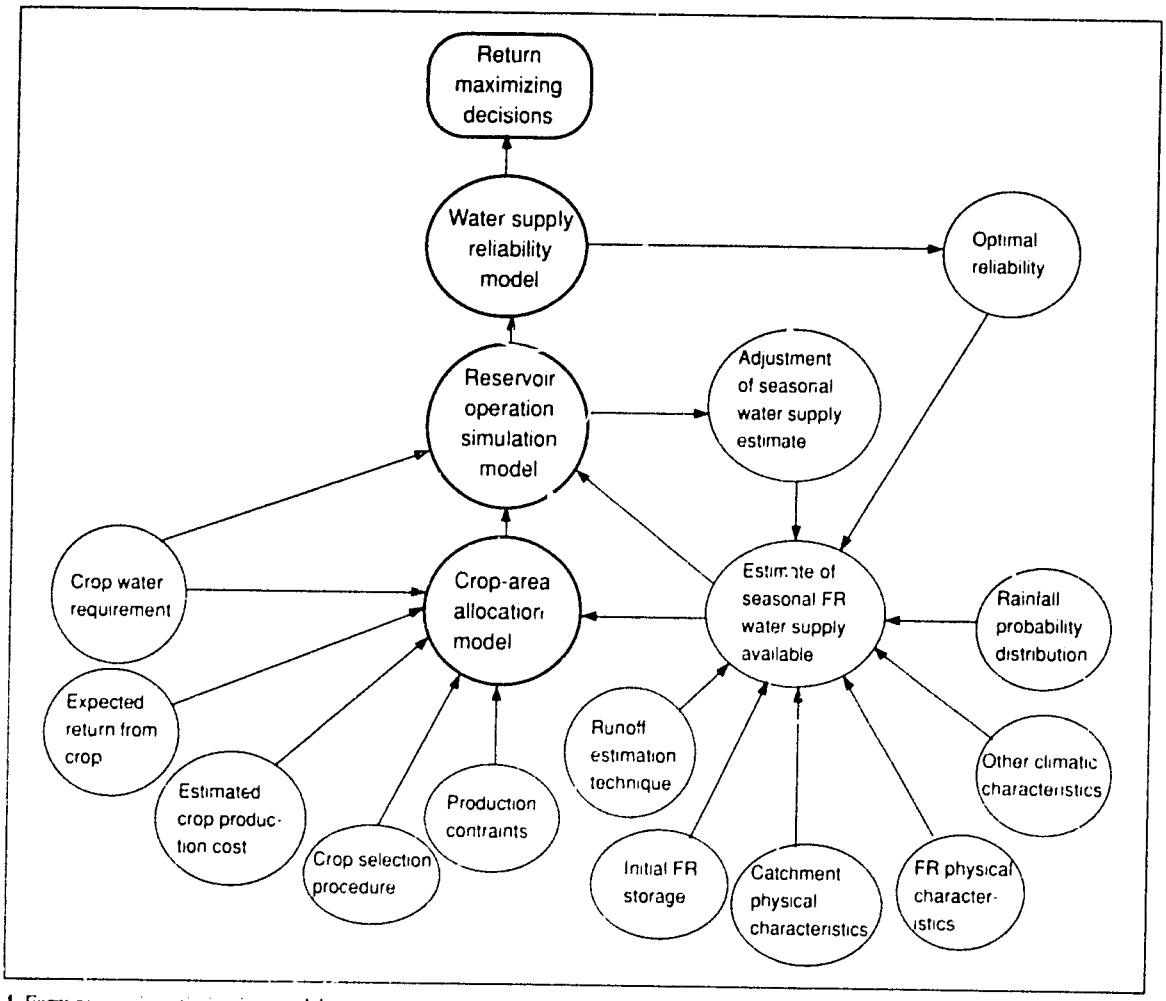
where

RL = water supply reliability (between 0 and 1),
$V0$ = initial reservoir storage (m^3),
W = total seasonal water supply,
= V0 plus expected rainfall during season (m^3),
P = rainfall probability (fraction),
ER = expected return ($),
TR = total return ($), and
TC = total cost ($).

From the definition of water supply reliability, W is composed of initial reservoir storage $V0$, which is 100% assured, and expected rainfall amounts during the season whose reliability is described by a probability distribution. For every probability value specified, there are corresponding ER and RL values. These values will be the inputs to submodel 1 to determine the level of P at which W should be estimated to maximize ER.

Water supply reliability submodel. This is a decision tree submodel to determine the appropriate value of P for estimating seasonal water supply. In this submodel, computed RL values and corresponding ER are evaluated. The cumulative rainfall probability value, which corresponds to a computed RL value that will give the highest ER, will be selected for estimating water supply that will be used in the subsequent submodels.

Reservoir operation simulation submodel. Reservoir operation is simulated using the crop-area



4. Farm reservoir optimization model.

allocation obtained from submodel 3. This submodel simulates water balance in the field and in the reservoir as the crop is grown. Water deficits and/or surpluses are monitored and used as the basis for further iteration until the variance and mean of water deficits and/or surpluses are minimized.

Crop-area allocation submodel. The estimated total seasonal water supply is allocated to different crops using the linear programming technique, which requires the following information:

- Water requirements for land preparation and crop maintenance for each crop.
- Expected income from each crop per unit of area, based on current prices of production inputs and the products.
- Production constraints with regard to available water (both in reservoir and from rainfall), farm size, and capital. An earlier study had established that most farmers want to grow some rice for their own consumption and 0.25 ha was an acceptable minimum area for rice. The model thus considered this mandatory rice area as a constraint.

The objective function can be formulated as follows:

$$\text{Maximize}: \; Z = \sum C_i X_i$$

$$\text{subject to}: \; \sum A_{ij} X_i \; [\leq, =, \geq] \; B_j, \quad X_i \geq 0$$

where

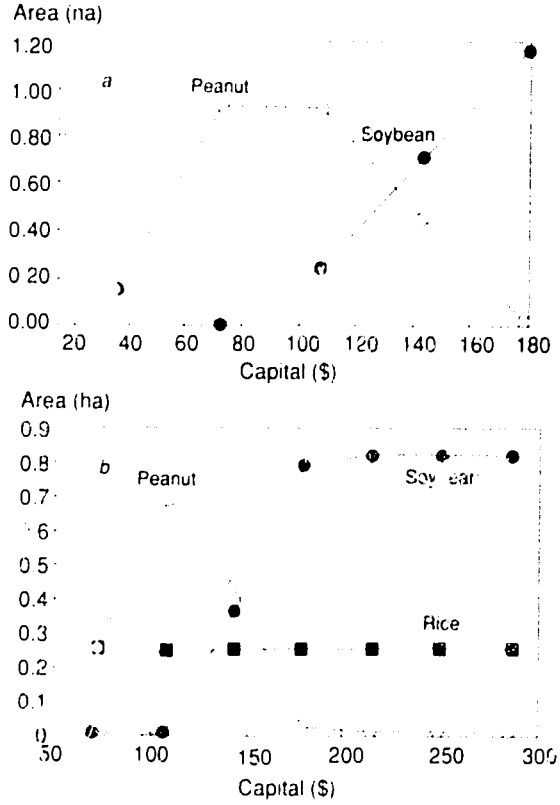
Z = total return,
X_i = ith crop area,
C_i = coefficient (return per unit area) of ith crop,
A_{ij} = coefficient of the jth constraint, for the ith crop area,
B_j = jth resource constraint,
i, j = 1,2,3...

Returns have associated reliability values that describe the chance of attaining them. A higher reliability value would be due to a higher proportion of initial reservoir storage in relation to the total expected water supply for the season.

Model application and evaluation. To evaluate the model's applicability, it was used for four farm reservoirs in Tarlac, Philippines, with known physical characteristics. Twenty-one years of rainfall data were used to estimate rainfall amounts at different probabilities and 17 yr of evaporation records were used for generating average evaporation rates. Four crops, which in earlier research were found most suitable for the area, were considered: soybean, peanut, mungbean, and rice. The model was run under different combinations of limiting situations such as imposing a minimum area for rice, limited capital, and limited water supply.

Results showed that with no constraints on available capital, soybean, with the highest cost and return per hectare among the crops considered, was the only crop chosen by the model for all farm reservoirs (FRs) tested (Table 7). When capital was limited to about $145, soybean and peanut were chosen by the model, the proportion of soybean area increasing as available capital increased (Fig. 5).

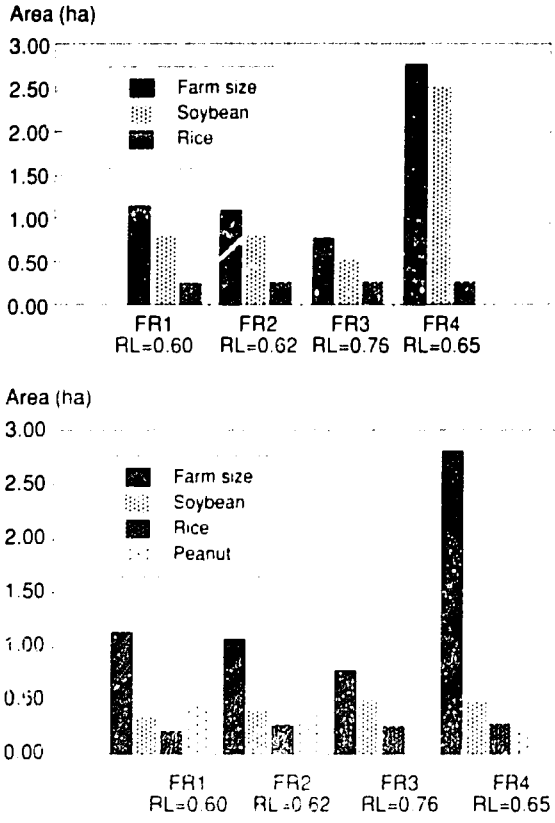
When capital was not limiting, soybean was the only crop chosen after the minimum rice area was satisfied (Fig. 5,6). When capital was very limited (e.g., when capital for FR1 is only about $100), peanut and rice (for the minimum area) were selected (Fig. 5b). Even when capital was limited to $143, the whole farm was used; the exception was FR4, which has a large service area of 2.77 ha (Fig. 6b). For all



5. Crop-area allocation for FR1 at different amounts of capital: a) with no minimum rice area constraint; b) with minimum rice area constraint.

Table 7. Optimum crop-area allocation for 4 farm reservoirs when capital was not limiting, with and without minimum rice area constraint.

Farm reservoir no.	Initial storage (% of capacity	Farm size (ha)	With minimum rice area: Area (ha) Rice	Soybean	Return ($)	Reliability	With no minimum rice area: Area for soybean (ha)	Return ($)	Reliability
1	50	1.15	0.25	0.69	328	0.56	1.14	496	0.56
	80		0.25	0.77	362	0.58	1.15	497	0.58
	100		0.25	0.82	384	0.60	1.15	497	0.60
2	50	1.08	0.25	0.64	308	0.57	1.08	466	0.57
	80		0.25	0.73	346	0.60	1.08	466	0.60
	100		0.25	0.79	371	0.62	1.08	466	0.62
3	50	0.75	0.25	0.50	245	0.68	0.75	324	0.63
	80		0.25	0.50	245	0.73	0.75	324	0.73
	100		0.25	0.50	245	0.76	0.75	324	0.98
4	50	2.77	0.25	2.50	1112	0.59	2.77	1197	0.59
	80		0.25	2.52	1112	0.62	2.77	1197	0.62
	100		0.25	2.52	1112	0.65	2.77	1197	0.65



6. Crop-area allocation for average (P=0.50) condition of rainfall, a) with minimum rice area of 0.25 ha and no constraint on capital, and b) when capital was limited to $143 and minimum rice area was 0.25 ha. FR = farm reservoir. RL = water supply reliability.

sites, soybean replaced peanut when capital constraint was progressively relaxed, as exemplified by FR1 (Fig. 5b).

Limitation of water supply affected the extent of the area planted to a chosen crop, not the choice of the crop itself. This is because the crop with the highest return per hectare was automatically chosen in the model. If a minimum rice area was considered, the water requirement of rice would be satisfied first and the rest of the cropped area would be allotted to soybean (Table 7), the extent of which would depend on the available water supply. This was especially true for FR1 and FR2, in which higher initial FR storage values produced higher returns. The area allotted to soybean did not vary with initial storage for FR3 and FR4 because even at lower initial storage values of these FRs, there was enough water to meet the requirements of the entire farm for these crops. The model was found sensitive to climatic parameters and resource availability constraints that influenced cropping decisions for small farms in rainfed areas. It promises to be a useful decisionmaking tool for optimal economic returns from such farms.

Land characterization for designing intensified cropping systems

A study conducted in collaboration with the Narendra Dev University of Agriculture and Technology, Uttar Pradesh, India, identified and analyzed physical factors constraining crop intensification in rainfed lowlands. Surface and subsurface hydrology, climatic data, landscape position of the fields, soil type, length of crop growing season, major crops and their methods of establishment, and crop management practices were monitored from October 1989 to December 1990 in 18 selected rainfed villages covering about 1,900 ha in 4 village clusters. Frequency and duration of drought and flood in relation to landscape position of fields and crop calendars with respect to the rainfall pattern were analyzed. A summary of the hydrological parameters of these sites is given in Table 8.

Available 5-yr records indicate these sites have a total average annual rainfall of 1,107 mm, with a highly erratic distribution pattern. About 85% of the total rain is received between June and September, but during the period drought spells lasting 2 consecutive weeks may occur. On the other hand, rainfall intensity of as high as 150 mm/d for 2-3 consecutive days is also common. During dry spells, soils crack in the upper paddies, but the lower portions remain moist. Thus when high rainfall occurs following drought spells, the upper paddies cannot hold

Table 8. Summary of hydrological parameters for selected rainfed lowland rice areas in Uttar Pradesh, India.

Annual total rainfall (mm)	1000-1200
Water table depth (m)	
Wet season	1.2-2.7
Dry season	1.8-5.7
Surface water depth (cm)	
Upper paddies	10-15
Mid-paddies	30-40
Lower paddies	50-60
No. of drought spells/season	1-2
Duration (d) of drought at each occurrence	15-20
Percent of total area classified as	
Drought prone	35
Drought and submergence prone	48
Submergence prone	17

water well and the lower paddies, where drainage outlets are limited, quickly accumulate water.

About 35% of the whole area is drought-prone, 48% drought- and submergence-prone, and the remaining 17% submergence-prone. Drought-prone areas generally suffer two drought spells, while drought- and submergence-prone areas suffer one drought spell in WS.

At the sites in Mungeshpur and Masodha village clusters, the first drought usually occurs during late August to early September and the second one in mid-October to early November. Farmers reported that normal droughts last up to 2 wk, but once in about 7 yr, a severe drought lasting more than 1 mo occurs. Drought is less severe in Chandpur and Sariyawan village clusters, which are in the lower landscapes. However, these sites suffer from flood damage in WS and delays in planting DS crops.

On the basis of the results, one site and several farmer cooperators were identified for each of the following studies aimed at increasing cropping intensity and land productivity: 1) rainwater collection and use at Mungeshpur, 2) utilization of shallow groundwater through low lift pumping devices at Masodha, 3) flood damage alleviation through drainage of excess water and using it for irrigating upper fields at Chandpur, and 4) adjustment of crop planting schedules, and use of suitable crop varieties and improved tillage practices at Sariyawan. Field experiments addressing items (2) and (4) have been established in 1990-91 DS. Other studies will be conducted beginning 1991 WS.

Next-step activities

On-going activities within the project continue to focus on developing strategies and methods for increasing cropping intensity and income of farmers in rainfed lowland rice environments. These include

- alleviating drought by better conservation of rainwater, and developing a simple procedure for use of the optimal decision model by farmers and technicians for allocation of resources;
- study of the effects of crop establishment methods, cropping patterns, and weed control measures on weed growth and crop performance, and of the effects of tillage and weeding on rice on the succeeding legume crops;
- field-testing of selected strategies to improve land use in eastern India sites; and
- understanding the role of hydrology and soil-water regime in farmers' decisionmaking for WS rice management practices, and in their choice of prerice and postrice cropping beginning 1991 WS.

Legume/BNF in rice-based cropping system

Farmers are reluctant to use purchased inputs for rainfed lowland rice-based cropping systems because climatic adversities often lead to low yield or crop failure. Consequently, farm productivity of this cropping system remains consistently low and often erratic. The overall objective of this project is to find ways to increase productivity through the efficient use of legumes/biological nitrogen fixation and soil N.

Relative contribution of stem and root nodule in nitrogen fixation of *S. rostrata*

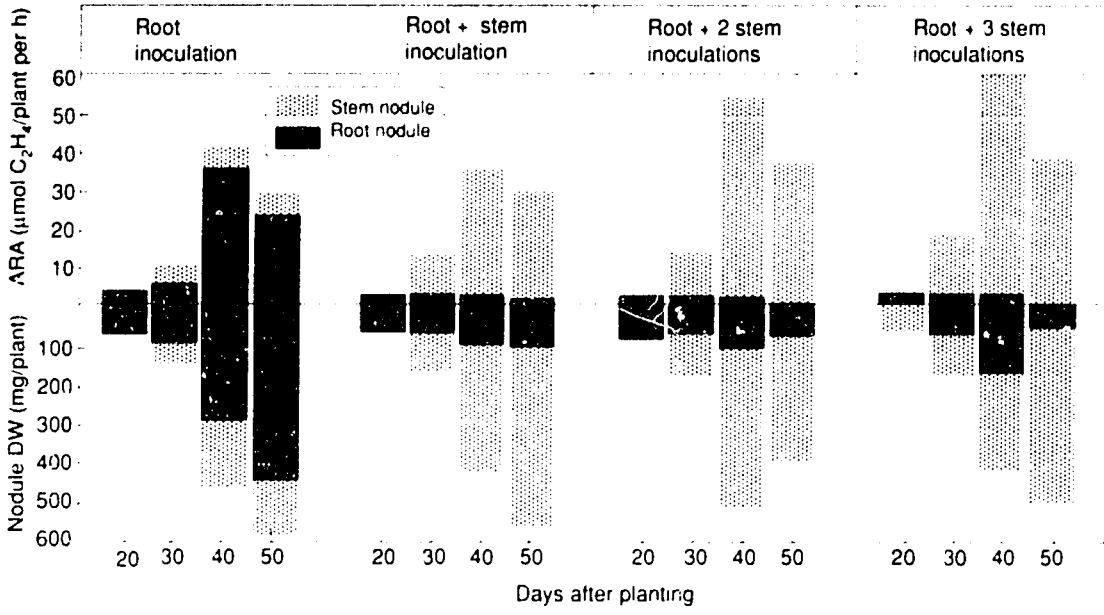
It is often presumed that stem nodulation is a better N_2-fixing system than is root nodulation, particularly under submergence. However, the relative N_2 fixation of root and stem nodules and how they affect one another is not known.

The objective of the study was to

- assess the contribution of N_2 fixation by stem nodules in the presence and absence of root nodules in *Sesbania rostrata* (SR); and
- compare N_2 fixation of the double-nodulating system *S. rostrata* with that of single-nodulating system *S. cannabina*.

Six experiments, two each in the phytotron, greenhouse, and field, were conducted under submerged conditions. Single and dual nodulation were achieved by inoculating either root or stem, or both. Nodule dry weight (DW), plant DW, nitrogenase activity (acetylene-reducing activity [ARA]), and percent contribution from N_2 fixation (^{15}N dilution, Ndfa) were measured at regular intervals. In the greenhouse experiment, the effect of detaching already formed stem nodules on restoration of root nodules and nitrogenase activity was examined. The field experiment compared *S. rostrata* and *S. cannabina*.

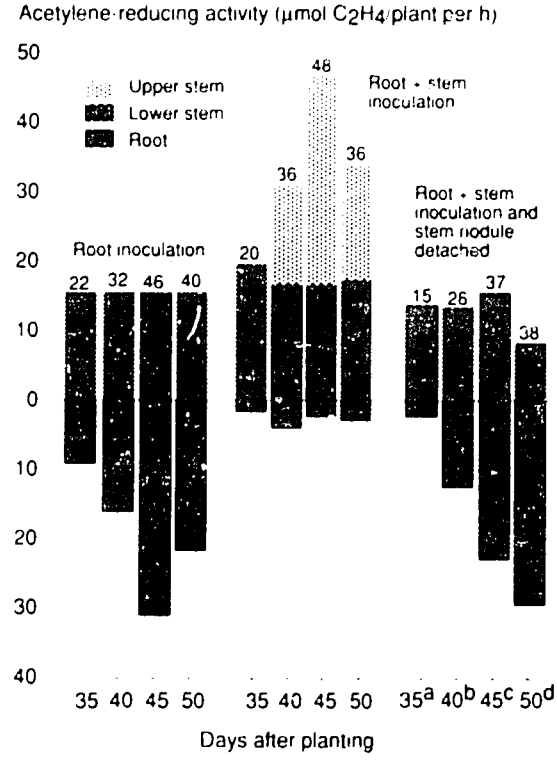
Total nodule DW, ARA, and Ndfa increased with age. Fifty days after planting (DAP), nodule DW ranged from 131 to 600 mg/plant or 22-45 mg on pergram plant DW basis. ARA peaked at 30 DAP in the



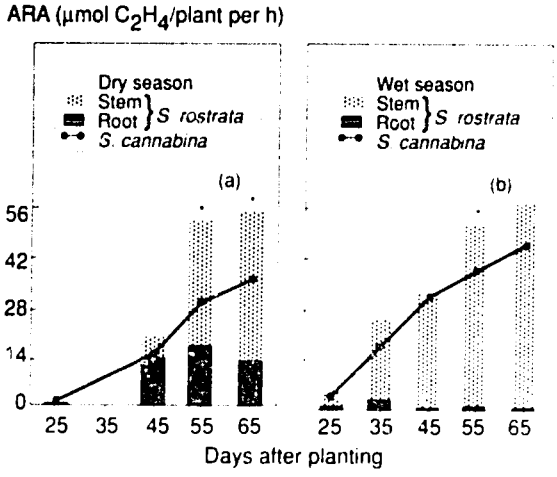
7. Effect of root and root + stem inoculation on nodule dry weight (DW) and ARA of root and stem nodules of *S. rostrata* grown in the greenhouse

phytotron and at 45-55 DAP in the greenhouse and field. Ndfa increased from 65% at 25 DAP to 85% at 50 DAP in the greenhouse in WS. Nodule DW, ARA, and Ndfa did not differ significantly among treatments with root inoculation alone or with root plus single or multiple stem inoculation. Stem inoculation decreased the root nodule DW and ARA significantly (Fig. 7,8). At 50 DAP, the contribution of root nodule DW and ARA in stem-inoculated treatments was less than 20%. The root nodule DW increased from 82 to 361 mg/plant and root nodule ARA from 2 to 29 µmol C_2H_4/plant per h within 15 d of detachment of aerial stem nodules. However, the DW and ARA of nodules on submerged stems in a) root inoculation, b) root plus stem inoculation, and c) root plus stem inoculation and aerial stem nodule detachment were unchanged (Fig. 8). In the field, stem nodules were readily formed and suppressed root nodulation, thus accounting for more than 75% of total nitrogenase activity. *S. rostrata* showed higher ARA than *S. cannabina*; it was significant at 55 and 65 DAP in DS and 55 DAP in WS (Fig. 9).

Dry weights were higher with stem nodulated plants than those with root nodulation (7.8 vs 11.2, 15.7 vs 20.7, and 13.0 vs 15.0 g/plant at 50 DAP in 3 experiments, respectively) in the phytotron and the greenhouse. In the field, increase in DW was more rapid in *S. rostrata* than in *S. cannabina*. At 55 DAP,



8. Effect of root and root + stem inoculation, and stem nodule detachment on root nodule ARA and stem nodule (upper and lower) ARA of *S. rostrata* grown in the greenhouse. Numbers on the top of bars are total (root + stem nodule) ARA (µmol C_2H_4/plant per h). a, b, c, d represent 0, 5, 10, and 15 d after the detachment of upper stem nodules, respectively.



9. ARA of root and stem nodule of *S. rostrata* and of root nodule of *S. cannabina* grown in the field in dry season (DS) and wet season (WS). * = significant difference at the 5% level

the dry weights of *S. rostrata* were significantly higher than those of *S. cannabina* (20.1 vs 26.3 and 16.8 vs 30.9 g/plant at 55 DAP in DS and WS, respectively).

When root-nodulating *S. rostrata* developed stem nodules by inoculation, root nodule DW and ARA sharply declined; root nodule and ARA were restored when stem nodules were removed. The control mechanism is probably the stem nodule's proximity to the photosynthetic apparatus, which permits them to control the supply of photosynthate to root nodules. The better growth of stem-nodulating plants may be due to an "O_2-sparing" effect of stem nodules, i.e., stem nodulation reduces the plant's demand for O_2. This may be more important when the plant's ability to supply O_2 is impaired by aging.

Intercropping sesbania green manure with mungbean at different row ratios under rainfed condition

Fast-growing and short-duration grain legumes in a prerice rainfed condition provides additional income for the farmer and legume residues as source of organic N. A field trial was conducted to determine the productivity of intercropping sesbania with mungbean (MB) Var Pag-asa 1 at various row ratios in the rainfed rice environment. MB at a seeding rate of 25 kg/ha and sesbania seeds at 30 kg/ha were hand-drilled in furrows 50 cm apart and covered with soil. Sesbania was clipped as fodder 35 DAP to lessen competition with the MB crop at flowering stage.

The treatments were randomly allocated in three replications in Los Baños and four replications in Guimba, Nueva Ecija. Three treatments were 0, 45, and 90 kg N/ha applied to the rice crop; other treatments were intercropping combinations of sesbania and MB at five different row proportions; two others were sole MB and sole sesbania (Table 9).

At Los Baños, sole sesbania significantly yielded higher dry matter herbage (8.3 vs 4.4 t/ha), with corresponding N accumulation of 105 vs 66 kg N/ha,

Table 9. Grain, total dry matter yields, and N uptake of rice as influenced by application of urea and green manure N under rainfed conditions. IRRI, Los Baños, and Guimba, Nueva Ecija, Philippines, 1989 WS.

Treatment[a]	IRRI, Los Baños			Guimba, Nueva Ecija		
	Grain yield (t/ha)	Total dry matter (t/ha)	N uptake (kg/ha)	Grain yield (t/ha)	Total dry matter (t/ha)	N uptake (kg/ha)
Fallow, 0 kg N/ha	1.97	3.90	31	1.32	4.98	27
Fallow, 45 kg N/ha	2.41	4.60	43	2.09	6.45	52
Fallow, 90 kg N/ha	2.88	5.67	64	2.55	8.00	64
1 MB: 1 SR	2.63	5.90	50	1.51	5.63	36
2 MB: 1 SR	2.44	5.53	45	1.51	4.83	34
4 MB: 1 SR	2.14	4.27	39	1.61	5.38	40
2 MB: 2 SR	2.37	5.17	43	1.66	4.53	38
4 MB: 2 SR	2.18	5.10	37	1.28	4.90	36
Sole mungbean	1.84	4.43	36	1.31	4.85	33
Sole sesbania	2.16	5.63	43	1.97	6.63	45
Mean	2.30	5.02	43	1.68	5.62	40
SE	0.25	0.72	4.2	0.17	0.64	3.5
CV (%)	14	18	12	15	12	12

[a]MB = mungbean, SR = *Sesbania rostrata*.

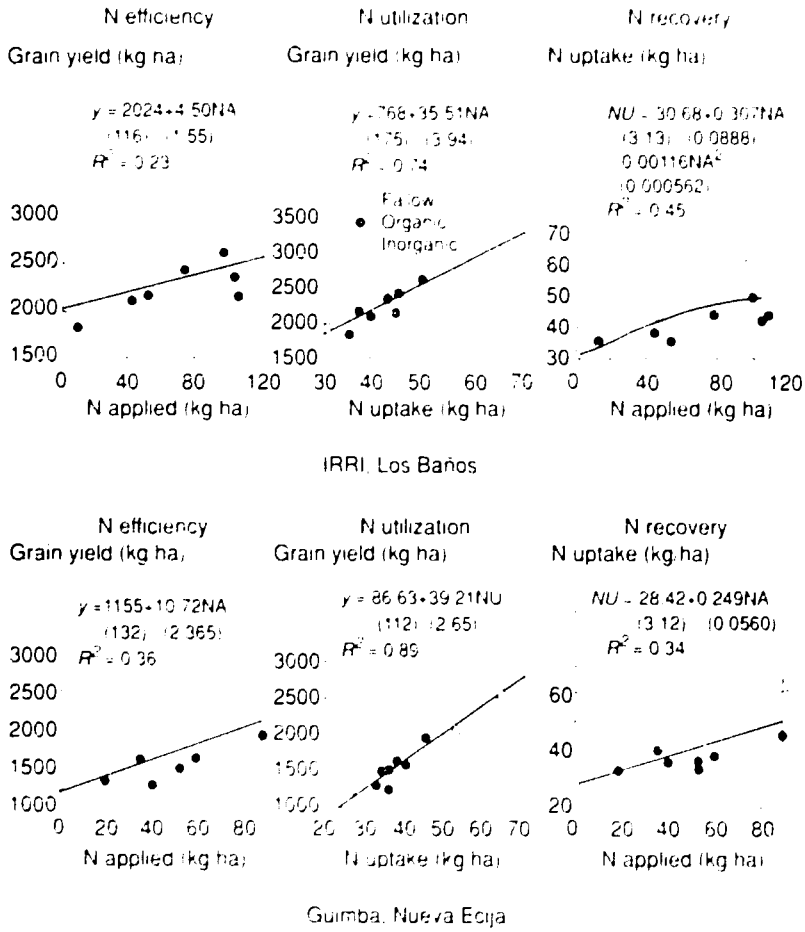
than did the rest of the treatments. Within intercropping treatments, 4MB:1SR row combination yielded significantly lower dry matter and lower N accumulation (42 kg/ha) than 1:1, 2:1, and 2:2 MB:SR combinations. This suggests that the latter three row arrangements were ideal for higher GM-N production. With N yield of 105 and 11 kg N/ha, sesbania was the better source of organic N than MB residues.

At Guimba, the sesbania monocrop yielded significantly ($P < .01$) higher dry matter and N yield (89 kg N/ha) than the other treatments. The effect of intercropping sesbania with MB varied with respect to location. Mungbean yield was reduced by 347 and 265 kg/ha, respectively, at Los Baños and Guimba because of the sesbania intercrop. The higher yield levels obtained at Los Baños is a reflection of better inherent soil fertility.

Grain, total dry matter, and N uptake of the rice crop as influenced by GM and urea N applications are shown in Table 9. N efficiency, utilization, and recovery responses using regression models are illustrated in Figure 10. N efficiency was 11:1 at Guimba and 5:1 in Los Baños, with corresponding uptake ratios of 39:1 and 36:1 gram:N. Although the apparent N recovery at Los Baños was higher than at Guimba, these were not reflected in either N efficiency or N utilization responses.

POSTRICE FOOD FORAGE PRODUCTION SYSTEMS

In most rainfed lowland environments, only one rice is possible within a year. However, the planting of early-maturing grain legume crops like MB after rice harvest has gained wide acceptance. After harvesting the legume crop, the land is left fallow and utilized as common grazing area for livestock. In addition to providing feed, the last herbage harvested can be incorporated in the soil to provide organic fertilizer (GM) to the next crop which may reduce the



10. N efficiency, utilization, and recovery responses of transplanted rice from application of green manure and urea N in rainfed fields, IRRI and Guimba, Nueva Ecija, Philippines, 1989 WS.

dependence on chemical fertilizer for rice production.

A grain legume + forage legume intercropping was tested in Carosucan, Santa Barbara, Pangasinan, in farmers' fields to identify best crop combinations. The soil is Bantog silt loam with pH 6.45, and 0.08% organic matter, 0.19 meq K/100 g, and 6.55 ppm available (Olsen) P_2O_5. The area was planted to rice during WS to determine the possible effect of intercropping on the succeeding rice crop. Crops used in intercropping were MB (Taiwan green) and cowpea (CP) IT 82D-889 as main crops and siratro and *Crotalaria juncea* as forage legume. Both grain and forage legumes were planted simultaneously in alternate rows spaced approximately 25 cm apart. During MB and CP harvest, all the fodder or residues were harvested and fed to animals. Forage legumes were harvested through clipping and the last herbage regrowth was incorporated in the plots in situ 2 wk before transplanting rice. Inorganic fertilizer at the rate of 60-30-30 kg NPK/ha was applied to the rice basally (30-30-30) and topdressed (30-0-0).

First-year results (1988-89) showed that intercropping siratro significantly increased the yield of MB and CP while crotalaria increased the yield of MB only. The combination MB + siratro yielded 0.65 t/ha and CP + crotalaria 0.16 t/ha. The relatively low yield of CP can be attributed to the shading effect caused by the fast-growing crotalaria intercrop and its rapid regrowth rate.

At an average of 4.8 t/ha, the intercrop total herbage dry matter yields of crotalaria and siratro did not differ significantly. During the last clipping of intercrops, no herbage regrowth was collected from crotalaria because a severe drought after the second clipping of crotalaria caused the crop to dry.

In the second year (1989-90) MB and CP yields were higher because of better weather at the site (Table 10). The yields of MB (1.2 t/ha) and CP (0.86 t/ha) with siratro intercrop were slightly higher than their monocrop yields (1.1 t MB/ha and 0.7 t CP/ha).

Forage yield was highest in CP + crotalaria with a dry matter (DM) yield of 10.9 t/ha; it was statistically higher than when crotalaria was intercropped with MB (8.1 t DM/ha) and sole crop (6.9 t DM/ha). Yields of siratro did not differ significantly among combinations (av. of 5.3 t DM/ha).

The last herbage regrowth of the forage legumes was not measured because of flooding before land preparation for the following rice crop.

Rice yield was highest in plots with sole cropping of crotalaria (5.6 t grain/ha and 5.2 t straw/ha), followed by plots of CP + siratro (5.4 t grain/ha and 3.7 t straw/ha). Yield was lowest in the fallow plots, with only 3.0 t grain/ha. On the average, the rice yields with siratro GM regardless of combination

Table 10. Performance of grain legume, forage legume, and yield of the following rice crop in grain legume + forage intercropping. Santa Barbara, Pangasinan, Philippines, 1989-90.

Treatment[1]	Grain legume yield			Total forage yield		Rice[2] yield		
	Grain (t/ha)	Fodder (t/ha)	1000-seed wt (g)	Dry matter (t/ha)	Clippings (no.)	Grain (t/ha)	Straw (t/ha)	1000-grain wt (g)
Mungbean monocrop	1.12 a	0.90 a	60	-		4.32 abc	3.09 de	27
Mungbean + siratro	1.22 a	0.74 a	57	5.50 c	4	4.65 abc	3.56 de	30
Mungbean + crotalaria	0.79 b	0.40 b	55	8.15 ab	6	5.16 ab	3.73 cd	28
Cowpea monocrop	0.74 b	0.44 b	135	-	-	3.83 bc	2.89 e	23
Cowpea + siratro	0.86 b	0.51 b	137	4.89 c	4	5.39 ab	3.75 cd	28
Cowpea + crotalaria	0.50 c	0.32 b	130	10.87 a	6	4.78 ab	3.70 cd	25
Siratro monocrop	-	-	-	5.64 c	4	4.60 abc	4.55 ab	25
Crotalaria monocrop			-	6.87 b	6	5.61 a	5.17 a	27
Fallow	-	-	-	-	-	3.04 c	4.37 bc	25
Mean	0.87	0.55	-	7.91	-	4.60	3.87	26
CV (%)	12.1	21.6	-	19.1	19.2	10.8	19.6	
F-test	**	**		**		**	**	ns

[1]Mungbean is Taiwan green, cowpea IT 82D-889, siratro *Macroptilium atropurpureum*, crotalaria *Crotalaria juncea*. [2]Rice is IR74.

were 4.88 t grain and 3.9 t straw/ha. With crotalaria GM, yields were 5.2 t grain and 4.2 t straw/ha.

In this study, incorporating forage legume with early-maturing food legume crops significantly increased the yield of the food crops besides providing a continuous supply of feed to livestock. The planting of leguminous crops increased the yield of the succeeding rice crop.

Concluding discussion and future research

Short-duration GM *Sesbania rostrata* and food or GM mungbean are suitable before WS rice when land experiences short-term waterlogging. Long-duration food and forage or GM legume has potential after rice when the moisture may be limiting. Because of stem nodulation traits, *S. rostrata* has a comparative advantage over traditional *Sesbania* under submerged condition. The data suggest that production can be increased by a judicious combination of food, GM, and forage or GM legumes. However, there is need to quantify the total inputs and outputs, particularly N, to assess the sustainability of the system.

Integrated nutrient management

Integrated nutrient management research for irrigated rice ecosystem was continued jointly with the Rainfed Lowland Rice Ecosystem Program.

The project activities were designed for greater understanding of the nutrient transformation processes, nutrient balance, and integrated nutrient management practices that will minimize dependence on purchased inputs in rainfed lowland rice.

Measurement of ammonia volatilization following incorporation of urea, *Sesbania rostrata*, and *Aeschynomene afraspera* in flooded transplanted IR72

Rationale. To further reduce reliance on purchased chemicals and integrate nutrient management using renewable resources for ecological reasons remains a significant challenge. The objective is to reduce farmers' dependence on inorganic fertilizer by 75%, without loss of yield, through a combination of improved recovery rates of applied N and using N from organic sources such as nitrogen-fixing organisms. Green manure offers considerable potential in harnessing atmospheric N and as a partial substitute to chemical fertilizers in agricultural production. Among the stem-nodulating legumes, *S. rostrata* and *A. afraspera* have received particular attention because of their extensive nodulation.

Other objectives of this study are to assess NH_3 volatilization following incorporation of urea, *S. rostrata*, and *A. afraspera* in TPR under irrigated and rainfed conditions and to measure NH_3 volatilization losses throughout the rice-growing period.

Methodology. Field experiments were conducted on an irrigated farm in Central Luzon State University, Nueva Ecija, in 1989 DS and under a totally rainfed condition in a field in Calauan, Laguna, Philippines, in 1989 WS.

The field (2.5-3.5 ha) was plowed, flooded with irrigation water in DS and with rainwater in WS, and harrowed to puddle and level the soil. After the last harrowing, two 25-m-radius circular plots for DS and three for WS were installed in the main field by constructing a levee 0.2 m high and reinforcing it with plastic sheets to eliminate lateral seepage. The circular fields, constructed along a line perpendicular to the wind direction, were used to measure NH_3 fluxes with full profile mass balance micrometeorological techniques. Ammonia fluxes were measured 6 times a day from 0800 to 1800 h for 10 d for both seasons at heights of 0.03, 0.1, 0.4, 0.8, 1.4, and 3.0 m. Horizontal windspeed for each run was measured with cup anemometers placed at the same height as the acid traps for NH_3 fluxes. Background NH_3 flux was measured at 0.2, 0.8, and 2.2 m. In WS, NH_3 flux measurements were continued up to crop harvest but sampling was done at 0800 and 1800 h from 5 d after fertilizer application.

S. rostrata and 87 kg urea/ha in DS, 60 kg urea/ha, *S. rostrata*, and *A. afraspera* in WS were basally applied and incorporated by power weeder or hydrotiller in the circular plots at soil-saturated condition. A floodwater depth of 0.03 m, maintained 1-10 d after fertilizer incorporation, was increased to 0.05 m after NH_3 flux measurements in DS. In WS, floodwater depths were monitored.

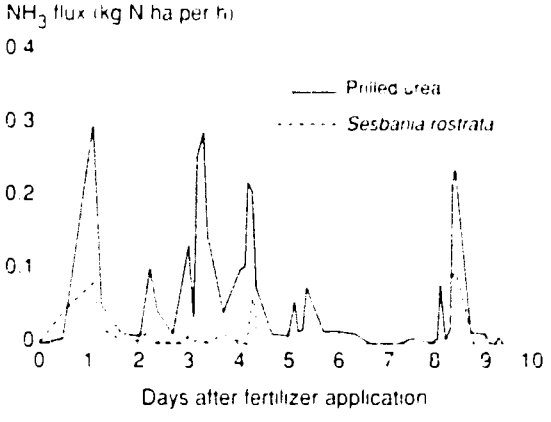
P (as single superphosphate) at 20 kg/ha in DS and 9 kg/ha in WS, and K (as muriate of potash) at 37 kg/ha in DS and 17 kg/ha in WS were incorporated before transplanting IR72 rice seedlings at 0.2- × 0.2-m spacing. Zn (as zinc sulfate) at 10 kg/ha was applied in DS and seedlings were soaked in 2% ZnO solution in WS to correct Zn deficiency. Insect and weed control was optimum.

Results and discussion. Incorporation of urea in saturated soil using a power weeder provided an acceptable range of NH_3 flux, with the highest flux of 0.3 kg/ha per h at 1 and 3 d after fertilizer application in DS (Fig. 11). Fluxes of NH_3 remained high up to 4 d after urea application, decreased to negligible values up to 7 d, but increased again to 0.3 kg/ha per h on the eighth day when windspeed increased from 4 to 7 m/s.

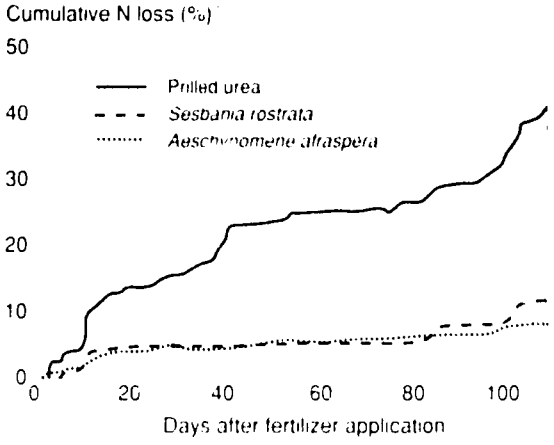
NH_3 volatilization loss was low in DS with *S. rostrata* incorporated in the saturated soil by power weeder. Maximum NH_3 flux was 0.1 kg/ha per h at 1 and 8 d after GM application (Fig. 11). The high NH_3 flux on day 1 was due to the delayed incorporation of *S. rostrata* in the soil. Ammonia loss commenced when cut GM was spread, or even before incorporation. Ammonia fluxes measured at 4 and 8 d after fertilizer application were due to NH_3 volatilization loss.

In WS, cumulative NH_3 loss from GM was lower than that from urea. Ammonia loss was 10% with urea, 3% with *A. afraspera*, and 4% with *S. rostrata* for 10 d (Fig. 12). When NH_3 flux measurement was continued up to crop maturity or harvest, fluxes of NH_3 continued to be measured after 20-40 d and then at 80-100 d after N application or during the crop reproductive stage. Cumulative NH_3 losses with GM species varied from 7 to 12%, compared with 41% with urea.

Further studies to measure denitrification loss are needed to determine other pathways through which N may have been lost. It was presumed that CO_2 production in the soil was enhanced with the addition of readily decomposable organic manure, thereby reducing NH_3 loss. Verifying the relationship between CO_2 and NH_3 loss could be an area for future research.



11. Ammonia fluxes with *Sesbania rostrata* and prilled urea applied basal and incorporated in soil as measured by micrometeorological techniques. Central Luzon State University, Nueva Ecija, Philippines, 1989 DS (irrigated).



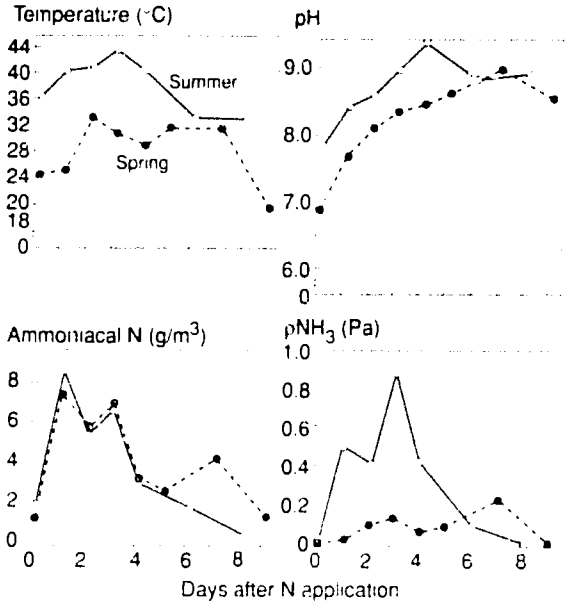
12. Cumulative NH_3 loss from *Sesbania rostrata*, *Aeschynomene afraspera*, and prilled urea. Calauan, Laguna, Philippines, 1989 WS (rainfed).

Management of urea fertilizer

IRRI and the International Fertilizer Development Center continued to collaborate with research organizations in Vietnam on development of management practices to increase the effectiveness of urea for lowland rice.

In the Red River Delta of northern Vietnam, two transplanted, irrigated rice crops are typically grown each year on alluvial soils. In the spring season (February to June), early growth of rice is constrained by low temperatures. The summer season (July to October) corresponds to the WS when typhoons can damage crops.

Researchers at the Institute for Soils and Fertilizers showed that floodwater temperature and pH, but not ammoniacal N, were markedly higher following basal urea incorporation in summer (July) than in spring (February) (Fig. 13). The higher pH in summer is presumably due to greater photosynthetic activity of floodwater during the hotter summer season. Even though temperature differences between seasons might lead to seasonal differences in growth and N assimilation by aquatic biomass, rates of N transformations, and rates of N transport processes, the net seasonal effect on floodwater ammoniacal N was minimal. The high floodwater temperature and pH in summer resulted in much higher mean pNH_3 in summer than in spring, sug-

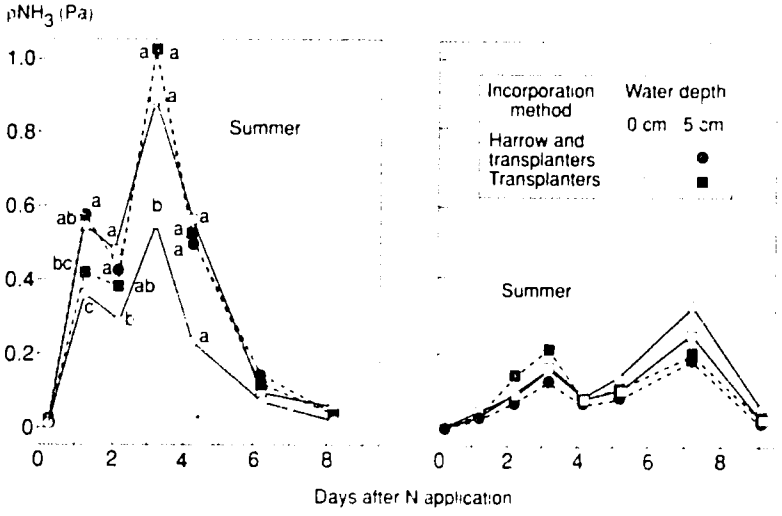


13. Effect of growing season on floodwater properties at 1400 h following basal application of urea to transplanted lowland rice. Hanoi, Vietnam, 1989-90.

gesting a high potential for ammonia volatilization in summer.

In summer, the pNH_3 was influenced by methods of basal urea incorporation and floodwater depth during incorporation (Fig. 14). Irrespective of water depth, the movement of transplanters through the field did not reduce pNH_3. Harrowing and transplanter movement through the field effectively reduced pNH_3 only in the absence of standing water. However, this reduction and presumably N fertilizer loss did not correspond to increased rice yield. Incorporation of basal urea without standing water might be an unattractive technology in the summer because drainage of floodwater could be difficult with the typically high rain in this season. Furthermore, the beneficial effects of partly reducing ammonia loss and mixing urea into soil may be negated by climatic conditions, such as low solar radiation and typhoons, that limit rice yield. Future collaborative research will focus on examining alternative timings of urea application, integrated use of urea with farmyard manure, and climatic and soils constraints to effective use of N fertilizer.

In the Mekong Delta of southern Vietnam, rice is typically broadcast seeded and not constrained by cold temperatures and typhoons. Rice yields on alluvial soils tend to be higher in the Mekong than in the Red River Delta. Researchers at Cantho University compared two timings (basal incorporation vs broadcast at 10 d after sowing [DAS]) for the first of 3 urea applications to broadcast seeded rice at 4 sites on alluvial soils. Rice yields with urea application at 10 DAS consistently matched or exceeded those with basal urea incorporation. Gaseous loss of applied urea at one site (Thapto-Histic-Sulfic Fluvaquent), as determined by ^{15}N balance techniques, was 53% for 50 kg urea/ha broadcast at 10 DAS, 25% for 50 kg urea/ha broadcast at 20 DAS, and 12% for 50 kg urea/ha broadcast at 45 DAS. Total losses for 150 kg urea/ha were 29% of the applied N on a



14. Effect of urea incorporation method and water depth during incorporation on partial pressure of ammonia (pNH_3), at 1400 h following basal urea application to transplanted lowland rice.

Thapto-Histic-Sulfic Fluvaquent and 17% on a Typic Tropaquept.

Future collaborative research will examine the effect of crop management (for example, plant population) and soil type on N fertilizer efficiency and identify factors affecting N fertilizer losses.

Dissolution of phosphate rock and partially acidulated phosphate rock fertilizers in acidic lowland rice soils

Maintaining available P in acid soils is the key to obtaining high rice yields on millions of hectares in South and Southeast Asia.

Two laboratory experiments evaluated the extent of dissolution and relative effectiveness in maintaining water-soluble P levels of some sparingly soluble phosphate rock (PR) and partially acidulated PR (PAPR) sources at different reaction periods in some lowland acidic rice soils (0-20 cm) in India, Indonesia, the Philippines, Thailand, and Vietnam. Samples were air-dried, crushed to pass through a 2-mm sieve to form the initial soil samples, and their properties measured (Table 11).

A reactive PR from Morocco (MPR) and two partially acidulated products from Jordan PR (PAPR) at 15 and 30% acidulation were compared with TSP. Table 12 shows some of the properties of the P sources used.

Kinetics of dissolution of sparingly soluble P sources in soil. Ten-gram samples of a soil were mixed with appropriate amounts of PR, PAPR, and TSP to give 1600 ppm P in the soil in 50-ml centrifuge tubes. The soil-fertilizer mixtures were next shaken with 30-ml distilled water continuously for 0.5, 1, 3, 5, 8, 16, 24, 48, 72, 120, and 168 h in a water bath shaker at 35 °C. At the end of each period, appropriate samples were centrifuged, and the concentration of P in the filtrate was determined by the ascorbic acid method.

Table 12. Some characteristics of P sources.

P source	Total P (%)	Water-soluble P (%)	Citrate-soluble P (%)	CO_3/PO_4
Morocco phosphate rock (MPR)	14.5	nil	2.4	0.098
Jordan PAPR (15%)	12.3	1.1	3.1	0.197[a]
Jordan PAPR (30%)	12.0	3.1	2.7	0.197[a]
Triple superphosphate (TSP)	21.2	17.7	3.5	-

[a]Values refer to Jordan PR

Data were fitted to the modified Elovich equation which reads,

$$C_t - C_i = \frac{1}{\beta} \ln (\alpha \beta) + \frac{1}{\beta} \ln t \ldots \quad (1)$$

where C_i and C_t are the soluble P concentrations at the initial time and at any arbitrary time (t), α and β are constants for a given sorption process. β was obtained from the negative inverse of the slope of the plot of C_t against ln t. To obtain α from the intercept, a knowledge of C_i was necessary. C_i was estimated by plotting C_t against t, and extrapolating to zero time.

An inverse relationship between C_i (and hence the dissolution rate of PR) and β was apparent (Table 13), the corresponding simple linear correlation coefficients being -0.725 for MPR, -0.835* for PAPR

Table 11. Some characteristics of soils used.

Soil	pH (1:1 wt/vol in water)	Organic C (%)	Clay (%)	Exchangeable Ca (cmol (+)/kg)	Bray 2 P (ppm)	Olsen P[a] (ppm)	LAMP[b] (µg P/g)
Bentre, Vietnam	3.46	2.95	54	2.45	10.7	n.d.	1013
Pathumthani, Thailand	4.44	0.67	54	9.13	4.60	1.80	1434
Sukamandi, Indonesia	4.96	0.89	41	6.09	14.6	14.7	895
Pangasinan, Philippines	5.40	2.14	29	12.9	2.61	n.d.	1934
Quezon, Philippines	4.32	2.90	59	13.9	0.48	1.91	1882
Port Blair, India	3.92	1.76	46	9.56	10.4	5.90	1818

[a]n.d. = not detectable. [b]Langmuir adsorption maximum for phosphate.

Table 13. Dissolution parameters for various P sources in different acidic soils.

Soil	P source	C_o (ppm P)	α (ppm P/h)	β (ppm P)	Mean dissolution (%) at 2000 µg Ca/g soil rate
Bentre, Vietnam	MPR	4.52	36.7	2.42	33.5
	PAPR 15%	6.73	22.2	1.54	37.6
	PAPR 30%	29.3	77.5	0.299	43.4
Pathumthani, Thailand	MPR	2.85	2.62	3.96	22.6
	PAPR 15%	4.91	1.75	3.51	24.7
	PAPR 30%	41.3	30.5	0.177	32.9
Sukamandi, Indonesia	MPR	2.63	1.68	2.74	21.0
	PAPR 15%	2.79	0.746	2.31	22.5
	PAPR 30%	42.5	33.6	0.154	29.9
Pangasinan, Philippines	MPR	1.43	5.94	4.70	13.6
	PAPR 15%	1.53	48.7	6.42	14.8
	PAPR 30%	15.9	144	0.549	24.7
Quezon, Philippines	MPR	0.375	1.60	21.7	8.77
	PAPR 15%	0.855	6.27	10.7	17.2
	PAPR 30%	5.08	5.13	1.36	27.7
Port Blair, India	MPR	5.65	30.0	1.78	23.3
	PAPR 15%	5.48	5.51	1.37	24.6
	PAPR 30%	24.9	51.8	0.311	33.5
LSD (0.05)		1.19	18.9	0.396	4.4
(0.01)		1.63	25.9	0.544	6.0
CV (%)		5	32	5	8

15%, and -0.887* for PAPR 30%. This is in agreement with the requirements of Eq. (1).

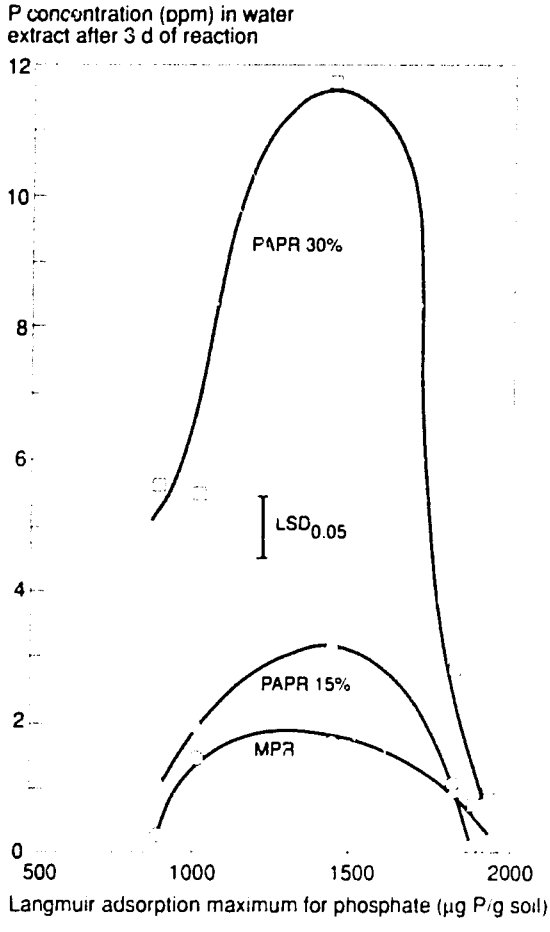
At an intermediate P-fixing capacity, the soluble P concentrations in soils after 3 d reached a maximum (Fig. 15). This may be attributed to the fact that a high P-fixing capacity of soil is necessary to encourage the initial dissolution of a PR in an acidic soil. A too high P-fixing capacity may, however, leave a low concentration of soluble P in soil on continued reaction.

By considering C_o values and soluble P concentrations at different time periods, effectiveness of the P sources in maintaining soluble P in soil was found to be in the following order: TSP > PAPR 30% > PAPR 15% > MPR.

The better performance of PAPR 30% than of PAPR 15% or MPR may be explained in terms of a higher inherent reactivity of Jordan PR for the two PAPR sources than with MPR and a partial acidulation of Jordan PR forming some amount of water-soluble monocalcium phosphate component, especially in the PAPR 30% product.

The performance of MPR, relative to TSP, in maintaining soluble P in soil improved with the reaction period. PAPR 15% and PAPR 30% behaved similarly. In soils with high exchangeable Ca and high P-fixing capacity (e.g., Quezon and Pangasinan soils; see Table 11), there is usually not much difference in the relative soluble P concentrations at shorter or longer periods of reaction. But in soils having relatively low exchangeable Ca, and an intermediate P-fixing ability (e.g., Bentre soil), there is an improvement at the longer period.

Incubation study. Twenty-gram samples of a soil were mixed with different amounts of the PR and two PAPR sources to give additions of 500 and 2,000 µg Ca/g soil. Subsamples of 2 g were weighed into 50-ml centrifuge tubes. After adding 0.5 ml water, the tubes were stored in darkness at 33 °C for 0, 1, 2, 5, 20, and 31 d. At the end of each time period, the corresponding samples were extracted with 2 M $BaCl_2$ buffered at pH 8.1 with triethanolamine for 1 h to determine the increase in extractable Ca due to dissolution of the P source. After centrifuging, Ca in



15. Water-soluble P concentration of 3 sparingly soluble P sources after 3 d of reaction as affected by the P-fixing capacity of soils (Langmuir adsorption maximum for phosphate).

the filtrate was determined by atomic absorption spectrophotometry.

Maximum dissolution of P sources (Table 13) for the higher rate of application occurred within the first day of incubation, and such initial rapid dissolution was followed by slower dissolution at longer periods. The mean dissolution after 31 d was much higher at the lower level of PR and PAPR application, although the absolute amounts dissolved were greater at the higher rate. Percent dissolution of the three sparingly soluble P sources was generally in the following order: PAPR 30% > PAPR 15% > MPR, which confirms the trend observed in the kinetic study.

For a given source, the order of dissolution percentages in different soils at 2,000 µg Ca/g soil are given in Table 13.

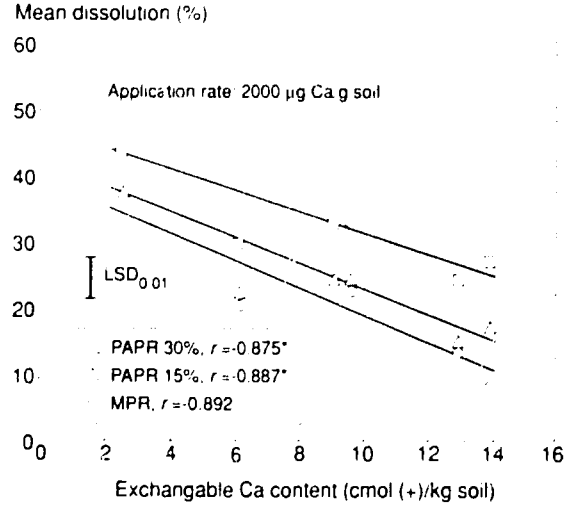
Figure 16 illustrates the important role of exchangeable Ca in soils in governing the dissolution of the given sparingly soluble P sources.

Correlations with field observations. Using TSP as a standard equal to a relative agronomic effectiveness (RAE) of 100%, the given sources were assessed, and the corresponding RAE values are recorded in Table 14. Note that in Bentre soil, MPR and the two PAPR sources were more effective than the soluble P source.

Results suggest that the maximum benefits of using the given sparingly soluble P sources may be expected in acid soils with low exchangeable Ca and an intermediate P-fixing capacity. In these soils, PAPR sources may perform better than PR materials.

Sulfur in flooded soil

Sulfur deficiencies in rice soils have increased as a result of increased use of high analysis, S-free fertilizers. Since the quantities of S required by rice are small in relation to N requirements, it might be desirable to apply S with N in multinutrient fertilizers. Two means of applying S and N fertilizers are in combined urea-ammonium sulfate and urea-elemental S mixtures. Because elemental S must be oxidized to sulfate before the S is available to rice, it can have the advantage of less susceptibility to leaching loss and the disadvantage of less availability to the rice crop. Field experiments were conducted in the



16. Mean percent dissolution of 3 sparingly soluble P sources over several incubation periods in soils having varying exchangeable Ca contents.

Table 14. Relative agronomic effectiveness (RAE) of P sources in different acidic soils.

P source	RAE[a] (%) in soils				
	Bentre	Pathumthani	Sukamandi[b]	Pangasinan	Port Blair
MPR	137	75	99	38	61
PAPR 15%	180	96	87	63	96
PAPR 30%	159	80	88	75	68

[a]RAE for TSP = 100%. [b]Yield data refer to no-fertilizer control.

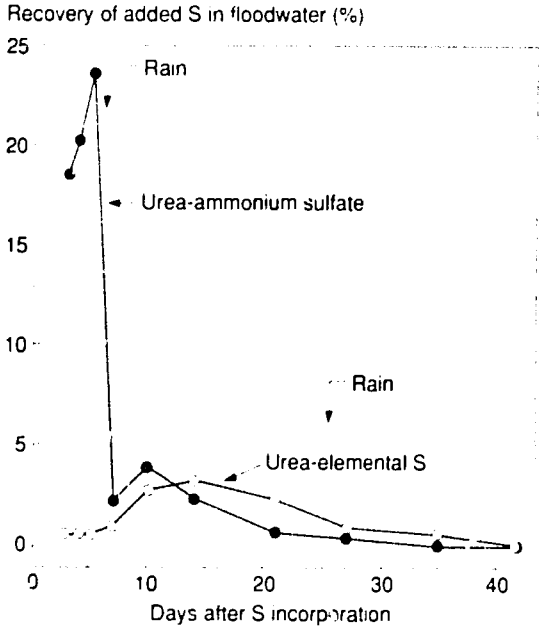
Philippines to obtain S balances for urea-ammonium sulfate (UAS) and urea-elemental S (UES) mixtures.

UAS and UES at 20 kg S/ha were basal incorporated to 10-cm depth in 80- × 80-cm microplots surrounded by 30-cm-high metal frames pushed 15 cm into the soil. Microplots were additionally surrounded by levees to isolate the experimental area. On this puddled soil, basal fertilizer incorporation without standing water followed by irrigation to 4-cm depth at 2 d after incorporation did not prevent substantial release of added sulfate S to the floodwater. At 5 d after S incorporation, 24% of the added sulfate S was in the floodwater, whereas the recovery in floodwater of added S from elemental S never exceeded 3.3% (Fig. 17). Heavy rains 6 d after S incorporation resulted in loss of floodwater and S over the 15-cm microplot border. S from added UAS unrecovered in the plant and soil to 30-cm depth at 42 d represented 21% of the added S, which corresponded closely to the decrease in floodwater S (22% of applied S) between 5 and 7 d after S incorporation. No S was lost from added UES.

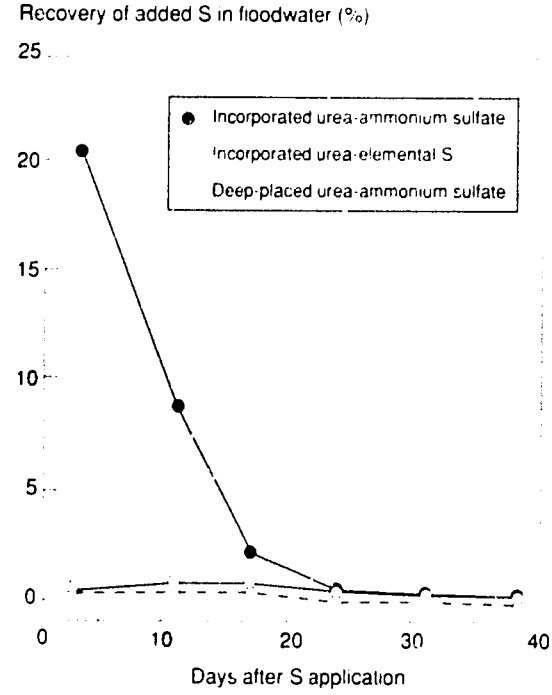
The results suggest that sulfate S may be lost through runoff even when basally incorporated without standing water. Such loss can be prevented by using elemental S rather than sulfate, or by deep placement of the sulfate-containing fertilizer (Fig. 18). In flood-prone rainfed environments, the deep placement of sulfate with urea can have the added benefit of preventing S losses by runoff as well as preventing runoff and gaseous losses of N.

Future research

In 1990, research was initiated to generate knowledge on transformation processes in GM species.



17. Effect of S fertilizer source on percentage of added S in floodwater following basal incorporation of the fertilizer. San Juan, Batangas, Philippines.



18. Effect of S fertilizer source and placement on the percentage of added S in floodwater. San Jean, Batangas, Philippines.

Quantitative field measurements were made to determine, with the use of micrometeorological techniques, the extent of ammonia volatilization losses from GM incorporated in lowland ricefields.

Collaboration with Vietnam resulted in knowledge that showed promise in urea fertilizer management practices in flooded ricefields.

Strategic research was initiated in the laboratory and greenhouse to relate the findings to field trials in India, Indonesia, the Philippines, Thailand, and Vietnam in identifying low-cost P sources for acid lowland rice soils.

Future research on N from GM will integrate ammonia volatilization with N_2 and N_2O flux measurements. CO_2 measurement will be made from the floodwater and soil system and from the rice canopy in GM- and urea-amended ricefields. Future collaborative research will focus on alternate timings of urea application with integrated use of urea with farmyard manure. Strategic research on P dissolution rate will generate information that should make sparingly soluble P sources desirable in acid lowland rice soils.

Subprogram II: Germplasm improvement

Physiology, genetics, and screening methods

The objective of this project is to understand the physiology and genetics of rice adaptation to adverse water regimes, and to develop appropriate screening methods for traits conferring adaptation. Our previous report emphasized physiology and genetics of resistance to drought; additional research on this topic is reported here. Photoperiodism is an important mechanism for escaping stress in rainfed lowland rice; therefore, research on photoperiod sensitivity is emphasized here.

Photoperiod sensitivity

Photoperiod sensitivity gene tagged with RFLP marker. Strong photoperiod sensitivity is usually controlled by a major dominant gene (*PSG*) on chromosome 6. The isozyme gene *Pgi-2* can be used to monitor segregation of *PSG*, but efficiency of such monitoring is low because *Pgi-2* and the *PSG* are only loosely linked. In collaboration with Cornell University, USA, we identified a restriction fragment length polymorphism (RFLP) marker that is closely linked with *PSG*.

DNA was extracted from F_1 lines from a cross segregating for photoperiod sensitivity, digested with restriction enzymes, and run on agarose gels. After transfer to nylon filters by Southern blotting, it was probed with clones mapping to chromosome 6. The genomic clone RG64 showed very tight linkage to photoperiod sensitivity. It has already been confirmed that RG64 and *Pgi-2* are loosely linked. The RFLP probe RG64 will be used to monitor segregation of photoperiod sensitivity and for transferring this trait to high-yielding cultivars.

Characterizing late-flowering cultivars. Whereas photoperiod-sensitive cultivars of the rainfed lowland rice belt extending from eastern India to Northeast Thailand flower in October or early November, those from more southern locations in Sri Lanka, Thailand, Cambodia, Malaysia, and the Philippines flower later. Progress in improving these late-flowering cultivars has been limited. To better characterize late-flowering rices, 29 genotypes were grown at five locations with different seeding dates (Table 15).

At higher latitudes, time to flowering was very long with early seeding. Most varieties from southern locations took 180 d or longer to flower when seeded on 30 May at Chinsurah. At lower latitudes, growth duration was much shorter and there was less difference in days to flowering between different planting dates within a location, but photoperiod-sensitive genotypes still had longer duration than

Table 15. Sites and seeding dates for characterization of photoperiod-sensitive cultivars or breeding lines during 1989-90.

Site	Latitude	Seeding date	Mean flowering date	Mean days to flowering
Chinsurah (India)	20° N	30 May	11 Nov	165
Chinsurah		11 Jul	14 Nov	126
Phatthalung (Thailand)	8° N	10 Aug	21 Dec	133
Phatthalung		15 Oct	18 Feb	126
Batalagoda (Sri Lanka)	7° N	30 Jul	10 Dec	133
Batalagoda		30 Aug	31 Dec	123
Prey Phdau (Cambodia)	12° N	16 May	15 Nov	183
Solana (Philippines)	18° N	17 Jul	10 Dec	146

would be observed for modern varieties. Although daylength response was less at lower latitudes, photoperiod sensitivity is still considered important for local adaptation.

Drought resistance

Drought stress index for rice. Because of differences in timing and severity of drought it is difficult to compare results of rainfed trials conducted in different locations. To develop a phenology-based index that relates rice productivity to water deficit, we conducted four greenhouse experiments to quantify the effects of different timings and severities of water deficit on rice transpiration and yield. Results of experiment 1 and 2 were reported previously (IRRI Annual reports for 1987 and 1988), and suggested that the ratio of cumulative transpiration in stress to transpiration in control treatments ($\Sigma Ts/\Sigma Tc$) may be used as an index to quantify stresses of different timings and durations.

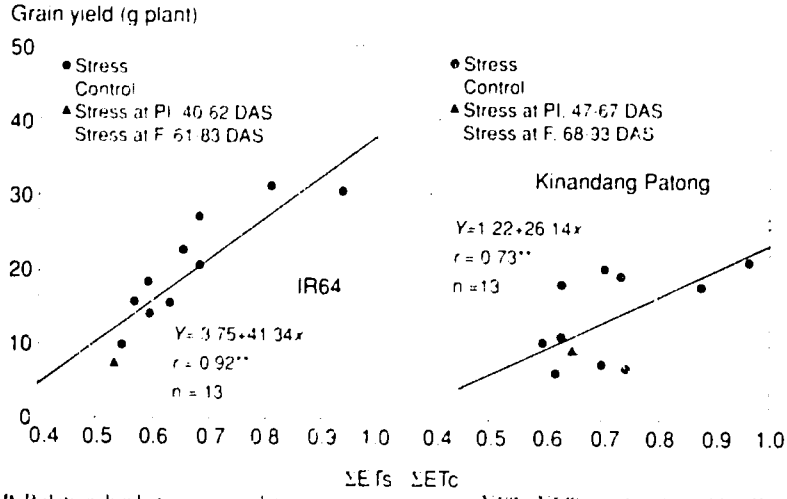
In experiment 3 using IR64 and Kinandang Patong, water deficit was imposed at different growth stages (the first stress was at 11 DAS and subsequent stress was at 7-d intervals) until the ratio of cumulative evapotranspiration in stress to evapotranspiration in control pots ($\Sigma ETs/\Sigma ETc$) during the stress period reached about 0.5. Stress duration was 26-33 d for younger plants and 18-25 d for older plants. In experiment 4 using IR64 and Salumpikit, water was withheld for 7 or 14 d beginning at 30 DAS and at 7-d intervals thereafter.

Grain yield was directly related to $\Sigma ETs/\Sigma ETc$ in experiment 3 (Fig. 19) and to $\Sigma Ts/\Sigma Tc$ in experiment 4 (Fig. 20). Thus either ET or T may be used in the stress index. Linear regressions were stronger for IR64 than for Kinandang Patong or Salumpikit. Results for IR64 are consistent with those of previous experiments. Contrary to what we observed earlier, however, growth stage had no apparent effect on the relationship between stress index and yield of Salumpikit or Kinandang Patong. That stress index was independent of growth stage is confirmed by regressions between shoot dry matter and yield (Fig. 21). Although a few points with flowering stage stress deviated from the regressions, overall there was little effect of water deficit on the regressions and therefore on harvest index.

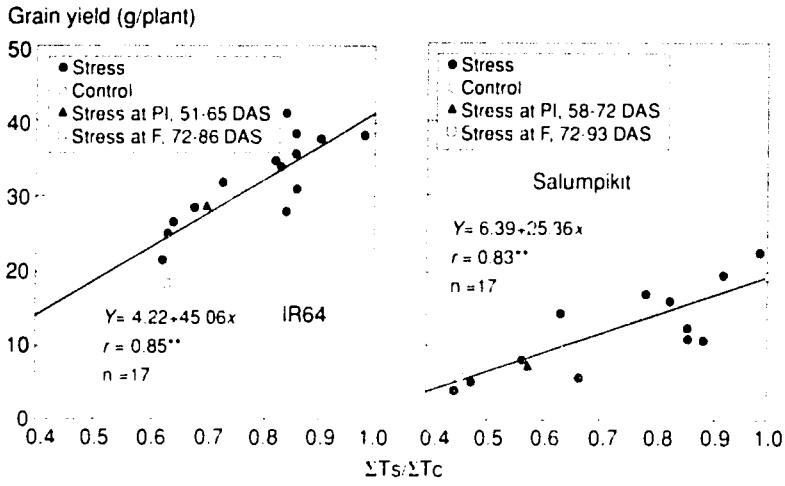
The next phase of this research will attempt to use these drought stress indices to compare results of screening trials from different locations.

Inheritance of leaf epicuticular wax. Leaf epicuticular wax (LEW) increases cuticle resistance to transpiration; the amount of LEW has been related to drought resistance in several crops. Rice has low LEW compared to other crops, but there are considerable differences among genotypes. To know whether this trait can be improved through plant breeding, inheritance of LEW was studied in a diallel cross among eight diverse rice genotypes.

General combining ability effects were highly significant while specific combining ability effects were not, indicating a predominance of additive



19. Relationship between cumulative evapotranspiration ($\Sigma ETs/\Sigma ETc$) and grain yield of IR64 and Kinandang Patong in experiment 3, IRRI, 1988. Plants were stressed for different durations at different growth stages. F = flowering, PI = panicle initiation, DAS = days after seeding.

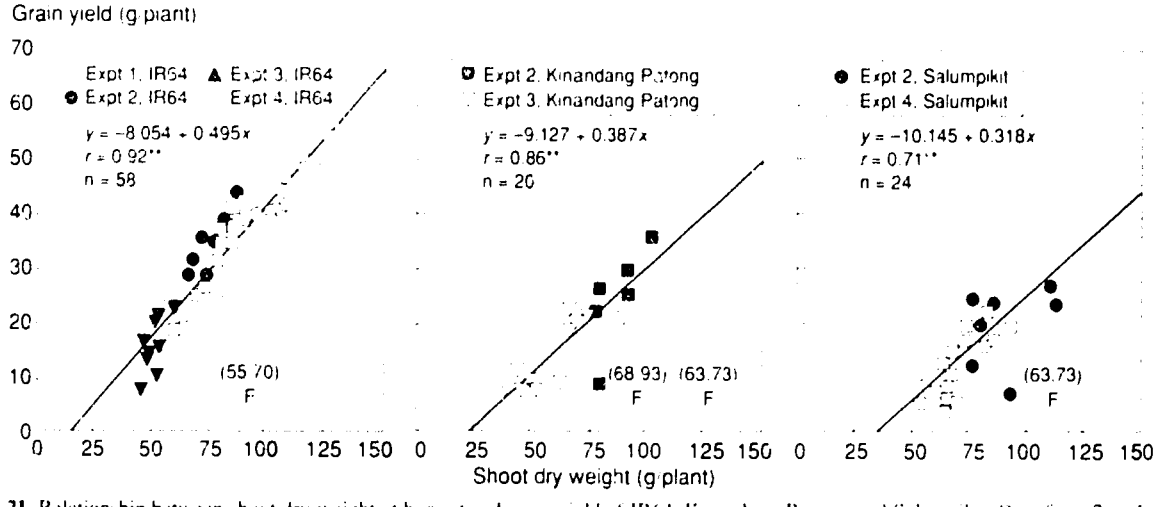


20. Relationship of cumulative transpiration ($\Sigma Ts/\Sigma Tc$) and grain yield of IR64 and Salumpikit in experiment 4, IRRI, 1989. Plants were stressed for 7 or 14 d at different growth stages. F = flowering, PI = panicle initiation, DAS = days after seeding

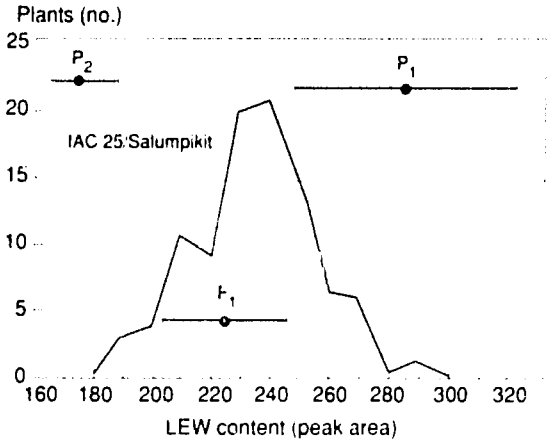
genetic variation. In an F_2 population, broad-sense heritability was low and few recombinants matching the parents were obtained (Fig. 22). This result implies polygenic inheritance. As LEW is difficult to measure in rice, it is unlikely that it can be used in selection unless genes conferring high LEW can be tagged with molecular markers.

Root growth under water deficit. Field research was conducted to measure the effect of water deficit on root growth of rice transplanted in a puddled field under simulated rainfed lowland conditions. A split-plot design was used with 2 main plot treatments: well-watered and not irrigated, from 26 to 48 d after transplanting (DT). Subplot treatments were four cultivars: IR20, IR46, IR72, and N22.

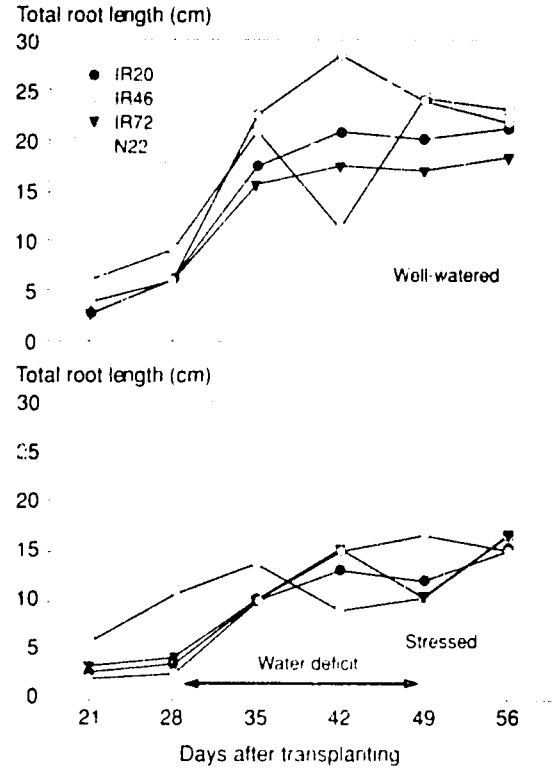
As observed with a minirhizotron to a soil depth of 70 cm, water deficit significantly reduced total root growth at 35, 42, and 49 DT (Fig. 23). By 56 DT, however, only 1 wk after reflooding, total root growth in well-irrigated and stressed plots was not significantly different. Significant differences among cultivars were observed before (21 DT) and during stress (42 and 49 DT; Fig. 23). Although there were no significant interactions between cultivar and water regime at any single observation date, cultivars showed distinctly different responses to water deficit. Before stress, N22, the most drought-tolerant cultivar in the experiment, had the greatest total root length. During stress, however, its root length decreased early (after 35 DT), whereas that of the other



21. Relationship between shoot dry weight at harvest and grain yield of IR64, Kinandang Patong, and Salumpikit. Data from 2 or 4 experiments were pooled.



22. Distribution of leaf epicuticular wax (LEW) content in the F_2 population of IAC25/Salumpikit and the range, mean (dot), and SE of the mean. The mean LEW content of P_1, P_2, and F_1 were 16.5, 5.9, and 10.5 mg/m², respectively.



23. Root growth of rice under well-watered and drought-stressed conditions.

cultivars increased until 42 DT. Total root length in N22 and IR46 (another drought-tolerant cultivar) increased more rapidly after relief of stress than did root length in IR20 and IR72. Thus, one characteristic of drought-tolerant cultivars seems to be that their roots respond quickly to changing soil water status.

Future research

In addition to following up the results reported in the preceding sections, future research in this project will investigate submergence and heat tolerance.

Breeding and evaluation

The objectives of this project are to develop improved germplasm for adverse rainfed lowland conditions, with particular emphasis on adaptation to water deficit and excess, and to identify appropriate breeding methods for these environments.

In 1990, 326 F_1 populations, 308 F_2 and early generation bulk populations, and 32,129 pedigree rows were grown. In DS and WSs, 1,149 unreplicated observation plots were grown, and 100 entries were evaluated in replicated yield trials. For drought-prone nurseries, 583 and 50 entries were evaluated in observational (OYT) and replicated yield trials (RYT), respectively. For medium-deep trials, 100 and 40 entries were evaluated in OYT and RYT.

Early generation and advanced breeding lines were screened for resistance to drought, submergence, disease and insect pests, and for grain quality traits. Several lines with excellent drought resistance under upland screening and other desirable characteristics were identified (Table 16). Several new lines with consistent submergence tolerance and good phenotypic acceptability were identified:

Designation	*Parentage*
IR53490-24-3-1-1-2	IR38699-27-2-3-3/ IR43559-132-3
IR54143-30-1-1-2-3	Shwetasoke/IR31406-333-1// IR26760-27-1-3-2-1
IR57463-2-2-1-2	In-Ma-Ye-Baw/B4259-48-1-1-3//IR43581-57-3-3-6
IR57478-2-3-2	IR19382-42-3-3-2/IR43559-132-3//IR37096-50-1-3-3
IR57512-6-1-2-3-3	IR43568-7-3-2-1/IR43559-132-3//IR43568-13-3-2-2
IR57512-6-3-1-3-3	IR43568-7-3-2-1/IR43559-132-3//IR43568-13-3-2-2
IR57551-9-1-3-1-1	B4259-48-1-1-3/IR42207-65-2-3//IR43581-57-3-3-6/ IR43559-132-3

The sources of strong submergence tolerance are underlined.

Table 16. Rainfed lowland breeding lines with drought resistance. IRRI, 1990.

Designation	Drought score[a]		Duration (d)	Height (cm)	Grain[b]				Resistance[c]	
	-10 bar	Recovery			AC	L	S	Clk	Bl	BB1
IR41431-16-2-2-2	2	1	140	120	26	3	1	1	5	1
IR43506-UBN-520-1-3-1-1	1	1	Sen	120	0	3	1	W	3	7
IR43552-80-3-1-3	2	1	Sen	120	25	3	1	1	7	1
IR46274-53-32-3-3-1	2	1	135	120	26	3	1	3	7	1
IR46288-20-1-1-3	2	1	135	130	25	3	1	0	6	1
IR46331-PMI-29-2-1-1	3	1	130	140	26	1	1	9	8	1
IR47959-9-3-3-3	3	1	125	140	23	5	5	1	1	1
IR54082-CPA-1-B-2-1	3	1	125	140	0	3	1	W	1	1

[a]Scores for drought resistance at -10 bar soil water potential and recovery after relief of stress follow the *Standard evaluation for rice scale* (SES) scale. The resistant checks generally score 3-4 at -10 bar. [b]Grain characteristics include amylose content (AC %), length (L), shape (S), and chalkiness (Clk). Scoring by SES. [c]Resistance to blast (Bl) and bacterial blight race 1 (BB1) scored by SES.

Breeding lines were screened for resistance to brown planthopper (BPH) and green leafhopper (GLH). Of more than 26,500 lines screened, 86% were resistant to BPH biotype 1; of 4,800 entries, 71% were resistant to BPH biotype 2; of 4,700 entries, 75% were resistant to BPH biotype 3. Of 20,800 breeding lines screened, 46% were resistant to GLH.

S_1-family recurrent selection was evaluated in the rainfed lowland composite cross CP103 (IR38499) segregating for genetic male sterility. S_1-derived S_3 and S_4 lines homozygous for male fertility were used to assess the effectiveness of selection in the S_1 generation. As S_1 seed is harvested from individual S_0 plants, the amount is limited, and segregation for male sterility further complicates the selection for agronomic traits including yield. There were highly significant correlations between S_1 and the derived S_3 and S_4 lines for plant height, brown rice length, brown rice shape, gelatinization temperature, spikelet number per panicle, number of panicles per hill, and 100-grain weight, indicating that these traits could be accurately selected in the S_1. Adjusted grain yield showed a nonsignificant correlation in WS, and a significant (r = 0.47) correlation in DS.

Evaluation of advanced breeding lines

In the medium-deep RYT at IRRI, lines were grown at a favorable site with stagnant flooding of 30- to 40-cm water depth, and at an unfavorable site, which experienced submergence stress. The highest yielding entry IR48120-49-5-3-2 yielded 2.9 t/ha in the more favorable medium-deep trial, and 1.4 t/ha in the unfavorable location. This line, from the cross Pankaj/IR56//IR20992-7-2-2-2-2-3, has been highlighted in previous reports for its adaptation to stagnant flooding. It was also one of the highest yielders in the shallow RYT at IRRI. It is 120 cm tall and has a duration of 145 d.

Advanced breeding lines from the Thai-IRRI collaborative breeding program were evaluated by staff at six stations in Northeast Thailand. Two waxy lines gave an overall yield similar to that of the waxy check varieties (Table 17). IR43070-UBN-501-2-1-1-1 is a photoperiod-sensitive line with intermediate plant height and moderate resistance to Bl. Several nonglutinous lines yielded higher than the checks. IR46331-PMI-32-2-1-1 is photoperiod sensitive with intermediate plant height, and has shown good drought resistance in screening at IRRI. IR43450-SKN-506-2-2-1-1 is insensitive to photoperiod and has aromatic grains.

Elite lines are ultimately submitted to the International Network for Genetic Evaluation of Rice (INGER) for evaluation in the International Rainfed Lowland Observational Nursery (IRLON). The breeding line IR43559-25-5-3-2, with strong submergence tolerance derived from the traditional cultivar FR43B, performed well at many sites. Several breeding lines from the cross IR37096 (CR1009/IR4568-86-1-3-2) received high ratings for phenotypic acceptability, and IR37096-52-3-1 has consistently shown moderate levels of submergence tolerance in screening at IRRI.

Field plot techniques for rainfed lowland rice

Data from INGER and uniformity trials were analyzed to determine if variation in rainfed lowland ricefields is larger than that in irrigated rice. Prelimi-

Table 17. Highest yielding breeding lines and check cultivars in the Thai-IRRI interstation yield trial, Northeast Thailand, 1989.[a]

Designation	Yield (t/ha)	Rank	Maturity (d) or flowering date[b]	Height (cm)	Grain length (mm)	Amylose (%)	Resistance[c] BI	Resistance[c] BB
Glutinous								
IR43070-UBN-501-2-1-1-1	4.1	1	17 Oct	119	7.41	0	MR	MR
IR43070-UBN-507-1-2-2-1	4.0	3	140	116	7.38	0	R	MR
RD6 (check)	4.1	1	25 Oct	153	7.18	0	HS	MS
RD10 (check)	3.9	4	131	114	7.66	0	HS	MS
Nonglutinous								
IR46331-PMI-32-2-1-1	4.2	1	23 Oct	115	7.65	27	R	MS
IR49738-SRN-16-B-1-2	4.2	1	17 Oct	126	7.49	28	MS	MR
IR46375-CPA-8-2-1-3	4.0	3	21 Oct	139	7.54	27	MR	MR
IR46329-SRN-31-3-2-1	3.9	4	14 Oct	110	8.17	25	HR	MR
IR43450-SKN-506-2-2-1-1	3.8	9	128	134	7.78	28	MS	MR
KDML 105 (check)	3.8	8	23 Oct	145	7.56	14	HS	MR
RD7 (check)	3.3	12	134	108	7.22	23	HS	MS

[a]Yield, maturity, and height data are averaged over 6 sites. All data were collected by Thai Rice Institute staff.
[b]Flowering date given for photoperiod-sensitive entries. [c]R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible.

nary results from analysis of INGER data (IIRYN, IRLRYN, and IRRSWYN) indicate a tendency for the experimental error of varietal trials conducted under rainfed lowland conditions to be higher than that from irrigated trials, consistently so for all countries. Results from uniformity trials, on the other hand, showed that the difference in the levels of inherent field variation between irrigated and rainfed lowland conditions may not be that distinct. The pattern of relationship between the variance and plot size is also not greatly different between the two rice systems, implying the possibility for having similar optimum plot sizes for both irrigated and rainfed lowland conditions.

Analysis of existing experimental data is being continued to obtain information needed for the development of appropriate field plot techniques for rainfed lowland rice.

Varietal adaptation to drought- and submergence-prone rainfed lowland conditions

Research was conducted in a rainfed lowland rice area in Solana, Cagayan, Philippines, to identify rice cultivars adapted to environments with severe hydrological stresses. The predominant cultivars grown are photoperiod sensitive and have tall stature, drought and submergence tolerance, and very late maturity. Hundreds of entries were tested in three strata of a toposequence whose characteristics represented three major classes of unfavorable rainfed lowland rice: drought prone (stratum I), drought and submergence prone (stratum II), and submergence prone (stratum III). Breeding lines from a drought-prone RYT were evaluated for yield on two strata under rainfed lowland conditions (Table 18). Two IR48781 (IR13146-45-2-3/5287) lines were the highest yielders. Three IR48725 lines (BR10/IR21567-9-2-2-2-1-2-2-2) have performed well in several trials, with IR48725-B-B-129-1 being the highest yielding entry in the shallow RYT at IRRI in 1990. The line IR43526-523-1-1-1 is an improved photoperiod-sensitive line (flowering on 23 Oct when seeded in June) which yielded well compared to the irrigated checks.

Table 18. Highest yielding breeding lines in a rainfed lowland replicated yield trial in Solana, Cagayan, Philippines, 1989-90.

Designation	Days to flowering	Height (cm)	Yield[a] (t/ha)	Rank
IR48781-17-1-2-2	104	103	3.6	1
IR48781-3-1-2-3	106	94	3.6	2
IR48725-B-B-38-1	103	103	3.5	3
IR48725-B-B-129-1	111	107	3.5	4
IR48725-B-B-88-3	104	103	3.4	5
IR43526-523-1-1-1	117	101	3.2	12
IR68 (check)	100	95	2.8	33
IR72 (check)	99	73	2.6	41
Mean			2.83	
LSD (0.05)			0.57	

[a]Values are means for 2 replications in stratum I and two in stratum II.

Table 19. Grain yield, days to flowering, and plant height of entries in Environment-Specific Yield Trials (ESYT). Stratum I, Solana, Cagayan, Philippines, CY 1989-90.

Cultivar	Grain yield (t/ha)	Days to flowering[a] (DAS)	Plant height (cm)
IR74	4.7	131	85
IR19319-1-2-1-1-2	4.6	112	94
IR19431-72-2	4.4	100	102
IR28526-44-1-1	4.3	110	116
IR19319-5-3-3-3	4.2	103	104
BR236-10-2-2-1	4.1	110	105
IR13149-43-2-P1	4.0	107	91
IR38499 CO-350-1-2-2	3.9	112	88
Peta	3.7	103	126
IR46	3.7	110	79
IR42241-76-2-3-3	3.6	100	98
IR32453-20-3-2-2	3.6	110	89
IR41111-13-1-1-2	3.5	110	99
IR48	3.5	110	90
IR36974-13-3-3-3	3.4	102	94
IR24705-11-3-2-3-3	3.1	117	84
IR43520-93-3-3-3	3.0	128	96
Wagwag Saigon	2.3	140	128
Wagwag Tawataw	2.0	140	102
Wagwag Faire	1.3	142	124
Wagwag Ramsi	1.3	142	116
LSD (0.05)	1.0		
CV (%)	13.7		

[a]DAS = days after seeding

Environment-specific yield trials (ESYT), composed of promising improved cultivars from the different rice adaptation trials, were grown on all strata over 2 yr. CY 1988-89 was a dry year in stratum I. The amount of rainfall in August to October, a period normally with sufficient rains for crop establishment, was too low for planting operations. In 1989, rains came sufficiently early to plant 23-d-old seedlings in mid-August.

For the duration of the improved cultivars, soil moisture was generally favorable. The cessation of rainfall caused the water table to decline from mid-November to mid-December. The long-duration local cultivars suffered severe terminal drought stress, starting shortly before flowering stage. IR74, IR19319-1-2-1-1-2, and IR19431-72-2 attained yields exceeding 4 t/ha, more than 2 t higher than the local varieties (Table 19).

In stratum II, crop establishment in 1988 was delayed because rainfall was insufficient for early land preparation and transplanting. Older seedlings (70 d) were transplanted in mid-October. The delay favored production of the local cultivars. Highest yields were attained by Wagwag Saigon and IR24705-11-3-2-3-3 with 2.3 t/ha each (Table 20).

Table 20. Grain yield, days to flowering, and plant height of entries in ESYT. Stratum II, Solana, Cagayan, Philippines, CY 1988-89.

Cultivar	CY 1988-89			CY 1989-90			Mean
	Grain yield (t/ha)	Days to flowering	Plant ht (cm)	Grain yield (t/ha)	Days to flowering	Plant ht (cm)	
IR19319-1-2-1-1-2	1.9	110	66	2.7	128	74	2.29
IR19431-72-2	1.7	102	72	2.8	124	84	2.21
IR48	1.7	115	68	2.4	135	72	2.06
IR46	1.3	92	62	2.8	124	73	2.04
IR36974-1-3-3-3	1.7	115	69	2.4	124	84	2.03
IR19319-5-3-3-2-1	1.4	112	62	2.6	135	80	1.95
IR13149-43-2-P1	1.6	118	62	2.1	136	76	1.82
IR28526-44-1-1	1.2	116	76	2.4	135	96	1.80
IR24705-11-3-2-3-3	2.3	128	61	1.3	149	62	1.76
BR236-10-2-2-1	1.2	103	69	2.2	135	90	1.72
IR43520-93-3-3-3	2.0	126	80	0.9	152	71	1.44
Wagwag Tawataw	2.2	141	99	0.6	148	100	1.42
Wagwag Saigon	2.3	150	116	0.5	158	105	1.41
IR33238-25-2-3-2	2.1	116	76	-	-	-	-
Peta	-	-	-	3.0	121	106	-
IR42241-76-2-3-3-3	-	-	-	3.0	124	88	-
IR74	-	-	-	2.7	137	70	-
IR32453-20-3-2-2	-	-	-	2.6	131	74	-
IR41111-13-1-1-2	-	-	-	2.4	128	84	-
IR38499-CO-350-1-2-2	-	-	-	1.1	131	64	-
Wagwag Faire	-	-	-	0.6	148	100	-
Wagwag Ramsi	-	-	-	0.6	155	85	-
LSD (0.05)	0.5			0.7			
CV (%)	13.0			17.2			

In 1989, 34-d-old seedlings were transplanted in late August. About 2 wk after transplanting, the area was flooded to subject the plants to 2 d total submergence. An early decline of the water table caused a severe drought effect on later maturing local cultivars. The earlier maturing cultivars (121-128 d) IR19319-1-2-1-1-2, Peta, and IR42241-76-2-3-3-3 yielded about 3 t/ha. The later maturing Wagwag cultivars (148-158 d) had low yields (0.5 to 0.6 t/ha). IR19319-1-2-1-1-2, IR19431-72-2, and IR48 had the highest 2 yr's average yield. These cultivars together with IR19319-5-3-3-2-1 and IR28526-44-1-1 were consistently superior across previous years of testing at the site.

In stratum III, CY 1988-89 was a favorable year for early crop establishment. Eighteen-day-old seedlings were transplanted on 27 August. The water table stayed below the soil surface for about 2 wk. IR24705-11-3-2-3-3, IR28526-44-1-1, and IR19319-1-2-1-1-2 obtained the highest yields. The following year the crop was severely flooded for 10 d immediately after transplanting; no plants survived the prolonged total submergence.

Future research. Improved submergence-tolerant lines will be characterized for yield potential and adaptation to flood-prone areas. Photoperiod-sensitive lines with various flowering dates and high yield potential will be developed for both drought- and flood-prone environments. Drought resistance from diverse sources will be incorporated into improved breeding lines.

FUTURE PLANS FOR RAINFED LOWLAND RICE PROGRAM

Rainfed lowland rice research has been partly decentralized in 1990. With the identification of eight key sites in six countries in March 1991, research will further be decentralized. However, installaion of experiments at key sites will be carried out with a few key sites at a time. Both strategic and applied research will be carried out, with greater emphasis on strategic research. All site research will be in accordance with the activities stipulated in the 5-yr work plan and will be fitted in with the existing project or with approved changes in the project.

Research programs
Upland rice ecosystem

SUBPROGRAM I: SUSTAINABLE LAND AND RESOURCE MANAGEMENT **98**
- Factors determining upland rice farming systems productivity **98**
  - Activities in 1990 **98**
  - Continued diagnostic research on shifting cultivation in northern Laos (APA, SS) **99**
  - Low and variable productivity in eastern India (APA) **100**
  - Nematodes (PP) **102**
  - Upland rice weeds (APA) **103**
  - Upland rice insects (E) **103**
  - Intercropping legumes in low-input upland rice-based systems (APA) **106**
  - Effect of a cereal- and legume-based rotation under acid upland conditions (APA) **107**
  - Upland rice-based crop rotations with legumes (APA) **108**
  - Farmer or researcher crop and cropping pattern choices (SS) **108**
  - Farmer adoption of contour hedgerows (SS) **110**
  - Soil-water conservation on sloping land and enhancement of productivity (SWS) **112**

SUBPROGRAM II: INTEGRATED GERMPLASM IMPROVEMENT AND CROP MANAGEMENT **113**
- Crop management for weed control and drought mitigation **113**
  - Agronomic and physiological bases for drought screening (APA, PBGB) **113**
  - Acid upland rice performance trials, 1990 wet season (APA, PBGB) **115**
  - Drought screening in field, 1990 dry season (APA, PBGB) **116**
  - Weed control in relation to seeding rate and spatial arrangement (APA, PBGB) **117**
  - Future research directions **117**
- Blast management **118**
  - Upland variety released (IRGC) **118**
  - Effect of soil on blast susceptibility (PP) **118**
  - Genetics of resistance in near-isogenic lines (PBGB, PP) **119**
  - Mapping blast resistance loci using molecular markers (PP, PBGB) **120**
  - Molecular markers for analysis of *Pyricularia grisea* populations (PP) **120**
  - Conclusions **122**
  - Conclusion (program outlook) **122**

Upland rice ecosystem

Rice is and will remain an important component of the upland global production system in Asia. The upland rice ecosystem is characterized by extreme diversity of soils and topography. Hence, the objectives of this program are to design a range of rice production practices that will help rehabilitate the uplands and transform them into sustainable agroecosystems, and to develop techniques and technologies for increasing and stabilizing rice yields. The research therefore focuses on:

- Factors that determine ecosystem productivity, stability, and sustainability, which can be broadly divided into three global sets: physical environment, with climate and soils; biological environment, which includes diseases and pests; and socioeconomic environment, taking into account resources of and potential income for the farmers. Interactions between those factors are complex, numerous, and specific to sub-ecosystems or even smaller units. The program addresses these issues in selected sub-ecosystems that are representative of the range of conditions that prevail in South and Southeast Asian uplands.
- Improved methods for on-farm research in upland rice cropping systems to suit the diversity and variability of the factors cited. Some standardization is necessary to interrelate the information from site to site. It is also necessary to improve data-gathering methods for greater accuracy and reliability, especially under risky and changing environmental conditions.
- Sustainable upland rice farm management systems to ensure 1) land sustainability under short- and long-term conditions, and 2) access to improved returns and income for farmers. Sustainability is an extremely powerful motivation in the uplands because of the unreliability of production in this ecosystem, and because of problems such as erosion, soil depletion, weeds, and other pests.
- Improved germplasm and crop management in relation to pests, drought, and crop nutrition. This can be significantly achieved by improving yield response to low moderate cash inputs, developing varieties with greater tolerance for adverse climatic and soil constraints, and resistance to major diseases and pests. The program focuses on phosphorus uptake and dynamics, blast resistance, drought resistance, and, more recently, on losses caused by nematodes.

Subprogram I: Sustainable land and resource management

Factors determining upland rice farming systems productivity

ACTIVITIES IN 1990

Work was conducted on three of five activities in 1990:

1. Identification through diagnostic surveys of the causes of low and variable levels of productivity at key, representative upland sites in Asia.
2. Characterization, analysis, and mapping of productivity variations in eastern India.

5. Identification and quantification of the contribution of rice pests to low and variable levels of productivity at key, representative upland sites in Asia.

Continued diagnostic research on shifting cultivation in northern Laos

A second diagnostic survey was conducted 23 Oct - 9 Nov 1990 by researchers from IRRI and the Lao Ministry of Agriculture and Food in Luang Prabang and Oudomsay Provinces in northern Laos to understand the practice of shifting cultivation from both farmers' and scientists' perspectives, observe fields, and identify and prioritize problems and necessary research.

Shifting cultivation in Luang Prabang and Oudomsay was characterized by cutting, drying, and burning secondary forest and fallow vegetation; largely rice monocropping; field fallowing; and rotation to other lands. Farm communities or cooperative work groups decided when to shift to a fallow area for the next season's cultivation; and movement was to another part of a large area held—via traditional use rights—by the village (i.e., shifting was to fallowed lands, while villages remained sedentary). Within new areas, each family returned to particular parcels over which it held traditional use rights.

Each farmer planted up to four upland rice cultivars; as many as 16 cultivars were grown in each area. Rice cultivars were mostly glutinous, of 100-180 d duration (mostly photoperiod sensitive). Yields ranged from 0.4 to 1.6 t/ha for first cropping after the land had been fallow in Luang Prabang. In Oudomsay, it declined to 1.1 and 0.6 t/ha in the second and third years, averaging 1.0 t/ha.

With continued cropping, as soil fertility declined and more weeds invaded the land, rice yields declined. Farmers also mentioned unfilled grain, poor panicle development, white grubs, and "tired," "hot," and "dry" soils as consequences of continued cropping. Cropping intensity was greater in Luang Prabang where farmers generally cropped rice for 2 yr and fallowed lands for 3. Oudomsay farmers fallowed fields for an average of 6 yr after cropping only once. Overall, farmers reported that they fallowed fields in response to worsening weed problems and declining fertility. Weeding required 80-200 d/ha and represented about 55% of rice cropping labor (Table 1). Worst weeds were *Ageratum conyzoides*, *Chromolaena odorata*, *Bambusa* spp., and unidentified species.

Farmers described plant succession in fallowed fields and identified large (15-50 cm diameter) trees and a few indicator species, good soils, and an

Table 1. Rice crop management inputs and outputs. Luang Prabang and Oudomsay Provinces, Laos, 1990.

Item	Luang Prabang			Oudomsay		
Farmers (no.)	12			20		
Parcel area (kg seed[a]; range of means per village)	60	(30-100)		85	(55-135)	
Years cropped:years fallow	2:3			1:6		
Cropping operations (d/ha, range, %)						
Slash	38	(10-60)	15%	49	(01-186)	13
Burn and clean	3	(1-9)	1	17	(1-98)	5
Dibble and seed	30	(9-62)	12	23	(10-60)	6
Weeding	144	(2-4 x 20-80)	57	198	(2-8 x 24-200)	54
Harvest and threshing	36	(14-50)	14	78	(12-120)	21
Total labor days	251		100%	365		100
Seed (no./hill)	12	(15-19)		20		
Yield (t/ha)	1.6 1st cropping 1.1 2d cropping 0.6 3d cropping			1.0		
Rice self-sufficiency (mo)	9	(2-12)		10	(2-12)	

[a]Parcel areas were expressed in seed quantities. Quantities given represent approximately 1 ha.

absence of crop weeds (and of *Imperata cylindrica* in Luang Prabang) as desirable in newly opened fields. Desirable soils were black or black-yellow rather than red, not stony, "hard"—i.e., clayey or silty rather than sandy—and "fresh," "cold," and "cooked" after burning. Farmers burned fields to reduce weeds in the crop, to "cook" the soil and to obtain fertilizer from ash.

Farmers' ranking of the causes of reduced yields showed weeds as the major problem in both places (Table 2). Researchers recommended that weeds be controlled and fallows improved before permanent cultivation (a government goal) is encouraged. The approach assumes that 1) although fertilizer (P and lime) may be needed periodically, maintaining continuous ground cover is the key to weed (and soil erosion) control; and 2) suitable innovations in plant species and cultivation techniques can help restore soil fertility faster than natural fallow. Live mulches such as *Desmodium ovalifolium* or *Mucuna utilis* can be tested to control weeds, hold soil moisture, delay spread of perennial grasses, and maximize time of plant cover on cropped land. Studies suggest that vine legumes such as *Pueraria phaseoloides*, *Centrosema pubescens*, and *Calopogonium mucunoides* planted before or at the start of field abandonment improve long-term nutrient cycling and help suppress weeds such as *I. cylindrica* or *Chromolaena odorata*. Legume trees and perennial cash crops can be tested as fallow components rather than as immediate rice cropping substitutes.

Research recommendations for upland agroecosystems featuring scrubland were aimed at increasing population and cropping intensity, decreasing fallow lengths, and expanding crop diversity.

Table 2. Ranking of problems in (rice-based) shifting cultivation in Luang Prabang and Oudomsay, Laos, 1990.

Problem[a]	Priority[b]	
	Luang Prabang	Oudomsay
I. Weeds	1	1
Rats	2 or 3	2 or 3
Insects	3 or 2	3 or 2
Drought	3	3
II. Low and declining soil fertility	1	2 or 3
Increasing cropping intensity	1	2 or 3
Soil erosion	?	?
Unsuitable	?	?

[a]Group I problems were identified by farmers, group II problems, by researchers. [b]Qualitative rankings by the survey team. ? = data from the survey were insufficient for ranking the problem.

Figure 1 contrasts overlapping sets of research appropriate to different types of upland agroecosystems.

Low and variable productivity in eastern India

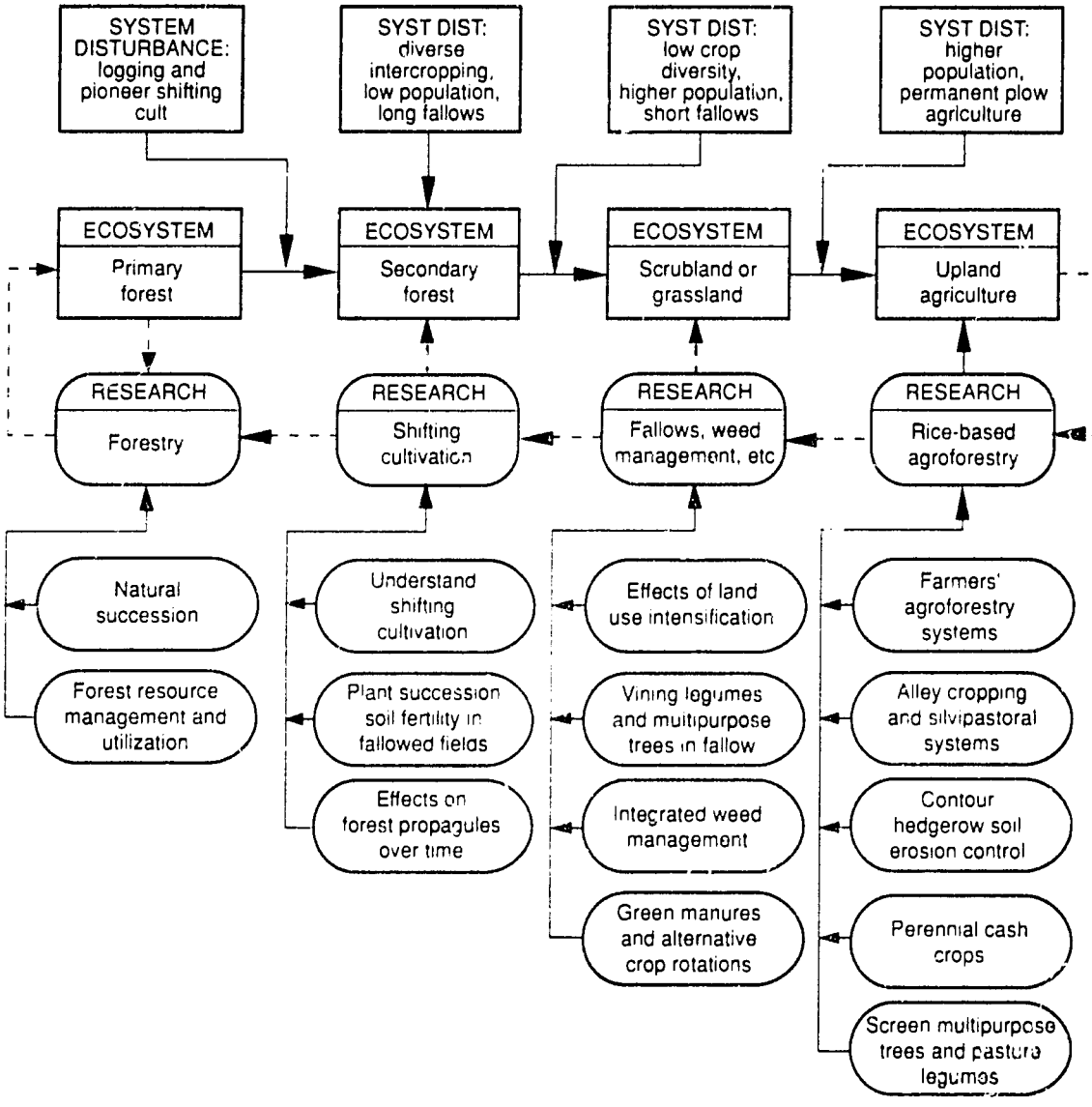
A collaborative study was conducted with the Central Rainfed Upland Rice Research Station of the Indian Council of Agricultural Research to determine reasons for divergence in rice productivity and constraints in the uplands of the Chhota Nagpur plateau in Bihar, India. Four sites (Meru, Hario, Gora, and Hazaribagh) were surveyed in the 1990 dry season. Various techniques (e.g., agroecosystems analysis, rapid rural appraisal) were employed to characterize sites and diagnose problems. Crop-cut samples from randomly selected farmers' fields were taken during the 1990 wet season to confirm yields reported by farmers.

Arable land was locally classified as upper (*tanr*) or lower (*don*), and further subclassified into categories I, II, or III based on productivity, proximity to the village, soil type and depth, soil moisture, and landscape position.

Upland rice productivity in all villages varied according to land type, available moisture, and varieties planted. Though variation in yields in upper, middle, and lower fields was small across study sites (Table 3), rice yields were lower in upper than in lower fields. In normal rainfall years, yields ranged between 0.6 to 1.1 t/ha in upper fields (*tanr* II, III), 0.7 to 1.5 t/ha in middle fields (*don* II, III), and 1.0 to 1.6 t/ha in lower fields (*don* I).

Farmers grew traditional varieties on *tanr* (Gora, Chandragrahi, Jonga, Nardha, and Dhusra), *don* II (Bhenda, Kabar, and Kalamdani), and *don* II and III (Dudh-Kandra and Kalamdani) lands. Commonly planted improved varieties were Kalinga III on all land types and Ratana, Saket, and Sujata on *tanr* I and *don* I lands. Yields from improved varieties were higher than those from traditional varieties. But in drought years, yields of both types were reduced, sometimes to the point of crop failure. Drought was reported to be severe once every 4 yr, usually in September.

Drought (or lack of drought-tolerant rice varieties), blast, brown spot, and weeds caused low yields across sites and land types within sites. Drought stress resulted from low water-holding capacity, soil erosion, erratic rains with long dry spells, inadequate



1. Research appropriate to different states of the ecosystem, given the level of system disturbance.

Table 3. Rice yields in different villages of Hazaribagh uplands, Chhota Nagpur plateau, Bihar, India, 1990.

Village	Rice yield (t/ha)					
	Upper fields (*tanr* II & I)		Middle fields (*don* III & II)		Lower fields (*don* I)	
	Traditional	Improved	Traditional	Improved	Traditional	Improved
Meru	0.3-0.7	0.5-1.4	0.3-0.8	0.5-1.6	0.4-1.0	0.5-1.6
Hario	0.3-0.6	0.5-1.3	0.3-0.6	0.5-1.8	0.4-1.0	0.5-1.6
Gora	0.3-0.5	0.4-0.9	0.3-0.6	0.5-1.4	-	
Hazaribagh	0.3-0.6	0.4-0.9	0.3-0.7	0.5-1.4	-	
Mean	0.3-0.6	0.5-1.1	0.3-0.7	0.5-1.5	0.4-1.0	0.5-1.6

groundwater, and weeds. Other causes of low yields varied by site and land type. Low soil fertility coupled with shallow soils, high runoff, and soil erosion were serious problems at Meru and Hario. Sandy soils and consequent low water-holding capacity led to poor plant stand at Gora and Hazaribagh (Table 4).

Poor soil fertility, soil erosion, and cattle grazing were the main problems in *tanr* III. Low soil fertility, seedling damage by termites (*Trinervitermes heimi*), blast and brown spot, and weeds were problems in *tanr* I and II. Weeds and blast were the main causes of low yields in *don* II and III. *Don* I lands had the fewest problems and the smallest area among land types.

Socioeconomic factors contributing to low yields included land fragmentation (due to high population and traditional inheritance patterns), and inadequate cash or credit. Villagers were poor and generally could not dig wells or construct water tanks because deep water tables and hard rock at shallow depths increased the costs of developing water resources. Undulating topography and traditional water-use rights precluded the use of channels to connect unirrigated areas to wells owned by higher caste families. At Hario, farmers constructed 8 water tanks and about 35 wells using credit extended by missionary NGOs and community labor. Such action was possible because all village families except one belonged to the same tribal group and practiced the same religion.

Nematodes

A survey in 1990 identified plant-parasitic nematodes associated with upland rice in the Philippines. Eleven genera of plant-parasitic nematodes were associated with upland rice (Table 5). The most

Table 4. Causes of low rice yields at different sites and land types in Hazaribagh uplands, Bihar, India, 1990.[a]

Cause	Upper		Middle	Lower	Sites
	tanr III	*tanr* I/II	*don* II/III	*don* I	
Moisture stress	x	x	x	x	all
Lack of suitable varieties	x	x	x	x	all
Blast	x	x	x	x	all
Brown spot	x	x	x	–	all
Weeds	x	x	x	–	all
Low soil fertility	x	x	–	–	Meru, Hario
Shallow soil	x	x	–	–	Meru, Hario
Water run off	x	x	–	–	Meru, Hario
Soil erosion	x	x	–	–	Meru, Hario
Sandy soil	–	x	x	–	Gora, Hazaribagh
Low water-holding capacity	–	x	x	–	Gora, Hazaribagh
Termites	x	x	–	–	Gora, Hazaribagh

[a]An (x) indicates presence of the cause; a dash (–) absence of the cause.

Table 5. Occurrence and abundance of plant parasitic nematodes associated with upland rice in the Philippines, 1990.[a]

Genus	Soil at preseeding		Maximum tillering			
			Soil		Root	
	Infested fields (%)	Density	Infested fields (%)	Density	Infested fields (%)	Density
Pratylenchus zeae	100	812	92	123	100	174
Rotylenchulus	87	260	28	20	-	-
Helicotylenchus	98	22	89	26	-	-
Tylenchorhynchus	60	33	28	52	-	-
Rotylenchus	43	20	-	-	-	-
Xiphinema	64	4	53	15	-	-
Hoplolaimus	30	3	29	6	-	-
Hemicriconemoides	2	3	15	22	-	-
Criconemella	38	2	41	8	-	-
Hemicycliophora	21	6	19	131	-	-
Meloidogyne	0	0	35	3	-	-

[a]Density = average population per liter of soil or gram of root in infested fields.

prevalent species, *Pratylenchus zeae*, had very high population densities always above the minimum threshold level in all fields. The nematode is a major pathogen of upland rice in the Philippines but *Meloidogyne* spp. and *Hemicycliophora penetrans* may be important in some locations.

Experiments were conducted to determine the effects of *P. zeae* on UPLRi-5 yields. After natural populations were controlled, each test plant was inoculated at the rate of 250-5,000 nematodes in the greenhouse, and 33-1,000 *P. zeae* in the field. Reductions in yield (20-70%), number of panicles, and root weight were significant at all inoculum levels in both experiments (Table 6,7).

Upland rice weeds

An experiment was conducted during wet season 1987, 1988, 1989, and 1990 in two villages in Claveria, Misamis Oriental, Philippines, to determine the effect of crop intensification on weed growth. Two crops were grown in sequence in fields that were previously planted to one crop per year. The sequence, starting with the onset of the rains in 1987, was upland rice - maize with a turnaround time of 8-12 d between crops. After the maize harvest, the area was kept as a weed-free fallow by tillage. Land preparation for rice consisted of three plowings and three harrowings at the onset of rains. Rice seeds were drilled at 80 kg/ha in *lithao*-constructed furrows spaced 30 cm apart. For maize, land preparation consisted of one plowing and one harrowing. Maize seeds were sown 25 cm apart in 60-cm furrows made with a moldboard plow.

Results in both villages were similar; those for one are presented. Weeds increased across years regardless of weed control treatment (Table 8); they weighed more in rice than in maize. Control tended to be better when hand weeding was included in the treatment and poor when interrow cultivation or herbicides were used.

Rice yields decreased over the 3-yr period (Table 9) partly because of weed buildup. Substantial yield declines (>50%) were observed even in the well-weeded plots despite addition of fertilizer (50-11 kg N-P/ha) to each crop. Maize yields were low and did not decline across years because of weeds or other factors. Irrespective of year or crop, yields were higher in plots that had been hand weeded.

Since weed problems became worse across years, there is need to develop alternative weed control strategies to achieve sustainable production. A matter of much concern is the decline in rice yield even when weed control was good; the reasons for declining productivity, particularly the contribution of soil nutrients, need to be investigated thoroughly.

Table 6. Effect of *P. zeae* inoculum level on rice (UPLRi-5) yield, panicle number, root weight, and plant height in a greenhouse experiment, 1990.[a]

Initial inoculum (no.)	Yield (g/plant)	Panicles (no.)	Root weight (g)	Plant height (cm)
0	12.7 a	8 a	8 a	98 a
250	2.7 bc	2.3 bc	3.9 ab	87 b
500	3.1 bc	2.5 bc	3.4 b	88 b
1000	2.6 bc	2.7 bc	3.6 b	85 b
2500	4.1 b	3.7 b	3.3 b	88 b
5000	2 c	2 bc	2.9 b	88 b

[a]Mean of 6 replications. Means followed by the same letter are not significantly different at the 5% level by *t*-test.

Table 7. Effect of *P. zeae* on plant growth in a field inoculation experiment, 1990.[a]

Inoculum (no. of nematodes)	Panicles (no.)	Yield (g)	Yield reduction (%)
	With fertilizer		
0	13.2 a	9.1 a	
33	8.8 b	5.6 ab	38.5
100	4.4 bc	3.9 b	57.1
500	7.2 bc	4.6 b	49.4
1000	6.4 bc	2.9 b	68.1
	Without fertilizer		
0	8.8 b	6.4 ab	
33	8.2 bc	6.4 ab	0
100	6.8 bc	4.3 b	33
500	4.4 bc	2.5 b	61
1000	3.6 c	1.8 b	71

[a]Panicles and yield per 50 cm of row, mean of 5 replications. In a column, means followed by the same letter are not significantly different at the 5% level by the Mann Whitney test.

Upland rice insects

The effect of insect damage on upland rice was measured in Claveria 1985-90. Trials replicated on four to nine farmers' fields each year produced a treatment that protected the crop against a wide array of insect pests. Soil pests, primarily white grubs and mole crickets, were controlled by lindane granules applied in the seed furrows. Seedling pests, mainly seedling maggot and root aphid, were eliminated by carbosulfan seed treatment. Stem borers, leaffolders, and armyworms were controlled by carbofuran

Table 8. Weed weight in rice (45 DE) and maize (50 DE) as affected by time and method of weed control. Patrocinio, Claveria, Misamis Oriental, Philippines, 1988-90.

Weed control treatment[a]	Weed weight (gm²)					
	Rice			Maize		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
HW at 14, 28, 42 DE	9 a	6 a	20 a	3 a	2 a	10 ab
HW at 14, 28 DE	10 a	7 a	40 a	4 a	4 ab	9 ab
IRC + HW at 14, 23, 42 DE	16 a	18 a	58 a	5 ab	4 ab	13 ab
IRC + HW at 14, 28 DE	9 a	20 a	47 a	3 a	3 a	16 ab
IRC at 14, 28 DE	239 b	400 b	613 c	41 c	22 c	87 b
HOEW + HW at 14, 28, 42 DE	10 a	28 a	41 a	5 ab	4 ab	9 ab
HOEW + HW at 14, 28 DE	59 a	13 a	32 a	6 ab	7 ab	15 ab
Pendimethalin (1.0) PE + HW at 28 DE	3 a	3 a	10 a	3 a	4 ab	6 a
Pendimethalin (1.0) PE + 2,4-D (0.05) at 28 DE	21 a	13 a	234 b	9 b	18 bc	39 b
No weeding	362 c	430 b	629 c	9 c	82 d	176 c

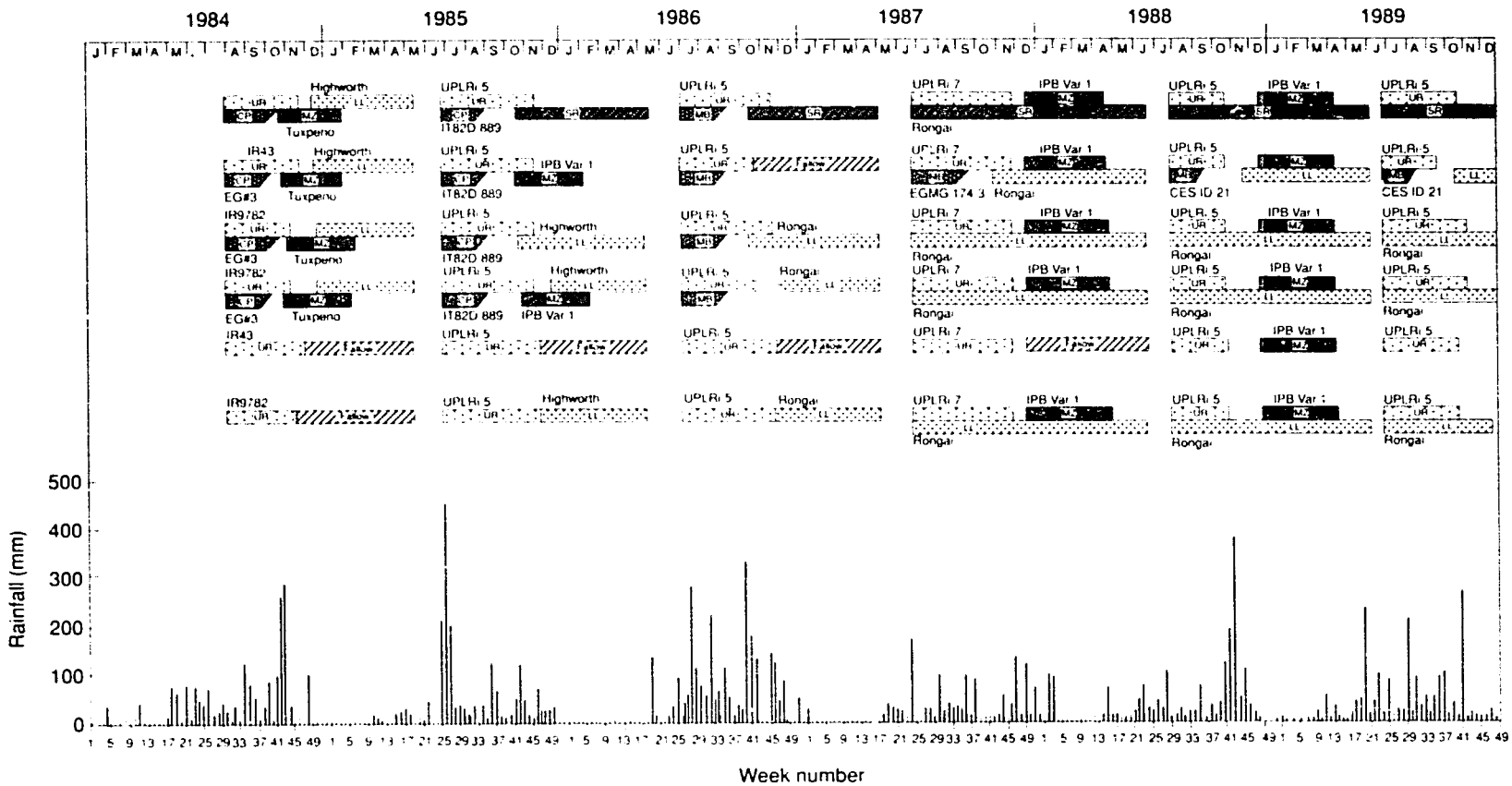
[a]HW = hand weeding, DE = days after emergence, IRC = interrow cultivation, HOEW = hoe weeding, PE = preemergence.

Table 9. Rice and maize yields as affected by time and method of weed control. Patrocinio, Claveria, Misamis Oriental, Philippines, 1988, 1989, 1990.

Weed control treatment	Yield (t/ha)					
	Rice			Maize		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
HW at 14, 28, 42 DE	5.3 a	4.7 a	2.5 ab	1.9 ab	1.9 bc	2.6 a
HW at 14, 28 DE	5.3 a	3.3 ab	1.0 de	2.2 ab	2.1 abc	1.9 abc
IRC + HW at 14, 28, 42 DE	5.1 a	4.1 ab	1.9 bc	2.0 ab	2.1 abc	2.5 ab
IRC + HW at 14, 28 DE	5.1 a	2.7 b	0.9 de	2.0 ab	1.9 bc	1.7 abc
IRC at 14, 28 DE	0.8 c	0.3 c	0.0 f	1.0 cd	1.4 cd	1.5 bc
HOEW + HW at 14, 28, 42 DE	5.4 a	4.3 ab	3.1 a	1.5 bc	2.0 bc	2.8 a
HOEW + HW at 14, 28 DE	4.3 b	2.8 b	1.0 de	2.3 a	2.4 ab	2.2 ab
Pendimethalin (1.0) PE + HW at 28 DE	5.8 a	3.7 ab	1.4 cd	1.7 ab	2.8 a	2.5 ab
Pendimethalin (1.0) PE + 2,4-D (0.05) at 28 DE	5.1 a	3.7 ab	0.2 ef	1.9 ab	1.9 bc	1.0 c
No weeding	0.4 c	0.2 c	0.0 f	0.5 d	0.9 d	0.9 c

granules banded under the soil at the beginning of the late vegetative and reproductive stages. Seed bugs were sprayed three times with deltamethrin. Compared with the yield of this set of treatments, the average loss for untreated plots was 0.80 t/ha or 28% over the 6-yr period (Table 10). Annual losses ranged from 7 to 58%.

Variation in crop loss was due to changes in insect pest prevalence. Losses were evenly distributed among the soil, seedling, late vegetative and reproductive pest groups in 1985. In 1988, however, all yield loss was traced to soil pests. Losses were measured from well-managed crops (UPLRi-5 in 1985-89 and IR30716 in 1990) with adequate fertilization, weed control, and high seeding rate. Losses would be much higher if the crop were under stress: in 1990, drought stress in the late vegetative period resulted in a crop loss of 20% although insect abundance was not abnormally high. Although losses are substantial, little other than insecticides can be offered to control upland rice pests. Because insecticide costs are prohibitive for most upland farmers, good crop management and early planting for insect control could be recommended.



2. Changes in design of cropping patterns graphed against weekly rainfall at IRRI during the 1984-89 crop years. UR =upland rice, CP = cowpea, MZ = maize, LL = lablab, SR = siratro, MB = mungbean.

Table 10. Yield loss from insects from upland rice in Claveria, Misamis Oriental, Philippines, 1985-90.

Year	Yield (t/ha)		Yield loss (%)				
	Complete control	Untreated	Soil pests	Seedling pests	Late vegetative stage pests	Reproductive stage pests	Total
1990	1.8	1.2	0	9	20	2	31
1989	3.2	2.9	0	2	3	2	7
1988	3.2	2.5	22	0	0	0	22
1987	2.4	1.9	6	6	5	3	20
1986	4.0	2.7	9	8	11	5	33
1985	2.6	1.1	15	10	17	16	58
Mean	2.9	2.1	9	6	9	5	29

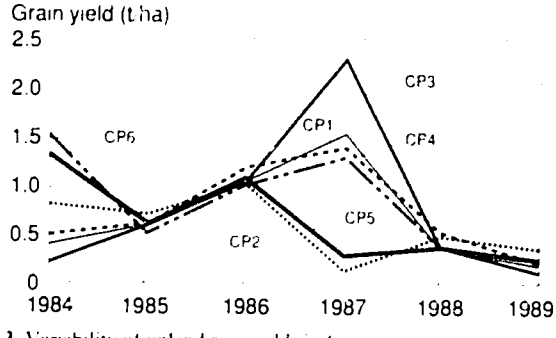
Intercropping legumes in low-input upland rice-based systems

There is much current interest in the potential role of legumes in sustainable upland cropping systems. An experiment on a moderately productive IRRI upland field aimed to develop a low-input system appropriate for upland environments that are poor in N. The soil is a silty clay Typic Tropudalf (pH 5.8, 1.37% organic C, 0.12% total N, 42 ppm available P, 1.04 meq exchangeable K/100 g, CEC 28.0 meq/100 g).

Six cropping patterns were tested between 1984 and 1989 (Fig. 2). The initial crops were rainfed upland rice (UR) and cowpea (CP) grown as intercrops or in monoculture without additional N. Treatments were modified in 1985-86 by adding siratro *Macroptilium atropurpureum*, a drought-tolerant forage legume, as a source of fodder and green manure (GM) for UR. In the 1987 wet season, each cropping pattern was subdivided to generate three levels of GM and inorganic N management. During the 1987 and 1988 crop years, the forage legumes *M. atropurpureum* and *Lablab purpureus*, which had been established in the rice crop in 1986 and 1987, were allowed to grow throughout the dry season and until the onset of rains. The biomass was then cut, chopped, and plowed under at 2 to 3 wk before wet season seeding. Two strategies were tested to manage the intercropped and relayed forage legumes: 1) the vegetative growth was clipped several times to prevent competition with UR, and 2) the biomass produced during the dry season was incorporated at the onset of the wet season before UR seeding in May or June.

Figure 3 presents a comparison of the year-to-year variability of upland rice yield (UPLRi-5 in 1984-86 and 1988-89, and UPLRi-7 in 1987) among treatments from 1984 to 1989. Yields varied greatly across years: in general, they increased from 1984 to 1987, and declined in 1988 and 1989. Low yields were due to drought during the reproductive stage of rice in 1985 and to typhoons at the same stage in 1988 and 1989. Monocrop rice yields in 1986, although low, were higher with intercropped CP. Treatment differences in rice yield were not significant in 1985 and 1986. But in 1987, intercropping with forage legumes resulted in yield increases of as much as 2.0 t/ha.

Table 11 presents the estimated N added to upland rice by the legume intercrops. *L. purpureus* contributed as much as 119 kg N/ha in 1987, a high 209 kg in 1988, and 174 kg in 1989. *M. atropurpureum* supplied 86 kg N/ha in 1987 and 102 kg in 1989. These additions represent the N content from clippings done 2-3 times during the rice cropping season, and biomass incorporated by plow before rice seeding. Figure 4 shows changes in the chemical properties of the surface soil after 4 yr of cropping.



3. Variability of upland rice yields in 6 cropping patterns across years at IRRI, 1984-89.

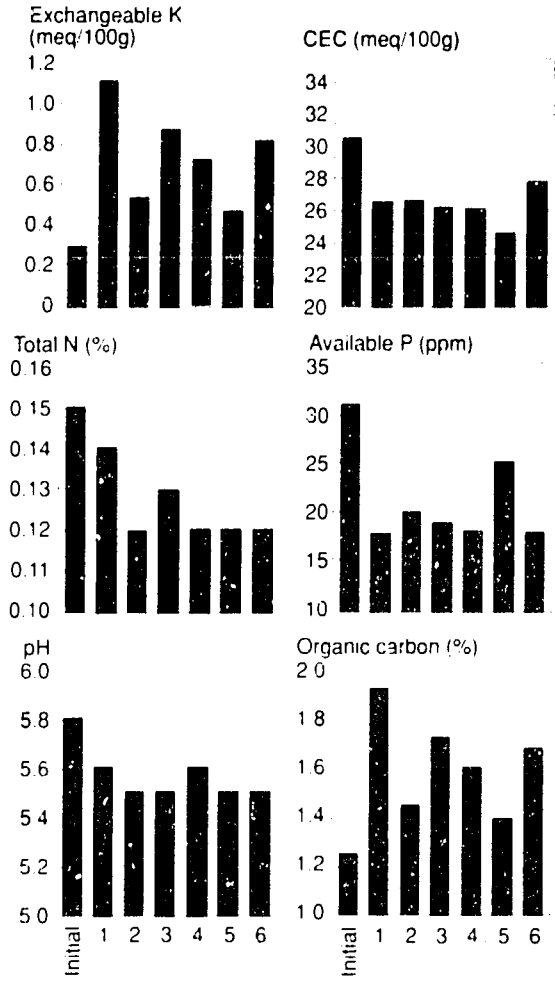
Table 11. N added by lablab and siratro in different cropping patterns. IRRI, 1987-89 wet season.

Cropping pattern[1]	N added (kg/ha)		
	Clipping	Plowed	Total
	1987 wet season		
UR + SR	-	-	86.5
UR + MB/LL	-	-	0.0
UR + LL	-	-	119.2
UR + LL	-	-	104.2
UR - fallow	-	-	0.0
UR + LL	-	-	115.1
	1988 wet season		
UR + SR	6.3	119.2	125.5
UR + MB/LL	0.0	0.0	0.0
UR + LL	6.6	152.7	159.3
UR + LL	6.9	184.1	191.0
UR - fallow	0.0	0.0	0.0
UR + LL	6.3	203.5	209.4
	1989 wet season		
UR + SR	3.7	98.2	101.9
UR + MB/LL	3.7	170.1	173.8
UR + LL	3.3	130.8	134.1
UR + LL	2.5	109.0	11.5
UR - fallow	0.0	0.0	0.0
UR + LL	5.2	106.9	112.1

[1]UR = upland rice, SR = siratro, MB = mungbean, LL = lablab

Except for exchangeable K, all other chemical properties depreciated regardless of cropping pattern. Soil chemical properties among cropping patterns did not vary greatly. The increase in the amount of exchangeable K may have been due to the continuous application of crop residues, especially forage legumes, with K pumped from deeper soil layers. A monocrop of UR gave the least increase in exchangeable K.

Results suggest that the sustainability of UR yields in an N-poor upland environment can be enhanced by the use of grain or forage legumes intercropped with or relayed into UR. But the positive effect of these on-farm nutrient sources may frequently be masked by an excess or deficit of water, and by high winds during the crop cycle.



4. Effect of 6 cropping patterns on soil chemical properties, IRRI, 1984-88. 1 = UR + SR, 2 = UR + MB/LL, 3 = UR + LL, 4 = UR + LL, 5 = UR + fallow, 6 = UR + LL.

Effect of a cereal- and legume-based rotation under acid upland conditions

Two experiments initiated in 1989 at two sites in Claveria, Misamis Oriental, had the following objectives: 1) to evaluate and identify crop rotations that could better sustain productivity in cereal-based and legume-based cropping systems, and 2) to evaluate the immediate and cumulative effects of different crop rotations on crop productivity.

Rice grain and dry matter yields did not respond to application of 50 kg N/ha as urea. However, rice planted after CP, after peanut (PN), and after clean fallow gave higher yields than rice after maize (MZ), after *Stylosanthes guyanensis*, or after weedy fallow. Yields from MZ following CP were higher than from MZ following MZ. These results imply a strong crop rotation effect, with the most deleterious effects experienced when a cereal crop (rice or MZ) is followed by a cereal.

Increased yields during rice and MZ planting may have been associated with higher soil nitrate content derived from the incorporated crop legume residues. Furthermore, there was high P offtake and less P in-

corporated into the soil by MZ compared with CP and PN. High P offtake in MZ may be disadvantageous to the succeeding rice or MZ crop in acid upland soils where P deficiency is a major problem.

Upland rice-based crop rotations with legumes

Crop calendars in the uplands of India are determined by rainfall pattern, land type, temperature, and daylength. In rice-growing areas, a common crop rotation is grain legume - upland rice - millet - fallow, with each crop grown once in 4 yr. Crops are sown in June after initial rains, millet harvested in early September, and legumes and rice in mid-September to early October. Fields are fallowed after harvest until the next wet season. Small plots of wheat and winter vegetables are grown from December to March where irrigation is possible, usually near the homestead.

Studies in collaboration with the Central Rainfed Upland Rice Research Station (CRURRS) of ICAR at Hazaribagh, Bihar, India, were conducted during the 1990 wet season to determine the effects of legumes in rotation and along with rice on the productivity of the acid uplands. Mungbean (MB) *Phaseolus mungo*, black gram (BG) *Phaseolus aureus*, PN *Arachis hypogaea*, soybean *Glycine max*, and CP *Vigna unguiculata* were evaluated as sole crops and as intercrops with UR in row ratios of 2-3 rows of rice to 1 row of legumes. Rice sole crops were sown at 20-cm row spacing, while sole legume crops were sown at 45-cm row spacing. Rice received 60 kg N/ha and legumes 20 kg N/ha. In the rice + legume intercrops, NPK were applied basally. N rates were adjusted according to the row ratios. P was at 17.6 kg/ha and K at 16.6 kg.

Yield of rice as a sole crop was highest (2.5 t/ha). Yield was affected to different degrees by the intercrops (Table 12), highest rice yields being recorded in rows with BG and PN at 2:1. Among legumes, a CP sole crop produced the highest yield (0.62 t/ha), followed by BG (0.55 t/ha). Cowpea yields were also highest as an intercrop with rice in both row ratios.

Farmer or researcher crop and cropping pattern choices

An understanding of farmers' systems with an evaluation of farmer technology and adaptation may be more effective than researcher-designed, farmer-implemented cropping pattern trials. Between 1987 and 1990, a study was conducted in Claveria to determine the appropriateness of on-farm research.

Table 12. Grain yield of rice and legume intercrops at Hazaribagh, Bihar, India, 1990.

Intercrop	Row ratio	Yield[a] (t/ha)		Land equivalent ratio
		Rice	Legumes	
Rice + mungbean	2:1	1.57	0.23	1.52
Rice + mungbean	3:1	1.49	0.18	1.30
Rice + black gram	2:1	2.10	0.26	1.33
Rice + black gram	3:1	1.80	0.19	1.10
Rice + peanut	2:1	2.10	0.29	1.62
Rice + peanut	3:1	1.84	0.27	1.54
Rice + soybean	2:1	1.96	0.37	1.72
Rice + soybean	3:1	1.86	0.32	1.55
Rice + cowpea	2:1	1.63	0.38	1.27
Rice + cowpea	3:1	1.43	0.32	1.08

[a]Grain yield of sole crop rice was 2.46 t/ha, mungbean, 0.36 t/ha, black gram, 0.55 t/ha, peanut 0.34 t/ha, soybean 0.40 t/ha, and cowpea, 0.62 t/ha.

Fifty randomly selected farmers from Claveria were interviewed regarding their reasons for crop, varietal, and cropping pattern choices. In 1988 and 1989, farmers were re-interviewed to calculate costs and returns of the main wet season crops; rice yields were determined from crop-cut samples and farmer estimates were used to determine yields of other crops.

Farmer-managed cropping pattern trials were conducted on 40 farms from 1986 to 1989. For 1987-88 and 1988-89, trials featured two 1,000-m^2 plots/farm representing low (25 kg N/ha and no hand weeding) and moderate (50-11-0 kg NPK/ha and one hand weeding) cash levels. Cropping patterns initially included rice plus CP with MZ relayed into rice after CP; PN, CP, or MB as a third crop; and various CP - cereal - legume sequences. In 1988 and 1989, researchers turned more attention to rice - MZ, MZ - MZ, rice - legume, rice + cassava, and CP - rice. Rice cultivars were evaluated in various trials, and by 1988, more than 1,000 entries had been tested and 9 promising selections identified. These were tested in 1988-89 with farmers' traditional and modern (UPLRi-5) varieties as checks.

Interviews with farmer-cooperators revealed that in the 1988 wet season, farmers in the lower, more drought-prone area ("lower Claveria") grew rice, MZ, and cassava; farmers in upper Claveria grew mostly MZ and tomato. Rice provided highest returns per single crop though it involved about twice the labor for and slightly higher material costs

than for traditional MZ, and the same amount of labor but much lower material costs than for hybrid MZ. However, such high returns from rice can be achieved only with adequate rainfall at crop establishment and at the reproductive stage, provision of adequate and timely labor for weeding (30-50% of the moderate labor needed for rice), and minimal pest damage (Table 13). Fallow after rice was common in lower Claveria because rainfall could not be counted on to support a second crop. Overall, farmer crop and cropping preferences in descending order were:

- Hybrid MZ in the first season followed by traditional MZ where rainfall was adequate and if credit or land previously planted to tomato was available;
- Tomatoes—if financing by a middleman was available;
- Traditional MZ in the first season followed by traditional MZ where rainfall was adequate;
- Modern rices in the first season if seed and labor for weeding were available but rainfall was inadequate for two crops;
- Traditional rices—if soils were poor but labor for weeding was available;
- Cassava—where soils were poor and if labor was unavailable.

Awareness of farmer perceptions about experimental goals, results, and technologies are important. Farmers only partly shared researchers' ideas about low and medium cash flow levels, and did not share a concept of cropping pattern trials. Twenty-one of the 25 respondents viewed the low and medium cash levels as fertilizer level trials; 16 of the 25 saw benefits of the higher level, which they then saw as a recommendation. Conversely, farmers considered the lower yield of the low cash level as ground for rejection. About half of the cooperators mentioned that the no hand weeding of the low cash flow was senseless since cropping rice meant controlling weeds.

Farmers evaluated trial components and management options rather than cropping patterns. Only 9 of the 25 cooperators in 1987 and 6 in 1989 claimed they could adopt at least one rice variety at tested input levels. Evaluation of superimposed rice trials was hindered because farmers did not consider side-by-side testing of varieties of different maturation dates practical in view of losses to birds and increased insect populations. Although farmers learned about management practices—drilling rice seed, fertilizer use, timing of interrow cultivation, and plant and row spacings—no one reported learning of a new cropping pattern.

Like researchers, farmers sought rice varieties with high and stable yields and which were acid tolerant, drought tolerant, and resistant to pests and diseases. Unlike researchers, farmers had little interest in legumes as they reported no soil nutrient benefits even after biomass incorporation. Researchers' evidence from Claveria that N is not limiting supported farmer observations and led to a reduction

Table 13. Costs and returns by crop at Claveria, Philippines, 1988 wet season.

	Rice			Maize			
	Traditional varieties	Modern varieties	Modern varieties + fertilizer	Traditional varieties	Hybrid varieties	Cassava	Tomato
Farmers (no.)	12	12	6	8	21	15	20
Total labor (d)	120	129	114	76	115	144	419
Total labor cost ($/ha)	193	208	185	124	145	206	394
Material costs ($/ha)	13	12	33	7	105	0	678
Total variable costs ($/ha)	206	220	218	131	250	206	1072
Yield (t/ha	1.9	2.8	3.2	1.3	3.5	5.5[a]	13.1
Value of yield ($/ha)	321	464	531	143	424	340	781
Returns above variable costs ($/ha)	115	244	313	12	174	134	-291
Returns to labor ($/ha)	1.6	2.2	2.7	1.1	2.2	1.7	0.3
Returns to material costs ($/ha)	9.8	21.3	10.4	2.7	2.7	-	0.6

[a]Dried chips.

of work on grain legumes at the site. Farmers with legume trials were unhappy that better insect and disease control was not provided. They found rice plus CP difficult to manage and rejected MZ relayed into rice after CP because rice shaded out MZ seedlings. They also rejected cassava relayed into rice because cassava competed too strongly for soil nutrients, and birds later perched on the cassava to feed on the rice. Farmers developed their own cropping patterns. Seven of the 25 relayed cassava into MZ and reported no intercrop competition for soil nutrients in this case.

Increasing attention to farmers' rice - MZ cropping pattern led to research seeking shorter duration rice varieties and testing in the rice - MZ pattern. It was found that IR30716-B-1-B-1-2 had higher yields and a 20-d shorter duration than UPLRi-5. In the rice - MZ sequence, MZ yields increased and rice yields decreased somewhat with decreasing rice duration. Productivity of rice - MZ (crudely based on gross cash value of rice and MZ yields) was higher with the new rather than the farmers' traditional and modern rice varieties (Table 14). However, even with a shorter duration rice, it is uncertain whether rice - MZ can be adopted; farmers may not achieve the 20-d turnaround time because they do not apply the tested fertilizer rates to rice if they could apply the amount to less risky hybrid MZ.

Although farmers participated in on-farm trials, it is necessary that a researcher-farmer partnership feature 1) an understanding of farmers' systems and choices, 2) research addressing key problem points in such systems, and 3) testing and adaptation combined with interactive communication that builds upon the skills and inputs of each party.

Farmer adoption of contour hedgerows

Claveria farmers have adopted contour hedgerow technologies over the past 4 yr. After training, adopters developed ways to reduce the labor needed for establishment and sought species that did not compete with the crop such as pineapple or mulberry with possible direct cash returns. Nonadopters had off- or nonfarm opportunities and/or substantial proportions of flatter lands. Although farmer-to-farmer technology transfer methods are being developed, it is clear that working with farmers who need the technology is a key factor.

Initial studies conducted in 1987 indicated that farmers with sloping lands were very concerned about soil erosion. They knew of several ways to conserve soils, had tried a few measures on their farms, and were knowledgeable about soil nutrient management alternatives, but they faced cash and labor constraints.

Contour ditches and bunds established by A-frame (a simple bamboo device consisting of a plumb line, two 2-m legs, and center-calibrated crosspiece—forming a letter "A") and planted to hedgerows seemed potentially appropriate for soil erosion control. The technology harnesses erosive forces to form terraces between planted strips and is appropriate for areas with sloping land, permanent plow agriculture, intense rainfall, and land scarcity. World Neighbors, an NGO working with upland farmers in Cebu combined the technology with farmer participation and cooperation. In response to a request by IRRI, farmers from Cebu introduced contour farming to farmers from Claveria; "hands-on" training in establishment of contour bunds, ditches, and hedgerows of fodder grasses—napier *Pennisetum purpureum* and legume trees such as *Gliricidia sepium*—was provided.

The first year. Working as a cooperative group before the 1987 wet season, farmers established almost 7,000 m of hedgerows on 10 parcels with mean size of 0.8 ha. Labor per ha (average 29 d/ha with 55% for shoveling) varied: the 673 to 1,555 m/ha reflected variation in slope and distances between strips.

Because of differences in soil compaction and groundcover, planted strips of 17-57 m/person-d

Table 14. Mean gross productivity of rice - maize for different types of rice cultivars, Claveria, Philippines, 1989-90.

Type of rice cultivar	Mean duration (d)	Mean value ($/ha)		Total ($/ha)
		Rice	Maize	
Newly tested modern varieties	109	604	499	1103
Farmers' modern variety (UPLRi-5)	130	607	296	903
Farmers' traditional varieties	140	434	272	706

were established. Farmers tested combinations of hedgerow species, including grasses (e.g., *Panicum maximum*), trees (local *Cassia spectabilis*), cash perennials (coffee, cacao, fruit), wild sunflower *Helianthus annuus*, and weeds that are otherwise pests (*Digitaria longiflora*, *Paspalum conjugatum*). Farmers noticed that *G. sepium* on the downslope of the bund suffered from competition with napier grass above. A farmer test of tree above and grass below provided a better alternative.

Farmers tried different ways of planting *G. sepium* cuttings once problems of termites and poor rooting became apparent. Since seedlings are not affected, farmers and researchers built a small nursery to supply and test *G. sepium* and *C. spectabilis* seedlings.

After four years. The initial adopters trained another 175 farmers from 1987 through 1989. On the average, each adopter contoured 0.7 ha, established 761 m of hedgerow per field, and used 16 d of labor per ha. Mean slope of the fields was 22%. By 1990 the contour hedgerows had formed embankments averaging 46 cm high. Besides labor, hedgerows cost 8.7% of the field areas.

Given placement of one hedgerow per meter of vertical drop within a field, length of hedgerows and labor per ha significantly increased as slope increased. In return, terracing (decreasing slope in alleys and increasing embankment) significantly increased as slope increased. Terracing was rapid, with 75% of total embankment being formed in the first year. Establishment labor ha significantly decreased as field size increased, suggesting some economy of scale.

Adopters saw benefits in terms of reduced soil erosion, and leveling of alleys for cropping (Table 15). However, neighbors grazed cattle on the hedgerows, causing hedgerow and bund destruction. Although napier grass controlled soil erosion and provided fodder, it was too competitive with the alley crop. Farmers, questioning the need for trees such as *Gliricidia*, continued their search for other hedgerow grass and tree species, especially those that could provide cash incomes. They were very positive about mulberry when a silkworm project was restarted in the area.

Technology adaptation was the most striking in the development of strategies to reduce hedgerow establishment labor. Farmers developed ways to reduce labor/100 linear m of hedgerow from 14 h in 1987 and 1988 to 10 h in 1989 and 8 h in 1990. In 11 strategies developed over time (Table 16), plowing was reduced, shovel work was largely eliminated, trees or grasses rather than combinations were planted, and contour lines were staked out, usually bunded, and then allowed to be covered by native grasses.

Table 15. Observations by 64 farmer-adopters regarding contour hedgerows, Claveria, Misamis Oriental, Philippines, 1990.

Observation	n	%
Hedgerows control soil erosion	50	42
Fertilizer can be applied and will not be lost downslope.	16	13
Alleys have been flattened and bunds have been strengthened.	15	13
Soil and water are evenly distributed along bunds.	13	11
Gully formation was minimized.	10	8
Miscellaneous	15	13
Total	119	100

The reasons for nonadoption were competing demands for labor on nonsloping parcels and off-farm and nonfarm opportunities, and lack of labor or draft (Table 17). Although a few mentioned tenant status, about 16% of the adopters were share-tenants.

Farmer participatory technology transfer. The goal is to develop methods for use by national agricultural programs that facilitate adoption. The IRRI team opted for the participation of farmers concerned about their soil losses, farmer-to-farmer training, and farmer participation in technology generation.

It appears that farmer-to-farmer training of "self-selected" farmers (farmers who seek training or advice on contour hedgerow methods) is effective once there is a critical mass of adopters. Likely adopters are 1) those without sufficient flatter lands such that they can ignore or do not really suffer from problems of soil erosion, and 2) those without substantial off-farm work opportunities.

Although 48 km of hedgerows on 50 ha by 75 farmers may not "save" the soil in Claveria, our goal is to develop methods by which farmers and national researchers can jointly adapt and extend appropriate technologies. In Claveria and similar upland environments, the recommended technology features contour layout, optional plowing, farmer-selected combinations of native grasses, planted grasses (e.g., *Setaria*, *Brachiaria*), pasture legumes (e.g., *Stylosanthes*), trees (e.g., mulberry), or perennial crops, and farmer-participatory technology transfer.

Table 16. Contour hedgerow strategies and farmers adopting them, by year of adoption: Claveria, Misamis Oriental, Philippines, 1990.

No.	Strategy	Labor		Adopters (no.)				
		d/ha	h/100 m	1987	1988	1989	1990	Total
1.	Plow + shovel + tree + grass	20	15	7	7	1	0	15
2.	Plow + shovel + tree	16	13	2	2	7	1	12
3.	Plow + shovel + grass	20	13	3	3	1	1	8
4.	Plow + tree + grass	10	13	1	1	1	0	3
5.	shovel + tree + grass	25	11	0	0	1	0	1
6.	Plow + tree	14	9	0	0	11	1	12
7.	Plow + shovel + native grass	14	9	0	0	2	0	2
8.	Plow + grass	12	7	1	0	1	1	3
9.	Plow + native grass	11	5	0	0	2	0	2
10.	Native grass	14	5	0	0	1	2	3
11.	Tree + grass	5	2	0	0	1	0	1
	Total			14	13	29	6	62
	Mean labor (h/100 m)			14	14	10	8	

Soil-water conservation on sloping land and enhancement of productivity

Barriers on sloping lands can reduce water runoff volume and velocity, and thereby conserve soil and water. Small farmers do not like manually constructed terraces or bunds because of cost. An alternative is the vegetative hedgerow which forms a dense barrier at the ground surface, is established in a relatively short period, and is not competitive with the crop. Field studies were designed to evaluate the effectiveness of contour *Vetiveria zizanioides* hedgerows in conserving soil and water, and enhancing crop productivity on gently sloping lands (about 2% slope) at the IRRI farm.

Hedgerows were planted at 0.25- and 0.50-m vertical intervals in 1990 wet season. Rice IAC25 and MB M79-13-60 were planted in the alleys. The hedgerows or corresponding lines in nonhedged portions served as guiding contours for planting rice at 25-cm row spacing and MB at 35-cm row spacing. The rice crop received a basal application of 60-13-30 kg NPK/ha, and a topdressing of 30 kg N/ha at flowering; MB received no fertilizer. Rice had one spraying of insecticide against stem borer; MB was sprayed once against bean fly and twice against leaffolders. Both crops were weeded twice. Six combinations of rice and MB with hedges at 0.25- and 0.50-m vertical interval, and a nonhedged control were established with 3 replications in a randomized complete block design.

Table 17. Trained farmers' reasons for nonadoption of contour hedgerows, 1990.

Reason	no.	%
Work demands on nonsloping or lowland parcels	40	29
High labor for contour hedgerow establishment	27	19
Off-farm and nonfarm work opportunities	18	13
Lack of draft animal	16	11
Lack of capital for labor and inputs	12	9
Left the area	10	7
Does not own the land	7	5
Miscellaneous	10	7
Total	140	100

Depth of soil accumulation, soil water content in the crop root zone, and crop growth and yield in the upper and lower parts of each alley were recorded. Because of differences in elevation between blocks and between upper and lower parts of the alleys, depths to the water table varied. Between 10 Jul and 18 Sep 1990, water table depths averaged 50, 92, and 84 cm in the upper parts and 24, 57, and 59 cm, respectively, in the lower parts of the alleys in three different blocks. Heavy rains after crop planting affected establishment more adversely under shallower water tables.

The hedges planted almost concurrently with the crops took time to establish. When full grown, they allowed substantial accumulation on upslope sides of eroded soil that otherwise would have been transported downslope. Soil water regime and crop productivity were not improved because the hedgerows were not fully established during most of the crop period. Hedgerows established at a shorter vertical interval of 0.25 m, however, gave marginal increases in water retained in the root zone and in rice and MB grain yields (Table 18). Mungbean without fertilizers gave higher economic returns than rice with

Table 18. Soil accumulation, soil water content (0-60 cm depth), and crop production for upper and lower alleys and across blocks under various treatments, 1990 wet season.

Treatment[a]	Soil accumulation depth (mm)		Soil water content (mm)		Crop yield (t/ha)	
	Rice	Mungbean	Rice	Mungbean	Rice	Mungbean
0.25-m VI	25	28	319	324	1.4	0.8
0.50-m VI	16	18	308	314	1.3	0.7
Nonhedged control	8	15	314	317	1.3	0.7

[a]VI = vertical interval.

fertilizers. Comparison of grain yields from crop rows adjacent to and away from the hedges suggested no competitive effect of the hedges.

Results suggest that fully established contour Vetiver hedgerows can provide protection against soil erosion on sloping lands. Efficacy would be greater with hedgerows at shorter vertical intervals. The effectiveness of established hedges in conserving soil and water and in enhancing crop production, and the competition between hedgerows and crops need to be further evaluated.

Subprogram II: Integrated germplasm improvement and crop management

Crop management for weed control and drought mitigation

Two of the major biophysical causes for low and fluctuating yields of upland rice are weeds and drought. Hence, this project focuses on the development of crop management practices and germplasm improvement to control weeds and overcome drought effects. Weed control factors being studied include competitive plant types, seedbed preparation, seeding method, and weed control methods; weed succession; and interactions between weeds and other biophysical stresses. Research to reduce water deficit impacts touches on the physiology and genetics of plant traits that confer drought resistance, cultural practices that improve crop water use efficiency, and interactions between drought and biological stresses.

Agronomic and physiological bases for drought screening

Mass screening for drought tolerance and recovery during vegetative growth has been conducted under dry season, upland conditions, at IRRI for over 20 yr. While this screening efficiently differentiates between tolerant and susceptible varieties, it does not elucidate the physiological bases for their tolerance or susceptibility; nor does it give information on to their ultimate productivity under water-deficit conditions (drought resistance). Therefore, research was conducted to identify agronomic and physiological bases of tolerance for drought during vegetative growth, and to investigate the relationship between vegetative drought tolerance and grain yield.

All plots were sprinkler-irrigated until 30 d after emergence (DE), at which time 4 water regimes were imposed as main plot treatments. In treatment 1, plots were well-watered (WW) to maintain a soil matric potential (SMP) >-0.03 MPa at the 10-cm soil depth. In treatments 2-4, SMP was allowed to decline to -0.2, -0.5, and -1.0 MPa, respectively, before the plots were re-irrigated to maintain WW conditions until harvest. From earlier screenings, nine varieties of diverse drought response were selected for subplot treatments.

No variety showed stress symptoms when the -0.2 MPa observations were made, but as plants aged all varieties showed leaf tip drying and partial rolling even in the WW treatments; stress increased drought score and reduced yields of all varieties (Table 19). There was significant interaction between grain yield and water regime, indicating that different varieties responded differently to water deficit. Although drought score significantly correlated with grain yield across all varieties and water treatments (r^2 = 0.43**), within water regimes there were no significant drought score vs grain yield correlations. Thus drought score during vegetative stress was not an indication of variety differences in drought resistance.

Across varieties, SMP -0.2 delayed panicle emergence and maturity by 17 d. The SMP -0.5 and -1.0 treatments delayed development by an additional 10 d. Although our objective was to evaluate vege-

Table 19. Drought score and grain yield in response to water deficit levels.[a]

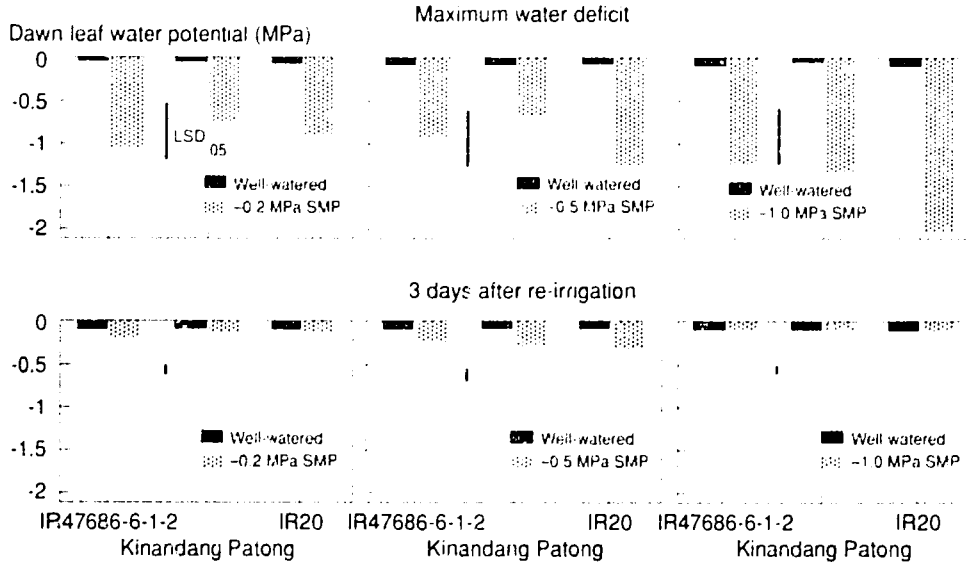
Genotype	Drought score[a]						Grain yield[b] (t/ha)			
	WW	-0.2	WW	-0.5	WW	-1.0	WW	-0.2	-0.5	-1.0
Tolerant										
IR9560-2-6-3-1	0	2	1	5	2	5	2.5 aA	1.0 bA	1.0 bA	0.6 cABC
Salumpikit	0	2	1	5	1	5	2.1 aB	1.0 bA	0.3 cC	0.4 cCD
Kinandang Patong	0	2	1	4	1	5	1.1 aE	0.1 bE	0.3 bC	0.3 bD
Moderately resistant										
UPLRi-5	1	3	1	5	1	6	1.4 aCD	0.9 bAB	0.4 cBC	0.8 bA
IR47686-6-1-2	0	2	1	5	1	7	1.2 aDE	0.6 bBC	0.7 bB	0.5 bBCD
Susceptible										
IR30716-B-1-B-1-6	0	3	1	7	1	8	1.5 aCDE	0.8 bAB	0.3 cC	0.3 cD
IRAT9	0	3	1	7	1	8	1.2 aCDE	0.5 bCD	0.3 bC	0.5 bBCD
IR20	0	3	1	7	1	8	0.8 aF	0.6 abBCD	0.3 bC	0.3 bD
IR43	0	3	1	7	1	7	0.6 aF	0.3 bDE	0.4 abBC	0.7 aAB

[a]By the *Standard evaluation system for rice* scale: 0 = no symptoms, 9 = dead. [b]A common lowercase letter shows no significant difference among water deficit treatments within a single variety. A common uppercase letter shows no significant difference among varieties within a given water deficit treatment. The test for differences among means was DMRT at the 5% significance level.

tative stress only, because of rainfall during the experimental period, stress was continued into the reproductive growth phase to reach the SMP targets. As water deficit both reduced yield and delayed development, it is not surprising that there was a significant, albeit small, correlation between days to panicle emergence and grain yield ($r^2 = 0.28^{**}$).

For a subset of test varieties, dawn leaf water potential (LWP) was significantly reduced by all stress treatments (Fig. 5), indicating no diurnal recovery in LWP. There was a significant difference among varieties only for SMP -1.0: IR20 had a significantly lower LWP than the two other varieties. Three days after re-irrigation, there were no significant water regime effects on LWP for SMP -0.2 and -1.0, but there was a small but significant reduction in LWP by stress for the SMP -0.5 treatment (Fig. 5).

The SMP -0.2 and -1.0 water regimes significantly reduced total root length in the top 40 cm soil to 0.61 and 0.52 that of the WW, respectively. But



5. Dawn leaf water potential of drought-tolerant IR47686-6-1-2, moderately tolerant Kinandang Patong, and susceptible IR20. SMP = soil matric potential.

there were no marked differences in root length among varieties. Twenty-one days after re-irrigation, neither water regime nor variety had significant effects on total root length. Thus root growth upon re-irrigation after stress exceeded that in continuously well-watered plants. Still, differences in drought score (drought tolerance) and grain yield (drought resistance) were not explained by differences in root length in these varieties.

Acid upland rice performance trials, 1990 wet season

The 1990 wet season Acid Upland Rice Yield Trial (AUYT) and Acid Upland Rice Observational Trial (AUOT) were seeded in Santo Tomas, Batangas, and in Ilagan, Isabela, to determine the performance under slightly acid soil condition of rices bred in adverse environments. AUYT consisted of 36 entries laid out in a randomized complete block design (RCBD) with 3 replications, while AUOT had 130 entries in RCBD with 2 replications. Both sites received adequate rainfall and the tests went through favorable weather conditions during the entire growth period.

Both AUYT and AUOT were basally fertilized with 40 kg P/ha and 30 kg K/ha. Eighty kg N/ha was split-applied at 10, 35, and 50 d after seedling emergence. Triazophos and endosulfan were used in Santo Tomas and Ilagan, respectively, to control rice bugs.

AUYT. Philippine variety UPLRi-7 gave the highest grain yield in Santo Tomas. Eight test entries produced yield statistically similar to that of UPLRi-7 at the 0.05 level:

Rank	*Designation*	*Grain yield (kg/ha)*
1	UPLRi-7	2932
2	IR49255-B-B-5-4	2842
3	CT6510-24-1-2	2770
4	IR55411-50	2755
5	B2997C-TB-60-3-3(AC1)-C	2743
6	IR49255-B-B-5-2	2613
7	IR57920(AC25-2)-C	2597
8	B2997C-TB-60-3-3(AC1-2)-C	2567
9	IR55411-53	2564

In Ilagan, the entries showed no significant differences in grain yield. Coefficient of variability was relatively high (30.7%) because of varying levels of sheath rot infection in most entries between replications. The top five yielders and the check are as follows:

Rank	*Designation*	*Grain yield (kg/ha)*
1	IR46122-B-B-B-7-1	2169
2	IRAT190	1757
3	IR57924-24	1646
4	IR57924-09	1563
5	IR55419-04	1554
26	UPLRi-7 (check)	1056

AUOT. Forty-six entries in Santo Tomas and 42 in Ilagan had yields similar to that of UPLRi-7. None produced significantly higher yield than UPLRi-7 at either site. The most prevalent disease at both sites was sheath rot, which infected the Ilagan test entries more severely.

Conclusion. Under the slightly acid soil conditions of Ilagan and Santo Tomas, a number of lines approximated the performance of UPLRi-7, but none was superior to it.

Table 20. Source of entries in field drought screening, and number of entries and outstanding selections, IRRI, 1990 dry season (DS).

Source	Entries (no.)	Outstanding entries		
		Equal to check[a]	Better than check[b]	Total
International Rice Germplasm Center	1552	76	11	87
International Network for Genetic Evaluation of Rice	2009	64	21	85
Plant Breeding, Genetics, Biochemistry Division				
Rainfed lowland lines	1435	58	54	112
Upland lines	248	3	1	4
Adverse environment lines	130	9	0	9
Deepwater lines	759	65	26	91
Irrigated lowland lines	638	15	1	16
Hybridization block parents	226	11	4	15
Bulu rices	1316	11	1	12
Oryza sativa x *O. australiensis*	175	1	0	1
Miscellaneous	20	1	0	1
Total	8508	314	119	433

[a]Drought reaction similar to that of drought-tolerant Salumpikit.
[b]Drought reaction better than that of Salumpikit.

Drought screening in field, 1990 dry season

Drought tolerance is essential in drought-prone upland, rainfed lowland, and deepwater ecosystems. A fast method of determining drought response was developed to identify, from the thousands of varieties collected and advanced generation lines that IRRI selects every year, those that possess tolerance for soil moisture deficit during the vegetative growth stage. The test was conducted at IRRI during 1990 dry season (DS) to determine the drought reaction of the accessions and lines and select those that could be utilized in crop production and breeding programs.

Methodology. On 27 January 1990, 8,508 cultivars and lines from International Rice Germplasm Center, International Network for Genetic Evaluation of Rice, and the Plant Breeding, Genetics, and Biochemistry Division were dry seeded on granular soil (Table 20). Each test entry was planted in two-row plots, in rows 2.5 m long and 0.25 m apart. Each of the drought-susceptible checks IR20 and IRAT9 and tolerant IR442-2-58 and Salumpikit were planted together with every 46 test entries. Thirteen kg P/ha and 25 kg K/ha were basally applied and 60 kg N/ha was split-applied in equal quantities at 10 and 20 d after emergence (DE).

The test was sprinkler-irrigated three times a week to maintain <30 kPa soil moisture tension (SMT) for proper stand establishment. Drought stress was imposed starting at 31 DE. Each test entry was scored and checked for drought reaction at 0.2, 0.5, and 1.0 MPa SMT. The test plots were re-irrigated three times, then scored for recovery ability.

Results. It took 25 d to attain 0.2 MPa SMT, another 4 d to reach 0.5 MPa, and 6 more d to reach 1.0 MPa. The susceptible check IR20 exhibited marked leaf desiccation at 0.2 MPa SMT; so did IRAT9 at 0.5 MPa (Table 21). The tolerant checks had only slight leaf tip drying up to 0.5 MPa and

Table 21. Best selections in field drought screening at IRRI, 1990 DS.

Source nursery and designation	Source nursery number	Drought score[a] at soil moisture tension			Recovery score[b]
		0.2 MPa	0.5 MPa	1.0 MPa	
Plant Breeding, Genetics, Biochemistry Division					
Rainfed lowland lines					
IR41431-16-2-2-2	R4022	1	1	2	1
IR43506-UBN-520-1-3-1-1	R4052	0	1	1	1
IR43552-80-3-1-3	R4055	0	1	2	1
IR46274-53-21-3-3-1	R4066	0	1	2	1
IR[illegible]288-20-1-1-3	R4068	0	1	2	1
IR48820-33-3-1-2	R4208	0	0	2	1
IR49778-KKN-9-B-1-6-1	R4333	0	0	2	1
IR52532-SKN-24-B-2-3	R4434	0	0	1	1
IR54132-KKN-11-B-1-2	R4492	0	0	2	1
IR54135-CPA-14-B-1-1	R4494	0	0	2	1
CT6515-18-1-3-1-2	R4006	0	0	2	1
CT6515-18-7-3-8-1	R4007	0	0	1	1
Jhingasail	R4499	0	0	2	1
18-7	R4648	0	0	1	1
Deepwater lines					
IR43969-121-3-3-3-1	D2839	0	1	2	1
IR43943-B-20-3	D3168	1	1	2	1
International Rice Germplasm Center					
Loha Dang	Acc 26716	1	1	2	1
International Network for Genetic Evaluation of Rice					
IR47690-5-2	IURON' 89 #6	0	1	2	1
Checks					
Salumpikit (tolerant)		1	1	4	1
IR442-2-58 (tolerant)		1	2	5	1
IR20 (susceptible)		3	4	7	3
IRAT9 (susceptible)		2	3	6	3

[a]*Standard evaluation system for rice* (SES) 0-9 scale: 0 = no symptom of soil moisture deficit, 9 = all plants fully desiccated. [b]SES 1-9 scale: 1 = 90% and more plants fully recovered and 9 = 0-19% plants fully recovered.

about 40% desiccation at the more severe imposed drought stress. The susceptible checks recovered 70% of its original stand; the tolerant checks recovered >90%.

Three hundred and fourteen entries performed as well as Salumpikit (drought and recovery scores of 4 and 1, respectively), while 119 performed better. Eighteen entries (14 rainfed lowland lines, 2 deepwater lines, an IRGC accession, and an INGER entry from IURON nursery) exhibited only slight leaf tip drying (Table 21). Four rainfed lowland lines and the two deepwater lines are progenies of Nam Sagui 19 and RD19, respectively (Thailand deepwater rice cultivars with excellent inherent drought tolerance). INGER entry IR47690-5-2 is a selection from a cross between drought-tolerant parents IRAT140 and Kinandang Patong. Loha Dang is an IRGC accession from Bangladesh

Weed control in relation to seeding rate and spatial arrangement

Weeds are the other major cause of limited yield in upland rice. An experiment in 1989 and 1990 evaluated the effects of various weed control practices, methods of crop establishment, and seeding rates on the yield and economics of upland rice.

Seeds of IAC25 in 1989 and IR30716-B-1-B-1-2 in 1990 were sown in furrows spaced 30 cm apart. The dominant weed species were *Borreria laevis* in 1989 and *Rottboellia cochinchinensis* in 1990. Seeding rates were 30 kg/ha in hill seeding and check row planting, and 30 and 100 kg/ha when the crop was row seeded.

Results in weed growth were similar in both years. Weeds were more abundant with hill seeding and check row planting than with row seeding, but decreased as seeding rate increased. Preemergence application of pendimethalin followed by hand weeding at 14 and 28 DE and interrow cultivation plus hand weeding at 14 and 28 DE significantly reduced weed weight irrespective of establishment method, spatial arrangement, and seeding rate (Table 22).

In 1990, weed weights were reduced significantly with check row planting, which permitted two-way cultivation, when the seeding rate was 100 kg/ha in the row-seeded plot.

The highest grain yields were obtained where weed control was best (Table 22). Interrow cultivation whether at 25 and 40 DE or at an earlier time (14 and 28 DE) gave poor weed control and the lowest yields irrespective of the seeding method used. No yields were obtained in 1990 because of drought.

In 1989, hand weeding gave the highest marginal benefit-cost ratios (MBCR) although there was some variation between seeding method and seeding rate. When rice was drilled in rows at 30 kg/ha, interrow cultivation plus hand weeding at 14 and 28 DE gave the highest MBCR.

Future research directions

Future research will investigate the potential of starting drought stress earlier than 30 DE to avoid stress during reproductive growth. Earlier stress imposition will also allow better evaluation of traits that confer drought recovery. Although there were a few significant variety differences in root length, further research is needed to understand how roots and water uptake capacity are related to drought tolerance.

Table 22. Weed weight at 45 DE and grain yield as affected by various weed control practices, seeding rate, and spatial arrangement of upland rice IAC-25.[a] Ane-i, Claveria, Misamis Oriental, Philippines, 1989 wet season.

	Weed weight (g/m²)				Yield (t/ha)			
Weed control practice[b]	Hill, row (30 kg/ha)	Check row (30 kg/ha)	Drill, row (30 kg/ha)	Drill, row (100 kg/ha)	Hill, row (30 kg/ha)	Check row (30 kg/ha)	Drill, row (30 kg/ha)	Drill, row (100 kg/ha)
Pendimethalin (1.0 (kg ai/ha) & HW, PE & 28 DE	6.8 a	3.4 a	6.0 a	5.2 a	2.0 a	1.8 ab	2.0 a	3.0 a
HW, 14 & 28 DE	8.7 ab	6.9 ab	17.9 ab	3.9 a	1.5 abc	2.3 a	1.7 a	2.9 a
IRC + HW, 14 & 28 DE	85.3 b	31.4 b	25.5 ab	9.2 a	1.1 bc	1.3 bc	1.8 a	3.0 a
IRC, 14 & 28 DE	308.1 c	262.0 c	147.3 c	116.8 b	0.8 c	1.2 bc	0.8 b	2.0 bc
IRC, 25 & 40 DE	347.2 c	243.1 c	61.3 bc	67.8 b	0.6 c	0.8 c	0.6 b	1.8 c

[a]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT. Seeding rates are in parentheses.
[b]HW = hand weeding, PE = preemergence, DE = days after emergence, IRC = interrow cultivation.

Materials from IRGC, INGER, and the breeding programs will continue to be screened to identify desiccation-tolerant rices for use by either the breeders or the farmers. Drought management schemes that would utilize the vegetative growth stage drought tolerance of these rices in attaining yield potentials will be developed.

Research will be continued in our attempt to find suitable alternative weed control technologies to labor-intensive hand weeding. Increased seeding rates, if the crop is row seeded, and check row planting for two-way cultivation need to be investigated further.

Blast management

This project focused on blast (Bl) disease, one of the primary constraints to increased yield and yield stability in upland rice worldwide. Progress in three areas is discussed: germplasm improvement, genetics of resistance to Bl, and the use of molecular markers to describe populations of the Bl pathogen.

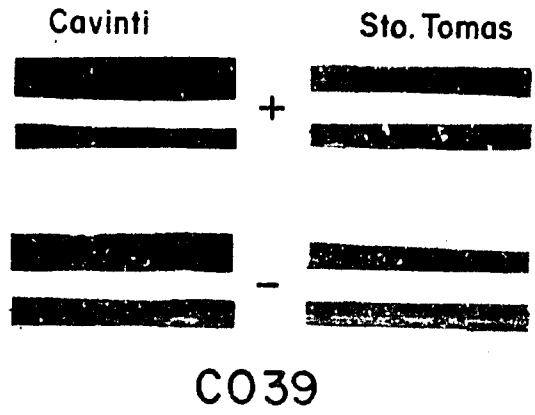
Upland variety released

The line IR10147-113-5-1-1-5 (popularly named Makiling) was released by the Philippine Seed Board for moderately acid upland areas in the Philippines. Makiling was derived from diverse parents of West African, Indonesian, Philippine, and U.S. origins. Grain quality tests conducted by the Rice Working Group of the board showed that Makiling has intermediate amylose, medium gel consistency, and highly acceptable grain quality in both raw and cooked forms.

Effect of soil on blast susceptibility

Past studies have demonstrated that rice plants grown in certain soils are more susceptible to Bl and may be "Bl conducive." Initial experiments were directed toward understanding the mechanisms of soil conduciveness and developing a bioassay to estimate that on various soils. The work was carried out in the greenhouse using conducive soil from Cavinti, Laguna, and nonconducive soil from Santo Tomas, Batangas.

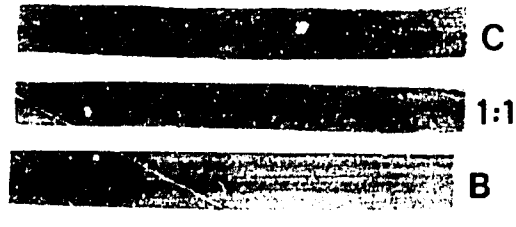
To determine if leaf surface composition was involved in the mechanism of soil conduciveness, the epicuticular wax and soluble cuticular lipids were partly removed by application of organic solvents. The susceptibility of variety CO 39 was



6. Effect of soil type (Cavinti or Santo Tomas, Batangas) and cuticle removal (- = cuticle removed, + = cuticle intact) on susceptibility of rice cultivar CO 39 inoculated with compatible isolate PO6-6 of *P. grisea*.

enhanced when the leaf surface was gently rubbed with a cotton pad moistened with methanol: chloroform (3:1, vol/vol) before inoculation with compatible isolates of *Pyricularia grisea* (= *P. oryzae*) (Fig. 6). The latent period was shortened by 24 to 28 h and the number of lesions per unit area increased, irrespective of the soil used. When the same treatment was applied to leaves of Bl-resistant varieties IRAT140, Moroberekan, and IRAT104, several small brown lesions developed within 48 h after inoculation with an incompatible isolate of the pathogen. The hypersensitive lesions appeared throughout the leaf surface of plants of IRAT140 (Fig. 7) and IRAT104 raised in Cavinti soil, but few lesions appeared when the plants were raised in Batangas soil (Table 23). Removal of the cuticle had little effect on Moroberekan.

Because of the clear-cut differences between soils, IRAT140 was used to test a bioassay for Bl conduciveness. Plants were raised in Cavinti and Batan-



7. Effect of Cavinti (C) and Batangas (B) soils and their mixture (1:1, wt/wt) on development of hypersensitive-type lesions in rice IRAT140 inoculated with incompatible isolate PO6-6 of *P. grisea*.

Table 23. Effect of soil type and cuticle removal on number of hypersensitive-type lesions per 100 mm² leaf on varieties inoculated with an incompatible isolate of *Pyricularia grisea* (= *P. oryzae*).

Soil	Leaf surface[a]	Lesions (no./100 mm²)		
		IRAT140	Moroberekan	IRAT104
Cavinti	Intact	1.7 d	0.8 d	0.8 d
	Partially removed cuticle	70.5 a	4.1 cd	39.5 b
Batangas	Intact	0.2 d	0.01 d	0.3 d
	Partially removed cuticle	3.3 cd	0.2 d	6.9 c

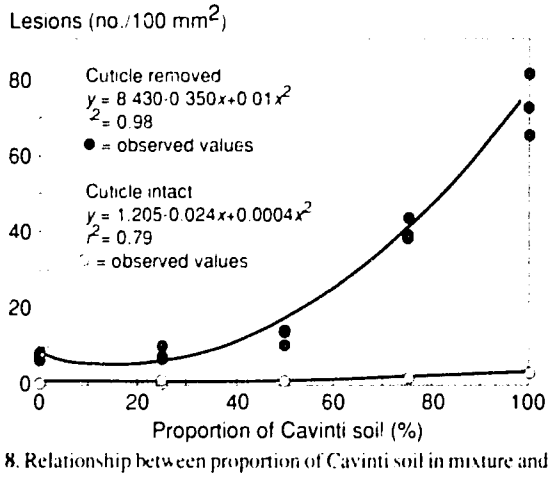
[a]Epicuticular wax and cuticle were partially removed by rubbing the leaf surface gently once with a cotton pad moistened with methanol: chloroform (3:1, vol vol)

gas soils mixed in different ratios and inoculated with PO6-6 after partial removal of the leaf cuticle. There was a direct correlation between increase of hypersensitive lesions and the proportion of Cavinti soil (Fig. 8).

Genetics of resistance in near-isogenic lines

To systematically study the genetics of resistance to Bl in tropical rices, we developed a set of near-isogenic lines (NILs) by backcrossing major resistance genes into a susceptible genetic background. Four donor parents (LAC23, 5173, Pai-kan-tao, and Tetep) were backcrossed to the recurrent parent CO 39, and five isolates were used to screen backcross F_1 generations for resistance. After six backcrosses, the plants were selfed for three generations to produce homozygous resistant lines.

Twenty NILs were inoculated with a diverse set of Philippine isolates of *P. grisea*. The NILs could be classified into six groups based on reaction to these isolates (Table 24). One NIL from each group was used to make all possible crosses among resistance groups. Results for C102PKT are not reported here as some segregation for resistance in this line was encountered. Susceptible recombinants were recovered in all crosses except C101PKT/C105TTP-4L23, representing groups III/VI. The absence of suscep-



8. Relationship between proportion of Cavinti soil in mixture and formation of hypersensitive-type lesions in IRAT140 with and without cuticle after inoculation with an avirulent isolate of *Pyricularia grisea*.

Table 24. Reaction of near-isogenic lines to 5 differential isolates of *P. grisea*.

Group	Isogenic line	Reaction[a]				
		1	2	3	8	9
I	C101LAC	0	4	0	0	0
	C103TTP	0	4	0	3	3
	C104LAC	0	4	0	0	3
II	C101A51	0	3	0	3	3
	C102A51	3	3	0	0	0
	C103A51	0	0	0	0	0
	C105A51	3	3	0	0	0
III	C101PKT	0	0	4	0	4
	C101TTP-1	0	0	4	0	4
	C101TTP-2	0	0	4	0	4
	C101TTP-3	0	0	4	0	4
	C101TTP-4	0	0	4	0	4
	C101TTP-6	0	0	4	0	4
	C102TTP	0	0	4	0	4
	C102TTP	0	0	4	0	4
	C105TTP-1	0	0	4	0	4
	C105TTP-2L23	0	0	4	0	4
	C105TTP-4L6	0	0	4	0	4
IV	C102PKT	0	0	4	4	4
	C105TTP-2L9	0	0	4	4	4
V	C104PKT	4	0	0	3	4
VI	C105TTP-4L23	0	0	4	0	0
Recurrent parent CO 39		5	5	5	4	5

[a]Scored on a 0-5 scale where 0-3 = incompatible reaction, 4-5 = compatible reaction. Isolate 1 = 101, 2 = 102, 3 = 103, 8 = 86013, 9 = Vd6010.

Table 25. Resistance genes identified in Bl-resistant near-isogenic lines.

Designation	Group	Representative NIL[a]	Source	Reaction pattern to isolates[b]				
				1	2	3	8	9
Pi-1 (t)	I	C101LAC	LAC23	R	S	R	R	R
Pi-2 (t)	II	C101A51	5173	R	R	R	R	R
Pi-3 (t)	V	C104PKT	Pai-kan-tao	S	S	R	R	S
Pi-4[a] (t)	III	C101PKT	Pai-kan-tao	R	R	S	R	S
Pi-4[b] (t)	VI	C105TTP-4	Tetep	R	R	S	R	R

[a]NIL = near-isogenic line. [b]R = resistant, S = susceptible.

tible recombinants in this cross indicates that resistance is controlled by two very tightly linked or allelic genes. All other crosses except one fit a 15:1 ratio for resistant:susceptible F_2 plants, implying that independent dominant genes confer resistance.

The resistance genes have been designated *Pi-1* to *Pi-4*, with allelic genes distinguished by a superscript (*Pi-4[a]* and *Pi-4[b]*). All genes are identified with the letter 't', indicating a temporary designation (Table 25).

In a collaborative project with Cornell University, USA, we are identifying restriction fragment length polymorphism (RFLP) markers that are linked to the resistance genes in the NILs. The RFLP clone RG64, which maps to chromosome 6, is tightly linked with the gene *Pi-2*, which is present in all the lines descended from 5173 (Group II in Table 24). This gene is close to (and may even be identical to) the gene *Pi-z* identified in Japan. It is effective against all Philippine isolates tested so far. The resistance gene in C105TTP-1 is linked to the RFLP clone RG869, which maps to chromosome 12. This NIL is in group III, and it may have *Pi-4*, but the relationship between C105TTP-1 and C101PKT has not yet been studied.

Mapping blast resistance loci using molecular markers

Certain upland cultivars, such as Moroberekan, are considered to have durable Bl resistance. To identify and map Bl resistance genes in those varieties, we are seeking associations between molecular markers (RFLPs) and genes conditioning quantitative and qualitative resistance to Bl. This approach has been used to identify quantitative trait loci (QTL) in other crops.

To allow mapping of QTL conferring Bl resistance, recombinant inbred (RI) lines were developed for three crosses and the process is in progress for three others. DNA markers were screened for polymorphism between the parents for each cross, and a high degree of polymorphism was observed (Table 26).

Molecular markers for analysis of *Pyricularia grisea* populations

Molecular markers—mitochondrial DNA (mtDNA), gel-visible *Eco*RI fragments, and repeated DNA elements—were generated and used for genetic analysis of *Pyricularia* populations. All isolates were *P. grisea* except *P. higinsii* isolated from *Cyperus brevifolius* and *C. rotundus*. The markers detected different levels of variation and differed in ability to discriminate isolates with different host specificities. RFLP analysis distinguished only six mtDNA types among 88 isolates tested from 18 host species. Most isolates attacking common ricefield weeds shared the same mtDNA type with all the rice-attacking isolates, suggesting a common ancestry for these populations. In contrast, *P. grisea* isolates from some host species showed distinct mtDNA types,

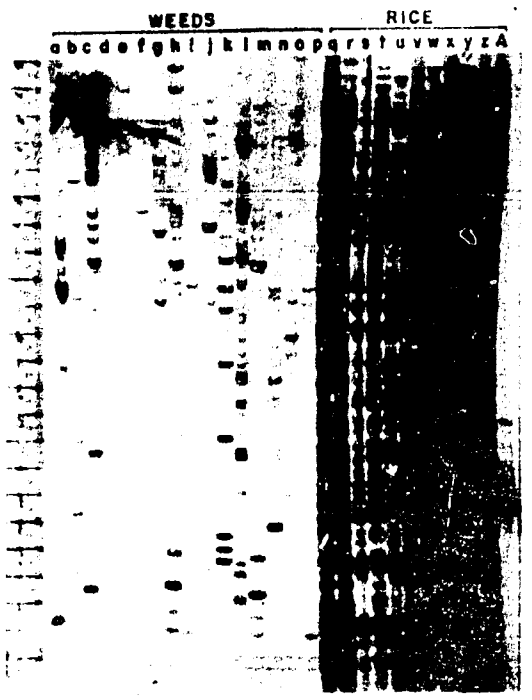
Table 26. Current status of work on production of recombinant inbred lines, and on screening of DNA probes for polymorphism between the parents for six crosses.

Cross	Generation	Probes hybridized (no.)	No. of polymorphic probes	
			no.	%
CO 39/Moroberekan	F7	127	95	75
CO 39/IAC165	F6	127	93	73
CO 39/IRAT13	F6	3	2	0
CO 39/IAC47	F3	60	50	83
CO 39/IRAT104	F3	69	59	86
CO 39/IRAT216	F3	68	57	84

indicating a more distant relationship. Analysis using gel visible-*Eco*RI fragments had slightly higher resolving power as it could distinguish a number of isolates with identical mtDNA restriction fragment banding profiles (termed "haplotypes"). RFLP analysis with repeated DNA probes provided the highest resolution, detecting differentiation among isolates with distinct host specificity. Repeated DNA analysis also revealed heterogeneity among isolates from identical hosts.

Molecular characterization of 88 isolates of *Pyricularia* obtained from rice and ricefield weeds including *Brachiaria mutica*, *B. distachya*, *Cynodon dactylon*, *Cyperus brevifolius*, *Cenchrus echinatus*, *Cyperus rotundus*, *Digitaria ciliaris*, *Eleusine indica*, *Eragrostis* sp. *Echinochloa colona*, *Leptochloa chinensis*, *Leersia hexandra*, *Paspalum distichum*, *Panicum repens*, *Pennisetum purpureum*, and *Rottboellia exaltata* indicated that isolates from different host species are genetically distinct. Isolates from the same hosts have characteristic molecular profiles, which distinguish them from isolates attacking other hosts. Genetic distinction between rice- and nonrice-infecting strains was clearly illustrated in the restriction fragment banding profiles generated by MGR 586, a repeated DNA probe from Du Pont Co. USA (Fig. 9).

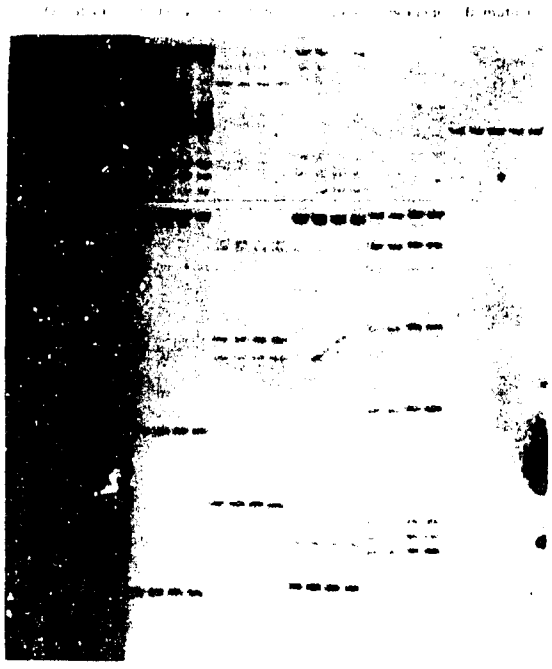
Genetic differentiation between rice- and nonrice-infecting strains was confirmed in fungus populations from two fields in Barrio Ulango, Tanauan, Batangas, and Barrio San Isidro, Cabanatuan, Nueva Ecija, where rice and several adjacent weed species were infected. Depending on the level of infection observed on each species, 6-23 isolates per host-specific subpopulation were obtained and analyzed. In Batangas, Bl lesions were observed in rice variety Dagge and weed species *D. ciliaris*, *Eleusine indica*, and *Cyperus rotundus* growing next to the ricefield. *P. grisea* from *D. ciliaris* and *P. higinsii* from *C. rotundus* were differentiated from the rice-infecting population of *P. grisea* on the bases of mtDNA restriction profile, whereas the pathogen population from *E. indica* was distinguished only on the basis of MGR 586 restriction pattern. Rice and adjacent weeds *Paspalum distichum*, *Leersia hexandra*, *Panicum repens*, *Cynodon dactylon*, and *B. mutica* were infected in the Nueva Ecija field. Although the *P. grisea* population attacking these hosts had identical mtDNA restriction profiles, restriction banding patterns generated by MGR 586 showed these populations to be distinct (Fig. 10). Genetic differentiation observed between rice- and weed-infecting population provides no evidence that populations of the Bl pathogen on weeds are of importance in rice Bl management.



9. Restriction fragment banding profile generated by MGR 586 in Southern blots of *Eco*RI-digested genomic DNA of *Pyricularia* isolates from various host species. Isolates were *P. grisea* except *P. higinsii* from *Cyperus rotundus* and *C. brevifolius*. Isolates used were from a) *B. distachya* (BdA8401), b) *B. mutica* (Bm88508), c) *C. dactylon* (Cd88215), d) *C. brevifolius* (Cb8959), e) *C. rotundus* (CrA8401), f) Cr88383, g) *D. ciliaris* (Dc88420), h) *E. colona* (Ec883), i) *E. indica* (Ei88424), j) *Eragrostis* spp. (Er88271), k) *L. hexandra* (Lh8840), l) *L. chinensis* (LcA8401), m) *P. repens* (Pr88335), n) *P. distichum* (Pd8824), o) *P. purpureum* (Pp8202), p) *R. exaltata* (ReA8401), q) *O. latifolia* (Ol88528), r) *O. sativa*/*O. latifolia* hybrid (R88531), and lanes s-A *O. sativa*.

A high degree of genetic variability was revealed among rice-infecting isolates of *P. grisea*. Repeated DNA probe PGR 613 detected 56 restriction fragment banding patterns in 146 isolates collected from 17 provinces in the Philippines.

Association between PGR 613 haplotype and the virulence pattern on a set of rice varieties was low. The Lambda statistic, which gives a measure of how well a molecular profile type predicts the virulence phenotype of an isolate, was 0.52. A value of 0 would indicate the profile has no value in predicting viru-



10. Genetic differentiation among host-differentiated subpopulations of *Pyricularia* in a ricefield in Cabanatuan, Nueva Ecija, detected by repeated DNA analysis using MGR 586 as the hybridization probe. All isolates were *P. grisea* except *P. hygrisa* from *Cyperus rotundus* and *C. brevifolius*. Representative isolates of each subpopulation have distinct restriction fragment banding patterns.

lence pattern and a value of 1 would indicate perfect predictability of virulence pattern using the PGR 613 haplotypes. Thus, DNA typing using PGR 613 can provide useful information on pathogen lineage and diversity, but cannot replace phenotypic analysis for determining virulence characteristics of the pathogen.

Conclusions

These experiments provide a firm basis for the following activities:

- Further studies will 1) determine if results using incompatible isolates causing hypersensitive lesions will parallel results using a compatible isolate causing sporulating lesions, and 2) survey several soils for their BI conduciveness.
- NILs with individual BI resistance genes will provide a tool for future study of BI. It will be easy to characterize virulence patterns of tropical races of *P. grisea* with lines possessing known BI resistance genes. Identifying new resistance genes will be easier; the reaction pattern of prospective donors against differential isolates can be compared with that of the NILs. The NILs can also be used to measure possible residual effects of "defeated" genes whose resistance has been overcome by corresponding virulence genes in the pathogen.
- The RI lines will be evaluated for segregation of DNA markers. They will be tested for resistance to many races of the BI fungus from the Philippines and for resistance at sites in other countries. Linkage between DNA markers and genes of interest will be analyzed.

Conclusion (Program Outlook)

A first and necessary step in building a research strategy is a careful analysis of the constraints and the potentials of the targeted subecosystems. Based on the information from surveys, the activities can be better focused to address the farmers' needs. The two steps given here are for Laos and eastern India, representing two different environmental conditions.

In the uplands, 20-70% reduction in yields were observed, which emphasizes the clear need for deeper investigation in several locations to quantify the impact of nematodes and to clarify their role as compared to other constraints. Weeds are another serious problem, which could cause over 50% yield declines while annual yield losses from insects range from 7 to 58%. These two observations in the Philippines highlight the major impact of constraints in a subecosystem. It is recognized, however, that good crop management can reduce the impact of the problem in the uplands.

Different varieties respond differently to water deficit, and the drought score is significantly correlated with grain yield across varieties. Drought scoring during vegetative stress does not predict variety differences in drought resistance. IR47690-5-2, a line developed by Upland Plant Breeding shows outstanding drought resistance in field screenings. Increasing the seeding rate if the crop is row seeded can play an important role in drought resistance.

It is estimated that legumes can provide between 80 and 200 kg N to upland rice when intercropped. Hence, sustainability in these upland poor soils can be enhanced by the use of grain or forage legumes intercropped with or relayed into upland rice.

The use of Vetiver hedgerows can provide protection from soil erosion. This technique is extremely useful for conserving water and soil in sloping lands

and contributes to enhanced crop production. However, more studies are necessary to maximize the impact of Vetiver hedgerows and to better understand their interaction with other crops.

The effect of soil on blast (Bl) susceptibility has been demonstrated using the upland variety IRAT140. Strongly acidic soils are more conducive to Bl than are other soils. Genetic distinction between rice- and nonrice-infecting Bl strain was shown and confirmed in specific fields in the Philippines. Results show no evidence that populations of the Bl pathogens on weeds are of importance in rice Bl management.

Research programs

Deepwater and tidal wetlands rice ecosystems

SUBPROGRAM I: INCREASED PRODUCTIVITY AND LAND-USE EFFICIENCY OF DEEPWATER RICELANDS **126**

Improved deepwater rice germplasm **126**

Modified shuttle breeding for deepwater rice (PBGB) **126**

F_1 hybrids (PBGB) **126**

Bulk population breeding (PBGB) **127**

Pedigree nursery (PBGB) **127**

Observational yield trials (PBGB, APA) **127**

Preliminary yield trial (PBGB) **129**

Elongation testing (PBGB) **130**

Submergence tolerance tests (PBGB) **131**

Drought testing at IRRI (PBGB, APA) **131**

Reevaluation of "resistant" varieties from the germplasm collection for submergence tolerance (APA) **131**

Mechanism of tolerance for shading (APA) **133**

Three varieties of deepwater rice released to farmers in Cambodia (APA, PBGB) **134**

Conclusion **134**

Improved crop and resource management for deepwater rice **135**

Deepwater rice ratoon crops (APA) **135**

Testing deepwater rice for fertilizer response (APA) **135**

Soil nitrate as a source of nitrogen for deepwater rice (APA) **136**

Residual effects of rock phosphate on deepwater rice (APA) **137**

Intercropping deepwater rice with upland crops (APA) **137**

Conclusions **137**

Integrated pest management for deepwater rice **138**

Resistance/tolerance of cultivated deepwater rice and elongating wild rices for yellow stem borer (E) **138**

Off-season behavior of stem borers in deepwater ricefields (E) **138**

Silica and stem borer resistance (E) **138**

SUBPROGRAM II: IMPROVED PRODUCTIVITY AND SUSTAINABILITY OF TIDAL WETLANDS RICE **139**

Improved germplasm and management for tidal wetlands rice **139**

Tolerance for salinity and submergence (PBGB, SWS) **139**

Performance of new salt-tolerant lines (SWS) **139**

Environmental effects on salt tolerance (SWS) **140**

Rhizosphere and iron toxicity (SWS) **141**

Generation of breeding materials (PBGB) **141**

Future plans **141**

Previous Page Blank

Deepwater and tidal wetlands rice ecosystems

Tidal wetlands rice is important in coastal lowlands where water levels in ricefields fluctuate under the influence of tides. Deepwater rice (DWR) grows in rainfed lowland fields or under shallow flooding for 1-3 mo; it is then flooded to depths that exceed 50 cm for 1 mo or longer. Although DWR can grow in up to 4 m water, our research concentrates on growing rice where maximum water depths are less than 150 cm.

These crops have been important in South and Southeast Asia for more than 1,000 yr and some 13 million ha are harvested annually. The objective is to achieve stable yields and thereby improve the lives of the 70 million people who depend on the productivity of these adverse ecosystems where current yields are less than 2 t/ha.

Subprogram I: Increased productivity and land-use efficiency of deepwater ricelands

Yields of deepwater rice are constrained by low soil fertility, drought, pests, weeds, soil stresses, and water requirements. We have developed cultivars capable of higher (3-4 t/ha) and more stable yields through improved tolerance for flood, drought, pests, and problem soils, but these must be fitted into specific ecological niches through the national testing programs. We seek to increase deepwater rice production by improving cultural methods, reducing constraints caused by environmental factors, and developing cropping systems that increase land-use efficiency.

Improved deepwater rice germplasm

Our objective is to improve the yield potential and yield stability of DWR cultivars by combining stress-tolerance traits, such as elongation ability and submergence tolerance, to identify potential donors of desirable traits and to ensure the availability of essential traits to plant breeders in various regions. Field testing in target environments is an essential part of the program.

Modified shuttle breeding for deepwater rice

For IRRI's deepwater rice breeding program (which supplies improved materials to national programs), we implemented a modified schedule that involves only one change of location instead of moving successive generations of seed between sites. After second-generation populations are screened for survival in deepwater tanks at IRRI, harvested seeds of surviving plants are moved to Prachinburi, Thailand, for field testing and to stratify the third to fifth generations for flowering date.

We implemented a geographically spread breeding program for deepwater situations, using sites at IRRI headquarters and in Solana (Cagayan) in the Philippines, and in Huntra (Ayutthaya) and Ban Sarng (Prachinburi) in Thailand.

F_1 hybrids

We grew 411 F_1 hybrids at IRRI and 118 hybrids at the Prachinburi Rice Research Center. Emphasis at IRRI was on crosses between floating rices from Assam (India) and improved DWR from the program at IRRI, while at Prachinburi crosses with Cambodian parents were grown.

Bulk population breeding

IRRI. We tested 1,745 rows of F_2-F_3 populations in water slowly rising to 1 m. Surviving plants were harvested (wet season) or transplanted into a shallow water field in the dry season. Submergence testing was done on 288 F_3 populations. The best surviving populations for submergence tolerance came from donors BKNFR76106-16-0-1-RESEL-2, IR31142-14-1-1-3-1-1-2, and IR31406-333-1.

For elongation ability, the following elongating parents occurred in more than 20 of the best surviving populations: Bazail 65, HTAFR77022-14-157-6, IR11141-6-1-4, IR28273-R-R-R-28-31-2-, IR37025-R-R-R-29-3, IR37025-R-R-R-9-1, IR38787-50-3-3-1, IR38787-50-5-3-2, IR40905-11-3-1-5-2, IR40905-R-R-R-21, IR43641-1-2-3-2-1, and Rayada 16-6.

Prachinburi. Bulk populations of 212 crosses that had been separated into bimonthly maturity classes in 1989, and 106 new crosses obtained from IRRI were broadcast on 4 May 1990 at the rate of 125 kg/ha. The populations grew under mild selection in 80-cm water depth, under natural conditions. Five rounds of harvest of mature panicles were made twice a month, the first round in late October and the last in late December. The 320 crosses were grouped by maturity date and selected for low chalkiness. Total seed yield of harvesting dates were 470, 2,205, 3,315, 4,672, and 1,809 g in late October, early November, late November, early December, and early January, respectively. The best surviving populations are given in Table 1.

Pedigree nursery

Prachinburi. We grew 5,907 pedigree lines at the Prachinburi Rice Experiment Station in natural flooding with a maximum depth of 85 cm. The best performing lines are listed in Table 2.

IRRI. We grew 11,556 pedigree lines at IRRI headquarters. Selections will be grown in natural deepwater conditions in Prachinburi.

Observational yield trials

IRRI. We grew 2,188 entries in observational yield trials in the field at IRRI. Six hundred of these were also planted in controlled floods 90 cm deep. Table 3 lists the lines that had the highest yields in 1-m-deep water on the IRRI farm.

Solana. We grew 526 breeding lines in an observational yield trial in rainfed conditions in a farmer's field in normally flood-prone stratum 3. Floods, however, were mild in 1990; all entries survived, but yielded differently. The best performing lines are listed in Table 4.

Table 1. Best surviving F_2-F_3 populations in 85 cm water, Prachinburi Rice Research Center, Thailand, 1990.

Designation	Cross
IR55855	IR33188-8-2-1-3-6 IR11288-B-B-69-1 IR38699-49-3-1-2
IR55986	Chenab 64-117/RD19/IR31086-12-1-3-3-1
IR56023	Nam Sagui 19/Patnai 23 IR11288-B-B-69-1
IR56066	IR11288-B-B-69-1 IR26760-27-1-3-2-1/ IR11288-B-B-69-1/IR26940-20-3-3-3-1
IR56067	IR11288-B-B-69-1 IR31086-12-1-3-3-1/IR11288-B-B-69-1/IR31086-12-1-3-3-1
IR56824	IR39334-1-3-6/3-2 IR11288-B-B-69-1
IR56832	IR44915-17-1/2-3/IR11288-B-B-69-1
IR57609	FRRS43-3/IR21567-9-2-2-2-1/HTAFR77022-14-157-6
IR57707	IR32429-47-3-2-2/IR11288-B-B-69-1 IR20992-7-2-2-2-2-3
IR57732	IR38699-27-2-3-3/BR118-3B-17//IR11288-B-B-69-1
IR59350	B-4259-48-1-1-1-2-2-2-1-3/FRRS43-3//B-4259-48-1-1-1-2-2-2-1-3/IR11288-B-B-69-1
IR62292	BKN6988-52-1-3/IR41418-R-R-R-22-2
IR62293	BKN6988-52-1-3/IR41418-R-R-R-25-1
IR62325	HTAFR77022-14-157-6/X-73-20-19
IR62326	HTAFR77028-6-2/IR38787-50-3-3-1
IR62359	IR43526-523-1-1-1/IR41418-R-R-R-22-2
IR62370	Nang Nhuan/IR38787-50-3-3-1
IR62602	IR37096-B-R-373-2/IR31432-6-2-1-3/BKN6988-52-1-3
IR62615	IR11141-6-1-4/IR38499-CO-350-1-2-2//IR38446-4-1-3-2
IR62618	IR11141-6-1-4/IR42221-14-1-3-1-2//IR40905-11-3-1-5-2-21
IR62621	IR11141-6-1-4/IR48120-49-5-3-2//BH2
IR62628	IR31142-14-1-1-3-1-1-2/Kashmir Basmati/IR38685-23-1-3-6-3-2-2-1

Table 2. Best performing pedigree lines from a nursery grown in natural flooding of 85 cm, Prachinburi Rice Research Center, Thailand.

Designation	Flowering date	Height (cm)	Elongation[a]	Yield[b] (g/row)
IR57757 IR38784-100-1-3-6-3/IR11288-B-B-69-1//IR11288-B-B-69-1				
IR57757-B-1	18 Nov	90	6	69.9
IR57757-B-2	18 Nov	90	6	122.7
IR58397 IR40905-R-R-R-21/B4259-48-1-1-1-2-2-2-1-3				
IR58397-B-4	18 Oct	80	4	73.7
IR59149 IR39334-1-3-6-3-2/IR11288-B-B-69-1//IR11288-B-B-69-1				
IR59149-B-11	24 Oct	90	7	109.3
IR59149-B-5	18 Nov	80	7	73.8
IR59352 BKNFR76026-3-2-2-3/IR38784-100-1-3-6-3//BKNFR76026-3-2-2-4/B4259-48-1-1-1-2-2-2-1-3				
IR59352-B-1	18 Nov	70	6	74.0
IR59352-B-20	18 Nov	70	5	73.9

[a]By the *Standard evaluation system for rice* (SES) scale 1-9: 3 = response better than that of elongating semidwarf, but not as good as that of the best local floating variety; 7 = response better than that of the nonelongating semidwarf, but not as good as that of the elongating semidwarf. [b]37 g/row corresponds to 1 t/ha.

Table 3. Highest yielding lines in a deepwater observational yield trial, IRRI, 1990.

Designation	Elongation[a]	Days to flowering	Plant height (cm)	Max yield (t/ha)
IR37025 RD19/IR46				
IR37025-R-23-2-1	5	112	126	3.7
IR38685 Chenab 64-117/IR7732-B-A96-3				
IR38685-23-1-3-6-3-2-2-1	6	104	154	3.1
IR38685-23-1-3-6-3-2-2-3	7	108	163	2.5
IR40905 Badal 613/IR11288-B-B-118-1				
IR40905-11-3-1-5-2-21	2	106	190	2.1
IR41364 RD19/IR19672-24-2-3				
IR41364-120-1-3-1	4	120	138	2.1
IR41364-R-B-B-B-16-3	6	102	159	1.9
IR42511 BR118-3B-17/BKN7022-6-4//IR13259-153-5E-P2-2/IR8234-OT-9-2				
IR42511-24-1-3-1-1	5	120	174	2.5
IR42511-66-2-2-2-3-1-3	4	100	164	2.7
IR42511-66-2-2-2-3-2-3	6	100	179	2.2
IR42511-7-1-1-B-1-3	5	100	169	2.1
IR42569 RD19/IR42//RD19/IR17494-32				
IR42569-465-3-1	5	106	138	2.6
IR42579 RD19/IR19661-131-1-2//RD19/IR15314-43-2-3-3				
IR42579-8-3-1-1-3	7	99	183	2.3
IR42579-B-B-B-10	7	105	158	2.0
IR42579-B-B-B-19	4	102	165	2.2
IR42580 RD19/IR19661-131-1-2//RD19/Khao Lo				
IR42580-23-2-1-1-1	4	108	170	3.1
IR43773 IR13423-10-2-3/DWCT156-1//IR19245-76-2-1-3-3				
IR43773-18-3-2-3-2-3	3	98	190	2.2
IR43773-18-3-2-3-2-3	2	97	169	2.3
IR43846 BR232-2B-3-4-A/IR11288-B-B-118-1/4/Bhadoia/IR8//HBJ A1///IR11288-B-B-118-1				
IR43846-21-1-1-2-2	1	106	165	2.2
IR43846-21-1-3-1-3	1	108	195	2.0
IR43936 HTA7403-1-2-2-5/CU-LA//DWCT156-1/IR11288-B-B-65-1				
IR43936-43-2-2-1	1	106	205	2.3
IR43950 HTA7406-111-0-0-2/SPR7292-151-2-1//RD19/IR17494-32-3-1-1-3				
IR43950-41-2-3-2-1-3	2	103	201	2.1
IR44004 Badal 613/IR11288-B-B-118-1//SPR7292-151-2-1/BR523-3-1				
IR44004-91-3-3-1-2-3	2	101	196	2.4

continued on next page

Table 3 continued.

Designation	Elongation[a]	Days to flowering	Plant height (cm)	Max yield (t/ha)
IR44035 KDML 65-G1U-45/IR11288-B-B-69-1//RD19/IR17494-32-3-1-1-3				
IR44035-520-2-3-3-3-1	3	106	193	2.2
IR44035-526-2-3-1-3	5	108	200	2.6
IR44035-533-3-2-2-1-3	4	101	164	2.4
IR44035-697-1-3-1-3-3	2	101	190	2.7
IR44035-734-3-2-2-2-2	3	103	200	2.3
IR44128 RD19/IR17494-32-3-1-1-3//BR222-B-263/IR11288-B-B-118-1				
IR44128-236-2-1-3-1-1	2	105	198	2.9
IR44128-307-3-3-2-3-3	1	105	200	2.8
IR47586 IR17491-5-4-3-3/IR11288-B-B-65-8-3				
IR47586-B-B-7-1	4	114	163	2.0
IR48299 IR11141-6-1-4/IR15413-4//IR11141-6-1-4/IR60				
IR48299-238-1-1-3	4	106	155	1.9
IR54432 TOX896-R-R-R-102/RD27//IR31363-1-1-3-3-3-2/RD27				
IR54432-B-4-3-1	5	109	195	1.9

[a]By SES scale 1-9.

Table 4. Best yielding lines in a field trial, Solana, Cagayan Valley, Philippines.

Designation	Grain yield[a] (g/plot)	Days to flowering	Height (cm)
IR38685 Chenab 64-117/IR7732-B-A96-3			
IR38685-49-2-1-6-3-1	791	123	108
IR41222 MTU7029/IR6402-OT-7			
IR41222-26-1-1-2-B-1-3	795	118	85
IR41364 RD19/IR19672-24-2-3			
IR41364-R-B-B-B-10-3	941	123	93
IR41364-R-B-B-B-13-1	805	129	93
IR41364-R-B B-B-1-1	809	125	99
IR42529 Chenab 64-117/IR15314-43-2-3-3//Chenab 64-117/IR19661-131-1-3-1-3			
IR42529-245-2-1-1-2-2	982	124	121
IR46630 IR20/Sitopas//BR118-3B-17			
IR46630-B-13-2-2-1	862	123	140
IR46630-B-28-3-1-1	820	129	152
IR46630-B-29-2-2-1	820	124	146
IR46630-B-29-3-1-3	850	127	137
IR46677 BKNFR76106-29-0-1/IR13423-10-2-3//TOX896/IR10110-23-1			
IR46677-B-3-1-1-1	839	122	114
IR46677-B-3-3-1-3	839	125	120
IR46679 BKNFR76106-29-0-1/IR64//CR1010/TOX896			
IR46679-B-12-3-1-1	843	131	114
IR46679-B-41-2-2-3	797	131	106
IR46704 IR9884-54-3/Pokkali//IR8234-OT-9-2			
IR46704-554-3-2-2	836	124	97
IR49924 IR17491-5-4-3-3/IR31406-333-1//IR31432-2-3/IR26702-25-1			
IR49924-B-B-B-16-2	806	132	97

[a]160 g/plot corresponds to 1 t/ha.

Preliminary yield trial

We drilled a preliminary yield trial of 1,376 5-row plots in dry soil in a naturally flooded field of the Huntra Rice Experiment Station. Flooding and attacks by the ragged stunt virus exerted strong pressures on the population, and many plots were destroyed. Conditions were exceptionally destructive; an adjacent field with floating rice Pin Gaew 56 was totally destroyed. Lines surviving this trial had low yields. Table 5 identifies the best surviving entries.

Table 5. Best surviving lines in a direct-sown trial subjected to abrupt flooding, Huntra Rice Experiment Station, Thailand, 1990.

Designation	Elongation[a]	Plant height (cm)	Yield (g/plot)
Anlong Phnom	1		108
IR28273 Ashini/RD19//IR48			
IR28273-R-R-R-28-31-2-2-1	1	182	59
IR37026 RD19/IR54			
IR37026-R-3-1-1	1	149	79
IR37026-R-3-1-3	1	133	56
IR40905 Badal 613/IR11288-B-B-118-1			
IR40905-11-3-3-5-2-1	1	157	54
IR40992 Chamara/IR11288-B-B-69-1			
IR40992-1-2-2-3-1	1	165	51
IR41132 IR11288-B-B-118-1/SPR7292-151-2-1			
IR41132-R-27-1-1	1	164	71
IR41271 NSPT/IR7732-RGA-B-A96-1			
IR41271-80-1-2-1-3-2	1	169	63
IR41271-98-1-3-1-2-1	1	159	52
IR41271-98-1-3-2-1-1	1	162	61
IR41275 NSPT/IR11288-B-B-65-1			
IR41275-R-15-3-2-1-1	1	154	58
IR41405 Shulpan/IR11288-B-B-118-1			
IR41405-13-4-3-1	1	180	99
IR42582 RD19/Murungakayan 101B//Nam Sagui 19/IR15314-43-2-3-3			
IR42582-303-2	1	166	55
IR43943 HTA7406-111-0-0-2/DWC(S)-2B-6//RD19/IR17494-32-3-1-1-3			
IR43943-50-2-2-3	1	158	204
IR43943-B-1-2	1	177	69
IR43943-B-20-1	1	177	50
IR43946 HTA7406-111-0-0-2/SPR7282-2-0-5-2//IR13423-10-2-3/IR11288-B-B-118-1			
IR43946-12-3-3-2-2-3	1	179	54
IR43946-82-3-2-1-1	1	166	150
IR44035 KDML65-G1U-45/IR11288-B-B-69-1//RD19/IR17494-32-3-1-1-3			
IR44035-353-3-3-3-1	1	177	54
IR47612 IR31432-2-3/IR11288-B-B-118-1			
IR47612-R-R-R-28	1	185	58
IR47612-R-R-R-54	1	206	58
IR59019 BKNFR76035-140-1/IR11141-6-1-4//IR40905-R-R-R-21			
IR59019	1		59
IR59021 BKNFR76042-18-1-1/B 4259-48-1-1-1-2-2-2-1-3//B 4259-48-1-1-1-2-2-2-1-3			
IR59021	1		64
Slet Yuon Vear	1		95
SPRLR77279 SIG//MLL/IR32//MLL			
SPRLR77279-41-12	1		72
Vear Krachak	1		67

[a]By SES scale 1-9.

Elongation testing

We tested 2,231 advanced lines for elongation ability at the Huntra Rice Experiment Station in controlled flooding starting at 21, 28, and 35 d after sowing (DAS). A few lines were able to elongate at all three seedling ages (Table 6).

Internode elongation tests were conducted in a concrete tank in an IRRI greenhouse. There were 320 entries from the hybridization blocks and IRTP nurseries and 11 entries from the germplasm bank, which originated from China. Six-week-old rice plants were placed in the tank and the water level was increased at the rate of 30 cm/d up to 110 cm; water was maintained at that level for 7 d. The outstanding entries were Bazail 65, IR40905-R-R-R-21, IR40957-PCR-01-1-4-1, Rayada 16-6, TCA 269, Jalmagna, Raj, Bawalia, Maguri, Negheribao (MS), and Padmapani.

Table 6. Best elongating deepwater rices in an elongation test at seedling ages 21, 28, and 35 DAS[a], Huntra Rice Experiment Station, Thailand, 1989.

Designation	Elongation[b] score average
IR42522 Chenab 64-117/IR4744-295-2-3// Chenab 64-117/IR19661-131-1-3-1-3	
IR42552-96-1-3	6.3
IR42577 RD19/IR19661-131-1-2//RD19/IR50	
IR42577-219-B-B-2	6.3
IR43969 IR11288-B-B-118-1/SPR7282-2-0-5-2// IR13423-10-2-3/RD19	
IR43969-103-2-3	6.3
IR43969-103-3-2	6.3
IR43969-116-2-2	6.3
IR47484 IR38/CN643	
IR47484-505-1	6.3
IR47484-505-2	6.3
IR47499 IR9764-45-2-2/HTAFR77022-14-157-6-1	
IR47499-27-2-1	4.3
IR47499-27-2-3	3.7
IR49223 Mahsuri/IR31361-8-3-1-1	
IR49223-B-78-1-3	6.3
IR49906 HTAFR79130-1-2-1//IR28905-4-1-1// IR6023-10-1-1/TOX896-R-R-R-102	
IR49906-B-B-B-3	5.7

[a]Days after sowing [b]By SES scale 1-9.

Table 7. Best surviving entries in a submergence test at seedling ages 21, 28, and 35 DAS, Huntra Rice Experiment Station, Thailand.

Designation	Submergence score average
IR37058 C168/FR43B	
IR37058-R-16-1-B-1	5.7
IR37105 IR4568-86-1-3-2/FR43B	
IR37105-50-21-B-B-1	5.7
IR37105-50-21-B-B-2	6.0
IR37105-50-21-B-B-6	6.3
IR37105-50-21-B-B-7	6.3
IR37105-R-14-3-3-2	6.3
IR41158 IR31031-P/BKNFR76106-16-0-1	
IR41158-11-25-B-3-2	6.3
IR41158-11-25-B-4-2	6.3
IR41158-11-25-B-4-3	6.3
IR42506 BKN7022-10-1-4/Caturinga 1// IR19382-42-3-3-2/BKNFR76106-16-0-1	
IR42506-531-1-2-1	6.3
IR42506-531-1-2-2	5.7
IR42529 Chenab 64-117/IR15314-43-2-3-3// Chenab 64-117/IR19661-131-1-3-1-3	
IR42529-200-4-2-1-2-1	6.0
IR45670 IR7732-B-A96-3/HTA7420-2-1-4-1-2	
IR45670-2-1-2	6.0

SUBMERGENCE TOLERANCE TESTS

We tested 551 advanced lines for submergence tolerance at the Huntra Rice Experiment Station in controlled flooding lasting 10 d, applied at 21, 28, and 35 DAS. Table 7 lists the best surviving breeding lines.

Submergence tolerance tests on a total of 20,746 entries included 4,853 entries from germplasm collections. Forty-eight percent of the entries were from rainfed lowland pedigree nurseries (Table 8). Outstanding entries from pedigree nurseries were selected and transplanted for further evaluations. Tolerant entries from the germplasm collections (Table 9), consisting of almost 8% of total entries, will be retested and compared with FR13A next year.

DROUGHT TESTING AT IRRI

We tested 721 DWR breeding lines at the IRRI farm for tolerance for drought at the seedling stage. Table 10 lists the parentage of the most drought-tolerant breeding lines that were on par with the resistant check Salumpikit.

Table 8. Entries tested for submergence tolerance in the greenhouse, IRRI, 1990.

Source	Entries	
	no.	%
Germplasm bank	4,853	23.4
Pedigree nurseries		
Rainfed lowland (DP)	1,028	5.0
Rainfed lowland (MD)	8,899	42.9
Deepwater	4,709	22.7
Rainfed Lowland Observational Yield Trial	627	3.0
IRTP nurseries	315	1.5
Tidal wetland	114	0.5
Hybridization block	201	1.0
Total	20,746	

REEVALUATION OF "RESISTANT" VARIETIES FROM THE GERMPLASM COLLECTION FOR SUBMERGENCE TOLERANCE

Varieties used in this test had previously been tested and evaluated for submergence tolerance at IRRI from 1974 to 1989. They are listed in the germplasm bank records as resistant at the seedling stage to

Table 9. Entries from the germplasm collection tested for submergence tolerance in the greenhouse.

Origin	Entries (no.) for each score					Total no. tested
	1	3	5	7	9	
India	99	23	97	235	1145	1599
Thailand	52	10	74	199	1718	2053
Indonesia	3	-	3	13	220	239
China	26	-	14	33	509	582
Philippines	1	-	-	-	30	31
Korea	2	-	-	-	21	23
Vietnam	3	-	1	-	15	19
Bangladesh	-	-	1	1	49	51
Rwanda Burundi	-	-	-	-	29	29
Japan	-	-	-	-	78	78
Sri Lanka	-	-	1	2	8	11
Cambodia	-	-	1	3	102	106
Brazil	-	-	-	1	15	16
Others[a]	1	-	-	-	15	16
Total	187	33	192	487	3954	4853
Percent	3.0	0.7	4.0	10.0	81.5	

[a]Includes USA, USSR, Portugal, Afghanistan, Turkey, Italy, Malawi, Iran, and Taiwan.

Table 10. Parentage of the most drought-tolerant[a] deepwater rice breeding lines, IRRI, 1990.

BKNFR81023	IR8234-OT-9-2/HTA7403-110-1
IR26708	FR13A/IR48//IR48
IR28273	Ashini/RD19//IR48
IR37449	IR17494-32-3-1-1-3/GEB24
IR38436	IR8234-OT-9-2/B-1050C-MR-18-2//Baisbish/BKNFR77004-5-3-4
IR38789	RD19/IR11288-B-B-288-1
IR39537	CR1009/IR48//Jaganath/IR4630-22-2-17
IR39592	Pokkali/IR19661-131-1-2//IR4547-6-3-2/IR19661-131-1-3-1-3
IR39595	IR8234-OT-9-2/B-1050C-MR-18-2//Baisbish/BKNFR77004-5-3-4/// IR8234-OT-9-2
IR41010	Chenab 64-117/IR17525-114-2-1-1
IR41222	MTU7029/IR6402-OT-7
IR41364	RD19/IR19672-24-2-3
IR41418	SPR7292-151-2-1/IR7691-B-4-2-1-1
IR42493	6209-X/IR15314-43-2-3-3//BKNFR76106-16-0-1
IR42529	Chenab 64-117/IR15314-43-2-3-3//Chenab 64-117/IR19661-131-1-3-1-3
IR42583	RD19/Murungakayan-101B//RD19/IR19661-131-1-2
IR42584	RD19/Murungakayan-101B//BIET1048/DWCT156-1
IR43772	IR13423-10-2-3/DWCT156-1//IR19242-58-2-3-2
IR43774	IR13423-10-2-3/DWCT156-1//IR19670-259-3-3-2-2
IR43846	BR232-28-3-4-A/IR11288-B-B-118-1/4/Bhadoia/IR8//HBJ Aman 1/// IR11288-B-B-118-1
IR43903	CR1002/DWCT156-1//MTU7029/IR11288-B-B-65-1
IR43934	HBJ Aman 2/DWCT156-1//DWCT156-1/IR7732-RGA-B-A96-1
IR43943	HTA7406-111-0-0-2/DWC(S)-2B-6//RD19/IR17494-32-3-1-1-3
IR43950	HTA7406-111-0-0-2/SPR7292-151-2-1//RD19/IR174943-32-3-1-1-3
IR43968	IR11288-B-B-118-1/SPR7282-2-0-5-2//IR13423-10-2-3/IR11288-B-B-118-1
IR43969	IR11288-B-B-118-1/SPR7282-2-0-5-2//IR13423-10-2-3/RD19
IR43971	IR11288-B-B-118-1/SPR7292-151-2-1//RD19/IR17494-32-3-1-1-3
IR44058	MTU7029/DWCT156-1//RD19/IR19735-5-2-3-2
IR44128	RD19/IR17494-32-3-1-1-3//BR222-B-263/IR11288-B-B-118-1
IR45436	IR21313-36-2-2/TOX896-R-R-R-102
IR45720	BKNFR76014-1-9-2/IR29753-42-4
IR45726	BKNFR76014-1-9-2/IR19671-75-2-2-3-2
IR46679	BKNFR76106-29-0-1/IR64//CR1010/TOX896
IR49924	IR17491-5-4-3-3/IR31406-333-1//IR31432-2-3/IR26702-25-1

[a]As drought tolerant as tolerant check Salumpikit.

submergence in 30-cm water depth for 7 d, using Nam Sagui 19 as the resistant check. However, because of its very consistent submergence tolerance, FR13A is now used as the resistant check.

The new tests were repeated three times with duplicate entries in each test. Ten-day-old seedlings were placed in a concrete tank inside the greenhouse, and water level was increased to 50 cm for 7 and 10 d. Seedling height (H) and number (N) were recorded before (I) and after (F) water treatment. Percent elongation (E) and survival (S) were calculated as follows:

$$\text{Elongation } (\%) = (FH - IH) \times 100/IH$$
$$\text{Survival } (\%) = FN \times 100/IN$$

Of 199 varieties tested, 68 and 38 had a survival at least 50% of that of FR13A when submerged for 7 and 10 d, respectively (Table 11). Most of the resistant varieties are from Sri Lanka and India (Table 12). RPA5929, Urarkaruppan, FR13A, and Kurkaruppan had consistently good survival with both 7- and 10-d treatments. Many of the resistant varieties had more than 100% elongation in both treatments, but not FR13A and Kurkaruppan. Testing these resistant varieties under low light intensities may provide additional information regarding their resistance to submergence.

Mechanism of tolerance for shading

A study from March to October 1990 examined the differential response and tolerance of rice seedlings for shading. Seedlings were grown in the phytotron glasshouse for 2 wk and then shaded for 2 wk at 50 and 20% of full sunlight or were unshaded. The experiment used a split-plot design with 14 cultivars and 7 replications.

Table 11. Comparative survival of 199 varieties, classed previously as resistant to submergence at 30 cm water for 7 d, when retested at 50 cm water for 7 and 10 d during seedling stage.

Comparative survival[a] (%)	Varieties (no.) surviving at	
	7 DAS	10 DAS
0	0	3
1-25	31	98
26-50	102	62
51-75	37	27
76-100	27	9
> 100	4	2

[a]% survival of test varieties divided by % survival of FR13A times 100.

The average total dry weight was 66% of the check at 50% light and 31% at 20% light. Of the total plant weight components, root weight had the greatest reduction when shaded, implying that when a plant is subjected to low light, the general tendency is for root development to be inhibited or for the shoot to develop at the expense of the root.

Of all the morphological characters measured in the rice cultivars, decrease in leaf area had the greatest spread in values at both shading levels. Leaf area was highly correlated with shoot weight at 50% light (r = 0.77) and at 20% light (r = 0.87%), and could be used as an index for selecting rice cultivars tolerant of low light at seedling stage. On the average, leaf area decreased to 16% of the check at 50% light and to 55% at 20% light. At 50% light FR13A was most tolerant, increasing its leaf area by 1% of the control, followed by Pachehai Perumal, Kurkaruppan, and IR9669, which had only 5-9% reduction in leaf area. At 20% light FR13A, Pachehai Perumal, and Kurkaruppan had a reduction of 37-47%.

The use of leaf area as parameter for selecting cultivars tolerant of low light is limited by its being destructive and laborious. However, change in leaf area was found to be highly correlated with change in plant height at 50% (r = 0.93) and at 20% (r = 0.85) light. At 50% light, most cultivars responded by elongating their stem and leaves. FR13A, Pachehai Perumal, Kurkaruppan, and IR9669 had the greatest increase in plant height. At 20% light only IR20 had a slight increase in height (0.3% of control) while the rest decreased in height; Pachehai Perumal and C21 had the least reduction.

Total chlorophyll of the last fully expanded leaf was highly correlated with leaf area at 50% light (r = 0.71), but not at 20% light (r = 0.50). At 50% light, cultivars like Pachehai Perumal, FR13A, Thavalu, and C21 increased the total chlorophyll content of the fifth leaf from the base. Tolerant plants adjusted to growth in low light by increasing their leaf area ratio (LAR), which meant higher partitioning of assimilates to the leaves for the plant to be able to trap available light. FR13A had the greatest increase in LAR both at 50 and 20% light.

Based on these results, FR13A and Pachehai Perumal are most tolerant of low light at the seedling stage. FR13A is also flood-tolerant, whereas Pachehai Perumal is commonly grown under coconut trees in India. These two cultivars tolerate low light condi-

Table 12. List of varieties resistant to submergence, their country of origin, elongation, plant height as result of submergence at 50 cm water for 7 and 10 d.

Acc. no.	Variety name	Country of origin	Sub-mergence score[a]	Initial plant height (cm)	7 d submergence			10 d submergence		
					Elonga-tion (%)	Sub-mergence (%)	Score	Elonga-tion (%)	Sub-mergence (%)	Score
28616	Urarkaruppan	Sri Lanka	1	11	192	95	1	221	88	1
26911	RPA5929	India	1	-	-	95	1	–	95	1
15331	Sudu Gires	Sri Lanka	1	15	125	87	1	211	70	5
11068	Eswarkorra	India	1	16	134	87	1	155	75	5
6144	FR13A	India	1	21	27	85	1	51	82	1
26956	Chiaung Sen Yu 6	Taiwan, China	1	17	100	85	1	115	60	7
15449	Kurkaruppan	Sri Lanka	1	21	59	85	1	78	78	3
15325	Thavalu	Sri Lanka	1	18	81	84	3	76	61	7
15330	Kalu Gires	Sri Lanka	1	15	146	83	3	190	52	7
28105	P 593	Pakistan	3	15	79	82	3	129	40	9
15314	Thavalu	Sri Lanka	1	23	88	82	3	101	48	7
26950	BG69-4	Sri Lanka	1	19	129	82	3	141	43	7
26957	CR1113	Costa Rica	1	18	71	82	3	103	28	9
15337	Pokurusamba	Sri Lanka	1	20	102	80	5	153	48	7
15333	Madabaru	Sri Lanka	1	15	105	80	5	183	72	5
29069	Aus 279	Bangladesh	3	21	148	78	5	190	52	7
26962	Juchitan A 73	Mexico	1	21	54	78	5	73	59	7
26955	Chianung Sen 11	Taiwan, China	1	14	130	77	5	122	36	9
15433	Weli Handiran	Sri Lanka	1	27	74	75	5	116	17	9
15294	Jamis Wee	Sri Lanka	1	22	84	75	5	144	43	7
26854	MR301 (Pushpa)	India	1	15	103	75	5	110	57	7
59132	Masinu Aroma	Nepal	1	13	100	73	5	83	42	7
27485	Tojuma	Indonesia	1	20	172	73	5	206	20	9
15185	Ratawee	Sri Lanka	1	18	57	70	5	113	78	3
15464	Vanan Vellai	Sri Lanka	1	22	136	70	5	175	25	9
58421	Vasista	India	1	16	50	70	5	51	67	5
15430	Kalukanda	Sri Lanka	1	22	60	68	5	120	17	9
15379	Kaharamana	Sri Lanka	1	23	94	68	5	135	42	7
26948	Bentobala	Africa	1	25	120	67	5	191	27	9
26961	Jayanti (IET1039)	India	1	18	80	65	5	130	44	7
15478	Naalumoli Karuppan	Sri Lanka	1	22	132	63	5	218	27	9
15435	Kottamalli	Sri Lanka	1	20	125	63	5	170	38	9
	IR42	IRRI	1	17	81	25	9	176	5	9

[a]At IRRI germplasm bank.

tions and minimize reduction in leaf area by elongation of stem and leaves, increase in total chlorophyll content of the last fully expanded leaf, and higher partitioning of photosynthates toward leaf production.

Three varieties of deepwater rice released to farmers in Cambodia

About 110,000 ha are currently under floating rice in Cambodia. Because of war, seed stocks of important varieties were lost and had to be replaced if the abandoned deepwater areas were to be utilized again. Introduced lines were tested in representative environments and the varieties Tewada, Khao Tah Petch, and HTAFR77022-45-3-2-1 (named Don) gave promising results during 1988, 1989, and 1990 field tests. During 1990, they were also given to farmers for testing in their own fields and with their own cultural practices. Of nine sets of on-farm trials, five were successfully concluded and farmers chose the new varieties over their old ones.

Conclusion

Fitting improved rice varieties into the wide range of environmental differences within the ecosystem is not easy, but we are having some success. Results from breeding nurseries in Thailand and from field testing of breeding materials in Asia are immediately applicable. National programs continue to test selected lines in their field trials.

The work on DWR tolerance for low light situations attempts to discover useful variation for this

trait in DWR. Should varietal differences prove consistent, the research agenda will include 1) development of an economical screening procedure, and, subsequently 2) prebreeding of lines with comparatively high photosynthesis under low light conditions such as in mutual shading of plants during declining water levels.

Improved crop and resource management for deepwater rice

Regional research on deepwater rice (DWR) focuses on plant nutrition, cropping systems, integrated pest management, and development of rice-fish culture. As in the other rice types, DWR cropping systems must be adapted to specific combinations of a wide range of soil, climate, and flooding conditions.

Deepwater rice ratoon crops

Twenty DWR cultivars were tested in a field experiment at Los Baños. Huntra 60, Khao Rachinee, and Luang Pratharn had high ratooning ability (Table 13), but Khao Puang Nak, Plai Ngahm, Khao Hoi, Leb Mue Nahng 111, Mali Tawng, Pin Gaew 56, Saibua, Sam Ruang, and Tapow Gaew produced less than 10% ratoons. Ratooning ability showed a positive relationship (R = 0.731*) with dry matter production of the main crop, and with biomass (R = 0.928**) and grain production (R = 0.808*) of the ratoon crop because growth duration of the ratoon crop is very short.

The amount of herbage produced in a short time and a high percentage of crude protein (Table 13) suggest the potential of ratoon crops as ruminant feed in rice-growing areas where green fodder is scarce after harvest of the main crop.

Average grain yield of the ratoon crop was similar to that of the main crop (Table 14), but the yield of individual cultivars after ratooning was not. Compared with the main crop, the ratoon crop had higher panicle number per unit area (+25%), but fewer spikelets per panicle (-11%). It also had shorter plants (-37%), fewer productive tillers (-32%), low dry matter production (-44%), and shorter growth duration (-55%) but higher tiller number at maturity (+96%) and higher harvest index (+86%). Fertility and 1,000-grain weight of the two crops were similar.

The DWR ratoon had a semidwarf stature that made it less prone to lodging, a high harvest index, and a short growth duration. However, it had a low percentage of productive tillers and uneven flowering caused by tiller development at different stages. The combination of herbage and grain production from a ratoon crop could increase land use efficiency and farmers' income, especially in single-crop DWR areas.

Testing deepwater rice for fertilizer response

Eight DWR entries were tested for fertilizer response in machine-sown 5-row and 11-row plots at Prachinburi, Thailand, to determine if sufficiently accurate results can be obtained with small, row-sown DWR plots and thus allow more lines to be tested than can be done with broadcast seeding. Three fertilizer rates were tested as main plots, and seeds of 8 DWR entries were sown in 5- and 11-row

Table 13. Ratooning ability and production from ratoon crops of deepwater rice.[a]

Cultivar	Ratoon hills (% of main crop)	Herbage yield (t/ha)		Crude protein (%)	
		30 DAR	60 DAR	30 DAR	60 DAR
Huntra 60	72	3.30	6.75	15.0	9.00
Khao Rachinee	64	3.30	8.35	15.8	8.37
Luang Pratharn	59	1.93	8.80	16.4	8.75
Pan Tawng	43	1.11	4.28	15.3	9.56
RD19	32	0.91	2.43	15.4	8.17
Khao Praguad	29	0.65	3.47	16.3	8.05
Khao Kaset	23	0.80	3.50	17.5	7.69
Khao Lod Chong	20	0.85	3.40	17.8	7.84
Nahng Khiew	13	-	-	-	-
Ban Daeng	11	-	-	-	-
Khao Mali	10	-	-	-	-
LSD (0.05)	16	1.24	3.22	ns	ns

[a]DAR = days after ratooning. Cultivars with less than 20% ratoons were not sampled for yield.

Table 14. Grain yield, yield components, and agronomic characteristics of deepwater rice.

Cultivar	Grain yield (t/ha)	Panicles (no./m²)	Spikelets (no./ panicle)	Fertility (%)	1000-grain wt (g)	Height (cm)	Tillers (no./m²)	Productive tillers (%)
Khao Rachinee	2.72	149	117	75	24.7	131	277	54
Luang Pratharn	2.72	144	119	78	26.0	123	336	42
Pan Tawng	2.54	119	115	70	24.4	122	258	51
Huntra 60	2.33	167	82	72	25.8	100	360	48
Khao Praguad	1.99	130	107	67	27.6	129	181	68
Khao Kaset	1.60	73	116	76	27.4	123	145	58
RD19	1.25	78	105	72	27.6	69	215	36
Khao Lod Chong	1.08	89	110	68	26.1	133	124	62
LSD (0.05)	0.93	58	21	ns	0.5	10	110	ns
Ratoon crop mean	2.03	119	109	71.8	26.2	116	237	52
Main crop mean	2.10	95	122	71.9	26.3	184	121	78
Correlation with main crop	–0.42 ns	+ 0.36 ns	+ 0.39 ns	–0.11 ns	+ 0.95**	+ 0.68 ns	+ 0.64 ns	–0.60 ns

subplots with 25-cm spacing between rows. The central three or nine rows were harvested for grain yield.

Plants were stunted by drought and in October when floodwater rose rapidly to 120 cm, 4 of the 8 entries were destroyed. Yields of the remaining 4 were very low, about 0.5-0.75 t/ha (Table 15). Although the yields calculated from 5-row plots were 19-38% higher than those from the 11-row plots (sig. diff. P>0.05), ranking of yields for entries and fertilizer rates was the same in both plot sizes, indicating the potential use of this type of DWR trial.

Table 15. Plot size x entry means for grain yield in a fertilizer response experiment. Prachinburi, Thailand, 1990 wet season.

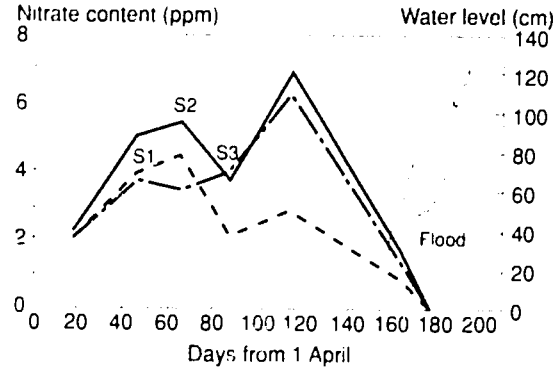
Entry[a]	5-row plots		11-row plots		Difference (%)
	Yield (g/m²)	Rank	Yield (g/m²)	Rank	
LMN111	76	1	64	1	19
DWCT' 82-2-2	58	4	43	4	35
BKNFR76042-18-1	66	3	48	3	38
RD19	-	-	-	-	-
SPR'76Com3-5-2	-	-	-	-	-
BKNFR76010-108-2	-	-	-	-	-
SPR7411-7-2-3-2	73	2	53	2	38
SPR7297-343	-	-	-	-	-
P-mean	68		52		32

[a]A flood destroyed 4 of the 8 entries

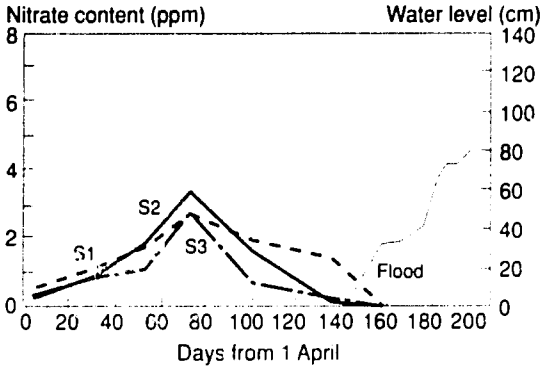
Soil nitrate as a source of nitrogen for deepwater rice

In Thailand, DWR responds well to N fertilizer on acid sulfate soils with pH 4.0 at Prachinburi, but not on soils with pH 5.5 at Huntra. DWR has a very sustainable crop production system, but very little is known of the source and forms of N available.

We determined the changes in soil nitrate and soil ammonia from the beginning of the wet season to flooding. DWR was sown at three different times. Maximum values for nitrate in the top 60 cm of soil were around 6 ppm at Huntra (Fig. 1) and 3 ppm at Prachinburi (Fig. 2). Initially most of the nitrate was in the surface 20 cm soil, but after the second sampling at Huntra nearly 50% was found in the 20-60 cm layers. There was a marked decrease in nitrate N after the first sowing of DWR, but drought obscured treatment differences for later sowings. Ni-



1 Changes in soil nitrate with time in a deepwater ricefield in Huntra, Thailand, 1990 wet season. S1, S2, S3 = first, second, third sowing of deepwater rice.



2. Changes in soil nitrate with time in a deepwater ricefield in Prachinburi, Thailand, 1990 wet season.

trate N decreased to zero at flooding. Soil ammonia levels were less than 0.2 ppm throughout the period of measurement, indicating that nitrate could be the main source of N during the preflood phase of DWR.

Residual effects of rock phosphate on deepwater rice

A long-term experiment was initiated in 1984 in Prachinburi to assess the response of DWR to annual dressings of phosphate rock (PR, 1.8% available P) or triple superphosphate (TSP, 19.6% available P) compared with the residual effects of single initial applications at higher rates. Soil data for 1989-90 and crop measurements for 1990 (7th year) are compared in Table 16. For added P treatments, mean dry matter was 57% of that of the previous year and mean grain yield 51%. The annual dressing of TSP and high initial rates of PR gave the highest dry matter production, but grain yields were not significantly different. On the average, a single initial application of a high amount of PR gave the highest production.

Intercropping deepwater rice with upland crops

Upland crops were sown in a DWR field with soil pH 5.5 at Huntra, Thailand, on 15 May 1990. Mungbean and sesame were broadcast, or sown in rows 50 cm apart (1:1), or in paired rows 25 cm apart alternating with two unsown rows (2:2). Sunflower was sown with 75 cm between rows. Drains were constructed between the 9- × 9-m plots to remove surface water after heavy rains. The DWR variety HTA60 was broadcast at the same time as the upland crops were sown or broadcast 65 d after their emergence.

Yields and value of the upland crops are given in Table 17. The low germination of sunflower seed resulted in poor stands and poor yields. Establishment and yield of broadcast mungbean were slightly less than those for row-sown plots, which gave yields over 1600 kg/ha. Sesame yields were lower than those of mungbean, but the price of seed in the market was higher and hence gross return was higher. Rapidly rising floods after harvest of the upland crops destroyed the DWR crop, emphasizing the value of including the upland crop.

A concurrent experiment tested the effect of time of broadcasting DWR on sesame yield and establishment of DWR. The relative yield of sesame increased from 46% when DWR was broadcast at the same time sesame was sown to 100% when DWR was broadcast 2 wk after emergence of sesame.

Conclusions

In Vietnam and Thailand, the DWR in agronomic trials was killed by rapidly rising floods, but early rice in Vietnam and upland crops in Thailand sown as mixtures with DWR performed well, emphasizing the benefits of including other crops in the system.

Table 16. Soil measurements and plant production of deepwater rice variety RD19 in a long-term phosphate trial. Prachinburi, Thailand, 1990 wet season.

P treatment[a]	Soil P (ppm)		Height (cm)	Stem (no./m²)	Dry weight (g/m²)	Panicles (no./m²)	Yield (t/ha)
	Bray II	Total					
Nil	6.9 c	265 c	131 bcd	95	368 b	79 c	0.71
8.7 TSP/yr	9.1 c	270 c	143 a	133	659 a	126 a	1.22
8.7 PR/yr	21.4 b	365 b	130 d	77	369 b	78 c	1.09
35 TSP, initial	4.5 c	235 c	133 cd	86	362 b	81 c	1.00
35 PR, initial	11.5 c	295 bc	143 abc	113	601 a	97 bc	1.10
140 TSP, initial	5.2 c	240 c	143 bcd	101	482 ab	89 bc	1.02
140 PR, initial	60.4 a	590 a	138 ab	124	645 a	114 ab	1.10
CV (%)	19.2	11.1	5.4	11.9	16.5	11.6	17.3

[a]TSP = triple superphosphate, PR = phosphate rock.

Table 17. Grain yield and value of upland crops sown before deepwater rice or intercropped with deepwater rice. Huntra, Thailand, 1990 wet season.

Treatment		Yield[a] (kg/ha)	Relative yield	Gross income ($/ha)
Upland crop and DWR sown at same time				
Mungbean	broadcast	1279	85	358
Mungbean	1:1	1426	96	399
Mungbean	2:2	1685	113	471
Sesame	broadcast	809	80	537
Sesame	1:1	569	57	378
Sesame	2:2	631	63	418
Sunflower		422	68	118
DWR sown 65 d after upland crop emerged				
Mungbean	2:2	1491	100	417
Sesame	2:2	1005	100	667
Sunflower		621	100	173

[a]Prices: mungbean and sunflower = 28 cents/kg, sesame = 66 cents/kg.

Sesame and mungbean can give yields of 1 t/ha when mixed with DWR, greatly increasing the potential gross income of the farmer. Nitrogen balance studies for DWR are identifying the sources of that nutrient in one of the most sustainable systems of production.

Integrated pest management for deepwater rice

Resistance/tolerance of cultivated deepwater rice and elongating wild rices for yellow stem borer

Yellow stem borer (YSB) is the most damaging pest of DWR. In an effort to identify resistant or tolerant DWR varieties, we evaluated 122 accessions of the cultivated deepwater and elongating wild rices for their resistance to or tolerance for YSB infestation. The test plants were planted in pots in a screenhouse. At 42 d after sowing, the seedlings were placed in empty oil drums where the water level was raised to 88 cm to promote elongation of the rice stems.

Plants at the rapid elongation stage were infested with YSB larvae at 2 larvae per tiller. At that stage, the stems were succulent and the plants were prone to insect attack. Four weeks after infestation, all stems of each accession were dissected, the number of damaged stems counted, and the damage percentage computed. Larvae and pupae of YSB recovered during dissection were counted, and their lengths and weights recorded to determine if the resistance was due to antibiosis.

The percentage of damaged plants among the rice accessions varied significantly. IRRI accession 103639 (*Oryza glaberrima*) had the lowest YSB damage (6.5%) while nine other accessions—100216 (*O. rufipogon*), 103636 (*O. glaberrima*), 103995 (*O. glaberrima*), 104000 (*O. glaberrima*), 104014 (*O. glaberrima*), 104081 (*O. barthii*), 104406 (*O. sativa/O. nivara*), 104513 (*O. glaberrima*), and 104514 (*O. glaberrima*)—had 100% stem damage.

The cultivated DWR varieties RD19 (BKN6986-147-2) with 50% external damage (deadheart/whitehead), Ban-Oh (IRRI accession 4790) with 32%, and Ba Thiet (IRRI accession 16693) with only 8% seem tolerant of YSB attack. They will be studied further for their mechanisms of resistance or tolerance.

Off-season behavior of stem borers in deepwater ricefields

In collaboration with Orissa University of Agriculture and Technology, Bhubaneswar, India, we studied off-season activities of rice stem borers (SBs) in DWR fields. Weekly observations on DWR stubbles from January to mid-March 1990 revealed 15-22% infestation of stems with different species of SBs. Three major SB species were recorded in the stubble: yellow stem borer (70%), striped stem borer (20%), and pink stem borer (10%).

During the first 3 wk of January, 71-77% of stubble stems were found to contain SB larvae. After the fourth week of January, the larval and pupal populations in the stubble gradually declined. In the first week of March only 55% contained pupae, and by the second week of March stubbles were found to contain no larvae or pupae.

Silica and stem borer resistance

Previous studies have demonstrated that silica can protect the rice plant from invading SB larvae. We evaluated 20 cultivated DWR varieties and 18 elongating wild rices for their silica-absorption capabilities. Plants were grown in culture solution with 50 ppm silica throughout the experiment. Plant samples taken 42 d after sowing were oven-dried, ground, and analyzed for silica content.

The amount of silica in the tissues of the different rice accessions differed significantly (Table 18). The cultivated DWR varieties absorbed more silica than did their wild relatives. RD19 absorbed the highest amount (17.31%), and the wild rice *O. nivara* (acces-

Table 18. Percent silica content of selected deepwater cultivars and elongating wild rices grown in culture solution with 50 ppm silica. IRRI.

Accession no.	Variety	Silica content (%)
39174	RD19 (BKN6896-147-2)	17.31 a
6542	Badal 106	16.75 ab
6539	Fulkari 715	16.62 ab
26427	Arichadiga	16.03 abc
6504	Khama 49-8	15.73 bcd
6554	Laki 720	15.46 b-e
6552	Laramon 720	15.21 c-f
6576	Laki 383	14.94 c-g
6508	Laki 491	14.90 c-h
104723	*O. rufipogon*	14.87 c-h
101967	*O. nivara*	14.84 c-h
6560	Joalbhanga 499	14.78 c-i
6568	Laki 557	14.76 c-i
101971	*O. nivara*	14.64 c-i
101943	*O. rufipogon O. nivara*	14.62 c-i
104081	*O. barthii*	14.60 c-i
6503	Biroin 539	14.54 d-i
6497	Laki 495	14.52 d-i
6537	Laki 488	14.47 d-j
6566	Baguamon 436	14.46 d-j
5811	Baisbish	14.04 e-k
105568	*O. rufipogon*	14.00 e-k
6540	Bazail 407	13.95 e-k
101991	*O. rufipogon*	13.87 f-l
101966	*O. nivara O. rufipogon*	13.86 f-l
101993	*O. nivara O. rufipogon*	13.62 g-m
105199	*O. longistaminata*	13.52 g-n
102168	*O. nivara O. rufipogon*	13.40 h-o
28539	Jaladhi 2	13.38 h-o
4347	Bir Co Tsan	13 37 h-o
6505	Katia Bagdar 348	13.29 i-o
101947	*O. latifolia*	13.01 j-o
100635	*O. rufipogon*	13.00 j-o
104711	*O. rufipogon*	12.87 k-o
101979	*O. nivara*	12.40 l-o
100939	*O. barthii O. glaberrima*	12.16 mno
104296	*O barthii*	12.05 no
100897	*O. nivara*	12.03 o

sion 100897), the lowest (12.05%). The reactions of these two accessions, grown under different silica levels, are being tested to determine if their silica absorption ability can affect their resistance or susceptibility to YSB.

Subprogram II: Improved productivity and sustainability of tidal wetlands rice

Wide variability in rice yields of tidal wetlands is attributed to submergence and stresses associated with salinity, acidity, and peatiness. Exploitation of tolerance genes found in traditional varieties, and the reduction of soil stresses by water management appropriate to different subecosystems would improve yield and its stability in tidal wetlands.

Improved germplasm and management for tidal wetlands rice

The main objective of the project is to conduct prebreeding research and laboratory or greenhouse experiments related to soil and climatic stresses of tidal wetlands. To assist national agricultural research systems (NARS) in their varietal improvement efforts, IRRI generates breeding materials and distributes them for evaluation and selection in target environments.

Tolerance for salinity and submergence

Tidal wetlands near seacoasts are subject to both salinity and submergence. Flash floods cause submergence but are helpful in that they reduce salinity and bring nutrients. Although the traditional varieties FR13A, FR43B, Kurkaruppan, and Thavalu are tolerant of 12-14 d of complete submergence, they are not salt-tolerant. On the other hand, good salt-tolerant varieties like Nona Bokra and Pokkali are sensitive to submergence.

A program to develop lines with improved plant type and tolerance for salinity and submergence was initiated in 1986. Crosses between traditional submergence-tolerant varieties and improved salt-tolerant lines were evaluated and selected for tolerance for both stresses; 11 advanced lines were found to possess the desired traits. Among them IR42598-B-B-B-B-12-1-2 from the cross FR13A/IR17494-32 showed the highest level of tolerance and is an ideal donor for improving tidal wetland rices.

Greenhouse and field mass screening of advanced lines against soil stresses including salinity, alkalinity, Fe toxicity, P deficiency, and Zn deficiency were continued. About 14% of the 16,677 entries screened were found to be tolerant and were used in developing breeding materials for NARS.

Performance of new salt-tolerant lines

Ten promising salt-tolerant rices, selected from mass screening trials since 1988, were tested for yield performance in coastal saline soils during 1990 in Santo Tomas, Pampanga, in the dry season and in Bani, Pangasinan, in the wet season. At both sites,

Table 19. Grain yield of 10 rices on 2 coastal saline soils in the Philippines, 1990.

Entry	Grain yield (t/ha)	
	0 kg N/ha	50 kg N/ha
Santo Tomas, Pampanga		
IR32843-92-2-2-3	2.14 a	2.06 a
IR14632-2-3	1.90 ab	2.03 a
IR19743-40-3-3-2-3	1.94 ab	2.00 ab
IR30168-63-1-5-2	1.67 bc	1.73 bc
IR31361-8-3-2-2	1.70 bc	1.66 cd
IR31375-5-2-1-3	1.55 c	1.62 cd
IR26916-13-1-1-2-1-1	1.58 c	1.55 cd
IR28178-111-1-2-3	1.33 cd	1.42 cde
IR51491-AC4-7	1.38 cd	1.40 de
IR38701-49-2-6	1.18 d	1.26 e
Mean	1.64	1.67
Bani, Pangasinan		
IR32843-92-2-2-3	2.51 a	2.48 a
IR14632-2-3	2.28 ab	2.45 a
IR19743-40-3-3-2-3	2.39 a	2.33 ab
IR30168-63-1-5-2	1.87 c	1.83 c
IR31361-8-3-2-2	1.90 bc	1.96 bc
IR31375-5-2-1-3	1.75 c	1.82 c
IR26916-13-1-1-2-1-1	1.92 bc	1.88 c
IR28176-111-1-2-3	1.83 c	1.86 c
IR51491-AC4-7	1.74 c	1.79 c
IR38701-49-2-6	1.62 c	1.71 c
Mean	1.98	2.01

soils are classified as Typic Haplaquept and salinity is caused by the inundation of brackish water from tidal creeks. Two levels of N were used to determine the effect of N on increasing yields.

Wet season yields in Bani were higher than the dry season yields in Santo Tomas. At both locations, IR32843-92-2-2-3 produced the highest yield. IR14632-2-3 and IR19743-40-3-3-2-3 also gave yields of about 2 t/ha (Table 19). In addition to soil variations, the seasonal effect on salinity levels accounts for the differences. The salinity level in Bani ranged from 7 to 10 dS/m, that at Santo Tomas was 9-12 dS/m. This difference was principally due to dilution from rain during the wet season.

The addition of 50 kg N/ha did not increase yields significantly at either site. The total N level in both soils was only moderate, 0.13 to 0.18%. It appears that any beneficial effect of N is nullified by salt stress.

Environmental effects on salt tolerance

In an effort to understand specific characteristics related to salt tolerance, we compared Nona Bokra (salt tolerant) and IR28 (sensitive). The effects of salinity, relative humidity (RH), and temperature were studied under controlled environmental conditions in the phytotron.

Salinity increased Na and Cl content. Concentrations were higher in sheaths than in blades in both varieties (Table 20). Within varieties, however, Na and Cl were higher in older blades and sheaths of Nona Bokra, but in younger blades and sheaths of IR28. Nona Bokra possesses a mechanism to keep the concentration of toxic elements at a low level in younger blades. Salinity depressed the K contents of all blades and sheaths as well as the ratios of K:Na and Cl:Na.

Increase in RH improved salt tolerance in both varieties. The Na and Cl content in blades and sheaths decreased with higher levels of RH (Table 21). On the other hand, increase in temperature raised the Na and Cl concentrations. The effect was more pronounced in Nona Bokra than in IR28. Transpiration was higher at higher temperature and lower RH for both varieties (Table 22).

Table 20. Effect of salinity on total uptake of Na, K, and Cl in blades and sheaths of 2 rice varieties.

EC (dS/m)	Uptake (mmol)					
	Nona Bokra			IR28		
	Na	K	Cl	Na	K	Cl
Blade						
Control	0.45	14.90	8.09	0.29	12.40	4.76
4	3.65	6.90	6.89	2.96	7.18	5.68
8	4.42	6.23	9.27	4.52	5.09	9.19
Sheath						
Control	1.12	24.60	9.59	0.58	13.80	4.86
4	6.28	12.10	8.72	4.53	7.29	6.60
8	12.76	8.84	14.20	9.26	3.44	10.00

Table 21. Effect of salinity and relative humidity (RH) on total uptake of Na, K, and Cl in shoots of 2 rice varieties.

EC (dS/m)	Uptake (mmol)					
	Nona Bokra			IR28		
	60% RH	80% RH	Mean	60% RH	80% RH	Mean
			Na			
Control	0.87	1.27	1.07 a	0.73	0.86	0.80 a
4	8.06	7.28	7.67 b	6.64	5.08	5.86 b
8	13.51	9.33	11.41 c	11.02	6.10	8.56 c
			K			
Control	32.84	35.43	35.14 a	21.49	22.01	21.75 a
4	19.63	27.28	23.46 b	7.95	13.07	10.51 b
8	8.32	14.49	11.40 c	3.76	5.74	4.75 c
			Cl			
Control	11.84	11.81	11.82 a	5.99	6.53	6.26 a
4	9.70	10.23	9.91 a	6.53	6.92	6.73 a
8	12.59	11.07	11.83 a	9.54	7.05	8.30 a

Table 22. Effect of salinity, RH, and temperature on transpiration of 2 rice varieties.

EC (dS/m)	Transpiration (g/dry shoot per d)							
	Nona Bokra				IR28			
	60% RH	80% RH	29 °C	35 °C	60% RH	80% RH	29 °C	35 °C
Control	10.9	13.3	18.6	26.1	24.0	16.5	20.9	27.5
4	18.3	12.6	17.2	26.8	23.3	16.8	21.2	26.8
8	15.8	11.7	14.6	22.1	20.3	15.4	21.2	26.9

Rhizosphere and iron toxicity

There is a dearth of information on the influence of the rhizosphere of submerged rice on nutrient uptake. We studied in the laboratory the effect with time of different rice varieties on the changes of pH, and exchangeable and total Fe in the rhizosphere of four reduced soils. Seven- to 11-d-old seedlings of four IR cultivars were inserted between 2 cylinders previously packed with an anaerobically reduced Paleudult (pH 3.3, active Fe 2.11%). Thin 0.2-mm sections from the root plane were analyzed. Results show that regardless of cultivar, the pH rose rapidly from 4.3 to 6.8 within 4 mm distance from the root. Oxidized Fe reached 9 mol/kg (×100) at 0.2 mm from the root plane, declining rapidly to zero within 4 mm. The lower pH and the presence of oxidized Fe nearer the root are likely to be a combined result of the efflux of H^+ from the root cells and oxidation by O_2 diffusing from the root. This prevents the accumulation of toxic amounts of Fe within the rhizosphere.

Generation of breeding materials

In 1990 we produced 50 advanced bulk populations for acid and acid sulfate soils, and 45 for saline soils. They were given to collaborating NARS (India, Indonesia, Sri Lanka, and Thailand) for evaluation and selection at their key sites. Acidity-tolerant materials were derived from crosses involving Mahsuri, Khao Dawk Mali 105, Suakoko, Kuatik Putih, and three bulu varieties—Ketan Banteng, Ketan Lumbu, and Osok. Nona Bokra and Pokkali are still the best salt tolerance donors.

Future plans

Mass screening for soil stresses will be continued to support the development of advanced breeding materials for use by NARS and to identify new sources of tolerance. Elite lines identified by NARS and IRRI will be evaluated for yield. Breeding materials for NARS will continue to be generated. Research on water management will be initiated.

Research programs
Cross-ecosystems research

SUBPROGRAM I: GERMPLASM EVALUATION **146**
- Evaluation of conserved germplasm **146**
  - Germplasm dissemination to IRRI staff for targeted evaluation (IRGC) **146**
  - International rice genealogy data base (IC) **147**
  - Development and updating of rice viruses data base (PP, IC) **148**
  - Screening and characterization of resistance to viral diseases (PBGB, PP) **148**
  - Resistance of conserved germplasm to nonspecialized pathogens (PP) **149**
  - Rice leaffolder rearing on maize seedlings and screening for resistance (E) **151**
  - Screening for insect resistance (E, PBGB) **152**
  - Resistance of wild rices to insects (E) **152**

SUBPROGRAM II: GENOME MANIPULATION **152**
- Saturated genetic maps **152**
  - Gene tagging (PBGB, PP, SM, APA) **153**
  - Linkage relations between isozyme and RFLP markers (PBGB) **154**
  - In situ hybridization (PBGB) **155**
  - Novel aneuploid stocks (PBGB) **156**
- Novel genetic variation **156**
  - Alien gene transfer (PBGB, PP) **157**
  - Genetic and molecular analyses of *O. sativa/O. minuta* derivatives (PP, PBGB) **157**
  - Production of homozygous (diploid) lines through anther culture (PBGB) **158**
  - Evaluation of anther culture-derived lines (PBGB) **159**
  - Improving efficiency of isolated microspore culture in indica rice (PBGB) **160**
  - Cell suspensions and somatic embryogenesis (PBGB) **161**
  - Protoplast culture and plant regeneration (PBGB) **161**
  - Next steps **162**

SUBPROGRAM III: ECOSYSTEM CHARACTERIZATION AND IMPACT ANALYSIS **162**
  - Spatial distribution of rainfed lowland rice flowering dates in South and Southeast Asia (APA) **163**
  - Rainfed riceland data base—an aid to technology transfer (APA) **163**
  - Human geography of rice in Southeast Asia (APA) **166**
- Characterization and simulation for riceland management and productivity **168**
  - Application and improvement of crop simulations (AE, APA) **169**
  - Combining GIS and a rice-crop simulation (AE, APA) **169**
  - Soil structural influences on soil-water relations and rice-soil management (AE, APA) **169**
  - Knowledge sharing for simulations methodology (AE, APA) **171**
  - Next steps **171**
- Adoption and productivity impact of modern rice varieties in Nepal **172**
  - Survey data (SS) **172**
  - MV adoption and productivity in villages of the extensive survey (SS) **172**
  - Determinants of MV adoption, fertilizer use, rice yields, and cropping intensity across Nepalese villages (SS) **173**
  - Determinants of MV adoption, fertilizer use, and rice yields across households in Terai villages (SS) **175**
  - Conclusions and next steps **176**

Previous Page Blank

Structural change in demand for cereal grains in Asia **177**
The model and data (SS) **177**
Results (SS) **178**
Next steps **182**

SUBPROGRAM IV: PEST SCIENCE AND MANAGEMENT **182**
Pest-yield interactions **182**
Coupling disease and insect effects to a rice model (PP) **182**
Crop management reduces stem borer losses (E) **184**
Next steps **184**
Physical, biochemical, and genetic bases of insect resistance **185**
Factors affecting leaffolder establishment (E) **185**
Calli and diets for bioassay of leaffolders (E) **186**
Biochemical basis of resistance to brown planthopper (PBGB, E) **186**
Genetic variation in populations of *N. virescens* (PBGB) **186**
Next steps **187**
Biology and etiology of rice pests and beneficial organisms, and seed health **187**
Purification of rice grassy stunt non-capsid protein (PP) **188**
Rice tungro bacilliform virus in xylem cells of tungro-infected rice (PP) **188**
Characterization of *Rhizoctonia solani* Kuhn in rice-based cropping systems (PP) **188**
Antagonistic effect of soil microbes on *Rhizoctonia solani* (PP) **190**
Assessing the importance of seedborne inoculum of selected rice pathogens (PP) **191**
A new mite pest of rice (E) **191**
Annelid worm pest of rice (E) **193**
Biology of the rice ear-cutting caterpillar (E) **193**
Effect of water stress and nitrogen application on photosynthesis of two upland rices and two upland weeds (APA) **195**
Physiological response of rice and *Rottboellia cochinchinensis* to applied nitrogen in monocultures and mixture (APA) **197**
Next steps **197**
Pest population dynamics **198**
Pheromone interactions (E) **198**
Using molecular probes to characterize pathogen strains and population diversity (PP) **199**
Influence of rice plant age on rice leaffolder survival and fitness (E) **200**
Community structure of arthropods in rice ecosystems (E) **200**
Serological techniques for virus disease monitoring (PP) **201**
Next steps **202**

SUBPROGRAM V: PLANT, SOIL, WATER, AND NUTRIENT PROCESSES **203**
Chemical processes in the rice rhizosphere **203**
Screening rice varieties for ability to stimulate rhizosphere microbes (SM) **205**
Reaction of phosphorus with submerged soil (SWS) **205**
Long-term straw management (SWS) **208**
Irrigation water quality at IRRI (SWS) **209**
Next steps **210**

SUBPROGRAM VI: RICE GRAIN AND SEED QUALITY, POSTHARVEST AND BIOMASS ISSUES **210**
Grain and seed quality, and improved nutritional value **210**
Effect of seed vigor on yield (INGER) **210**
Grain quality factors (PBGB) **210**
Nutritional value (PBGB) **211**
Next steps **212**
Postharvest technologies and biomass utilization **212**
Harvesting (AE) **212**
Drying (AE) **212**
Rice processing (AE) **213**
Next steps **213**

Cross-ecosystems research

In 1990, the first year of IRRI's new program structure, the Cross-Ecosystems Program developed and improved its operational mechanisms, made substantial advances in research, and identified and adopted new thrusts and emphases in pursuit of IRRI's strategy and work plan.

In genome manipulation, we have transferred genes for brown planthopper (BPH) resistance from *O. australiensis* to an elite breeding line, and have created hybrids from crosses between IR cultivars and the wild species *O. eichingeri, O. alta,* and *O. rhizomatis.* Genes for blast (Bl), bacterial blight (BB), and whitebacked planthopper resistances have been located by restriction fragment length polymorphism (RFLP). Cultivars that are able to stimulate biological nitrogen fixation have been identified. Linkage relationships between isozyme markers and RFLP markers have been determined. A single dominant gene has been identified conferring the Bl resistance in *O. minuta/O. sativa.* We also have evidence that Bl resistance derived from *O. minuta* may result from decreased spore adhesion. Anther culture has been used to develop true-breeding lines for resistance to rice tungro disease (RTD); materials tolerant of salinity and alkalinity have also been identified and included in international test nurseries.

Evaluation of IRRI's conserved germplasm has similarly identified sources of resistance to sheath blight (ShB) and has vigorously screened for resistance against several insect species. In screening wild rices for resistance to viral diseases, we have identified various accessions showing antibiosis to green leafhopper (GLH) and also resistance to both forms of RTD virus. Our germplasm data bases have been substantially expanded, especially in relation to viral diseases and cultivar genealogy.

Varietal differences were found among values determined for that critical grain moisture below which cracking occurs during drying. Prototypes and laboratory models of dryers have been successfully tested as have low-cost rice mills of three sizes suited to women operators, to small groups of farmers, or to village-level cooperatives, respectively. Trials have been concluded for two models of a stripper harvester and for a thresher designed to cope with long damp straw. Instrumental techniques for measuring cooked-rice hardness have shown correlation with judgments of a sensory panel; hence, we improved our procedures for measuring rice-gel consistency.

Factors affecting adoption of modern rices and technologies as well as policy constraints to increased rice productivity have been assessed. IRRI's world rice statistics data base was strengthened; predictive models have been developed for future global demand for rice, and for regional demand for rice, wheat, and coarse grains. Our simulation models for crop growth—for both rice and nonrice species—have been refined, and deterministic soil-hydraulic functions identified. In ecosystems analysis, we have characterized IRRI's rice research sites in several collaborating countries, and have digitized various geographic informa-

tion system data bases for electronic processing.

Simulations and detailed microscale studies of microbial and chemical (oxidation) processes near rice roots in submerged soil showed that conditions within 4 mm of a root can be substantially different from those in the bulk soil. Simulations were structured for the transport of gases through rice plants and roots. Microbiological studies showed that mineralization of N was more rapid following incorporation of *Sesbania* than of rice straw.

In pest science and management, structured simulation models for the development of BI and for the effect of BI on rice growth predict that earlier BI onset causes greater yield loss. We have evidence that ShB in rice can infect succeeding nonrice crops. We have differentiated BB strains according to their DNA type, thereby determining that within individual (Philippine) fields there exist several distinct strains. Among bacteria isolated from Philippine rice seed samples, about 4% have been found to be pathogenic fluorescent pseudomonads. Studies of the ragged stunt virus showed that the noncapsid protein was similar to that of other tenuiviruses. Measurements indicated that GLH can transport RTD over distances of 3 km. Rice resistance to leaffolder (LF) is associated with deterrence of neonate larvae by surface chemicals, and we can now rear LF and yellow stem borer using appropriate artificial diets. Taxonomic research has identified new invertebrate pests of rice and fungal pathogens of LF. Measurements in upland ecosystems have shown two weed species to have higher photosynthetic rates and greater efficiencies in using both water and N than two upland rices.

Subprogram I: Germplasm evaluation

Evaluation of conserved germplasm

This project seeks to gain greater knowledge of the germplasm collection at IRRI, so that its potential for use in rice improvement will be more fully and efficiently exploited in the future.

Germplasm dissemination to IRRI staff for targeted evaluation

A total of 51,321 samples of rice germplasm, including wild species and *O. glaberrima*, were distributed within IRRI. The largest users were the pathologists, entomologists, and the physiologists in the cross-ecosystems program. Of 102 accessions directly used by plant breeders for hybridization purposes, 19 were requested for in situ hybridization under the wide hybridization project.

Expanding the passport data base for developing core collections. During 1990, we further expanded the data base that gives information about the sites where germplasm was collected. The data base now contains records on over 12,000 accessions and 2,000 newly received samples of germplasm.

Using information on origin and cultural type from the passport data base, we have been able to designate a preliminary core collection for the West African cultivated rice *Oryza glaberrima*. The geographic distribution and cultural types of this core collection have been determined.

Studies suggest that stratification of germplasm and choosing germplasm that represents broad genetic diversity would enable us to efficiently find resistance to various traits. For stresses that have been extensively evaluated in certain places, concentrations of resistant germplasm can often be found among germplasm from other places. There is a high proportion of germplasm resistant to the GLH in some Middle East countries where this pest is not reported. Germplasm resistant to the WBPH is more frequent in South Asia although the pest is distributed worldwide (Table 1).

When the distribution of specific traits is studied in sequential sets of accessions, some traits, such as resistance to BI and GLH, are rather uniformly distributed throughout the germplasm collection. Other traits are clustered among accessions of a particular type, such as improved breeding lines (Table 2) or those of a particular geographic origin.

Table 1. Percentage of *O. sativa* accessions conserved at IRRI that were found to be resistant to 4 pests in 6 geographic regions.[a]

Region	Accessions (%) with observed resistance to				
	Blast	Green leafhopper	Brown planthopper	Whitebacked planthopper	Expected resistance[b] (%)
East Asia	12.4	4.3	5.8	5.1	16.7
Southeast Asia	16.6	12.0	14.9	18.2	16.7
South Asia	16.3	29.4	56.2	53.8	16.7
Middle East and Europe	16.6	38.0	5.1	6.4	16.7
Africa	24.5	12.0	13.2	11.3	16.7
America	13.7	4.3	4.8	5.1	16.7
	a	b	b	b	n.a.

[a]A letter below each column indicates consistent (a) or not consistent (b) with the expected distribution at 5% level of significance using the chi square statistic with 5 d.f. [b]Assuming a uniform distribution across geographic regions.

Table 2. Actual occurrence of resistance to 4 pests in sequential blocks for the first 50,000 rice accessions conserved at IRRI.[a]

Acc. no.	Occurrence (%) of resistance observed				
	Bacterial blight	Blast	Green leafhopper	Brown planthopper	Expected[b] (%)
40,001-50,000	10.1	18.0	18.3	9.3	20
30,001-40,000	18.0	28.2	29.5	25.9	20
20,001-30,000	14.8	17.7	20.2	4.8	20
10,001-20,000	6.9	18.4	18.0	38.0	20
1-10,000	50.1	17.5	14.0	21.9	20
	b	a	a	b	n.a.

[a]A letter below each column indicates consistent (a) or not consistent (b) with expected distribution at 5% level of significance using the chi square statistic with 4 d.f. [b]Assuming a uniform distribution in sequential sets of accessions.

An understanding of how traits of interest are distributed geographically or among certain types of germplasm can lead to better evaluation of specific traits.

We expect the number of samples distributed to decline as evaluation focuses on specific subsamples for targeted evaluation. On the other hand, we expect the number of samples distributed off the IRRI campus to increase as consortia are established and new country programs begin. An improved data base in relation to the cultural type of germplasm in the International Rice Germplasm Center and extended isozyme classification of germplasm will help improve our knowledge of varietal groups of different areas.

International Rice Genealogy Data Base

IRRI is developing a permanent computer data base of records on the genetic ancestry of rice varieties and of hybridizations made in national programs.

Our files now include genealogies of almost 1,800 post-IR8 varieties released by national programs, 1,600 older (pre-IR8) varieties that farmers still grow or that rice breeders use as parents, and 86,000 crosses made in national programs. "Progenitor cards" have been filled out on the parents and grandparents of all cultivars.

From these data, the ancestry of most cultivars can be traced back to the original land races. The "foundation data" are now being computerized. The format is compatible with the IRRI History of Crosses computer program (65,000 IR crosses). Next, we will integrate the two data bases. We plan to make the system far more extensive, with more potential benefits, by "harmonizing" it with the voluminous INGER and IRRI germplasm bank data bases, then with IRRI Library's computerized International Bibliography of Rice Research. Eventually, this will be a worldwide computer program on the genealogy of rice varieties and crosses so that scientists any-

where can request pedigrees of varieties or breeding lines.

Not only can the computer program be used as a tool to search for sources of genetic resistance, it can also help determine genetic diversity if rice researches, like animal scientists, develop measurements of consanguinity.

Development and updating of rice viruses data base

A Rice Viruses Data Base (RVDB) has been developed, involving changes in trait names. RTV (rice tungro virus) has been changed to RTD (rice tungro disease). The current RTV data in the gene bank (GB) files will be referred to as RTD-%. A new trait, called RTD-SS, used since the 1987 screening, will be added. This new trait makes use of a modified screening method and a different scoring system. RSV will now be called rice ragged stunt virus (RRSV) to avoid confusion with another virus known in East Asia as rice stripe virus. GSV will now be called rice grassy stunt virus (RGSV). Its two strains and two corresponding traits in the GB file namely, GSV_1 and GSV_2 will now be called $RGSV_1$ and $RGSV_2$, respectively. Data since 1987 will be classified under $RGSV_2$.

The new system will 1) provide access to information on variety name and country of origin for a given germplasm bank (GB) accession number, 2) output information for a particular batch of materials to be screened, 3) print data sheets to be used in scoring with information on accession number and variety name, 4) provide input and edit screens to update the RVDB, 5) enable users to query the data base and print summary reports, 6) provide a facility to store additional information based on further tests to be conducted on resistant varieties (after RTD-SS mass screening, data sheets will be generated for all accessions with RTD-SS score of less than or equal to 4), and 7) provide a facility to input remarks on the resistance/tolerance of a variety to the virus/vector, based on the results of the RTD mass screening and retesting.

The updated RVDB revealed that for RTD, 15,795 accessions or 20.5% of the total germplasm bank collections have been tested for RTD-%, of which 560 (3.5%) were resistant (R) (less than 30% infection) (Table 3). These R varieties originated mostly in South Asia (India, Bangladesh, and Pakistan) (Table 4). Only 4,473 accessions, or 5.8% of the total germplasm bank collection originating mostly in India and Bangladesh have been screened for RTD-SS with 112 R accessions (2.5%). For RRSV, 13,759 accessions or 17.1% of the total GB collections have been tested and 336 (2.4%) found resistant. These R varieties came mostly from Southeast Asia (Indonesia and Malaysia), India, and Sri Lanka. For $RGSV_1$, 8,376 accessions or 10.9% of the total GB collection have been tested and 809 (9.7%) were resistant, originating mostly in India, Indonesia, and the Philippines. Of the 259 accessions tested for $RGSV_2$, 8 originating in China and India were resistant.

Screening and characterization of resistance to viral diseases

Wild species of rice are expected to have some useful genes for resistance to tungro. A core collection of 263 accessions, representing the genetic diversity in the genus *Oryza*, was selected from various regions and species. We have been multiplying the seeds of these accessions and screening them for tungro resistance. Prior to screening the core collection, 20 accessions (16 of wild species and 4 of *O. glaberrima*) were tested for antibiosis to GLH, resistance to

Table 3. Distribution of varietal reaction of germplasm bank accessions evaluated against rice tungro disease (RTD), scores based on percentage (%) and severity score (SS) for rice ragged stunt virus (RRSV) and rice grassy stunt virus (RGSV) strains $RGSV_1$ and $RGSV_2$.

Trait	Tested[a]		Accessions (no.) with given varietal reaction		
	no.	%	Resistant	Intermediate	Susceptible
RTD-%	15,795	20.5	560	3,348	11 887
RTD-SS	4,473	5.8	112	1,455	2,906
RRSV	13,759	17.1	336	4,906	8,517
$RGSV_1$	8,376	10.9	809	1,985	5,582
$RGSV_2$	259	0.3	8	212	39

[a]Percent of the total collections (77,175 as of December 1990) tested as of November 1990.

Table 4. Geographical distribution of accessions resistant to rice tungro disease (RTD), rice ragged stunt virus (RRSV), and rice grassy stunt virus strain 1 ($RGSV_1$).

Geographical region[a]	% of total accessions			% of resistant accessions		
	RTD	RRSV	$RGSV_1$	RTD	RRSV	$RGSV_1$
South Asia	6	2	11	88	28	53
Southeast Asia	1	3	12	9	66	27
East Asia	0.4	1	1	0.7	1	2
Middle East	2	0	36	0.5	0	3
Latin America	0	2	5	0	2	1
Africa	0.6	1	26	1	1	11
North/Central America	0	2	4	0	0.9	2

[a]Values were zero for Europe, USSR, and Oceania.

rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV) infection, and tolerance for tungro.

A 10-d-old seedling of each accession was placed in a test tube with 5 GLH nymphs (2d instar) at 10 replications to test for antibiosis. The antibiosis of each accession was rated on a scale of 1-5 for the daily number of GLH nymphs surviving for 3 d after caging. Fifteen-day-old seedlings were inoculated for 4 h with 10 viruliferous GLH adults per seedling. Three weeks after inoculation, the leaves were sampled individually to test both RTBV and RTSV by enzyme-linked immunosorbent assay (ELISA). The severity index of each accession was scored at 4 wk after inoculation.

One accession of *O. officinalis* (105365) showed high antibiosis to GLH and resistance to both RTBV and RTSV infection (Table 4). Two accessions each of *O. nivara* (102175, 105333), *O. punctata* (103896, 105158), and *O. minuta* (101126, 101141) showed high antibiosis to GLH and resistance to RTSV infection. In spite of low antibiosis to GLH and severe infection with RTBV and RTSV, three accessions of *O. nivara* (102463, 105409, 105417) showed a low score of symptom severity, indicating tolerance for RTD. When four accessions of *O. glaberrima* were inoculated with viruliferous GLH, they showed severe systemic necrosis, and no plants survived beyond 3 wk after inoculation. This necrosis was also observed in all accessions of *O. barthii* tested. The accession of *O. officinalis* from Thailand may be a useful genetic resource for its resistance to both RTBV and RTSV infection (Table 5). When the accession was reexamined with two other accessions of the same species from Thailand, no plant showed infection with RTD (Table 6). We are currently transferring its resistance gene(s) into *O. sativa*.

Our next step will be to complete the screening of the core collection, and determine whether resistance to RTD is specific to genome, species, and/or habitat.

Resistance of conserved germplasm to nonspecialized pathogens

Resistance to sheath blight. Over 800 accessions of cultivated rice, including 160 accessions of the African cultigen *Oryza glaberrima*, were evaluated for resistance to ShB caused by *Rhizoctonia solani*. Among the *O. sativa* accessions, 280 were traditional rice varieties from Laos and 371 from Banaue in the Philippines. The entries were manually seeded in three 50-cm rows with 5 hills each per entry. The distance between rows was 15 cm with 10 cm between hills. IR62 and IR58 were the resistant and susceptible check. Plants were inoculated 45 d after seeding (DAS), using 10- to 14-d-old inoculum of *R. solani* grown in rice hull/rice grain medium (3:1 vol/vol). About 5 ml of the inoculum was placed at the center of each hill. To provide optimum conditions for ShB development, the inoculated plants were sprayed with water three times daily with a power sprayer. Lesion height from 10 randomly selected tillers of the center row of each entry was measured at 15-20 d after flowering. The relative lesion height—lesion height as a percentage of plant height—was designated as severity index. No entry was rated highly resistant (Table 7). Accessions with reactions of resistant (R) and moderately resistant (MR) will be reevaluated.

Evaluation of wild rice for resistance to sheath blight. Of 25 representative accessions of *O. minuta* evaluated in the greenhouse for resistance to ShB, 23 were resistant, and 2 moderately resistant (Table 8). Relative lesion height ranged from 1.4 (Acc. no.

Table 5. Reactions of accessions from several *Oryza* species to green leafhopper (GLH) and tungro disease (RTD).

Genome	Species	IRRI acc. no.	Origin	Anti-biosis to GLH[a]	Plants tested (no.)	Infected plants (%)			Average severity[b]
						RTBV+ RTSV	RTBV alone	RTSV alone	
AA	*O. nivara*	102463	Bangladesh	5	38	74	26	0	3
		102175	India	1	18	0	78	0	5
		105333	India	1	49	2	59	0	2
		105409	Sri Lanka	5	39	69	18	3	2
		105417	Sri Lanka	4	18	50	11	6	2
		105456	Sri Lanka	4	3	67	33	0	5
A^gA^g	*O. glaberrima*	100139	Guinea	5	-[c]				
		100153	Guinea	3	-				
		102569	Liberia	3	-				
		103437	Senegal	4	-				
BB	*O. punctata*	103896	Tanzania	1	17	0	53	0	2
		105158	Kenya	2	49	0	37	0	3
BBCC	*O. minuta*	101126	Philippines	1	20	5	50	0	3
		101141	Philiopines	1	36	0	56	0	5
CC	*O. eichingeri*	105414	Sri Lanka	2	47	47	43	0	5
CC	*O. officinalis*	105365	Thailand	1	27	0	0	0	2
		105394	China	3	32	9	81	0	3/7[d]
CC	*O. rhizomatis*	105660	Sri Lanka	1	13	15	31	8	5
		105448	Sri Lanka	-	4	50	25	0	3
CCDD	*O. latifolia*	100914	Mexico	1	23	57	0	13	3
AA	*O. sativa*	(check varieties)							
	ARC11554	21473	India	1	54	2	39	0	3
	Utri Merah	16680	Indonesia	5	54	2	52	0	3
	TN1		Taiwan	5	53	96	4	0	9
	IR22		Philippines	5	57	90	10	0	9

[a]1 (resistant) to 5 (susceptible). [b]1 (no symptoms) to 9 (more than 50% plant height reduction and yellow to orange leaf discoloration) using the scale of Hibino et al (1989). [c]- = no plant survived at 3 wk after inoculation. [d]Segregating.

101081) to 23.1% (Acc. no. 101141), all of which were significantly different from that of the susceptible check IR58. All entries will be retested. If resistance is confirmed, *O. minuta* could possibly provide a useful source of resistance to ShB.

Detached-leaf technique for sheath blight screening. A detached-leaf technique was used to assess the response of 11 rice varieties with known levels of resistance to ShB namely: Suduwee (MR), Ta-poo-cho-z (MR), Gyehwa 1 (MR), Taducan (MR), Tetep (MR), Zenith (MS), Dawn (S), IR36 (S), IR64 (S), Labelle (HS), and IR58 (HS).

Table 6. Tungro resistance of 3 accessions of *O. officinalis* from Thailand.

IRRI acc. no.	Plants tested (no.)	Infected plants[a] (%)		Average severity[b]
		RTBV alone	RTSV alone	
100986	35	3	9	2
105365	14	0	0	2
105376	29	0	3	2

[a]No plants showed RTBV + RTSV infection. [b]1 (resistant) to 5 (susceptible).

A 10-cm section from the three uppermost leaves (at booting stage) was obtained from the central portion of the leaf blade (where width is uniform). The sections were washed with 0.05% chlorox solution, rinsed with distilled water, then placed in 25-× 150-mm petri dishes lined with wet filter paper at 5 sections/plate per replication. Three isolates of *R. solani*, a rice isolate (LR1), a sesbania isolate (RS26), and a sorghum isolate (RS54) were used in the inoculation. The inoculated sections were incubated at 30 °C under continuous light. ShB lesion length was measured after 72 h of incubation. Another set of intact plants in three replications was inoculated in the same manner as the three uppermost leaves, which were then incubated in a moist chamber with continuous light at 30 °C. ShB lesions were measured 1 wk after inoculation.

Table 7. Reaction of some rices to *Rhizoctonia solani*. IRRI, 1990.

Entry	Total entries (no.)	Entries (no.) with given reactions[a]					Entries (no.) for retest[b]
		R	MR	MS	S	HS	
Oryza glaberrima	160	5	39	35	1	2	78
Traditional/Laos	280	16	74	112	6	0	72
Traditional/Banaue, RP	371	51	174	8	0	0	138
Total	811	72	287	155	7	2	288

[a]HR = highly resistant (0%), R = resistant (1-20%), MR = moderately resistant (21-30%), MS = moderately susceptible (31-45%), S = susceptible (46-65%), HS = highly susceptible (>65%). [b]Entries that were inoculated but developed no ShB symptoms.

Although varietal differences can be differentiated by both the detached-leaf and intact-plant techniques, ShB lesion measurements from the detached-leaf technique did not correlate with those from intact plants or leaves. The results confirmed a previous observation (IRRI Annual report 1987) that resistance varied between the two techniques: a variety may be resistant to ShB with one technique but susceptible with another. However, Gyehwa 1 was resistant using both techniques. The observations indicate that, in general, the detached leaf cannot substitute for an intact plant when screening for ShB resistance.

Table 8. Reaction of selected accessions of *Oryza minuta* to sheath blight.[a] IRRI, 1990.

Acc. no.	Plant height (cm)	Relative lesion height (%)	Grade[c]
Oryza minuta			
101080	109	9	1
101081	127	1	1
101083	122	10	1
101094	110	15	1
101101	89	10	1
101125	118	10	1
101126	107	12	1
101132	113	13	1
101141	96	23	3
101386	95	20	1
101387	96	10	1
101141	96	10	1
103874	103	9	1
103878	86	17	1
104674	111	16	1
104676	115	21	3
104677	101	11	1
105123	99	19	1
105124	84	11	1
105131	106	13	1
105125	102	8	1
105126	82	14	1
105132	106	13	1
105253	62	18	1
Oryza sativa			
IR58	71	59	7

[a]Av of 3 replications. All entries are significantly different from susceptible check (IR58) at the 5% level, using the LSD test. [b]0 = highly resistant (0), 1-20% = resistant (1), 21-30% = moderately resistant (3), 31-45% = moderately susceptible (5), 46-65% = susceptible (7), >65% = highly susceptible (9).

RICE LEAFFOLDER REARING ON MAIZE SEEDLINGS AND SCREENING FOR RESISTANCE

The biological fitness of rice leaffolder (LF) *Cnaphalocrocis medinalis* reared on 10-d-old XVH-5 maize seedlings was compared with that from rearing on 35-d-old TN1 rice plants. The maize-reared pupae were heavier and bigger than those reared on susceptible TN1 plants (Table 9). Although in a choice test, rice-reared LF moths laid more eggs on rice plants, the maize-reared moths were as fecund as those on rice plants. Damage caused by maize-reared larvae on selected resistant and susceptible rice cultivars was comparable to that caused by rice-reared larvae (Table 10). Thus LF can be mass-reared readily and more efficiently on maize seedlings than on rice plants without affecting the feeding behavior of larvae and the damage on test cultivars.

Table 9. Biological fitness of *C. medinalis* reared on 10-d-old XVH-5 maize seedlings and on 35-d-old TN1 rice plants. IRRI, 1990.

Fitness parameter	Leaffolder rearing medium[a]	
	Maize	Rice
Pupae		
Weight (mg/pupa)	20.3 a	17.8 b
Length (mm)	9.9 a	9.1 b
Width (mm)	2.1 a	1.9 b
Fecundity (no. of eggs/female)	256 a	241 a

[a]In a row, means followed by a common letter are not significantly different at the 5% level by DMRT.

Table 10. Survival of maize-reared and rice-reared *C. medinalis* larvae at 15 d after infestation (DAI) and damage on selected rice cultivars.[a] IRRI, 1990.

Cultivar	Survival (%) at 15 DAI for larvae reared on			Adjusted damage rating (%) with larvae reared on			Damage score[b]
	Maize	Rice	Mean	Maize	Rice	Mean	
TKM6	21	20	21 a	25	29	27 a	3
Ptb 33	51	41	46 c	43	40	42 b	5
W1263	35	24	29 ab	43	45	44 b	5
IR36	33	43	38 bc	99	100	100 c	9
TN1	44	36	40 bc	100	100	100 c	9

[a]Av of 15 replications, each with 10 larvae/5 tillers. [b]Based on a 0-9 scale: 0 = highly resistant (0%), 1 = resistant (1-20%), 3 = moderately resistant (21-30%), 5 = moderately susceptible (31-45%), 7 = susceptible (46-65%), 9 = highly susceptible (>65%).

Screening for insect resistance

Of several thousand cultivars from the germplasm bank evaluated for insect resistance, additional likely sources of resistance to BPH, GLH, WBPH, yellow stem borer (YSB), striped stem borer (SSB), and LF were identified (Table 11). Only moderate resistance was noted in cultivars selected for YSB resistance. These cultivars could possibly be used to incorporate resistance through diallel crossing.

Resistance of wild rices to insects

We evaluated 13 wild rice accessions for resistance to YSB, SSB, GLH, and BPH. No YSB and SSB larvae survived on *Oryza australiensis* (IRRI Acc. no. 105165) (Fig.1). YSB and SSB larvae were underweight and only a few survived on *Oryza alta* (IRRI Acc. no. 100111) and *O. minuta* (IRRI Acc. no. 105126). Likewise, GLH and BPH biotype 3 did not develop populations on the above wild rice accessions. Although GLH laid a few eggs on wild rices, egg hatchability was unaffected.

Table 11. Screening of cultivars for resistance to various insect pests. IRRI, 1990.

Insect pest	Tested cultivars (no.)	Resistant cultivars (%)
Brown planthopper		
Nilaparvata lugens		
Biotype 1	1428	40
Biotype 2	1436	17
Biotype 3	1435	16
Whitebacked planthopper		
Sogatella furcifera	2883	1
Green leafhopper		
Nephotettix virescens	5163	5[a]
Yellow stem borer		
Scirpophaga incertulas	2164	10
Striped stem borer		
Chilo suppressalis	602	13
Leaffolder		
Cnaphalocrocis medinalis	1333	2[a]

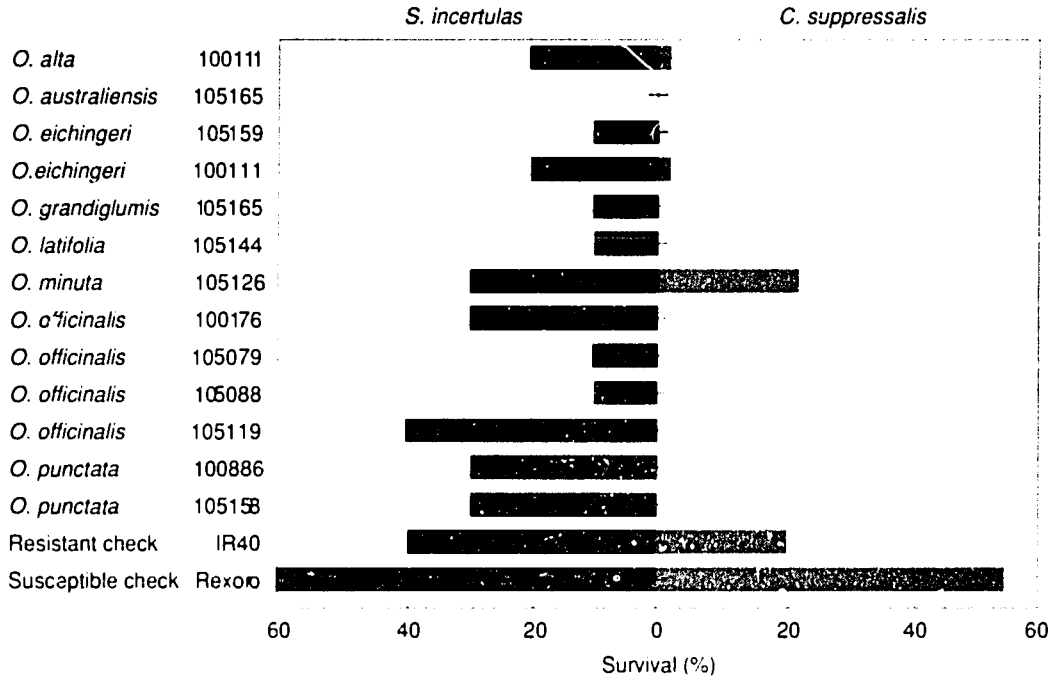
[a]For retesting.

Subprogram II: Genome manipulation

Knowledge of the genetic architecture of the rice plant is essential in applying the new tools of biotechnology. Genome manipulation aims to develop improved rice germplasm for various ecosystems through genetic manipulations at cell and molecular levels, to widen the rice gene pool, and to increase the efficiency of conventional breeding. The objectives are to develop a saturated genetic map for rice, to tag genes governing traits of agronomic importance, to create novel genetic variation through wide hybridization and DNA transformation, and to develop homozygous lines in a single generation through anther culture. The material thus developed will be made available to various rice improvement programs.

Saturated genetic maps

Gene tagging will facilitate marker-based selection for traits that are highly influenced by the environment and are difficult to select through conventional breeding procedures. In 1990, efforts involved establishing a genome mapping laboratory, developing plant materials for gene tagging, determining linkages between isozyme and RFLP markers, isola-



1. Survival of yellow stem borer and striped stem borer on selected wild rices, IRRI, 1990.

tion of novel aneuploids such as secondary trisomics to locate centromeres on the linkage map, and assigning genes to specific chromosome arms.

The new genome mapping laboratory is fully equipped to conduct molecular biology research primarily devoted to DNA marker technology.

Gene tagging

Characters of interest for gene tagging include resistance to diseases and insects (bacterial blight [BB], BI, RTD, GLH, BPH, WBPH), tolerance for abiotic stresses (drought, salt, submergence), N use efficiency (NUE), and ability to stimulate biological N_2 fixation (BNF), wide compatibility, fertility restoration, heterosis, and grain quality (amylose content, aroma).

Vegetative cuttings of the interspecific RFLP mapping population (120 plants of *O. sativa*/*O. longistaminata*) were transferred from Cornell to IRRI during 1990. Only 66 survived the quarantine; during 1991, replacements for the 54 plants that died will be re-imported to establish the entire mapping population at IRRI.

A second mapping population (200 recombinant inbred [RI] lines) is being developed from the indica/japonica cross IR34583/Bulu Dalam used to construct the first RFLP map of rice. This population will provide a permanent mapping resource; the original map was based on a transient F_2 population. The RI lines are currently in F_5; F_6 lines will be ready for RFLP analysis during 1991. Transfer of the current RFLP map will be undertaken and genes governing resistance to BI, BB, and BPH will be tagged.

In collaboration with Cornell University, RFLP surveys on the isolines and F_2 populations have confirmed the location of genes for resistance (one for BB, four for BI, and one for WBPH) via linkage to RFLP markers. A gene for photoperiod sensitivity has also been tagged with an RFLP marker (reported under the Rainfed Lowland Ecosystem). Isolines for resistance to RTD and GLH are in the BC_4F_4 generation. An F_2 population of 1,000 plants segregating for *Xa-21* (resistance derived from *O. longistaminata*) was derived from a BC_3F_4 isoline. This material is being scored for BB resistance and DNA will be isolated and used for RFLP analysis at Cornell University. F_2 populations segregating for other resistance genes (*Xa-3*, *Xa-4*, *xa-5*, *Xa-7*, *xa-8*, and *Xa-10*) are being analyzed at IRRI for linkage to mapped RFLP markers.

Experiments have been initiated to tag genes with molecular markers governing traits that are difficult to select through conventional procedures. We have

identified appropriate parents and are generating populations for the location of quantitative trait loci (QTL) through RFLP analysis for traits such as quantitative resistance to BI and BB, drought resistance, elongation ability, NUE, BNF, and salt tolerance.

Three RI populations of 200-300 lines each, designed to tag genes for quantitative BI resistance, were brought to the F_6 during 1990. These populations are of interest for drought tolerance, growth duration, and yield components such as grain weight, number of filled grains per panicle, number of panicles per tiller, and panicle length. RFLP parental surveys have been completed on the populations (reported in the Upland Rice Program).

Cultivars showing high and low NUE and relative ability to stimulate BNF in greenhouse and field experiments have been identified. Potential parents will be scored for molecular polymorphism to identify appropriate cross combinations for RFLP analysis.

A similar approach is being taken with respect to submergence tolerance for deepwater rice. For the tidal wetlands ecosystems, parents for crossing were selected 2 yr ago on the basis of RFLP analysis. Two hundred RI lines derived from Nona Bokra/IR28 have now been advanced to F_2 for tagging genes for vegetative stage salt tolerance.

A collaborative program (under the IRRI/Japan Shuttle Program) has been formalized to tag the genes for wide compatibility. Populations for tagging fertility-restorer genes are being generated. These populations will also be evaluated for grain quality and heterotic response. Seed from the parental lines have been multiplied to allow field testing of these characters.

A population of 130 doubled haploid (DH) lines produced from an indica/japonica cross (IR64/Azucena) has been selected for studying the genetics of drought resistance, subspecies fertility barriers, and BI resistance. (The project is in collaboration with UPLB and CIRAD/IRAT.) Preliminary surveys have demonstrated an acceptable level of RFLP. Seed for these lines is being multiplied and percent fertility scored.

Linkage relations between isozyme and RFLP markers

Linkage relationships between isozyme and RFLP markers were determined from IR36/Ma Hae F_2 segregation. IR36 (Acc. 30416) and Ma Hae (Acc. 23754) show polymorphism for 14 isozyme loci: *Adh-1*, *Amp-1*, *Amp-2*, *Amp-3*, *Amp-4*, *Est-1*, *Est-2*, *Est-9*, *Fdp-1*, *Mal-1*, *Pgd-1*, *Pgi-1*, *Pgi-2*, and *Sdh-1*. In F_2, 85 plants were examined for their RFLP pattern. Cosegregation for the isozyme and RFLP markers was analyzed in F_2 to determine linkages, which were calculated using the LINKAGE 1 program.

The DNA isolated from the leaves of F_2 plants was digested with seven restriction enzymes (*Eco*RI, *Eco*RV, *Pst*1, *Bam*HI, *Hind*III, *Xba*1, *Dra*1). The Southern blots were hybridized using nonradioactive digoxigenin-deoxyuridine triphosphate (dUTP)-labeled DNA probes. The allelic constitution of IR36 and Ma Hae for five isozyme loci and six RFLP markers is shown in Table 12. RFLP segregation was analyzed using nonradioactive digoxigenin-dUTP-labeled RG probes (Fig. 2.) The results of cosegregation for isozyme and RFLP markers are given in Table 13. The RFLP marker RG213 was found to be linked with *Est-2*, *Amp-3*, and *Pgi-2* with distances of 1.7, 1.7, and 7.9 map units, respectively (Table 14). The three isozyme loci *Est-2*, *Amp-3*, and *Pgi-2* are linked with RG64 with a distance of 22.5, 22.5, and 11.5 map units, respectively. Linkage relationships between three isozyme and two RFLP markers belonging to chromosome 6 are shown in

Table 12. Allelic constitution of IR36 (Acc. 30416) and Ma Hae (Acc. 23754) at 5 isozyme and 6 RFLP[a] loci.

Cultivar	Isozyme					RFLP markers with restriction enzymes					
	Est-2	*Amp-3*	*Pgi-2*	*Mal-1*	*Adh-1*	RG64 (*Hind* III)	RG172 (*Hind* III)	RG213 (*Xba*1)	RG173 (*Hind* III)	RG2 (*Hind* III)	RG118 (*Pst*1)
IR36	2	1	2	2	1	1	1	1	1	1	1
Ma Hae	1	2	1	1	2	2	2	2	2	2	2

[a]RFLP allele designation: 1 (IR36), 2 (Ma Hae).

2. RFLP pattern of *Pst-1* digested DNA from IR36 (P_1), Ma Hae (P_2), IR36/Ma Hae (F_1) and the F_2 population hybridized with RG118 (2.0 kbp) previously mapped on chromosome 11

Figure 3. Similarly, RG118 is linked with *Adh-1* with a distance of 7.3 map units. In addition to the four isozyme loci reported in 1989, *Mal-1* was located on chromosome 7 through linkage analysis with RFLP markers. It is situated at a distance of 22.7 crossover units from RG173.

In situ hybridization

In situ hybridization, which involves hybridization of labeled DNA probes with chromosome preparations, is an important technique for locating genes on

Table 13. Cosegregation for isozyme and RFLP markers in F_2 of IR36/Ma Hae.

Marker	Allelic constitution	Plants (no.) with marker genotype			Recombination (%) ± SE	Probability (p)
		11	12	22		
			Pgi-2			
Amp-3	11	0	3	14		
	12	10	37	4	11.3 ± 2.6	0.000
	22	16	1	0		
Est-2	11	16	2	0		
	12	10	37	4	11.3 ± 2.6	0.000
	22	0	2	14		
RG64	11	0	1	2		
	12	1	22	2	11.5 ± 3.9	0.000
	22	7	2	1		
RG213	11	0	1	8		
	12	3	32	4	7.9 ± 2.6	0.000
	22	11	1	0		
			Amp-3			
Est-2	11	1	0	17		
	12	0	51	0	1.2 ± 0.8	0.000
	22	16	0	0		
RG213	11	9	0	0		
	12	1	38	0	1.7 ± 1.2	0.000
	22	0	1	11		
RG64	11	1	2	0		
	12	4	20	1	22.5 ± 5.6	0.056
	22	1	5	4		
			Est-2			
RG213	11	0	0	9		
	12	0	38	1	1.7 ± 1.2	0.000
	22	11	1	0		
RG64	11	0	2	1		
	12	1	20	4	22.5 ± 5.6	0.056
	22	4	5	1		
			RG213			
RG64	11	1	2	0		
	12	3	21	1	18.5 ± 5.0	0.011
	22	1	4	5		
			Mal-1			
RG173	11	7	2	0		
	12	4	16	5	22.7 ± 5.3	0.001
	22	2	2	5		
			Adh-1			
RG118	11	9	1	1		
	12	2	23	1	7.3 ± 2.7	0.000
	22	0	1	12		

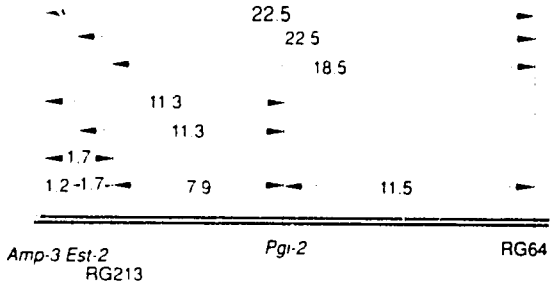
Table 14. Summary of linkage relationships among isozyme and RFLP markers.

Marker combination		Chromosome	Probability (p)	Recombination (%) ± SE
Amp-3	*Est-2*	6	0.000	1.2 ± 0.8
Amp-3	RG213	6	0.000	1.7 ± 1.2
Est-2	RG213	6	0.000	1.7 ± 1.2
Pgi-2	RG213	6	0.000	7.9 ± 2.6
Pgi-2	RG64	6	0.000	11.5 ± 3.9
Pgi-2	*Amp-3*	6	0.000	11.5 ± 2.6
Pgi-2	*Est-2*	6	0.000	11.3 ± 2.6
RG213	RG64	6	0.011	18.5 ± 5.0
Amp-3	RG64	6	0.056	22.5 ± 5.6
Est-2	RG64	6	0.056	22.5 ± 5.6
Mal-1	RG173	7	0.001	22.7 ± 5.3
Adh-1	RG118	11	0.000	7.3 ± 2.7

chromosomes. Mitotic chromosomes were prepared from root tip cells of IR36 and primary trisomics digested with cellulose enzymes. An rDNA probe (7.8 kb) was biotinylated and the labeled rDNA probe was hybridized with the somatic chromosomes of rice. Two pairs of relatively short chromosomes of IR36 showed hybridization signals (Fig. 4). Five somatic chromosomes (2 normal chromosome pairs and one extra chromosome) each in trisomics 9 and 10 showed hybridization signals. The results confirm earlier findings that ribosomal RNA genes are located on chromosomes 9 and 10 of rice.

Novel aneuploid stocks

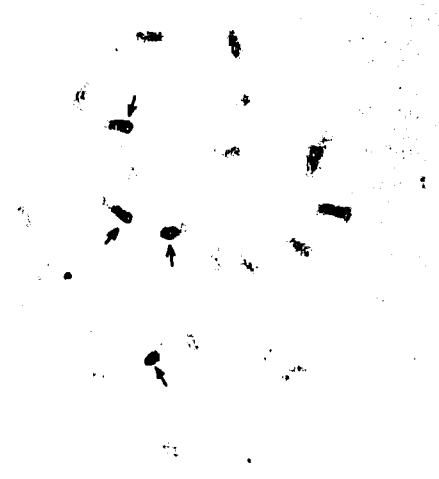
We have isolated novel aneuploid stocks from the progenies of primary trisomics and from pollen-irradiated progenies. These aneuploids (2n=25), referred to as secondary trisomics, have the normal chromosome complement and an extra chromosome, which has identical arms. On the basis of morphological and cytological characteristics, 14 secondary trisomics have been identified representing 10 of the 12 rice chromosomes. These aneuploids are being characterized using RFLP markers. Such aneuploids are important tools for locating centromeres on the linkage map and for assigning genes to specific arms of rice chromosomes.



3. Chromosome 6 showing linkage relationships among isozyme and RFLP markers.

Novel genetic variation

The objectives are to widen the rice gene pool by creating novel genetic variation through wide hybridization and genetic transformation, and to utilize materials generated by breeders working in the upland rice, deepwater, and tidal wetland rice ecosystems for fixing tolerance for cold, salinity, and drought through anther culture. Research in 1990 involved production of hybrids between cultivated and wild species of rice, transfer of BPH resistance from wild species, monitoring alien introgression through



4. Somatic metaphase of IR36 showing hybridization signal (arrow) of biotin-labeled rDNA probe on 4 chromosomes (2 homologous pairs).

RFLP analysis, and developing a large number of homozygous lines through anther culture from segregating materials generated for various ecosystems.

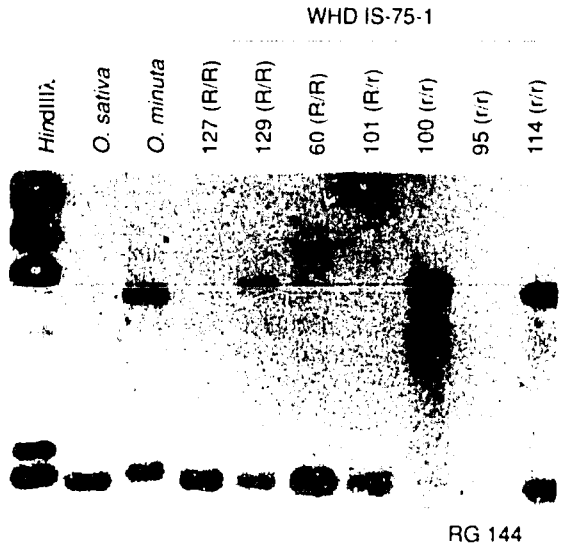
Alien gene transfer

The genes for BPH resistance have successfully been transferred from *O. australiensis* (2n=24 EE) into an elite breeding line (IR31917-45-3-2) of rice. Alien gene introgression for awns, early maturity, and pigmented stigma have also been obtained. The advanced progenies of *O. latifolia*, *O. minuta*, and *O. brachyantha* are being evaluated for transfer of resistance to diseases and insects. Alien addition lines and the derived disomic progenies are being monitored through isozyme analysis and, in the future, RFLP analysis.

To widen the rice gene pool, we have produced by embryo rescue hybrids between IR varieties and three wild species of *O. eichingeri*, *O. alta*, and *O. rhizomatis* (Table 15). This material is being advanced through backcrossing with the respective IR parents.

Genetic and molecular analyses of *O. sativa*/*O. minuta* derivatives

Last year we reported the transfer of resistance to BI and BB from *O. minuta* to *O. sativa*. Euploid line WHD IS 75-1 showed resistance to BI, but showed no morphological features, isozymes, or repetitive DNA sequence hybridization in common with the *O. minuta* parent (Acc. 101141). In 1990, BC_2F_2 progeny of WHD IS 75-1 were analyzed using DNA markers (RFLP), to assess the extent of alien DNA introgression. Of the 64 probes tested, 40 showed polymorphism between *O. minuta* and *O. sativa*, and four showed introgression from the wild parent (Fig. 5). The introgressed markers mapped to chromosomes 1, 4, and 6; none, however, showed close association with BI resistance.



5. *Hin*dIII-digested DNA from *O. sativa*, *O. minuta*, and progeny of the blast-resistant BC_2 plant WHD-IS-75-1. Introgression of DNA from the wild species is indicated by the presence in some of the progeny of a band inherited from *O. minuta*.

The inheritance of resistance was investigated in BC_2F_3 plants. Fifteen plants from each of 99 BC_2F_3 progenies of the BI-resistant derivative were tested with BI isolate PO6-6. The results indicated the presence of a single dominant gene for resistance in WHD IS 75-1 ($\chi^2 = 0.76$). In 97% of the progenies tested, results confirmed the findings at the BC_2F_2 generation; resistant and susceptible reactions were very distinct. Bimodal distribution of reaction types was clear; for some progenies, however, there was a more continuous range of reactions.

To further confirm the presence of a single dominant gene, a larger number of plants was tested for two segregating BC_2F_3 families. One of the two families, WHD IS 75-1-101, showed a bimodal distribution of reaction types in the 15-plant progeny test. The analysis of 147 plants showed 3 R:1 S segregation expected of a single gene ($\chi^2 = 0.06$).

Table 15. Hybrids between cultivated and wild species of rice produced through embryo rescue.

Hybrid combination		Spikelets pollinated (no.)	Seeds set (no.)	Embryos cultured (no.)	Hybrid plants (no.)
Female	Male				
IR31917-45-3-2	*O. eichingeri* (Acc. 101422)	184	33	5	1
IR64	*O. eichingeri* (Acc. 101422)	220	23	5	2
IR42	*O. eichingeri* (Acc. 105181)	48	20	18	13
IR31917-45-3-2	*O. rhizomatis* (Acc. 105432)	125	26	20	8
IR64	*O. alta* (Acc. 101395)	54	18	3	2

The other BC_2F_2 family, WHD IS 75-1-149, did not show a bimodal distribution of reaction types. When 149 BC_2F_3 plants from this family were tested, 104 had reaction types 0, 1, or 3, and 45 plants had reaction types 5, 7, or 9. The WHD IS 75-1-149 family did not show a clear bimodal distribution of reaction types, but it segregated as 3 R: 13 (χ^2 = 1.88). The results suggest that a single dominant gene is present in the progeny of WHD IS 75-1, and that some of the progeny may carry genes that modify their reaction to the Bl fungus.

The euploid BC_2F_1 plant WHD IS 78-1 and its BC_2F_2 progeny were reported in 1989 to be resistant to BB. This family showed morphological features, isozymes, and repetitive DNA sequences inherited from *O. minuta*. The disease reactions of BC_2F_2 and BC_2F_3 plants were tested; results confirmed the presence of a single gene or closely linked genes conferring resistance to races 2 and 3 of the pathogen (strong correlation between the lesion lengths for races 2 and 3 in the BC_2F_3; $r = 0.94$) and of a separate gene conferring resistance to race 6 (weaker correlation between lesion lengths for races 2 and 6 and for races 3 and 6 in the BC_2F_3; $r = 0.8$ for both). Progenies resistant to race 4 were also recovered in the BC_2F_3 generation. Since resistance to race 4 was not observed in the BC_2F_2 generation, this trait may be governed by a recessive gene. Our results further suggested the presence of a gene conferring resistance to races 1, 2, 3, and 5, and of other genes conferring resistance to race 1 and to race 5.

Mechanism of blast resistance in *O. minuta* and derivatives. Histopathological methods were used to determine whether *O. minuta*-derived resistance to Bl could be different from resistances already present in rice. The reactions of a resistant (IR68) and a susceptible (CO 39) rice cultivar were compared with the reaction of *O. minuta*, using ultrathin leaf sections and two methods of sample preparation: staining by Sass-safranin-fast-green and visualization by light microscopy, and staining by the fluorescent brightener Uvitex and visualization by epifluorescence microscopy. The observations indicated that the resistant reaction of the wild species is associated with less or no browning of the parenchyma cells, relative to the resistant reaction of IR68.

The leaf-surface morphology of resistant and susceptible BC_2F_1 derivatives of the *O. minuta* cross were examined by scanning electron microscopy (SEM). Several differences were observed between the leaf surfaces of *O. sativa* and *O. minuta*, including the presence or absence of trichomes, number of papillae, and size of silica-cork cells. None of these, however, was correlated with resistance in the BC_2F_3 progeny.

Preliminary observations using SEM suggest that spores of *Pyricularia grisea* adhering to the leaf surface of *O. minuta* were fewer than those adhering to the leaf surface of *O. sativa*.

Two methods of inoculation were used in further studies of spore adhesion: spraying of a spore suspension, and application of a thin film of agar onto which spores had been sprayed. The spraying method was to evaluate the relative efficiency of adhesion of spores to the surfaces of leaves of different genotypes. The agar method was assumed to force the adhesion of spores, and was used to determine the absolute efficiency of adhesion.

Spores of *P. grisea* strain PO6-6 were inoculated by the spray and agar methods onto young leaves of *O. sativa* variety CO 39 and line IR31917-45-3 (both susceptible to Bl), *O. minuta* (resistant), and three resistant and three susceptible BC_2F_1 plants derived from *O. sativa/O. minuta*. Twenty-four hours after inoculation, the leaf samples were prepared, stained with Uvitex, and analyzed by epifluorescence microscopy.

Inoculation using the agar method resulted in 5- to 15-fold greater number of adhering spores. Adhesion after agar inoculation was not different for the resistant and susceptible genotypes tested. This suggests that for all genotypes, spore adhesion after spray inoculation is inefficient. After spray inoculation, a significant difference was observed between the numbers of spores adhering to the resistant and susceptible plants (Table 16). Reduced spore adhesion appears to be a mechanism of resistance in *O. minuta* and its resistant derivatives. If subsequent experiments support this observation, it may be concluded that a unique prepenetration form of resistance to Bl has been transferred from a wild species to rice.

Production of homozygous (diploid) lines through anther culture

The materials for anther culture consisted of 42 indica/indica and indica/japonica crosses generated by breeders for use in upland, deepwater, and tidal

Table 16. Number of spores adhering on 125-mm² leaf area of agar and spray-inoculated plants (parents and derivatives of *O. sativa/O. minuta*).

Material	Adhering spores[a] (no. x 10³)	
	Agar	Spray
IR31917-45-3-2 (susceptible)	1.25	0.232
75-1-93	2.20	0.220
75-1-100	1.59	0.249
75-1-103	1.58	0.245
Mean	1.65 a[b]	0.236 a
O. minuta (resistant)	0.98	0.113
75-1-105	1.67	0.123
75-1-130	1.55	0.202
75-1-144	1.73	0.078
Mean	1.48 a	0.129 b

[a]Av of 5 leaf samples measuring 125 mm² from each plant. [b]In a row, different letters indicate a significant difference at P >0.01 according to DMRT.

Table 17. Plants regenerated through anther culture, 1990.

Material for different ecosystem or condition	Crosses (no.)	Diploid lines regenerated (no.)
Salt tolerance	7	77
Cold tolerance	11	142
Irrigated/bulus	10	140[a]
Upland	3	118
Blast resistance	5	72
Hybrid rice	6	21
Total	42	570

[a]Sixty-nine AC lines planted for field evaluation under irrigated condition, 1991 dry season.

wetland and irrigated ecosystems. From the 42 crosses, 570 diploid lines were developed through anther culture (Table 17).

Twenty F_1 crosses were received from Egypt during 1990. About 1,170 anther culture lines with a total of 4,008 plants with seeds have been produced from these crosses and will be tested in Egypt for yield potential, salinity tolerance, and resistance to Bl.

Evaluation of anther culture-derived lines

Four anther culture (AC)-derived lines—IR51491-AC4-6, IR51491-AC4-7, IR51500-AC9-7, and IR51500-AC11-1—performed as well as or better than the salt-tolerant varieties Pokkali and Nona Bokra in different locations in Bangladesh, Egypt, and India in the 1989 14th International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON) (Table 18).

AC lines IR51500-AC9-7 and IR51500-AC11-1 have very good salinity tolerance at the maturity stage, with an average rating of 4.0 and 4.3 across Sonagazi (Bangladesh), Canning Town (India), and Sirw (Egypt). The two AC lines under high EC (14.0) have very good phenotypic acceptability scores of 3 compared with 9 for Pokkali and Nona Bokra.

In four locations in India, AC lines IR51491-AC4-6 had very good alkalinity tolerance at the vegetative stage with an average rating of 3.8 compared with 4.0 and 4.3 for Pokkali and Nona Bokra, respectively (Table 19).

Four highly promising lines selected from the 14th IRSATON were included in the 1990 15th

Table 18. Performance of anther culture lines on saline soils, 14th International Rice Salinity and Alkalinity Tolerance Observational Nursery, 1989.

Country and test location	EC (dS/m)	Salinity and phenotypic acceptability scores[a]			
		IR51500-AC9-7	IR51500-AC11-1	Pokkali	Nona Bokra
Bangladesh					
Sonagazi, Feni	9.0	5 (-)	5 (-)	5 (-)	5 (-)
India					
Canning Town, West Bengal	8.5	5 (5)	4 (4)	5 (6)	4 (2)
Port Blair, Andaman	7.5	- (4)	- (7)	- (7)	- (7)
Egypt					
Sirw	14.0	3 (3)	3 (3)	7 (9)	9 (9)
Av		4.3 (4)	4.0 (4.7)	5.7 (7.3)	6.0 (6.0)

[a]Lower numerical values indicate higher degree of tolerance for salinity and higher phenotypic acceptability. Figures in parentheses are phenotypic acceptability scores.

Table 19. Performance of anther culture lines on alkaline soils in India, 14th International Rice Salinity and Alkalinity Tolerance Observational Nursery, 1989.

Test location	Soil pH	Alkalinity scores at vegetative stage[a]					
		IR51491-AC4-6	IR51491-AC4-7	IR51500-AC9-7	IR51500-AC11-1	Pokkali	Nona Bokra
Faizabad	8.9	3	3	3	3	3	1
Bihar	9.2	5	5	5	7	5	5
Haryana	9.5	4	5	7	6	3	4
Kanpur, Uttar Pradesh	9.6	3	5	5	5	5	7
Av	9.3	3.8	4.5	5.0	5.3	4.0	4.3

[a]Lower numerical value indicates higher degree of tolerance for alkalinity.

IRSATON for final evaluation. Two new AC lines, IR51500-AC11-3 and IR53649-AC5-2 were also included in the 15th IRSATON for evaluation.

AC lines IR51500-AC9-7 and IR53649-AC3 were included in the 1990-8th International Rice Acid Lowland Soils Observational Nursery (IRALON). Ten AC lines from four crosses for salt tolerance were sent to the Socialist Republic of Vietnam for testing and evaluation.

AC line IR37358-AC8 (Taipei 309/Tatsumi mochi) had an average phenotypic acceptability rating of 3.0 in five test locations compared to 5.4 of the cold-tolerant check varieties (Table 20). The AC line was also rated excellent (1.0 score) in Los Baños, Philippines, and very good (3.0) in Unbong, South Korea, when screened for cold tolerance at seedling stage in water at 12 °C. In Chuncheon, South Korea, AC line IR37358-AC8 showed no leaf discoloration when subjected to cold water treatment at 17 °C from tillering to maturity. In Jarabacoa, Dominican Republic, where the temperature was relatively low during flowering, the AC line IR37358-AC8 showed a high degree of spikelet fertility.

The AC line IR51491-AC4-6 was used as a parent in 16 crosses for salinity tolerance during 1990. A total of seven AC lines were used as parents in eight crosses for cold tolerance. Two AC lines for salt tolerance were included in the Philippine Rice Research Institute (PhilRice) national crop trials during 1990 wet season.

Improving efficiency of isolated microspore culture in indica rice

Isolated microspore culture can be a source of haploids and a vehicle for gene transfer. However, the adoption of the technique either for pureline production or for genetic manipulation is constrained by its

Table 20. Phenotypic acceptability scores of anther culture line IR37358-AC8 in different test locations for cold tolerance. 14th International Rice Cold Tolerance Nursery, 1989.

Country and test location	Av temp (°C)		Phenotypic acceptability[a]			
	Max	Min	IR37358-AC8	Stejaree 45	Barkat	IR15569-22-2-3
Myanmar						
Heho	26	15	3	5	3	3
Indonesia						
Sitiung	24	19	3	5	5	5
India						
Almora, Uttar Pradesh	29	17	3	7	9	3
Cameroon						
Ndop	28	16	3	7	5	5
Italy						
Vercelli, Sezione	26	15	3	3	5	5
Av	26.6	16.4	3.0	5.4	5.4	4.2

[a]Lower numerical value indicates higher degree of phenotypic acceptability.

low efficiency in terms of both callus induction and plant regeneration, especially in indica rice.

We investigated the role of media containing maltose as well as proline and glutamine in isolated microspores of IR43. Media with maltose alone or in combination with proline or glutamine gave about nine times higher plating efficiency in isolated microspore culture of IR43.

Cell suspensions and somatic embryogenesis

Formerly, it took 6 mo on the average to establish a cell suspension. However, this time has been shortened by half for some selected varieties. We have established cell suspensions from more than 15 cultivars or lines: IR43; IR58; Nipponbare; Taipei 309; Zhonghua No. 6 and 9; Taipei 177; Kitaake; G14; GZ38003-1; Calrose 76; Egypt 19, 20, and 43; 02428; and three F_1 hybrids. Our objective is to establish embryogenic suspensions in the shortest possible time for high frequency of plant generation.

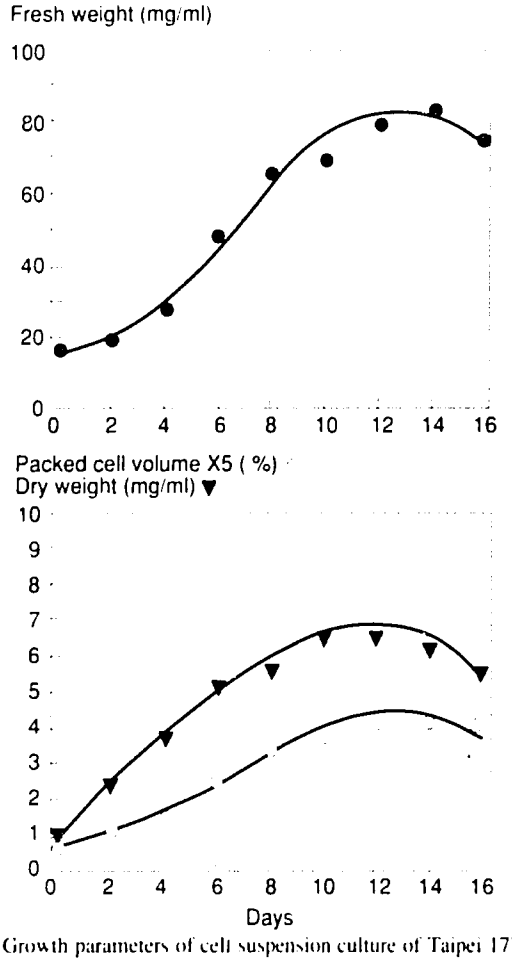
A wide range of media for initiation and maintenance of cells was tested including basal N6, R2, AA, MS, general media and modifications using various levels of hormones, type of carbon source, amino acids, and other components. In some instances, initiation and subsequent maintenance of cell suspensions necessitated the use of different basal media.

Plants have been regenerated through somatic embryogenesis from cell suspensions in IR43 and its F_1 hybrids. The plant regeneration medium was based on N6 with the addition of various concentrations of naphthalene acetic acid and benzyl adenine.

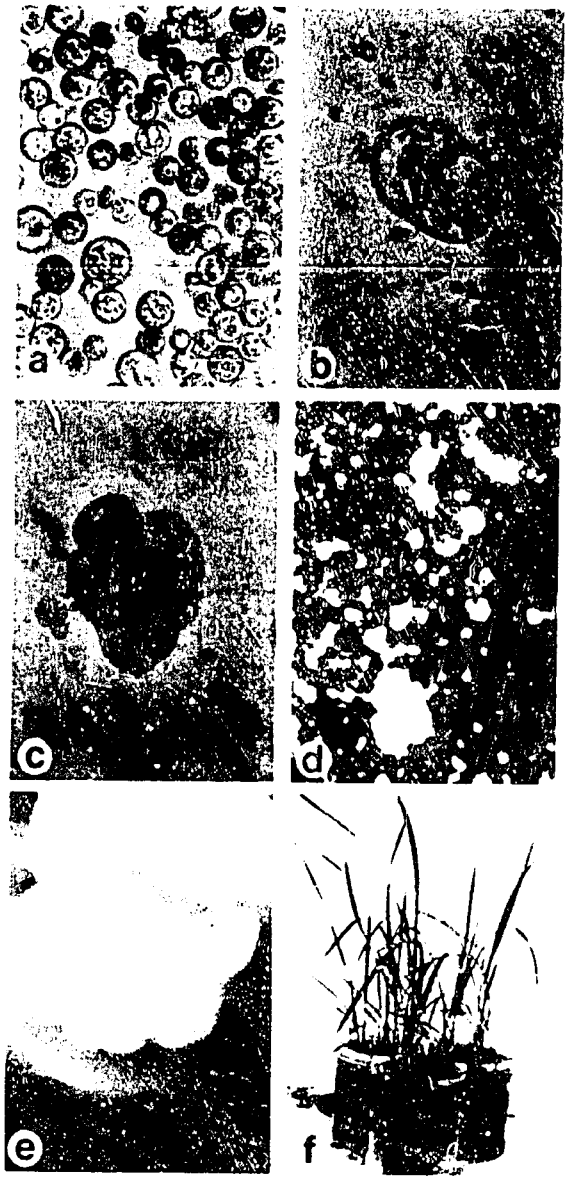
Protoplast culture and plant regeneration

Protoplasts were isolated from established cell suspensions, and primary or secondary calli. Different basal media such as MS, KPR, and R2 have been used for protoplast culture. In most cases, the use of nurse cells of the wild rice *O. ridleyi* enhances colony formation. Colonies or callus have also been produced from protoplasts of Taipei 309, Zhonghua No. 6 and 9, Nipponbare, 02428, Egypt 43, IR58, and IR72.

We have regenerated plants from protoplasts isolated from young inflorescence-derived embryogenic suspension culture of Taipei 177. The growth of the cells in liquid culture (fresh weight, dry weight, and packed cell volume) as a function of time is shown in Figure 6. Very active growth occurred between days 2 to 8 and maximum fresh weight was reached on day 14. Five-month-old suspensions were used for protoplast isolation. A high yield of viable protoplasts (80-95%) was routinely obtained (Fig. 7a) and first division was observed as early as the fifth day of culture (Fig. 7b). Further divisions led to the formation of compact cell masses after 12 d of culture (Fig. 7c). Maximum plating efficiency of 1.1% (Table 21) occurred in a medium containing macroelements of Kao and Michayluk, microelements and vitamins of Gamborg's B5, 0.5% Sea plaque agarose, 1.0 mg 2,4-D, and glucose as an osmotic stabilizer. These colonies developed into protocalli (Fig. 7d) and 1-2 mm calli were transferred to Murashige and Skoog semisolid medium, each liter containing 4 mg BAP, 0.5 mg NAA, and 500 mg casein hydrolysate (Fig. 7e). Around 21% of



6 Growth parameters of cell suspension culture of Taipei 177. Each point represents the mean of 4 cultures.



7. Callus formation and plant regeneration from protoplasts of rice (*Oryza sativa* L. cv. Taipei 177). a) Population of freshly isolated protoplasts; b) a two-celled stage following the first division of the protoplast; c) compact protoplast-derived colony after 12 d of culture; d) various sizes of protocalli after 4 wk of culture; e) callus formation after 6 wk of culture; f) plants regenerated from protoplasts.

Table 21. Effect of gelling agent on plating efficiency in rice protoplasts from Taipei 177.

Gelling agent	Plating efficiency (%)
Liquid (control)	0.47 b
Agar (Difco)	0.53 b
Agarose (Sea plaque)	1.06 a

the calli produced green (11%) and albino (13%) plants. A total of 32 green plants (Fig. 7f) were reared to maturity.

Next steps

New staff is being trained, and long-term experiments aimed at tagging genes controlling agronomically important traits have been initiated.

On-going research to develop a saturated genetic map will continue. We will locate centromeres on the linkage map of rice through RFLP analysis of novel aneuploid stocks. Some of the mutant markers and isozyme loci will be mapped onto specific chromosome arms through crosses with secondary trisomics. Linkage relationships of isozyme and RFLP markers will be determined. We will generate and analyze plant materials for tagging genes governing various agronomic traits with the isozyme and RFLP markers. Nonradioactive techniques will be further refined for use in RFLP analysis.

To widen the rice gene pool and develop useful germplasm for various ecosystems, research on wide hybridization will continue. Additional crosses with wild species possessing resistance to diseases and insects and tolerance for abiotic stresses will be emphasized. To diversify the cytoplasmic male sterility (CMS) sources for hybrid rice improvement, crosses of A-genome wild species will be made with elite restorers. Isozyme and RFLP techniques will be used for precise monitoring of alien gene introgression. Anther culture of selected materials generated by breeders for various ecosystems will be used to develop homozygous lines possessing useful traits. Our success in plant regeneration from protoplasts of japonica and indica rices during 1990 has enabled us to expand our work on DNA transformation. Initially, reporter genes will be used in transformation experiments; but later, agronomically desirable genes will be incorporated into rice.

Subprogram III: Ecosystem characterization and impact analysis

Research in 1990 delineated and mapped for South and Southeast Asia the flowering dates of rainfed rices, an important determinant of rice system productivity. An extensive survey of the human geography of rice in Southeast Asia was concluded. A methodology for presenting geographic information

in a handbook usable by extension technicians at the village level was developed. Electronic geographic information systems have been used increasingly in combination with crop-growth simulation to predict rice yield across a major rice-growing region. Simulation was also used in designing an ideotype for a rice of high yield potential. One essential component in any crop-growth simulation is quantification of soil-water dynamics. The soil properties that determine those dynamics have high spatial variability. New approaches for quantifying such variability for both upland and lowland rice soils are discussed.

This year the report on the impact of rice technologies focuses on Nepal. Factors determining the adoption of modern rice cultivars and the effects of such adoption on cropping intensity, rice yield, and fertilizer use are analyzed. For Asia, we quantify the effects of changes in incomes and prices and of socioeconomic structures such as urbanization on future demand for cereals (including rice). Concerns related to the environmental impact of rice production have featured in research on land management; that research, conducted as part of this Subprogram, is reported in the Upland Rice Program.

Spatial distribution of rainfed lowland rice flowering dates in South and Southeast Asia

Knowledge of the spatial variation of flowering dates in rainfed rice guides international research efforts to improve rainfed rices and to intensify cropping systems for the subecosystems of the rainfed ricelands of South and Southeast Asia. These ricelands, extending to 90 million ha, are predominantly shallow rainfed, medium deep, and deepwater environments and grow mostly photoperiod-sensitive rice cultivars.

For the rainfed lowland ecosystem, five major subecosystems have been identified: drought-prone, drought- and submergence-prone, submergence-prone, medium deepwater, and favorable rainfed.

A data base and a set of 6 maps of 1:4.5 m scale of the rainfed rice flowering periods for the 12 rice-growing countries of South and Southeast Asia were developed for each of the 3 major rainfed rice types: shallow (<0.3 m), medium deep and deepwater (0.3-1.0 m), and very deep water (>1.0 m). Thematic maps on the same scale were developed for three ecological determinants hypothesized to spatially influence the timing of the flowering period: the cutoff rainfall period at the end of the rainy season, the cutoff period at which minimum temperature drops below 20°C, and the number of wet months in the growing season.

Interpretations revealed the following:

- The flowering period of rainfed rice varies widely. It tends to be more geographically homogeneous and concentrated within a narrower range of dates in northerly rice-growing areas, and is exceedingly diverse in the island nations of Southeast Asia because of greater spatial complexity in rainfall patterns and lack of low temperature constraint.
- The cutoff rainfall strongly influences the flowering period of shallow rainfed lowland rice, but not that of medium deep and deepwater rice (DWR). In northerly latitudes, the flowering of deepwater rice coincides with the minimum temperature cutoff.

Rainfed rice land data base—an aid to technology transfer

Rice production in South and Southeast Asia varied in response to both biophysical and socioeconomic environments. During the last three decades, several promising rice production technologies did not reach or were rejected by farmers.

To understand and remedy this situation, we seek to assemble riceland geographic information in a form usable for extension technicians. The information, in manual form, will allow extensionists to demonstrate to farmers how informed judgments on the choice of cropping system and levels of technology in spatially complex environments are made. The manual is also designed to assist farming systems researchers in setting on farm trials in the most representative locations and in interpreting and extrapolating research results. The manual layout features

- a page showing the tabulated geographic data, and
- a facing page showing a map of the smallest administrative unit (e.g., village) with the respective land types delineated.

The map and its data base are functionally linked by mapping unit numbers.

Preparing the manual. The methodology is based on the relationship between landform, hydrology, and rice technology.

The choice of area covered by individual maps and data bases may vary between countries, but it should be guided by the facility of preparing the map and data base and its usefulness.

The geographic data base. The data base covers 20 items:

1. Name of village or smallest administrative unit.

2. Mapping unit (MU) number, a vital link to the map. Numbering is confined within a village and the number of MUs for a village may be one or many. A particular MU may be an extension of MUs occurring in adjacent villages, especially if the ricelands are narrow and elongated.

3. Rice culture type, which determines whether a MU is rainfed (RFE), irrigated (IRE), or other type. It can be determined from irrigation system maps and soil classification maps or from field survey and interviews.

4. Rainfed land type (RLT) combines landform, hydrology, and soils data to define cropping pattern extrapolation zones. RLTs are specified from correlations of landform, soil, and hydrology with crop adaptation. An example is given in Table 22.

5. Area (in ha) of MU, as measured from the base map using a planimeter.

6. Landform, such as alluvial terrace (AT), interhill miniplain (IMP), interfluve (IF), as determined from soil physiography maps.

7. Soil type, expressed in numerical code for the soil series name and surface soil texture; this should be consistent with the country's soil classification system, and explained in a data base footnote.

8. Soil textural class.

9. Soil drainage class encoded according to the country's soil classification system. It may be determined from soil and landform maps or by reconnaissance survey.

10. Slope, expressed either as percent or degrees, and included as an indicator of surface drainage and drought proneness.

11. Soil pH.

12. Organic matter content (%).

13. Phosphorus: expressed as P_2O_5.

14. Potassium: expressed as K_2O.

15. General soil fertility limiting factors, based on the number and intensity of fertility-limiting factors, e.g., alkalinity, salinity, Fe toxicity, P deficiency, Zn deficiency, and acid sulfate condition.

16. Rice variety type, indicating whether the predominant rices are local (LV), traditional, pho-

Table 22. Environmental characteristics, present and potential cropping patterns for the 6 rainfed land types in the lowland rice-growing areas of Cagayan.

Property or feature	Rainfed land types					
	I	II	III	IV	V	VI
Designation	Favorable	Submergence-prone	Drought-prone	Drought- and submergence prone	Submergence- and -drought prone	Waterlogged, severely submergence-prone
Submergence threat	None, but flash flooding may occur after heavy rain	Short-term (1-2 d) crop submergence	None	Very short-term (1-2 d) crop submergence during the growing season; severe flooding occurs 1 in 12 yr	Frequent and severe crop submergence expected every growing season; major long-term flooding every 3 yr	Prolonged flooding and several short submergence period expected annually
Drought threat	None, occasionally mild	Moderate in some years	Severe during the rice season	Severe drought stress threat during the crop season	Moderate in some years	Slight

continued on opposite page

Table 22. continued.

Property or feature	Rainfed land types					
	I	II	III	IV	V	VI
Hydrological year	Long (July to January), extended by catchment interflow	Medium July-December; has interflow from higher land	Short (July-November); water regime depends on direct rainfall; limited surface interflow	Relatively short (Jul-Oct); water accumulation mainly from direct rainfall	Jul-Dec/ surface and interflow from facet 1 extends the hydrological year	Very long (10 mo)
Landform units	Alluvial fan and interhill miniplain with large watershed	Lower face of interhill miniplain	Upper and facet of interhill miniplain with small watershed; interfluve	Recent river terrace; land facet 1 (or stratum 1) of alluvial terrace	Land facet 2 (or stratum 2) of alluvial terrace	Backswamp (or land facet 3) of alluvial terrace
Soil types	Bantog clay, Bigaa clay, Bago silty clay loam, Tagulod clay	Bantog clay, Bigaa clay, Tagulod clay loam, Isabela clay, Padapada clay	Bago sandy loam Bantog clay Tagulod clay Tagulod clay loam Bigaa clay loam Bigaa sandy clay loam Isabela clay Padapada clay Quingua silty clay loam	Tagulod clay loam Quingua silty clay loam; Tagulod clay Bigaa clay Bantog clay	Bantog clay; Bigaa clay; Tagulod clay loam; Isabela clay; Padapada clay Tagulod clay Quingua silty clay loam; Zaragoza clay loam	Bigaa clay Tagulod clay loam
Drainage	Fair to poor internal drainage; good surface drainage	Poor internal as well as external drainage	Fair internal drainage; good surface drainage	Fair to poor internal drainage; poor surface drainage	Very poor internal and external drainage	Very poor internal and surface drainage; medium-deep (25-50 cm) to deep water (>50 cm)
Present cropping pattern[a]	TPR-TPR (MV)	F-TPR (LV)-F	F-TPR (LV)-F	F-TPR (LV) - F MB (bc)-TPR (IC)-F	F-TPR (LV)-F	F-DSR (LV)-F F-TPR (LV)-F
Potential cropping pattern[a]	WSR-TPR (MV)	WSR (MV)-TPR (MV)	MB(rp)-TPR(IC)-F	MB (rp)-TPR (IC)-F	WSS-TPR (IC)-F	No change
Representative location	Maguirig, Solana; Talinaganay, Tuguegarao	Bayo, Iguia; Pengue, Tuguegarao	Bayo, Iguia, Pengue & Larion Alto, Tuguegarao	Andarayan, Solana, Bauan, Solana	Bauan, Solana	Bauan, Solana; Libag, Tuguegarao Cordova, Asulong

[a]F = fallow, TPR = transplanted rice, DSR = dry seeded rice, WSR = wet seeded rice, MB = mungbean, rp = ridge planting, bc = broadcast, LV = local rice variety, photoperiod sensitive, MV = modern rice variety, IC = improved rice cultivar.

toperiod sensitive, or modern photoperiod insensitive (MV) varieties. Types may change with season or year, and the data base may be used to monitor the dynamics of use of LVs and MVs.

17. Yield level, giving a general indication of current rice yields at the village level, as based on interviews and key informants, and separating levels of LVs and MVs.

18. Present cropping pattern.

19. Suggested cropping patterns found suitable for specific land types on the basis of research from similar environments.

20. Remarks covering important information not included.

Use of the manual. The maps and data base can help differentiate among major land categories as classified through modal characteristics—the conditions that tend to occur most frequently.

Rainfall and drought may cause field conditions to vary dramatically from year to year. Thus, flexibility is essential in developing cropping patterns.

Since the data base contains only biophysical information, suggested cropping patterns may only be biologically or agronomically feasible, not necessarily economically viable. Therefore, the manual should be used in conjunction with socioeconomic information to enhance adoption or acceptability of the recommended patterns. Socioeconomic information should eventually be incorporated in the data base.

Some data base information, such as rice type and yield, and cropping pattern, changes with time as new information becomes available; hence, the data base and maps should be periodically updated. Major infrastructure changes, such as new irrigation systems or roads, should be entered in the data base and maps. Changes in rice variety should also be noted, since introduction of MVs may increase productivity.

Human geography of rice in Southeast Asia

Human geography of rice in Southeast Asia was published in 1990. For each country in Southeast Asia, it gives information on rice cultural type, farmholding, and employment (Table 23), and shows how rice production is characterized by highly varied farm systems and strongly contrasting human resources over a region of diverse physical environments ranging from dry and semiarid (in Myanmar and Thailand) to wet and humid (Indonesia and the Philippines). The region is heavily populated—8% of the world's population live on 3% of the world's land area, with rice as the staple food of roughly 80% of the population. And although the last three decades produced substantial improvements in rice technologies and rice yields, not all farming communities benefited. Thus there is need to identify and understand the physical and human environments of those farming communities that did not benefit so as to develop new farming systems appropriate to their situations.

Cambodia. The total wet season (WS) rice area in Cambodia is 1.36 million ha, with rainfed rice (shallow and intermediate) occupying 60% of the total. Dryland rice and DWR respectively occupy 18 and 16% of Cambodia's rice area. Irrigated rice (IR) extends to only 84,000 ha during WS, but 164,000 ha in dry season (DS). The large DS area can be explained by one of two facts: there is sufficient water during WS, hence irrigation is not necessary; or sufficient water accumulates in reservoirs during WS so that more land can be irrigated.

Ninety-two percent of farmland in Cambodia is planted to rice. Farms are collectively operated by neighborhood or "solidarity groups" of about 12 families that operate farm units with an average area of 13.9 ha. Rural families are composed of slightly more than 5 persons; about 1.5 members in each family work mainly on the farm. Of the total number of people employed in agriculture (2.04 million), 89% work on rice-related activities.

Indonesia. WS rice in Indonesia extends to 6.36 million ha. Rainfed lowland rice (RLR) and upland rice (UR) are the dominant culture types, occupying 49 and 23% of the total WS rice area. IR in WS extends to 1.30 million ha (20% of the total); this area more than doubles during DS.

The average landholding is 0.96 ha, and only 37% of farmlands grow rice, indicating that many other crops are grown. About 43 million people are involved in agriculture, 45% of them in rice-related activities. Family and marginal labor comprise 58 and 57% respectively of the total agricultural plus rice-related labor.

Laos. RLR (53%) and UR (41%) are the major rice cultural types in Laos. WS IR accounts for only 5.6% (38,000 ha) of the total rice area, and only 6,000 ha are irrigated in DS.

Table 23. Summary of rice area by culture type, farmholding data, and employment in agriculture and rice farming, Southeast Asia.

Country	Rice area by culture type (000 ha)										Farmholdings			
	Upland		Deepwater		Irrigated				Rainfed					
					Wet		Dry		Shallow	Intermediate	No. (000)	Area (000)	Mean size (ha)	Area sown to rice (%)
Cambodia	245	(7.6)	223	(11.1)	84	(1.4)	164	(2.6)	391 (3.0)	420 (8.3)	110	(0.2)	1534	13.9	92
Indonesia	146	(45.9)	467	(23.3)	1295	(21.8)	2895	(45.2)	1627 (12.4)	1485 (29.5)	18965	(45.2)	19251	1.0	37
Laos	279	(8.6)	0	0	38	(0.6)	6	(0.0)	363 (2.8)	0 0	364	(0.9)	801	2.2	86
Malaysia	96	(8.6)	0	0	236	(3.9)	185	(2.9)	193 (1.5)	66 (1.3)	887	(2.1)	2149	2.4	22
Myanmar	322	(9.9)	557	(27.8)	630	(10.3)	69	(1.1)	2[illegible]1 (18.7)	806 (16.0)	4271	(10.2)	9235	1.9	59
Philippines	165	(5.0)	8	(0.4)	999	(16.4)	839	(13.1)	1121 (8.6)	272 (5.4)	3420	(8.2)	9510	2.8	89
Thailand	241	(7.4)	340	(17.0)	1251	(20.5)	638	(10.0)	6045 (46.2)	1686 (33.5)	4738	(11.3)	20050	4.2	59
Vietnam	407	(12.6)	410	(20.4)	1565	(25.7)	1616	(25.2)	901 (6.9)	300 (6.0)	9181	(21.9)	6361	0.7	75
Total/average	3240		2008		6098		6412		13092	3035	41936		66891	1.6	52

Country	Employment data									
	Total agricultural labor (000)					Rice-related labor (000)				
	Owner household	Tenant	Family and marginal	Family		Owner household	Tenant	Family and marginal	Family	
Cambodia	1378 (3.9)	0	661 (1.2)			1230 (6.1)	0	500 (1.7)		
Indonesia	13153 (37.3)	3820 (73.2)	24005 (42.7)			5593 (30.0)	2762 (73.3)	10972 (76.6)		
Laos	364 (1.0)	0	637 (1.1)			316 (1.6)	0	533 (1.8)		
Malaysia	583 (1.6)	304 (3.8)	1056 (1.9)			137 (0.7)	78 (2.1)	238 (0.8)		
Myanmar	4271 (12.1)	0	1189 (2.1)	4279		2422 (12.1)	0	674 (2.2)	2422	
Philippines	2361 (6.7)	1060 (13.3)	9120 (16.2)			1058 (5.3)	475 (12.6)	3986 (13.3)		
Thailand	3975 (11.3)	765 (9.6)	10787 (19.2)			2344 (11.7)	451 (12.0)	6362 (21.2)		
Vietnam	9181 (26.0)	0	8729 (15.5)			6907 (34.5)	0	6568 (22.0)		
Total/average	35266	7948	56104			20007	3766	29943		

Note: Figures in parentheses are proportion (%) of the totals of the Southeast Asian region.

The Socialist Government of Laos owns all land, and exercises control through cooperatives. Average farm size is 1.2 ha; there is little mechanization and minimal agrochemical inputs. On the average, 80% of each farm area grows rice.

The agricultural labor force numbers about one million. Family size is slightly more than 6, of whom 2.5-3.0 are heavily involved in agriculture. Rice-related labor accounts for almost 87% of the total agricultural labor force; family and marginal labor make up 69% of the total agricultural plus rice-related labor.

Malaysia. In Peninsular Malaysia, Sabah, and Sarawak, rice is generally cultivated in small plots with varying degrees of intensification. In the Peninsula, over 90% of the rice area is irrigated, of which 85% grows 2 rice crops a year. In Sabah and Sarawak, there is little irrigation or rice double-cropping.

RLR, the dominant cultural type, occupies 44% of the WS rice area, of which 82% is in Sabah and Sarawak, which grow 29% of Malaysia's UR as well.

The average farm in Malaysia is 2.7 ha, with rice growing on 23% of the area. About 1.94 million people work in agriculture, but only 23% on rice-related work; rice in Malaysia is of less importance than plantation crop.

Family and marginal labor compose 54% of the total agricultural labor force and 53% of the rice-related force. Owner households contribute 33% of total labor, and tenants about 16% of total and 17% of rice-related labor.

Myanmar. Rainfed rice (lowland and upland) extends over 2/3 of the total rice area in Myanmar; IR comprises 17% (0.63 million ha) during WS, but only 0.07 million ha in DS.

Mean farm size is 1.9 ha, of which 59% is planted to rice. About 9.73 million people depend on agriculture, of whom 57% engage in rice-related activities. The state owns all lands and grants all rights to work the land. Almost all production is on small family-operated holdings.

Philippines. RLR (54%) and IR (39%) dominate rice culture in the Philippines; the IR area is 16% less in DS than in WS.

Mean farm size is 2.8 ha, and 39% of all farmland grows rice. Some 12.5 million people are engaged in agricultural activities, 44% of them on rice-related activities. Family and marginal laborers comprise 73% of the total agricultural labor force, and 72% of the rice-related force.

Thailand. Rice is grown on 60% of Thailand's farmland. RLR occupies 7.7 million ha, about 81% of the total WS rice area. UR and DWR extend to 2.5 and 3.6% of the total rice area. In WS, 1.25 million ha of rice is irrigated; but the area is reduced by half in DS.

Average farm size, at 4.2 ha, is larger than in other Southeast Asian countries. The total agricultural labor force is 15.5 million, of whom 59% are involved in rice-related work. Family and marginal labor form 69% of both the total agricultural and the rice-related work force.

Vietnam. IR and RLR are in 44 and 34% respectively of Vietnam's WS rice area. The DS irrigated area is 3% larger than that in WS.

Collective farming is the dominant practice, but there is a trend toward individual operation of farm units. Average farm size is 0.7 ha, the smallest among Southeast Asian countries. About 25% of all agricultural land grows rice. Of 17.9 million people who work in agriculture, 75% pursue rice-related activities.

Comparison among Southeast Asian countries. The total area of WS rice in Southeast Asia is 29.5 million ha, of which Thailand has 32%, Indonesia 22%, and Malaysia only 2% (Table 24). The dominant rice type is rainfed lowland, extending to 18 million ha, or 62% of the total WS area.

Of the IR area in WS, 26% is found in Vietnam, and 21% in each of Indonesia and Thailand. For IR in DS, Indonesia with 2.9 million ha contributes 45% of the region's total. In Indonesia, IR in DS is 2.2% higher than in WS; Cambodia (+ 1.45) and Vietnam (+ 1.02) are the only countries that have more IR in DS than in WS. In Myanmar and Laos, the IR areas in DS extend to only 11 and 16% of the respective WS areas.

The proportion of total agricultural labor that works on rice-related activities is highest in Cambodia (89%) and Laos (87%), and least (23%) in Malaysia.

Characterization and simulation for riceland management and productivity

Methods for characterizing variability of rice soils, together with the tools of Geographic Information Systems (GIS) and crop simulations, are here ap-

Table 24. Comparison of total wet season rice area, % of agricultural labor involved in rice-related work and % increase or reduction in irrigated rice area among Southeast Asian countries.

Country	Total rice area of wet season crop		Agricultural labor (%) working on rice-related work	Increase or reduction (%) in irrigated rice area from wet to dry season
	ha x 10^3	%		
Cambodia	1,363	4.6	89.26	+95.23
Indonesia	6,360	21.6	44.97	+123.55
Laos	680	2.3	86.81	−84.21
Malaysia	591	2.0	23.31	−21.61
Myanmar	4,766	16.2	56.71	−89.0
Philippines	2,564	8.7	44.0	−16.01
Thailand	9,563	32.4	59.21	−49.0
Vietnam	3,583	12.2	75.24	+3.26
Total	29,470			

plied to develop procedures that can improve rice-soil and soil-water management, help determine extrapolation domains for research findings, and indicate future targets for rice research. We also report efforts to strengthen the capability of rice research systems to adopt and adapt soil characterization, GIS, and crop simulation procedures.

Application and improvement of crop simulations

An existing rice-crop simulation model was used to help identify a tropical rice ideotype with the potential of yielding the target 15 t/ha specified in IRRI's *Strategy toward 2000*. A prospective ideotype has a long (45-55 d) grain-filling period, a smaller maximum vegetative biomass than existing cultivars, and the capacity to absorb substantial amounts of N after flowering.

The various modules of MACROS simulation models have been translated from CSMP into FORTRAN 77, and made available to our NARS colleagues so that they can apply on their own FORTRAN-served computers the various simulations originally developed in the not-widely-available simulation language CSMP. A version of MACROS for soybean (SOYCROS) was developed and used to simulate water use, growth, and prospective net profits for soybean following rice in rainfed upland, rainfed lowland, and irrigated systems in Tuguegarao, Philippines. For the rainfed systems, predictions were made corresponding to the rainfalls expected to occur over the long term in 25, 50, and 75% of years.

Each simulation analysis requires values for several variables and parameters for crop, soil, and weather properties. A manual has been prepared and distributed to indicate the minimum required set for such variables and parameters.

Combining GIS and a rice-crop simulation

An exploratory procedure was developed to combine an existing rice-crop simulation with a GIS soil and weather data base created (in partnership with Philippine Government agencies) for the lowland rice regions of the Philippine Province of Tarlac. The combination was successfully used to predict rice yield across the chosen regions as a function of the soil characteristics and historic weather regime (assuming optimal nutrition and no pests). Predictions were made and mapped both for fully irrigated and for nonirrigated rainfed lowland conditions; a difference between the predictions indicated the prospective benefit that would ensue from expansion of irrigation.

Soil structural influences on soil-water relations and rice-soil management

Soil hydraulic resistance. An important determinant of water economy and rice production in puddled soil systems is the hydraulic conductivity—and hence resistance—of the compact soil zone at the base of the puddled layer. Measurements in situ of water-percolation rate and soil-water pressure potential were used to determine hydraulic gradient, resistance, and conductivity of soil throughout the 0 to 30-cm depth at each of 36 positions within a 0.10-ha puddled field with saturated surface soil and unsaturated subsoil. The compact (and hence least permeable) layer was about 6 cm thick, and distribution of the 36 values of hydraulic conductivity for that layer

were log-normally distributed with a mean of 0.27 mm/d and 95% confidence limits at 0.22 and 0.37 mm/d. Supporting observations showed that puddling decreased percolation by a factor of 500, and that measured values of soil-water pressure in the unsaturated subsoil were consistent with predictions made from measured values of hydraulic resistance in the surface soil and subsoil.

Spatial variability of water percolation in puddled soil. Simulation and management of rice-field water require representative values of water percolation rate for individual fields and rice-growing regions. The representativeness of measurements and their means depends on the spatial variability of percolation; this variability may be quantified through the geostatistical semivariogram and its parameters of slope, range, and nugget variance (Annual report for 1989, p. 160). Variability of percolation within a particular clay-soil puddled IRRI field comprising 16 plots of 4.5 × 5.5 m (total size 42.0 × 11.0 m) was determined from measurements at the center and at one additional randomly chosen position in each plot, together with 3 extra randomly selected positions in each of 8 randomly chosen plots (56 positions in total).

Percolation rates were log-normally distributed, and their spatial dependence was represented by a semivariogram with a well-defined nugget variance, a small slope, and ill-defined range. The small slope (determined from a 20-m maximum separation between measurements) was consistent with there being no spatial correlation among water percolation values, i.e., a "pure nugget effect."

The minimum number of measuring sites needed to determine areal-mean water-percolation rate with a specified degree of precision was calculated through a sequential t-test analysis of various subsets of the 56 percolation-site measurements. Analysis showed that, with 90% confidence, the mean of any 8 plot-center measurements was as precise as the mean of all 56 measurements. That any selection of eight plot-center percolations gave an equally representative mean indicates that the risk of choosing an inappropriate configuration of measurement locations is small.

Soil-hydraulic functions for an upland rice soil. Research programs in soil management and productivity, including those using simulations and especially those for upland rice, need precise knowledge of the relation of soil-water content to soil-water potential (the water-retention characteristic), the dependence of soil-hydraulic conductivity on water content, and how these two functional relations vary within fields and across regions. For large areas (several hectares), hydraulic functions could be estimated efficiently if major pedological horizons (MHs) could be identified that extend over large areas and for which hydraulic properties are essentially constant across the area and at all depths within the MH. If two or more vertically contiguous MHs have similar hydraulic functions, then such MHs could be treated in soil and crop simulations as one "soil-physical building block," with consequential savings of the numbers of samplings and hydraulic measurements needed (Annual report for 1989). For a 100-ha area of the IRRI upland farm, 5 MHs were identified, and hydraulic functions determined for each of the 6 (or 8) measured locations in each by fitting the 6-parameter formula of Van Genuchten, using independently measured values for water content and hydraulic conductivity at soil saturation and setting the residual moisture content (corresponding to −7.0 MPa water pressure) to 0.010 vol/vol. Parameters for each MH for the average function (from the six or eight individual determinations) are listed in Table 25.

Table 25. Parameters for Van Genuchten's soil-hydraulic functions as calculated for the 5 major pedological horizons identified for a 100-ha area of IRRI upland farm.

Major horizon code	Saturated hydraulic conductivity (m/d)	Volumetric water content at saturation (vol/vol)	Parameter a (-)	Parameter n (-)	Parameter l (-)
Ap	1.40	0.52	0.112	1.113	−6.2
Bt	0.35	0.55	0.060	1.085	−10.8
Bg	0.02	0.57	0.015	1.116	−7.3
C	1.03	0.61	0.089	1.072	−11.3
R	0.42	0.64	0.035	1.073	−10.9

Hydraulic similarity or difference among the 5 MHs was then evaluated in terms of values derived from the MH-average functions for each of 3 functionally important soil properties: the soil-water content at field-capacity, soil-water pressure of −10 kPa, the plant-available water retained between field capacity and wilting-point soil-water pressure at −1.6 MPa, and the maximum depth of water table that is capable of sustaining an upward water-flux density of 2 mm/d to the lower surface of a crop root zone, assuming that zone to have dried to wilting point. Results showed that all five MHs were significantly different hydraulically, and that, consequently, the number of soil-physical building blocks could not be lowered to less than five (the number of MHs).

Bypass flow. Water flow in a vertically continuous soil macropores (such as cracks or worm channels) that bypasses a surrounding unsaturated soil matrix is termed "bypass flow." It can be important in rainfed lowland or irrigated rice systems when, at the end of a soil-cracking DS, soil is resetted for land preparation for rice; much land-soaking water can flow to depth (or to groundwater) bypassing the soil matrix, whose moisture will be lower than that needed for effective puddling. Correspondingly, when nonrice DS crops are grown after rice on crack-prone previously puddled soil, irrigation or post-monsoon rainwater may percolate beyond the then active root depth. If such water is eventually retained above some noncracked slowly permeable horizon that is not substantially deeper than maximum crop-rooting depth, bypass flow may give some small production benefit by lessening evaporation from otherwise saturated surface soil.

Bypass flow has been measured for a previously puddled Vertic Tropaquept riceland soil by applying simulated rainfall in a laboratory to 12 cylindrical columns of field soil that were extracted without disturbing their structure. All cylinders had 21-cm diameter; 6 were 15 cm high and 6 were 25 cm high. All cylinders had one major crack that extended through the full column height, and their soils had moisture in the range 0.25-0.35 vol/vol (compared to saturation moisture of about 0.6 vol/vol). Simulated rainfall was applied through an array of 48 needle jets to the top surface of each column: 3 columns of each size received three 3-h "showers" at intensity of 10 mm/h, and the remaining sets of 3 received three 1-h showers at 30 mm/h. All columns thus received 90 mm water in all. Outflow from the bottom of each column was collected at 5-min intervals and weighed, and the "bypass ratio" (BR) calculated as outflow rate/application rate and the absorption rate (AR) as 1.00 −BR.

Bypass flow occurred sooner through the shorter columns. For all columns, a constant BR was established during the third shower, with a high BR value of 0.92-0.94 for each column length and each rainfall intensity. Consequently, AR was low, equivalent to only 0.6-1.7 mm/h. The higher values corresponded to the lower "shower" intensity. Wetting was uniform throughout the soil columns, but moisture contents attained only 0.40-0.45 vol/vol—significantly lower than this soil's liquid limit of 0.52 vol/vol. This finding is consistent with farm observations that substantially more than 90-mm water application is needed to soak many ricefields in preparation for puddling.

Knowledge Sharing for Simulations Methodology

A training course in crop simulation (the third so far organized) was presented in Los Baños to participants from both national agricultural research systems (NARS) and IRRI. The NARS participants were drawn from the 16 institutes and universities that had provided teams to the first two courses, thereby reinforcing existing strengths. Independently, the previously trained teams at Zhejiang Agricultural University in China instructed additional PROC teams in simulation techniques, supported them in their case studies, and organized a national workshop. Linkages between previously trained teams were also strengthened through two thematic national workshops: at Tamil Nadu Agricultural University (India) on simulations for cropping systems research, and at the National Rice Research Institute (PROC) on simulation of production potential of rice. Within IRRI, simulation activities are coordinated through a new multidisciplinary Simulation and Systems Analysis Group.

Next Steps

In 1991 new activities will include an International Symposium on Systems Approaches to Agricultural Development, and simulations in partnership with various national agricultural research systems to assess the impact of global climate change on rice. Most activities in simulations research in 1990 were financed by the Netherlands Government. Follow-

ing a favorable external review of those activities in 1990, an extension of the project will be formulated to consolidate and expand such activities in the future with particular attention to extending training through in-country programs staffed largely by graduates from the three Los Baños courses.

Technically, efforts to link crop simulations to GIS requires the generation of daily weather values from monthly means, and specification of representative physiological and phenological properties when several rice cultivars are grown within a geographic region targeted for a single simulation. Similarly, we shall use 3 yrs' weather and field observations to quantify the effects of hydraulic variability within a single MH on simulated soil-water balance and upland rice productivity. The soybean model will be used to simulate water relations for soybean when water supply is limited.

Adoption and productivity impact of modern rice varieties in Nepal

We analyzed the determinants of modern variety (MV) adoption, and the effect of that adoption on fertilizer use, rice yields, and cropping intensity in Nepal, with the specific objective of determining the criteria of adoption and impact for two types of MVs: those developed since the mid-1960s by IRRI and the non-IRRI type. The IRRI MVs are characterized by short stature, short growth duration, fertilizer responsiveness, and high yield, but their farm yield is constrained by the availability and timeliness of irrigation water. In Nepal, only 23% of the total rice area is irrigated. The non-IRRI MVs, such as Mahsuri, are medium-statured, have longer duration, and are less fertilizer-responsive and lower yielding. They are more tolerant of drought, and therefore more suitable for adverse production environments. Although the yield advantage of Mahsuri over traditional varieties is less than that of IRRI MVs in favorable areas, Mahsuri has higher yield stability in poorly irrigated and favorable rainfed areas.

Survey data

Two sets of surveys (Annual report for 1988) were used. The first was an *extensive* survey of 42 villages in Central and Eastern Nepal, which together account for nearly two-thirds of the national rice area and production. Villages were selected through stratified random sampling, based on proportion of irrigated area. Characteristics of production environment, technology adoption, farm size, tenure, prices, yields, and cropping patterns in 1987 WS were obtained through farmer interviews. Precise information on adoption rates for IRRI MVs and non-IRRI MVs was derived from an *intensive* survey of 55 farm households in each of 4 terai villages with different environments. Two adjacent villages in each of the Central and Western regions were chosen to represent differences in market and natural environments and in irrigation regimes.

MV adoption and productivity in villages of the extensive survey

Sample villages were classified into three environmental categories depending on degree of water control. Irrigated villages are those where most riceland is served by run-of-the-river systems, managed either by a government agency or by farmers. Favorable rainfed villages are lowland areas not prone to severe drought. Unfavorable rainfed villages, usually on sloping lands, suffer frequent droughts and significant yield losses.

Socioeconomic and production characteristics for the three categories are presented in Table 26. Average farm size and rice area per farm were similar in irrigated and favorable rainfed villages, but smaller in unfavorable rainfed. The proportion of owner-cultivators was lower in irrigated villages, but similar in both categories of the rainfed villages.

Almost two-thirds of riceland was actually irrigated in irrigated villages. In the favorable rainfed, a small proportion of land was irrigated by shallow tubewells and natural springs; in unfavorable rainfed, hardly any land was irrigated. The proportion of riceland planted to MVs followed the same pattern as area irrigated, suggesting MVs were adopted where there was irrigation. In favorable rainfed areas, half of the rice area had MVs, but in unfavorable rainfed, adoption was only 7%.

The most widely planted MV was Mahsuri, which was developed in Malaysia in 1965 and introduced in Nepal in 1973. However, the proportion of area planted to IRRI MVs (as compared to non-IRRI MVs predominantly Mahsuri) could not be determined at village level from the 1987 extensive survey, because of changes from year to year. But it was possible to identify villages that adopted only non-IRRI MVs or the two types of MVs. Invariably, non-IRRI MVs were used in villages that adopted IRRI

Table 26. Socioeconomic, cultivar, and rice productivity indicators by production environment, based on extensive village surveys in Nepal in 1987 WS.

	Irrigated	Favorable rainfed	Unfavorable rainfed
Villages (no.)	22	11	9
Farm size (ha)	1.7	1.6	1.0
Rice area (ha)	1.3	1.0	0.6
Proportion of owner-cultivators (% of farm households)	58	80	81
Irrigation (% area)	63	13	1
MV adoption (% area)	73	50	7
MV adoption (% villages)	100	90	33
IRRI and non-IRRI type MVs	23	18	0
Non-IRRI MVs only	77	72	33
Nitrogen use (kg/ha)	22	15	8
Rice grain yield (t/ha)			
IRRI and non-IRRI MVs[a]	4.1	3.0	-
Non-IRRI MVs only[b]	3.2	2.8	2.8
Traditional varieties	2.0	1.8	1.6
Total cropping intensity (%)	218	190	193

[a]Av yield of MVs in villages growing both IRRI and non-IRRI type MVs. [b]Av yield of MVs in villages growing only non-IRRI type MVs

MVs. Almost one-fourth of irrigated villages adopted IRRI MVs, but the proportion was slightly less in favorable rainfed and zero in unfavorable rainfed villages. Although imprecise, the estimate for IRRI MV adoption was high for irrigated villages. In contrast, non-IRRI MVs were adopted more widely across production environments. The adoption of IRRI MVs may be more dependent on water control.

MVs, particularly the IRRI type, are more fertilizer responsive, and this feature, together with lower production risks in more favorable areas, affects farmers' incentives to invest in cash inputs. Fertilizer use as measured by N application was indeed higher in irrigated areas, where adoption of MVs was higher and yields more stable. Fertilizer was restricted to MVs in favorable rainfed areas, and to Mahsuri in unfavorable areas, particularly in the hills.

Rice grain yields across production environments reflected differences in adoption rates of IRRI MVs and fertilizer use. Yields of IRRI and non-IRRI MVs could not be distinguished where both types were grown; yields of MVs in Table 26 thus indicate averages for the two types or for non-IRRI MVs only. MV yields were significantly higher in irrigated than in favorable rainfed villages, which adopted IRRI MVs. Conversely, yields were similar in all three production environments when only non-IRRI MVs were adopted. Yields of IRRI MVs were significantly higher only in irrigated environments. Yields of TVs were lowest and similar across production environments. IRRI MVs may have higher yield potential than non-IRRI MVs, but this potential is not realized when water control is inadequate.

Total cropping intensity was higher in irrigated villages than in any category of rainfed villages. In Nepal, rice is a major crop only in WS; other crops such as wheat and lentil, which require less water than rice, are grown in DS. The higher cropping intensity (Table 26) in irrigated areas is explained partly by the availability of DS irrigation, but the shorter growth duration of IRRI MVs (as compared with Mahsuri and TVs) may also have contributed to increased cropping intensity.

Determinants of MV adoption, fertilizer use, rice yields, and cropping intensity across Nepalese villages

MV adoption, fertilizer use, rice yield, and cropping intensity functions were estimated in relation to irrigated rice area, farm size, ratio of owner-cultivators, distance from the nearest commercial center, and terai dummy. Both farm size and owner-cultivators account also for the better access of large owner-cultivators to new information on technology and institutional credit. The terai dummy was included to allow for other environmental factors, such as topography, which are not captured by the irrigation ratio. Fertilizer and rice prices were not included as explanatory variables because fertilizer prices are controlled and the transportation cost is subsidized

by the government. Although rice prices were slightly higher in the hills than in the terai, little variation was observed in the ratio of fertilizer to rice prices across villages. Since the dependent variable was expressed as the ratio of rice area planted to MVs, ranging from zero to unity, a two-limit probit regression was used in the MV adoption function. Conversely, the Tobit method was applied to estimate fertilizer response function, since this method avoids sample bias caused by omission of observations with zero application of fertilizers. Yield and cropping intensity functions were determined through least squares analysis. A linear model was adopted because most variables are ratios or dummies.

Table 27 shows that irrigation is significant only in the MV adoption function. This is consistent with accumulated evidence that irrigation, not tenure or farm size, is a major factor affecting MV adoption. The coefficient of the irrigation variable suggests that the rate of MV adoption in a completely irrigated village is approximately 79% points higher than in a completely rainfed village.

Because of the strong linkage between irrigation and MV adoption, it is difficult to isolate the effects of these variables on fertilizer use, rice yield, and cropping intensities. To avoid simultaneity problems, the MV variable is specified as two dummy variables, i.e., villages where both IRRI and non-IRRI MVs were grown, and villages where only non-IRRI MVs were grown; villages growing only TVs served as the control. Such specification assumes that these dummy variables capture not only the "pure" effects of MVs but also the effects of environmental factors on the choice of varieties that are unaccounted for by the irrigation ratio.

In the fertilizer-use function, only the MV dummies were significant; MVs were more responsive than TVs, so that it is more profitable to use higher doses of fertilizer on MV than on TV rice. Coefficients for the two MV variables suggest that villages growing both IRRI and non-IRRI MVs apply more fertilizer than those growing non-IRRI MVs only, even though the difference between the two coefficients is not statistically significant. However, these coefficients include effects not only of type of MVs but also of environmental factors. In fact, the estimated coefficient of irrigation ratio is not significant, presumably because the MV variables already capture the impact of irrigation on fertilizer use.

The two MV dummy variables are also significant in the yield function. Yields in villages growing both types of MVs are higher by about 1.5 t/ha than in those growing TVs as implied by the coefficient of the IRRI MV dummy. The coefficient for non-IRRI MV is only 0.64, which is significantly smaller than the coefficient for IRRI MV. Irrigation contributes

Table 27. Estimated results of MV adoption, fertilizer use, rice grain yield, and total cropping intensity functions based on the extensive village surveys in Nepal in 1987 WS.[a]

	MV[b]	Fertilizer[b] (nitrogen)	Grain yield	Total cropping intensity
Irrigation ratio	0.79**	11.8	1.01*	0.50**
	(4.01)	(0.63)	(2.15)	(2.91)
Farm size	0.01	0.82	−0.06	−0.03
	(1.6)	(0.31)	(−0.62)	(−0.96)
Ratio of owner to cultivator	0.38	12.2	0.17	0.25
	(1.45)	(0.57)	(0.41)	(1.62)
Distance	0.01	0.19	−0.01	0.00
	(0.48)	(0.13)	(−0.57)	(0.40)
Terai dummy	0.13	−6.3	0.06	0.00
	(1.13)	(−0.77)	(0.23)	(0.02)
IRRI + non-IRRI MV dummy	-	52.8**	1.52**	0.06
		(3.78)	(3.40)	(0.35)
Non-IRRI MV dummy	-	41.17**	0.64*	0.04
		(3.59)	(1.94)	(0.31)
Intercept	−0.15	−26.0	1.42**	1.68**
	(−0.64)	(−0.92)	(2.75)	(8.83)
r^2	-	-	0.60	0.31
(log-likelihood)	(−10.11)	(−166)	-	-
F-value	-	-	7.74	2.3
(chi-square)	(24.86)	(17.14)	-	-

[a]*t*-values are in parentheses. [b]Tobit regressions.

positively to yield. In a completely irrigated village, average yields are higher by about 1 t/ha than those in a completely rainfed village, regardless of type of variety, indicating that IRRI MVs have higher yield potential than non-IRRI MVs or TVs. Farm size, tenure, and distance variables did not show any effect on intervillage differences in yield levels.

Intervillage differences in total cropping intensities were explained only by irrigation, reflecting increased opportunity for DS nonrice cropping. Access to irrigation can increase total cropping intensity in a rainfed village by 50%, i.e., about half of the cultivated area of the village can be planted to a DS crop. Adoption of early-maturing IRRI MVs was expected to allow increased cropping intensity; however, the corresponding coefficient, though positive, was not significant partly because the proportion of riceland using IRRI MVs is too small to increase significantly the overall cropping intensity and because there is insufficient irrigation for additional crops even in favorable areas adopting IRRI MVs.

Determinants of MV adoption, fertilizer use, and rice yields across households in terai villages

Table 28 presents socioeconomic and production characteristics of the four villages covered by the *intensive* 1987 household survey. WR1 and WR2 are the two villages in the Western region, and CR1 and CR2 the villages in the Central region. The irrigated village in the Central region (CR1) had smaller farms.

Both WR1 and CR1 have gravity irrigation systems; however, irrigation was more reliable and complete in WR1, where MVs were fully adopted in WS. In CR1, TVs were still prevalent in small areas. MV adoption was 80% in the favorable rainfed village WR2, and was substantially higher than the 50% in the extensive survey (Table 26). It should be noted that adoption of IRRI MVs was significant only on WR1. In general, the non-IRRI MVs were still more popular. In the unfavorable rainfed village (CR3) mostly TVs were planted.

As in the extensive survey, nitrogen use and rice yields were higher in the irrigated than in the rainfed villages. Among the irrigated villages, values were higher for WR1 than for CR1 because of a higher use of IRRI MVs and more assured irrigation. The yield difference between IRRI and non-IRRI MVs becomes smaller as water control declines: the relative advantage of IRRI MVs over non-IRRI MVs is more than 25% in irrigated environments, but only 12% in the favorable rainfed environment.

Factors affecting MV adoption among the four villages can be explained in terms of three interac-

Table 28. Socioeconomic, cultivar type, and rice productivity indicators based on an intensive farm-household survey of 4 terai villages in Nepal in 1987 WS.

	Irrigated		Favorable rainfed (WR2)	Unfavorable rainfed (CR2)
	WR1	CR1		
Households (no.)	55	55	55	55
Farm size (ha)	2.0	1.6	2.1	2.1
Rice area (ha)	2.0	1.6	2.0	1.3
Proportion of share tenancy (%)	23	22	14	27
Proportion of leaseholders (%)	22	27	4	20
Irrigation (% area)	100	89	11	9
MV adoption (% area)	100	85	80	5
IRRI type MVs	41	5	6	0
Non-IRRI type MVs	59	80	74	5
Average nitrogen use (kg/ha)	30	15	9	8
Rice grain yield (t/ha)	2.88	2.45	2.22	1.90
IRRI MVs	3.25	2.80	2.58	-
Non-IRRI MVs	2.55	2.40	2.31	-
Traditional varieties	-	2.12	1.80	-
Cropping intensity				
Total	203	193	170	196
Rice	100	98	97	68

tion variables involving the proportion of irrigated (or rainfed) area and regional dummies (IRG×WEST, IRG×CENT, and RF×WEST); the rainfed area in the Central region served as control. The regional dummies reflected not only the difference in irrigation supply between the two regions but also other differences such as climate and soil type. Thus, the pure effects of irrigation can be seen most clearly in the difference among coefficients for IRG×WEST, RF×WEST, and IRG×CENT. Education, represented by the proportion of farm workers between 15 and 60 yr of age having more than 3 yr of schooling, was included to account for differences in decisionmaking ability. Tenancy is represented by two dummy variables to distinguish the effects of share tenancy and fixed-rent tenancy.

Table 29 indicates that environmental factors are the most important constraints to adoption of MVs, but the adoption of IRRI MVs is particularly constrained by irrigation supply, as suggested by the significant coefficient of the IRG×WEST term in the corresponding adoption function. All three interaction variables are significant in the total and non-IRRI MV adoption functions. The coefficients of IRG×WEST are higher, but not significantly higher, than those of IRG×CENT and RF×WEST. Thus, in contrast to IRRI type MVs, the adoption of non-IRRI MVs is not determined by availability of irrigation in the Western region. Farm size, education, and tenancy do not affect adoption for either type of MV.

Table 29. Determinants of MV adoption by cultivar type based on an intensive farm-household survey of 4 terai villages in Nepal in 1987 WS.[a]

	Total	IRRI MVs	Non-IRRI MVs
Farm size	−0.01	0.02	−0.01
	(−0.68)	(1.15)	(−0.44)
Education	−0.01	0.11	−0.01
	(−0.31)	(0.76)	(−0.27)
Fixed-rent tenant dummy	−0.6	−0.10	−0.04
	(−0.11)	(−0.65)	(−0.63)
Share-rent tenant dummy	−0.02	−0.06	0.01
	(−0.24)	(−0.37)	(0.13)
IRGxWEST	1.31**	2.36	1.07**
	(9.84)	(0.00)	(8.49)
IRGxCENT	1.04**	−0.03	1.16**
	(10.81)	(−0.00)	(8.51)
RFxWEST	1.16**	1.48	1.27**
	(12.23)	(0.00)	(9.44)
Intercept	−0.29**	−2.20	−0.41**
	(−3.81)	(0.00)	(−3.94)
(log-likelihood)	(−18.30)	(−49.00)	(−65.11)
(chi-square)	(282)	(125)	(162)

[a]Figures in parentheses are *t*-values.

Because MV adoption, fertilizer use, and yields were simultaneously determined, a two-stage regression procedure was applied in which the adoption rates of the two types of MVs predicted by regressions for MV-adoption functions were used as independent variables in second-stage regression. Because of identification problems, however, the three interaction variables (i.e., IRG×WEST, IRG×CENT, and RF×WEST) could not be included in the second-stage regressions. The estimated coefficients of MV variables in the second-stage regressions will thus capture the effects not only of rice varieties but also of irrigation and other unspecified factors. To allow for such effects, at least partially, a regional dummy, WEST, was included.

Table 30 shows that adoption of both types of MVs increases fertilizer use, but the IRRI MVs induce much higher levels of N use: they are known to be more responsive to N than are non-IRRI MVs. Other things being equal, Western region villagers apply less N to rice than do Central region villagers. Moreover, the yield advantage of IRRI MVs over TVs is much higher than that of non-IRRI MVs, and Western region villages have lower yields than those of the Central region. Fixed-rent tenants or leaseholders obtain higher yields than owner-cultivators.

Total cropping intensity is increased by IRRI MVs; the combined effect of IRRI MVs and irrigation promotes multiple cropping. But total cropping intensity was not significantly higher with non-IRRI MVs than with TVs. The effects of IRRI MV and non-IRRI MV on rice cropping intensity cannot be clearly distinguished: both variables have significantly positive coefficients that do not significantly differ. Farm size generates a negative and significant coefficient for total cropping intensity, reflecting the fact that smaller farms are cultivated more intensively than larger farms. However, this feature is not evident in the rice-cropping intensity regression.

Conclusions and next steps

Both the extensive and intensive surveys showed that water control is a critical factor affecting the adoption of MVs across villages and across farms within a village. This is particularly true for the IRRI-bred semidwarf rice varieties, which are more responsive to fertilizer and higher yielding than

Table 30. Estimated results of fertilizer use, rice grain yield, rice and total cropping intensity functions, based on an intensive farm-household survey of selected terai villages in Nepal in 1987 WS.[a]

	Fertilizer (nitrogen)	Grain yield	Total cropping intensity	Rice cropping intensity
Farm size	1.49	-0.01	-0.02*	-0.00
	(1.48)	(-0.82)	(-2.44)	(-0.31)
Education	1.66	0.06	0.03	-0.01
	(0.45)	(0.76)	(0.66)	(-0.39)
Fixed-rent	7.22	0.27*	0.03	0.06
tenant dummy	(1.25)	(2.31)	(0.41)	(1.39)
Share-rent	-0.69	-0.11	-0.10	-0.03
tenant dummy	(-1.50)	(-0.10)	(-0.18)	(-0.66)
IRRI MV	128.84**	2.84**	1.67**	0.32**
	(8.54)	(8.66)	(5.77)	(2.51)
Non-IRRI MV	21.86**	0.82**	-0.08	0.52**
	(2.46)	(4.91)	(-0.91)	(7.93)
WEST dummy	-24.84**	-0.66**	-0.24**	-0.08
	(-3.60)	(-5.34)	(-3.71)	(-1.58)
Intercept	-7.20	2.03**	1.99**	0.63**
	(-1.53)	(19.52)	(36.0)	(15.21)
r^2	-	0.34	0.21	0.34
(log-likelihood)	(-642.25)	-	-	-
F-value	-	14.78	7.85	15.13
(chi-square)	(84.70)	-	-	-

[a]t-values are in parentheses

other MVs. Adoption of such IRRI varieties in Nepal is generally slight and concentrated in more favorable environments, thus contributing to the widening gap in productivity between favorable and unfavorable rice-growing areas. Despite lower yields, the relatively longer duration non-IRRI MVs such as Mahsuri are still popular in a wider range of production environments because their performance is more stable than that of the shorter duration IRRI varieties.

Since characteristics of MVs have changed over time and vary across locations, it is important in adoption and impact studies to distinguish variety-specific differences in traits, such as yield potential, growth duration, grain quality, and resistance to pests. On-going research is therefore developing methodologies for measuring the effects of different characteristics of MVs on total factor productivity, which relates change in output to total inputs.

Structural change in demand for cereal grains in Asia

Future demand for rice is of major concern for policy formulation. We examine whether and to what extent changes in income and prices, and especially structural changes such as rate of urbanization, affect the patterns of rice consumption. Urbanization is expected to reduce rice and coarse grain consumption in favor of wheat and other noncereal foods because of the higher opportunity cost of time for food preparation and lower physical energy requirement in urban work compared to farm work. A complete demand system is estimated from time-series aggregate data from 1960 to 1988 for nine major rice-growing countries that together account for about 85% of the world's rice consumption and production: Bangladesh, India, Indonesia, Philippines, Thailand, Japan, Pakistan, South Korea, and China.

The model and data

We modified the Almost Ideal Demand System (AIDS) model to include the effect of structural change as proxied by the ratio of urban population (Z), and expressed it as:

$$w_{it} = \alpha_i + \alpha_{iz} Z_t + (\beta_i + \beta_{iz} Z_t) \ln (Y/P_t) + \Sigma_j \gamma_{ij} \ln p_{jt} + u_{it} \qquad (1)$$

where w is the budget share, Y is expenditure or income, p is commodity price, P is price index approximated by $\Sigma w_i \ln p_i$, i and j are commodity indices, t time, α_i, α_{iz}, β_i, β_{iz}, γ_{ij} are coefficients, and u_{it} is the error term. Since the sum of equation (1) over all commodities i equals unity and therefore the variance-covariance matrix of the error terms is singular, one of the equations in (1) is dropped at the estimation stage.

The elasticities of income or expenditure (e_{i0}), price (e_{ij}), and structural change (e_{iz}) are calculated using the following formulas:

$$e_{i0} = 1 + (\beta_i + \beta_i Z)/w_i - [(\beta_i + \beta_i Z)/w_i] \Sigma w_k \ln p_k (e_{k0} - 1) \quad (2)$$

$$e_{ij} = -\delta_{ij} + \gamma_{ij}/w_i - (\beta_i + \beta_i Z)/w_i - [\beta_i + \beta_i Z)/w_i] [\Sigma w_k \ln p_k (e_{kj} + \delta_{kj})] \quad (3)$$

$$e_{iz} = [Z/w_i][\alpha_i + \beta_i \ln(Y/P) - \beta_i \Sigma w_k \ln p_k e_k] \quad (4)$$

where δ_{ij} is the Kronecker delta.

To minimize data requirement and number of parameters, the demand system was estimated in two stages by assuming separability of utility function. In the first stage (I), commodities were grouped broadly into two: cereal grains, and noncereal goods that include all other commodities besides cereal grains. In the second stage (II), the model consists only of cereal grains disaggregated into rice, wheat, and coarse grains. Coarse grains included maize, barley, sorghum, rye, millet, and other mixed grains and differed among countries.

Stages I and II were estimated separately, and the observed total group expenditure (i.e., total cereal expenditure) was specified as the income in the conditional demand system (cereal grains demand system). Whenever a serial correlation problem was encountered, the first difference specification of equation (1) was estimated before the iterative (seemingly unrelated) regressions were applied.

Data were derived from both international and national sources; for consumption of cereal grains the data source is the USDA. The structural change was represented by the ratio of urban to total population (UN statistics). Population and private consumption expenditures (PCE) used in first-stage budgeting came from the International Monetary Fund (IMF). To derive the aggregated price index of all cereal grains, the geometric mean was calculated. The consumer price index was used as a proxy for the price of noncereal commodities. Prices came from official country sources.

Results

Stage I. Table 31 presents results of the stage I model and the implied demand elasticities for total cereal grains in seven of the nine countries; Bangladesh and Pakistan were excluded from stage I because they did not have separate statistics in the 1960s. With the exception of Japan and Thailand, total expenditure elasticities of demand for cereal grains are positive. Indonesia has the highest expenditure elasticities of total cereal grains (0.51), followed by South Korea (0.5) and China (0.41). The low expenditure elasticity of total cereal grains for India was unexpected and in the final calculation of the total expenditure elasticities of rice, wheat, and coarse grains, IFPRI estimates of total cereal expenditure elasticity for Bangladesh (0.48), India (0.47), and Pakistan (0.23) were used.

Structural changes (i.e., urbanization effects) still appear to increase cereal grains consumption in low-income countries such as China, India, and the Philippines, where annual income is below US$500. This may be due to substitution of cereal grains for

Table 31. Parameters and elasticities in a generalized LA/AIDs model for total cereal grains demand.[a]

Country	Demand parameters								Elasticity	
	Intercept	Z	ln (X/P*)	Zln (X/P*)	ln(P Cereal)	ln(P Other)	r	DW	Expenditure[c]	Structural change
China	-4.40	4.97	0.91	-0.99	0.24	-0.24	0.96	1.70	0.41	0.57
	(-1.90)	(2.34)	(1.88)	(-2.33)	(12.98)	(-12.98)				
India	1.23	0.24	-0.18	-0.04	0.21	-0.21	0.96	1.96	0.22	0.12[d]
	(0.88)	(0.22)	(-0.71)	(-0.20)	(5.64)	(-5.64)				
Indonesia	0.95	0.02	-0.09	-0.00	0.17	-0.17	0.97	2.20	0.51	-0.07[d]
	(2.40)	(0.05)	(-1.93)	(-0.01)	(11.04)	(-11.04)				
Japan		-2.32	-0.29	0.19	0.05	-0.05	0.71	1.62	-0.18	-0.36
		(-2.32)	(-3.06)	(2.24)	(3.72)	(-3.72)		0.85		
South Korea	2.73	-0.81	-0.23	0.07	0.20	-0.20	0.98	1.94	0.50	-0.93
	(13.29)	(-3.08)	(-9.63)	(3.04)	(8.09)	(-8.09)				
Philippines	1.10	-0.28	-0.17	0.06	0.13	-0.13	0.95	1.85	0.20	0.69
	(0.80)	(-0.23)	(-0.77)	(0.29)	(7.35)	(-7.35)				
Thailand	1.78	-0.47	-0.21	0.06	0.10	-0.10	0.92	1.85	-0.12	-0.09[d]
	(1.94)	(-0.42)	(-1.93)	(0.45)	(4.66)	(-4.66)				

[a]*t*-values in parentheses. [b]The income elasticities for India, Indonesia, and Thailand were derived from the original LA/AIDs model, since tests for structural change in consumption showed that they were not statistically significant in Stage I. [c]Raw moment *r*-square. [d]Statistically insignificant.

inferior root crops such as sweet potato and cassava. Indonesia and Thailand are exceptions although estimated elasticities are statistically insignificant. In countries with income levels above US$1000 (Japan, South Korea), structural change reduces cereal grains consumption. Structural change thus induces substitution between cereals and other foods such as animal products in high-income countries.

Stage II. Results for the cereal grain demand model (Table 32) show that most coefficients

Table 32. Parameters in cereal grain demand subsystem models.[a]

Country	Commodity	Intercept	Z	lnY P*	ZlnY P*	lnPR	lnPW	lnPC	r^2	DW
Bangladesh	Rice	0.252	0.827	0.164	-0.173	-0.058	0.058		0.94	1.37
		(0.25)	(1.24)	(0.86)	(-1.35)	(-3.24)	(3.24)			
	Wheat	0.748	-0.827	-0.164	0.173	0.058	-0.058		0.94	1.37
		(0.76)	(-1.24)	(-0.86)	(1.35)	(3.24)	(-3.24)			
China	Rice			0.018		0.303	-0.131	-0.173	0.75	1.72
				(0.22)		(8.68)	(-2.92)	(-4.42)		
	Wheat			0.070		-0.131	0.164	-0.034	0.21	1.69
				(0.70)		(-2.92)	(2.00)	(-0.55)		
	Coarse grains			-0.088		-0.173	-0.034	0.207	0.39	1.61
				(-0.64)		(-4.42)	(-0.55)	(2.88)		
India	Rice	0.473	-0.480	0.015	0.072	0.334	-0.180	-0.155	0.69	1.69
		(0.12)	(-0.15)	(0.02)	(0.11)	(5.60)	(-3.96)	(-4.89)		
	Wheat	-3.328	3.619	0.638	-0.648	-0.180	0.180	0.000	0.84	1.23
		(-0.98)	(1.30)	(0.96)	(-1.19)	(-3.96)	(3.73)	(-0.01)		
	Coarse grains	3.855	-3.139	-0.653	0.575	-0.155	-0.000	0.155	0.94	2.15
		(1.45)	(-1.44)	(-1.26)	(1.35)	(-4.89)	(-0.01)	(5.27)		
Indonesia	Rice	3.019	-1.411	-0.429	0.277	0.050	0.012	-0.039	0.87	2.03
		(6.51)	(-3.95)	(-4.65)	(3.99)	(8.76)	(3.38)	(-8.31)		
	Wheat	-2.154	1.722	0.412	-0.322	-0.012	0.007	0.005	0.88	2.23
		(-5.18)	(5.43)	(4.99)	(-5.23)	(-3.38)	(2.04)	(1.44)		
	Coarse grains	0.136	-0.311	0.017	0.045	-0.039	0.005	0.034	0.68	1.82
		(0.23)	(-0.68)	(0.15)	(0.51)	(-8.31)	(1.44)	(6.00)		
Japan	Rice		-4.319	-0.726	0.785	0.203	-0.165	-0.038	0.89	1.57
			(-1.40)	(-.05)	(1.32)	(15.57)	(-20.58)	(-4.25)		
	Wheat		-2.630	-0.837	0.558	-0.165	0.159	0.006	0.95	1.83
			(-1.57)	(-2.23)	(1.73)	(-20.58)	(18.77)	(1.22)		
	Coarse grains		6.949	1.563	-1.344	-0.038	0.006	0.032	0.59	1.55
			(2.82)	(2.84)	(2.82)	(-4.25)	(1.22)	(4.14)		
South Korea	Rice	3.479	-1.459	-0.539	0.282	0.095	-0.038	-0.057	0.75	1.70
		(1.37)	(-1.02)	(-1.14)	(1.06)	(1.34)	(-0.96)	(-1.32)		
	Wheat	-3.842	2.098	0.742	-0.390	-0.038	0.052	-0.014	0.45	2.25
		(-2.44)	(2.37)	(2.51)	(-2.36)	(-0.96)	(1.87)	(-0.66)		
	Coarse grains	1.363	-0.640	-0.203	0.108	0.057	0.014	0.071	0.82	1.29
		0.83)	(-0.69)	(-0.68)	(0.63)	(-1.32)	(-0.66)	(2.15)		
Pakistan	Rice	6.444	-6.690	-1.222	1.292	0.243	0.222	0.021	0.58	1.38
		(1.33)	(-1.57)	(-1.29)	(1.55)	(5.43)	(5.94)	(0.89)		
	Wheat	-12.700	12.596	2.575	-2.409	-0.222	0.326	0.104	0.72	1.85
		(-2.83)	(3.15)	(2.93)	(-3.09)	(-5.94)	(7.93)	(4.28)		
	Coarse grains	7.257	-5.905	-1.352	1.117	-0.021	-0.104	0.125	0.80	1.53
		(2.54)	(-2.32)	(-2.42)	(2.25)	(-0.89)	(-4.28)	(5.03)		
Philippines	Rice			0.179		0.161	-0.058	-0.104	0.68	1.71
				(3.36)		(7.04)	(-3.23)	(-5.91)		
	Wheat			-0.097		-0.058	0.074	-0.016	0.37	1.18
				(-1.61)		(-3.23)	(3.34)	(-1.02)		
	Coarse grains			-0.082		-0.104	-0.016	0.120	0.51	1.60
				(-1.72)		(-5.91)	(-1.02)	(5.85)		
Thailand	Rice		-1.553	-0.272	0.298	0.030	-0.025	0.005	0.63	1.94
			(-2.04)	(-1.68)	(1.97)	(3.07)	(-4.05)	(-0.63)		
	Wheat		1.249	0.214	-0.235	-0.025	0.026	-0.0	0.74	1.68
			(2.39)	(1.93)	(-2.27)	(-4.05)	(3.64)	(-0.17)		
	Coarse grains		0.304	0.058	-0.063	-0.005	-0.001	0.006	0.08	2.92
			(0.51)	(0.46)	(-0.53)	(-0.63)	(-0.17)	(0.67)		

[a]t-values in parentheses. [b]System r^2 for India, Indonesia, Korea and Pakistan 0.98, 0.97, 0.84 and 0.93. In China, Japan, Philippines and Thailand where estimates are on first-difference forms, the system r^2 is not reported. Models for China and the Philippines are estimated from original LA/AIDs model.

have the expected signs and magnitudes. Prospective serial correlation problems in time series analysis were largely avoided by the statistical procedure used as evidenced by the Durbin Watson test. The goodness of fit is generally high, except for wheat and coarse grains in China and coarse grains in Thailand. Low r^2 for China may be due to rationing in that country so that income, prices, and urbanization do not fully explain consumption of those commodities. For coarse grains in Thailand, r^2 was low, but consumption accounted for less than 1% of total cereal expenditure during 1960-90.

As might be expected, coefficients for rice price tend to be more statistically significant than those for wheat and coarse grains: the dominant role of rice in the Asian diet ensures that changes in the price of rice significantly affect the budget shares for real cereal grains. Insignificant coefficients for real cereal expenditure indicate that the budget share of individual cereal grains is not sensitive to changes in the total cereal expenditure.

To test for structural demand shifts, Wald Chi-square and likelihood-ratio tests were applied. The Wald Chi-square test (Table 33) showed that structural change shifted the intercepts for 5 of the 9 countries at 5% significance; but (Thailand excluded) the slopes of real total cereal expenditure also changed significantly among those 5 countries. Both tests indicated that structural change had a significant impact in seven of the nine countries, specifically in Bangladesh, India, Indonesia, Japan, South Korea, Pakistan, and Thailand. The insignificant result in China is due in part to the slow rate of urbanization over the period of study (interregional migration was highly restricted) and to the system of grain rationing. For the Philippines, the insignificant coefficient for urbanization may reflect a relatively higher correlation between real income and urbanization, which increased the variances of estimates more than for other countries.

Table 34 shows the elasticities of demand (at the sample mean) for cereal grains as derived from the parameters of Table 32.

The own-price elasticities, except for coarse grains in China and Pakistan, have the expected signs. The higher absolute values of own-price elasticities for rice compared to wheat and coarse grains reflect the greater income effects of a price change in rice, which dominates total cereal expenditure in most countries. Similarly, countries with a smaller cereal budget share for rice (such as China, India, Pakistan) have lower own-price elasticities.

Total expenditure elasticity for a particular grain is the product of expenditure elasticity for total cereal grains (Table 31) and cereal expenditure elasticity for the particular grain (rice, wheat, or coarse grains). Cereal expenditure elasticity of rice is about unity among countries where rice is the staple; values ranged from 0.85 in Bangladesh to 1.25 in the Philippines. Pakistan, where wheat is the staple accounting for 65% of the cereal budget, has the highest value (2.12).

Total expenditure elasticity for specific grains shows three general patterns: elasticity for rice remains positive (0.25 to 0.53) for 7 of the 9 countries; it is highest in India (0.53), and lowest in the Philippines (0.25). The negative total expenditure elasticities of demand for rice in Japan, which has one of the world's highest per capita income, is to be expected. The negative income elasticity for Thailand is also plausible; it now has the highest per

Table 33. Tests of structural changes within cereal grain demand subsystem models.

Country	Wald test			Likelihood ratio test value of LOLF		
	Intercept df = 2*	lnY P slope df = 2*	Both df = 4	Original	Generalized	Twice diff df = 4
Bangladesh	1.6	1.8	182.3**	53.1	82.6	59.0**
China	2.8	2.8	2.9	147.4	149.1	3.4
India	3.2	2.7	167.3**	134.2	338.8	409.1**
Indonesia	41.5**	39.5**	59.7**	173.6	195.0	43.0**
Japan	11.2**	11.8**	27.6**	217.7	230.0	24.4**
South Korea	7.3*	7.10*	14.9**	145.6	153.3	15.5**
Pakistan	12.9**	12.3**	92.[illegible]**	1321.9	155.1	44.4**
Philippines	2.3	2.2	[illegible]	173.7	175.8	4.2
Thailand	6.2*	5.6	9.6*	212.9	217.7	9.7*

*df = 1 for Bangladesh; **df = 2 for Bangladesh; df = 2 for Bangladesh

Table 34. Mean budget share and estimated elasticities at sample mean.

Country	Commodity[1]	Budget share	Elasticities			
			Own price	Cereal expenditure	Total expenditure[2]	Structural change
Bangladesh	Rice	0.95	−0.92	0.85	0.38	−0.15
	Wheat	0.05	−2.48	4.07	1.82	2.95
China	Rice	0.46	−0.35	1.04	0.43	0.19
	Wheat	0.33	−0.58	1.20	0.49	1.08
	Coarse	0.21	0.04	0.60	0.25	−2.09
India	Rice	0.55	−0.52	1.18	0.53	−0.24
	Wheat	0.25	−0.16	0.44	0.20	1.56
	Coarse	0.20	−0.26	1.18	0.53	−1.24
Indonesia	Rice	0.86	−0.88	0.93	0.47	−0.03
	Wheat	0.05	−0.83	0.47	0.24	4.54
	Coarse	0.09	−0.71	1.87	0.94	−1.30
Japan	Rice	0.78	−0.94	1.21	−0.21	−0.34
	Wheat	0.18	−0.06	0.06	−0.01	1.83
	Coarse	0.04	−0.25	1.13	−0.20	−1.40
South Korea	Rice	0.75	−0.81	0.92	0.46	0.11
	Wheat	0.10	−0.55	1.80	0.90	0.27
	Coarse	0.15	−0.50	0.87	0.43	−0.72
Pakistan	Rice	0.24	−0.40	2.12	0.49	−0.11
	Wheat	0.65	−0.31	0.62	0.14	0.29
	Coarse	0.11	0.18	0.82	0.19	−1.45
Philippines	Rice	0.69	−0.96	1.25	0.25	−0.46
	Wheat	0.14	−0.35	0.31	0.06	2.32
	Coarse	0.17	−0.24	0.52	0.10	−0.05
Thailand	Rice	0.95	−1.07	1.11	−0.14	−0.04
	Wheat	0.04	−0.27	−0.96	0.12	1.22
	Coarse	0.01	−0.15	−2.28	0.28	−2.96

[1]Coarse = coarse grains. [2]Total expenditure elasticities of rice, wheat, and coarse grains are the product of total cereal expenditure elasticity obtained from Stage I and cereal expenditure elasticity from Stage II. Statistically insignificant.

capita income and initially the highest per capita rice consumption in South and Southeast Asia. The relatively high elasticity for South Korea is due partly to the fact that shifts in consumption from barley to rice occurred as income increased and partly because of overestimate of total expenditure elasticity of demand for cereal grains in Stage I.

Expenditure elasticity for wheat ranged from −0.96 in Thailand to 4.07 in Bangladesh; consumption patterns of wheat (in contrast to rice) differed more widely among countries. Elasticity for coarse grains had similarly wide variation.

Wheat is not preferred to rice (as evidenced by its lower total expenditure elasticity) in India, Indonesia, Pakistan, and the Philippines. Bangladesh has the highest total expenditure elasticity for wheat (1.82), but the budget share of wheat is less than 5%. Japan is the only country where all cereal grains are regarded as inferior goods, but absolute values of the expenditure elasticities, −0.21 for rice, −0.01 for wheat, and −0.20 for coarse grains, are relatively low.

In all countries, consumption and, hence, total expenditure elasticity for coarse grains may be overestimated because of corresponding underestimation of grains fed to livestock. Notwithstanding positive elasticities for coarse grains as indicated in Table 34, the continually declining consumption might be due to unfavorable effects of structural changes.

For structural change, elasticity is defined as the percentage change in demand for a one percentage change in the ratio of urban to total population. Urbanization, as can be expected, has negative effects on consumption of rice and coarse grains, but positive effects for wheat.

Japan has the most negative structural change elasticity (−0.34) of demand for rice, which implies that omission of structural change in the specification of cereal grain demand model for Japan would lead to a large downward bias in estimated income or expenditure elasticity. The highly negative structural change elasticity (−0.24) in India explains partly why per capita rice consumption in India remained

relatively unchanged during 1960-90 despite having the highest total expenditure elasticity of demand for rice in Asia. Similarly, the decrease in per capita rice consumption by 28 kg in Bangladesh despite the relatively high expenditure elasticity during 1960-90 may be explained by the negative effects of structural change. The structural change elasticity of rice in Pakistan is also negative but small because rice there is not a staple; moreover, unlike in other Asian countries, wheat is not generally consumed as commercial breads, and therefore is not more convenient to consume than rice. Thailand also has an unexpectedly small negative elasticity. The positive structural change elasticities in China and South Korea are unexpected. The elasticity for China is based on statistically insignificant parameters. For South Korea, positive elasticity implies that substitution of rice for barley occurred not only because of higher income but also because of higher rate of urbanization.

In contrast to those for rice and coarse grains, structural change elasticities for wheat are all positive and large. Hence, increased wheat consumption in all countries is due not only to increase in income but also to growing urbanization. In Pakistan, structural change elasticity is relatively small (0.29) because wheat is the staple. South Korea had the lowest elasticity (0.27) which is explained by a different nature of substitution among cereal grains: whereas wheat is typically substituted for rice as urbanization increases, in South Korea the substitution of rice for barley was even more important during 1960-90. In general, countries with small initial budget share for wheat had higher structural change elasticities.

For coarse grains, structural change had negative effects on consumption for all countries (Table 34): wheat and rice are both generally more accessible and convenient to consume than coarse grains.

Omission of structural change in demand analysis for grains will therefore underestimate income or expenditure elasticity for rice and coarse grains and overestimate that for wheat.

Next steps

Future efforts will analyze the effects of grain rationing in China, extend the analysis beyond Asia, and develop medium- and long-term projections of future rice demand.

Subprogram IV: Pest science and management

Pests continually co-evolve with their rice host; hence it is necessary to develop strategies for minimizing the potential and actual losses they cause. Innocuous organisms may become pests because of changes in the physical and biological environments. Four projects in this subprogram conduct anticipatory research on issues that concern the biology of pests, the basis of host resistance to insects, the dynamics of pest populations, the interactions between pests and rice, and their impact on seed health. Throughout, the emphasis is on techniques or knowledge that has potential application in several ecosystems or is ecosystem-neutral. Research on such subjects as the use of molecular probes and serology to improve understanding of pathogen variability in field populations utilizes the latest developments in biotechnology, and evaluates their role in accelerating the generation of knowledge on pathogen ecology. Other research makes use of recent developments in computer simulation to quantify the effect of interacting pest populations on rice.

Pest-yield interactions

An understanding of the effects of selected pests on rice plant and crop yield provides a scientific basis for decisionmaking on pest management. In 1990, conceptual and empirical work was done on the mechanisms by which individual pest (insect, pathogen, weed) species influence yield physiology and morphology. Pest combinations were also studied for their potential interactive effects on yield at the plant and crop levels, while algorithms were developed to enable evaluation of strategies for minimizing yield loss through the use of coupled pest-rice computer simulation models. The general objectives of the project are to 1) quantify and model pest-plant and damage-yield relationships of selected pests of rice, 2) couple pest effects to existing rice models for yield predictions under different situations, and 3) quantify the effect of crop management variables on pest-loss relationships.

Coupling disease and insect effects to a rice model

Our work seeks to develop a "generic" approach for predicting the damage effects of insects and diseases

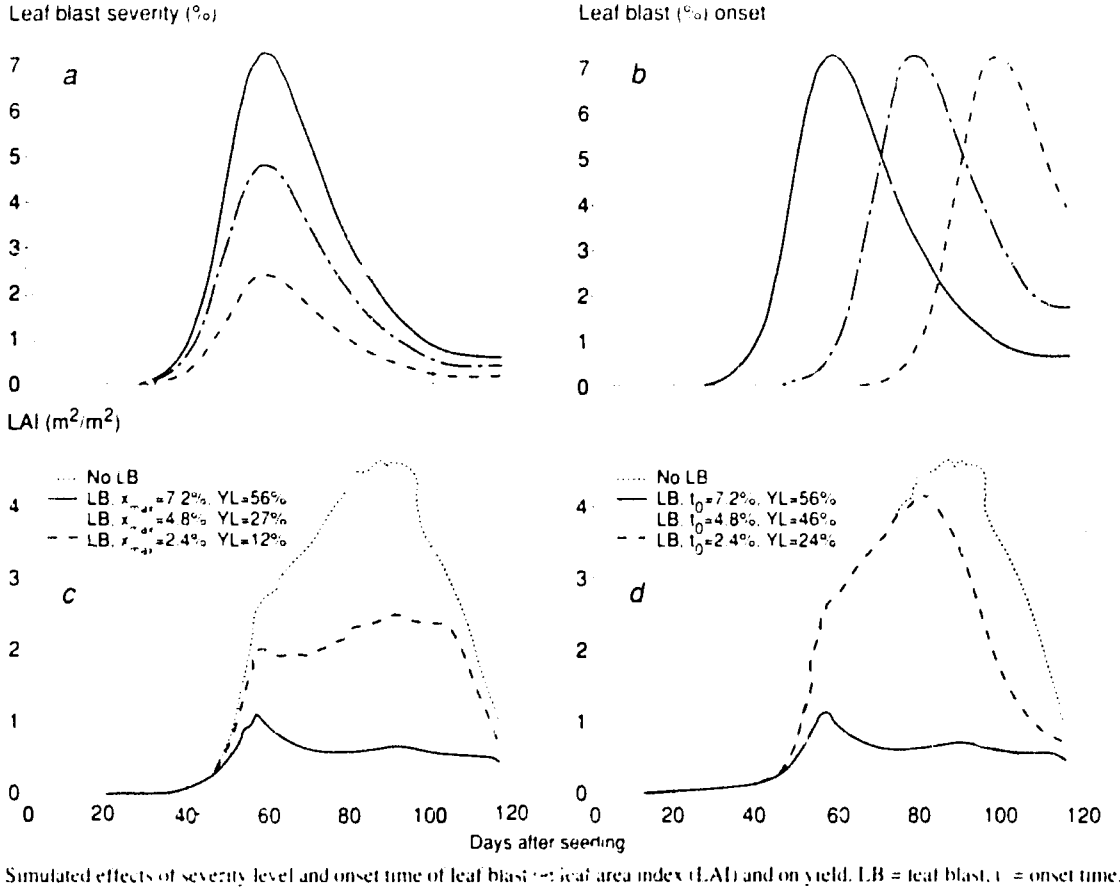
on the development and yield of rice crops. The approach is strictly mechanistic and couples the effects of pests to the physiological processes and parameters of the relevant crop as represented by corresponding rate and state variables in the CERES-rice crop simulation model. The pest-coupled CERES-rice model has a capability to create and analyze any kind of pest infestation to obtain decision aids for pest-crop management.

Leaf blast (BI) progress curves of different severity levels (Fig. 8a) and onset times (Fig. 8b) were read into the crop model; photosynthesis was affected negatively and leaf senescence rate positively in relation to the respective leaf BI severity level. The earlier the onset of the disease and the higher the disease severity level, the higher were yield losses (Fig. 8c, d).

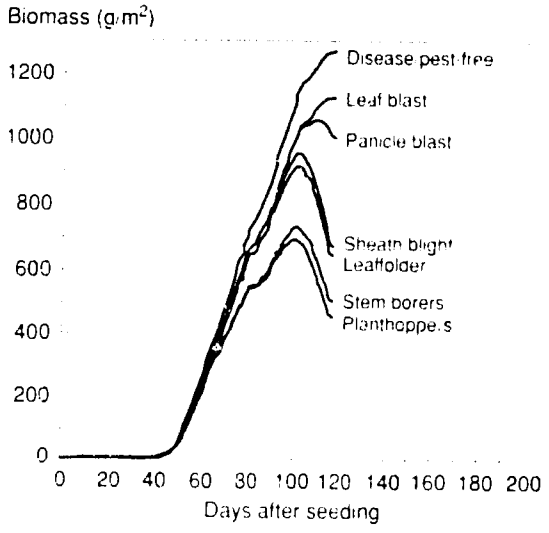
Similarly, infestation curves of leaf and panicle BI, sheath blight, leaffolder (LF), stem borers (SB), and planthoppers were subsequently linked to the crop model. The physiological processes and parameters that the pests affected included leaf area index (LAI), photosynthetic potential, amount of assimilates produced, partitioning, leaf senescence rate, transpiration, and stand density. Adding pest species to the system resulted in a steady decline in biomass production (Fig. 9).

Simple population models for leaf BI and LF were coupled to CERES-rice with bilateral feedbacks. In the coupled model, both pests compete for leaf area as a driving variable for their population dynamics and interact as regards their effects on the leaf area available for photosynthesis. The simulation showed that interspecific competition of the two pest species greatly reduced the buildup of their populations, but that their combined effects on the progress of LAI and on yield were higher than the effects of one pest species alone.

The timing and number of control measures on SB population dynamics and crop performance were simulated using a simple SB population model coupled to CERES-rice with bilateral feedbacks.



8 Simulated effects of severity level and onset time of leaf blast (→) leaf area index (LAI) and on yield. LB = leaf blast, t_0 = onset time, x_{max} = maximum disease severity level, YL = yield loss.



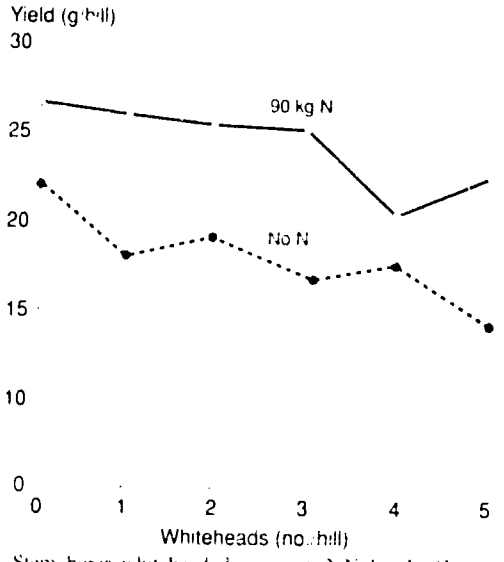
9. Simulated effects of multiple pests on biomass production.

The SB larvae were assumed to reduce the stand density and inhibit the partitioning of assimilates to leaves, stems, and grains. Applications of a nonpersistent insecticide with 80% knockdown effect were introduced into the coupled model at 45, 75, and 105 d after seeding (DAS). In the simulation, one insecticide application at any of the three times was not enough to prevent substantial yield loss because the SB population was always able to recover. Subsequent insecticide applications resulted in better SB control, higher biomass production, and lower yield loss.

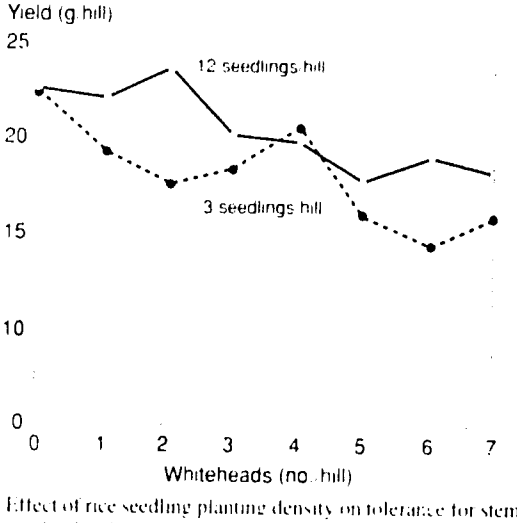
Crop management reduces stem borer losses

Modern high tillering varieties can tolerate high levels of SB damage under appropriate levels of crop management. Two sets of IR72 plots were established: 1 set with 0 and 90 kg N applied in 2 splits, and the second transplanted at 3 and 12 seedlings/hill. The standard researchers' practice in the dry season (DS) is 3 seedlings/hill and 90 kg N/ha. Farmers normally use 60-90 kg N/ha and often transplant at 12 seedlings/hill. In each of 4 plots, 10-15 hills with 0-5 or 7 whiteheads/hill were randomly removed for the N and seedling rate trials, respectively; subsequently, the yields were averaged. Hills without N averaged lower yields than those with 90 kg N/ha, and showed much greater intolerance for SB damage (Fig. 10).

Without SB damage, yields from 3 and 12 seedlings/hill were similar (Fig. 11). Compensation



10. Stem borer whitehead damage at 2 N levels, Zaragoza, Nueva Ecija, Philippines, 1989 dry season (DS).



11. Effect of rice seedling planting density on tolerance for stem borer whitehead damage, Zaragoza, Nueva Ecija, Philippines, 1989 DS.

occurred at 12 seedlings/hill up to 2 whiteheads/hill; at 3 seedlings/hill, loss occurred even at 1 whitehead/hill. The higher yield at 4 whiteheads/hill does not follow the decreasing trend and may be an outlier value. While there are indications that the results may vary according to season, management practices can increase the ability of a crop to tolerate SB damage. Integrating more practices is a logical next step.

Next steps

In addition to pest-*yield loss* research, this project will focus on *crop loss assessment*. We are undertak-

ing methodology development in collaboration with two national programs.

Much of the future research will be done at IRRI. Work on loss from BI is currently coordinated in an informal manner among laboratories in India, Korea, Japan, and IRRI. Strong tripartite collaboration is in place on pest-crop modeling between the USAID/IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project of the University of Hawaii, IRRI, and the SARP (Simulation and Systems Analysis for Rice Production) project of the Centre for Agrobiological Research (CABO), Agricultural University, The Netherlands. This will allow us access to the latest versions of rice models and software. A consortium to include key national program scientists and IRRI may be needed to improve the efficiency of cooperation on modeling selected pest-crop systems.

To derive scarce knowledge on how rice pests cause yield losses, IRRI needs to collaborate with national program scientists who have the interests and expertise, and with advanced institutions with the latest in modeling technology. This two-pronged approach will ensure that we can generate sufficient data and synthesize these into useful knowledge for integrated pest management (IPM). Our work is part of an effort to link pest damage modules to crop simulation models in a decision support system called DSSAT (Decision Support System for Agrotechnology Transfer) developed by the IBSNAT project. Once validated, further simulation results can be used to obtain response surface models that relate yield or yield loss to parameters that characterize the population dynamics of pests and/or to different control strategies.

Pest population models that are coupled to CERES-rice with bilateral feedbacks will lead to a better understanding of their behavior by giving insights into the effects of mutual interactions within multitrophic systems such as pathosystems. We anticipate that this research will lead to the development of specific decision tools for pest management in irrigated rice, rainfed lowland, and upland rice.

Physical, biochemical, and genetic bases of insect resistance

Susceptibility or resistance of rice cultivars to insects results from an interaction between the plant's physical and chemical characteristics and the insect's behavioral and physiological responses. The understanding of subtle plant-insect relations can help in developing cultivars with durable and multiple insect resistance.

Factors affecting leaffolder establishment

In collaboration with ICIPE, we found that deterrence to establishment of neonate larvae is an important aspect of LF resistance in rice. Although LF moths lay eggs on mature leaves, first-instar larvae travel to feed at the base of young leaves. Larval movement was slower and trichome density higher on the abaxial surface of mature leaves of resistant TKM6 rice plants than on that of susceptible IR36 (Table 35). Susceptible Rexoro plants were also less

Table 35. Trichome density on abaxial surface of mature leaves of susceptible and resistant rice varieties and wild rice *Oryza perennis*, and establishment of first-instar larvae of *C. medinalis*.[a] IRRI, 1990.

Plant character and insect response	Test plants			
	Rexoro	IR36	TKM6	*O. perennis*
Trichome density (no./cm²)				
Apical portion	94 ± 24 b	42 ± 12 b	553 ± 65 a	0 ± 0
Middle portion	19 ± 7 b	94 ± 19 b	500 ± 55 a	0 ± 0
Basal portion	48 ± 11 b	57 ± 14 b	346 ± 42 a	0 ± 0
Leaf length (cm)	--[b]	26 ± 1.2 a	29 ± 1.7 a	--[b]
Insect response				
Min to reach leaf whorl from outer leaf	--[b]	6 ± 0.7 b	14 ± 2.1 a	--[b]
Min to settle in leaf whorl	--[b]	10 ± 1.1 b	24 ± 3.3 a	--[b]
Rate of progression (cm/min)	--[b]	5 ± 0.5 a	3 ± 0.4 b	--[b]

[a]Avg of 15 replications, each consisting of a single first-instar larva. Means of trichome density and insect response in a row followed by the same letter are not significantly different at $P<0.05$ by DMRT and by *t* test, respectively.
[b]No data

pubescent than TKM6, but the highly resistant wild rice *Oryza perennis* was completely devoid of trichomes, indicating that plant surface chemicals strongly influence larval movement and settling.

In another resistant wild rice, *O. brachyantha*, silica cells in epidermal layers of leaves were more closely packed than those in susceptible line IR31917-45-3-2 and contributed to physical resistance through enhanced mandibular wear in LF larvae (Table 36). In addition to silica, the absence of attractants or feeding stimulants and the presence of deterrents are also resistance factors in *O. brachyantha*.

Calli and diets for bioassay of leaffolders

Rice LF *Cnaphalocrocis medinalis* larvae showed marked preference for calli of susceptible Rexoro (≥40%) than for the resistant *O. ridleyi* (<20%). After 1-d infestation, >60% of larvae settled on Rexoro and <10% on *O. ridleyi*. The larvae took 3-5 wk to pupate while feeding on Rexoro calli.

Incorporating linseed oil or corn oil into the LF artificial diet increased the percentage of *C. medinalis* with normal wings or survival rate compared with those reared on the control diet containing linoleic acid. Rearing yellow stem borer (YSB) on a commercial beet armyworm diet (BIOSERV #F9219) fortified with casein (vitamin-free), wheat germ, cornstarch, agar, and sucrose resulted in a certain degree (25%) of success. Addition of 2% rice pollen improved larval survival. Emerged moths laid viable eggs.

Biochemical basis of resistance to brown planthopper

Some rice varieties are resistant while others are susceptible to brown planthopper (BPH). Crude headspace volatiles and hexane extract of the stem surface of susceptible IR8 plants had greater attraction for BPH biotype 1 females than those of resistant IR26 (*Bph 1*) (Table 37). The major volatiles in IR8 comprised trans-2-hexanal, 1,3 dimethyl benzene, limonene, and 1-2-dicarboxy benzene; IR26 possessed 1,2, dimethyl benzene, p-cymene, about four times more limonene, and some unidentified volatiles (Table 38). Other resistant varieties, such as IR36 (*Bph 3*), Babawee (*bph 4*), and the tolerant Utri Rajapan, possessed characteristic volatile profiles, indicating that chemical "fingerprinting" of selected varieties or donors of resistance is possible. The allelochemicals—nonnutritional plant volatiles—from resistant plants were more toxic to BPH than those from susceptible varieties. Rice leaves and leaf sheaths had more allelochemicals than do the culms. IR8 and IR26 phloem sap, obtained by BPH stylectomy with a laser beam, did not differ much chemically and contained mainly sucrose and a few amino acids. Thus rice resistance to BPH is conferred mainly by allelochemicals.

Genetic variation in populations of *N. virescens*

Adaptation of green leafhopper (GLH) populations to resistant cultivars enhances the transmissibility of tungro infection. We found that *Nephotettix virescens* populations differed in several cytological parameters, such as meiotic division, length of pachytene chromosomes, and length and width of chromosomes at diakinesis. Estimation of the genetic variability among greenhouse populations reared on different cultivars showed 1.1 to 1.4 alleles per locus, highest for the TN1 population, followed by populations on Moddai Karuppan 301 and Ptb 8,

Table 36. Silica (Si) content and pattern of silica deposition in epidermal layer on adaxial surface of leaves of 40-d-old susceptible IR31917-45-3-2 (IR31917), resistant *O. brachyantha*, and their hybrid.[a] IRRI, 1990.

Si deposition pattern	IR31917	*O. brachyantha*	Hybrid
Gap between adjacent rows of double Si cells (µm)	55 ± 5 a	41 ± 1 b	41 ± 3 b
Gap between adjacent rows of single Si cells (µm)	172 ± 6 a	116 ± 5 c	143 ± 8 b
Si cells (no./mm²)	72 ± 5 b	86 ± 4 a	70 ± 5 b
Si content (%)	5 ± 0.3 a	5 ± 0.1 a	5 ± 0.7 a

[a]Av of 10 replications. Means in a row followed by the same letter are not significantly different at the 5% level by DMRT.

Table 37. Response of *Nilaparvata lugens* biotype 1 females to odors of resistant and susceptible rice plants in a paired choice test.[a]

Exposure time (min)	Insects (%) responding to		Difference (%)
	IR8	IR26	
4	23	6	17 ns
6	35	6	29*
8	38	8	29*
10	38	8	29*
12	33	6	27**
14	40	8	31**
16	42	8	33**
18	40	8	31**
20	33	12	21**
25	38	17	21*

[a]Av of 4 replications. *t*-test comparison: ns = not significant, * = significant at the 5% level, ** = significant at the 1% level.

Pankhari 203, TAPL 796, and IR8. At the 0.95 criterion of polymorphism, Moddai Karuppan 301 population was the most polymorphic (16.7%), followed by that of Ptb 8, TN1, and IR8 (11.1%), TAPL 796 (5.6%), and Pankhari (0%). Unbiased heterozygosity values showed that Moddai Karuppan 301, TN1, and IR8 populations had higher values (0.027-0.048) than Ptb 8 and TAPL 796 populations (0.02), and Pankhari 203 populations (0.002). Thus, local *N. virescens* populations associated with different host cultivars are genetically different.

Next steps

Further characterization of the hexane fraction of IR26 stem epicuticular material and of the volatiles of plants resistant to other BPH biotypes is under way. With LF, both volatile and nonvolatile biocidal factors are probably important and should be characterized in plants and calli. Studies are under way on trypsin activity of chewing insects feeding on susceptible and resistant varieties and on trypsin inhibitor levels in the rice plants.

Research conducted in this project is strategic and ecosystem-neutral. We expect the benefits to be directly evident in irrigated rice and rainfed lowland rice ecosystems where these pests are a problem.

Biology and etiology of rice pests and beneficial organisms, and seed health

Research in pest management and formulation of pest management in specific ecosystems must rest on an understanding of the biological and physiological properties of potential pests. This project studies biological properties of rice pathogens, insect pests, and their natural enemies, and the ecophysiology of weeds. It also aims to develop techniques for detecting and identifying pests and beneficial organisms, and to examine interactions among rice-related organisms in rice ecosystems.

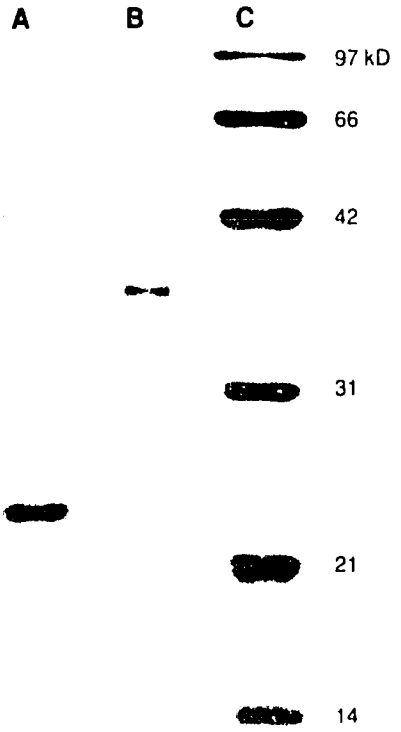
Table 38. Major volatile composition from headspace of 45-d-old IR8 and IR26 plants (4 hills each/24-h collection).

Volatile	Retention time (min)	Area ($10^{\ }$)					
		IR8	IR26	IR36	Fathu Heenati	Babawee	Utri Rajapan
Cyclohepten-1-one	17.759			0.60			
Trans-2-hexanal	18.396-18.407	4.02				1.98	
Ethyl benzene	20.554-20.627			0.68			
1,2 dimethyl benzene	20.572		6.09				1.86
1,3 dimethyl benzene	20.725	4.42		1.57			
2-heptanone	21.745-21.830			0.72			1.58
2-hexanone	22.740				25.1		
2-heptanol	24.075-24.081				25.0		
1,2,3-trimethyl benzene	30.921						
2,4,6 trimethyl octane	32.393			0.92			
p-cymene	33.495		7.01				2.12
Limonene	34.218-34.663	5.30	19.58				9.62
Linalool	39.647					2.19	
Caryophyllenic acid	64.539					2.23	
1,2-dicarboxy-benzene	90.970	7.82					
Unidentified			6.54				
Total area		51.75	215.20	9.04	299.51	30.33	42.43

Purification of rice grassy stunt non-capsid protein

Rice grassy stunt virus (RGSV) is a possible member of the tenuivirus group. Other tenuiviruses produce a large amount of so-called non-capsid protein (NCP). Examining the production of NCP by RGSV, we easily detected it in infected rice plants, but not in healthy ones, by using SDS-PAGE following Laemmli's method. NCP was purified with a slight modification, following Gingery's method for maize stripe virus NCP. NCP yield was about 20 mg/100 g tissue. Purified NCP formed needle-shaped crystals at pH 5.0-6.0. The crystals were 1.8-9.6 long and 0.04-0.4 wide (Fig. 12). Molecular weight (MW) of NCP and coat protein of RGSV were determined using SDS-PAGE. Figure 13 shows that NCP is composed of a single protein having a MW of 24,000 dalton. The purified NCP had a typical protein absorption spectrum with maximum absorbance at 278, a minimum absorbance at 252, and absorbance ratio (A_{278}/A_{252}) 0.62. RGSV-NCP is very similar in characteristics to that produced by other tenuiviruses.

12. Needle-like crystals in purified extract from rice ragged stunt virus (RGSV) infected rice tissues, by phase contrast microscopy



13. SDS-PAGE slab gel showing the following: A = purified RGSV non-capsid protein, B = purified RGSV coat protein, C = protein standards (from top to bottom: phosphorylase b, bovine serum albumin, ovalbumin, carbonic anhydrase, soybean trypsin inhibitor, and lysozyme.

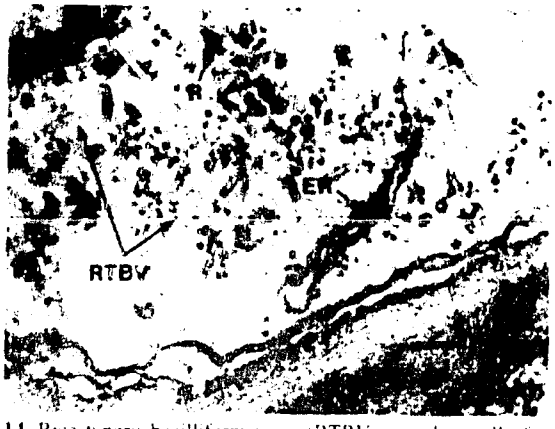
Rice tungro bacilliform virus in xylem cells of tungro-infected rice

Earlier studies revealed that rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV) are restricted to the phloem of infected plants and it is suggested that only phloem feeding causes tungro infection. On resistant cultivars, however, it was observed that GLH fed mainly from the xylem and transmitted mostly RTBV. This study was conducted to determine the location of RTBV on host cells in relation to tungro transmission.

Seedlings (15 d old) of a tungro-susceptible rice variety, TN1, were inoculated with rice tungro virus by adult GLH. Infected plants were collected at 30 d after inoculation (DAI) for electron microscope study. Ultrathin sections of leaf blade revealed the presence of RTBV in xylem parenchyma cells of a tungro-infected rice (Fig. 14). Initial observations showed RTBV in xylem cells on the third and fourth leaf of infected plants at 30 DAI. These results suggest that GLH can transmit RTBV directly to xylem cells; the virus multiplies and causes infection.

Characterization of *Rhizoctonia solani* Kühn in rice-based cropping systems

Rhizoctonia solani causing sheath blight (ShB) of rice contributes to yield loss and plays a substantial role as a pathogen in crops grown after rice. Although there is moderate to low degrees of resistance, rice cultivars with a high level of resistance to *R. solani* were rarely reported. Pathogen variability on different physiological media, pathogenicity, and a wide range of hosts are problems encountered in differentiating *R. solani*. We report our work on grouping the isolates present in rice-based ecosystems using cultural and pathogenic variation.



14. Rice tungro bacilliform virus (RTBV) in xylem cell of a tungro-infected rice. R = ribosomes, ER = endoplasmic reticulum. Bar = 200 nm.

Thirty-three isolates of *R. solani*, representing 11 isolates from Laguna and 22 from Visayas, Philippines, were characterized based on anastomosis, cultural characteristics on potato dextrose agar (PDA), hyphal growth, number of sclerotia formed, sclerotia distribution, size of sclerotia, appearance of pseudosclerotia, formation of aerial mycelium, and pigmentation on different media. For pathogenicity tests, the isolates were grown in rice hull-grain medium for 14 d at 25°C. The inoculum was inserted in the tillers of 50-d-old IR36 rice plants. The plants were incubated in a moist chamber and relative lesion heights were measured 4 wk later. Each treatment was replicated three times in completely randomized design. For cluster analysis, 39 continuous and 24 binary attributes for 33 isolates were obtained.

The isolates from Laguna were multinucleate, with nuclei averaging 5.2-10.6 per cell of vegetative hyphae. The occurrence of hyphal fusion in all 11 isolates from different places indicated that they belong to the same anastomosis group (AG) but are less closely related because of imperfect fusion of these isolates. *R. solani* (Rs) isolates pathogenic on maize, sorghum, baguio bean, and mungbean also showed imperfect fusion with rice isolates (Table 39). Four types of reaction on PDA—indistinct fusion, clearing zone formation, appearance of two distinct colonies, and formation of tuft line by the aerial mycelium—were exhibited by different pairs of Rs isolates in this study. The formation of sclerotia and production of pigment also support the hypothesis that Rs isolates could exist independently in tropical rice ecosystems, suggesting that ShB in

Table 39. Percent fusion of different types of some *Rhizoctonia solani* isolates from different hosts in rice-based cropping system with rice isolates

Pairs		Percent fusion[a]		
		P	IP	C
RSI10	RSI10[b]	91	0	10
RSI10	RSI11	0	67	33
RSI10	sorghum	0	43	57
RSI10	maize	0	64	36
RSI11	RSI11	97	0	2
RSI11	baguio bean	5	50	45
RSI11	sesbania	0	100	0
RSI11	mungbean	0	69	31
RSI11	sorghum	0	71	29
RSI11	maize	0	60	40
Baguio bean	baguio bean	84	0	16
Baguio bean	sesbania	0	47	53
Baguio bean	mungbean	0	79	21
Baguio bean	maize	0	94	4
Baguio bean	sorghum	0	63	37
Sesbania	sesbania	62	0	38
Sesbania	mungbean	0	100	0
Maize	maize	98	0	2
Maize	sorghum	0	97	3
Sorghum	sorghum	97	0	3

[a]P = perfect fusion, IP = imperfect fusion, C = contact fusion. [b]RSI10 and RSI11 isolated from lowland rice. Isolates from each host.

Laguna is caused by different clones under the same AG.

The reactions on PDA plates of 22 isolates from the Visayas were similar to those of the 11 isolates from Laguna. Such reactions as clearing zone, distinct colony formation, and formation of a thin tuft line are in agreement with imperfect fusion and all can be considered as killing reaction (Table 40).

All 33 isolates showed extracellular phenoloxidase activities and were thiamine autotrophs on the basis of pigmentation on PDA supplemented with tannic acid and growth on CZA and CZATh, respectively. Cluster analysis based on continuous variables showed that isolates with perfect type of fusion grouped in the same cluster. The isolates obtained from different culms of a rice plant as Rs112, Rs113, Rs114, Rs115, and Rs116 were in the same cluster. Single isolates and isolates from the same region could form the single cluster. Rs115 and Rs116 found in one group when clustered by continuous variables became separated into different groups on the basis of binary variables. A single Rs isolate or cluster maintained its own stable characteristics, possibly controlled by different kinds of genetic mechanisms. This supported the existence of genetic variations among the naturally occurring Rs isolates causing ShB in rice-based cropping systems.

Table 40. Colony fusion types[a] on potato dextrose agar between any 2 possible combinations of 22 isolates of *Rhizoctonia solani*, causal pathogen of rice sheath blight, collected from different places and culms of a rice plant from Visayas.

Name of Rs isolates	Rs isolates																					
	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
12	F																					
13	C	F																				
14	C	C	F																			
15	C	C	F	F																		
16	C	C	C	F	F																	
17	C	C	C	C	C	F																
18	C	C	C	F	C	C	F															
19	C	C	C	C	C	C	C	F														
20	C	C	C	C	C	C	C	C	F													
21	C	C	C	C	C	C	C	C	C	F												
22	C	C	C	C	C	C	C	C	C	F	F											
23	C	C	C	C	C	C	D	C	C	C	C	F										
24	C	C	C	C	C	C	C	C	C	-	C	C	F									
25	C	C	C	C	C	C	C	C	C	C	C	C	F	F								
26	C	C	C	C	C	C	C	C	C	C	C	C	V	V	F							
27	C	C	C	C	C	C	C	C	C	D	C	C	C	C	C	F						
28	C	C	C	C	C	C	C	C	C	F	C	C	C	C	C	F	F					
29	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	–	C	T				
30	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	F			
31	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	-	C	C	F		
32	C	C	C	C	C	-	C	C	C	C	C	C	F	C	C	C	C	C	C	C	F	
33	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	F

[a]F = indistinct fusion, C = clearing zone formed, D = distinct colonies, T = a thin line of aerial mycelium, V = various types of fusions formed where the two colonies meet, – = not tested

Antagonistic effect of soil microbes on *Rhizoctonia solani*

The sources of inoculum of *R. solani* are sclerotia left on and under the soil surface, and sclerotia and mycelium in infected crop residues. In some cases, these sclerotia are destroyed by the activity of mycoparasitic microorganisms or mycophagous animals and by abiotic factors. Among the abiotic factors, water potential is crucial to the activity of microbes in the soil.

The growth of *R. solani* and *Trichoderma koningii*, one of the biocontrol agents in upland and lowland soils, at different water potentials and temperatures was determined. The sclerotia of *R. solani* retained 44.0% of total water content 17 d after incubation and did not restrict the outward movement of moisture.

Sclerotia of Rs111 were mass-produced in rice hull-grain mixed with sterilized air-dried upland soil (1:2 vol/vol ration). Sclerotia measuring about 2-3 mm, formed singly on the medium, were picked up at 15 d after incubation and placed in a beaker with distilled water. One hundred sclerotia were placed in glass vials, incubated at 25 °C in a desiccator filled with 500 g dehydrated silica crystals. Total water content and weight loss were determined. The colonies of microorganisms growing on dilution plates and microorganisms isolated from ungerminated sclerotia were tested for antagonism to Rs111 by dual-culture method on PDA plates.

Fluorescent pseudomonads, *Aspergillus niger* and *Humicola fuscoatra* var. *fuscoatra* inhibited the colony growth of *R. solani*. *Trichoderma* spp. showed mycoparasitic activity. The viability of sclerotia placed about 4 to 5 cm under the surface of upland and lowland soil and submerged between 28 and 42 d was reduced. The loss of viability was higher in lowland soil than in upland soil under submerged condition. Sclerotia in intermittent watering regimes maintained their viability for 56 d.

The growth of *R. solani* was significantly higher than that of *T. koningii*. *R. solani* had maximum growth at -0.33 to -5.0 bars. Both organisms grew better at 25 and 30 °C in upland and lowland soils. The growth of *R. solani* and *T. koningii* in upland soil at all water potentials ranging from –0.01 to –1.0 bar did not significantly differ at 30 and 35 °C.

ASSESSING THE IMPORTANCE OF SEEDBORNE INOCULUM OF SELECTED RICE PATHOGENS

Seed quality is important to ensure the genetic potential of modern rice varieties. This is also a major concern in germplasm exchange and crop production. Although many rice diseases are seedborne, the importance of seedborne pathogens of rice is very poorly understood. The aim of this project is to understand the nature of seedborne pathogens and the danger seedborne inoculum poses on crop production and germplasm movement.

Discolored sheath, seedling and seed samples were collected from many provinces in the Philippines and examined for bacteria and fungi. Through routine seed health testing, we also compiled data on detection of rice fungal pathogens using standard blotter test (based on 400 seeds/seed lot). For the bacterial pathogens, pathogenicity as well as bacteriological and biochemical tests were conducted to initially establish their genus and, if possible, species.

Of a total of 4,684 bacteria isolated from the samples, 185 or 4% are plant pathogenic, derived mostly from sheath (72%), seed (20%), and seedlings (8%). Initial phenotypic (physiological and biochemical) tests showed that 78% are fluorescent pseudomonads, which could be *Pseudomonas marginalis* or *Ps. syringae* pv. *syringae* (Table 41, 42). Isolates with distinct characters resembling those of *Ps. fuscovaginae* have not been identified. A set of the pathogenic fluorescent pseudomonad isolates, tested in Japan following Miyajima's procedures, showed no relation to *Ps. fuscovaginae*. Among the nonfluorescent pathogens were isolates similar to *Ps. glumae*, *Ps. avenae*, *Ps. setariae*, and *Erwinia herbicola* (Table 42). From data in routine seed health testing and with a sample of size of 400 seeds/seed lot, we established the infection levels of selected rice fungal pathogens on seed and the frequency of their detection using the blotter method (Fig.15).

A NEW MITE PEST OF RICE

Aceria saccharini Wang (Acari: Eriophyidae) is a new blister mite pest of rice. It has previously been recorded on sugarcane in Indonesia; Australia; Taiwan, China; and India where it damages leaf sheaths and transmits streak virus disease. It transferred to rice and in 1988 was recorded as reaching pest status in Sulawesi, Indonesia. In 1989 it was found on rice in Central and Southern Luzon, Philippines. Mites from different localities vary in color from cream, pale yellow or orange pink; the last is more prevalent. The adult mite is microscopic in size (0.16 ± 0.04 mm long, 0.05 ± 0.002 mm wide) but can be seen on the leaf surface with the naked eye. With magnification, the adults appear maggot-like with a shield-shaped head. The body bears two pairs of slender legs anteriorly. All legs have claws with 6-7 feathered ray hairs. The abdomen is annulated with 78-82 rings and has 3 pairs of ventral setae. The spherical egg (0.05 mm in diameter) is pale yellow

Table 41. Pathogens identified by some physiological and biochemical tests.

Province	Pathogens (no.)	Fluorescent pathogens[1] (no.)			Nonfluorescent pathogens[2] (no.)		
		ADH OXI+	ADH OXI-	ADH OXIvar	OXID	FERM	NO RXN
Albay	1	1	0	0	0	0	0
Cagayan	6	0	0	0	6	0	0
Camarines	4	0	0	0	4	0	0
Cotabato	6	2	0	0	0	4	0
Davao	12	7	0	1	3	1	0
Ifugao	79	68	0	2	2	7	0
Iloilo	40	37	1	2	0	0	0
Isabela	2	0	0	0	2	0	0
Laguna (IRRI)	19	8	0	0	6	1	4
Nueva Vizcaya	10	10	0	0	0	0	0
Palawan	5	5	0	0	0	0	0
Sultan Kudarat	1	1	0	0	0	0	0
Total	185	139	1	5	23	13	4

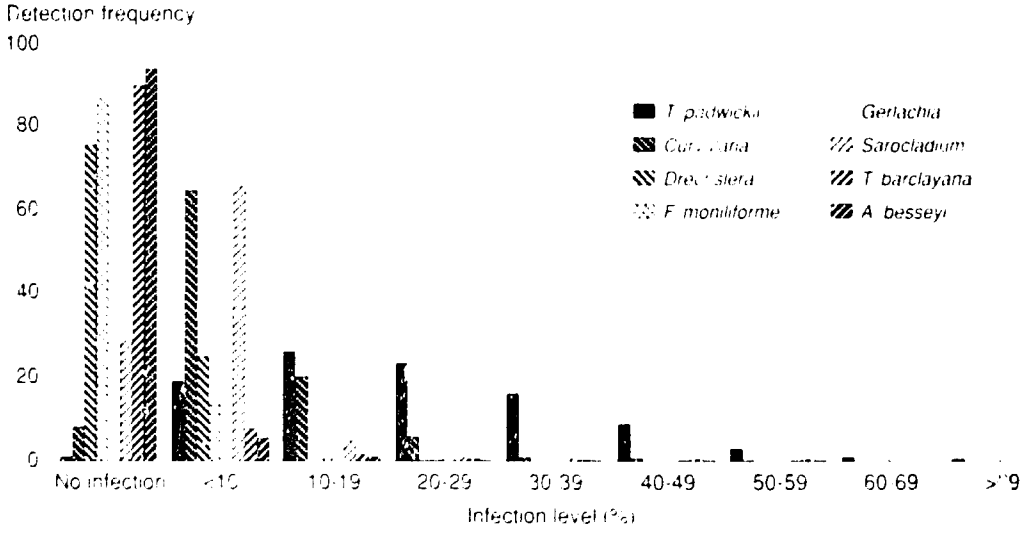
[1]ADH OXI+ = arginine dihydrolase and oxidase positive. ADH OXI- = arginine dihydrolase and oxidase negative. ADH OXIvar = arginine dihydrolase and oxidase variable. [2]OXID = oxidative. FERM = fermentative. NO RXN = no reaction

turning orange pink when about to hatch. The pale yellow larva is droplet-like in shape with a large globular anterior, tapered posterior, and a pair of moderately long anterior legs. The slender protonymph, twice the size of the larva, is whitish to light yellow with a thin layer of golden yellow hairs laterally. Deutonymph, the fourth developmental stage, has a robust body and thick layer of golden

Table 42. Nonfluorescent oxidatives and their possible identities based on some biochemical tests.[a]

Province	Biochemical test			Possible identity based on OXI ADH ST	Identity based on API 20 NE and fatty acid analysis (Gent)	Same API 20 NE profile as references used	Isolate no.
	OXI	ADH	ST				
Cagayan	–	–	+	*Ps avenae*	*Comamonas acidovorans*	*Ps setariae*	1837
Cagayan	–	–	+	*Ps avenae*	*C acidovorans*	*Ps avenae*	1839
Cagayan	–	–	–	*Ps glumae*	*C acidovorans*	*Ps avenae*	1840
Cagayan	–	–	+	*Ps avenae*	*C acidovorans*	NDA	1891
Cagayan	–	–	w	*Ps avenae*	*C acidovorans*	*Ps avenae*	1845
Cagayan	–	W	+	*Ps avenae*	*C acidovorans*	*Ps avenae*	1851
Camarines	–	–	–	*Ps glumae*	NDA	NDA	2057
Camarines	W	–	–	Ps avenae	NDA	NDA	2051
Camarines	–	–	–	*Ps glumae*	No match	NDA	2056
Camarines	–	–	–	*Ps glumae*	NDA	NDA	2076
Davao	–	w	–	*Ps glumae*	*C acidovorans*	*Ps avenae*	3916
Davao	+	+	–	*Ps glumae*	NDA	NDA	7342
Davao	+	+	–	*Ps glumae*	NDA	NDA	7343
Ifugao	–	–	–	*Ps glumae*	NDA	NDA	4956
Ifugao	–	–	–	*Ps glumae*	NDA	NDA	5202
Isabela	W	–	–	*Ps avenae*	NDA	NDA	1857
Isabela	W	–	–	*Ps avenae*	NDA	NDA	1858
Laguna	–	–	–	*Ps glumae*	No match	NDA	2235
Laguna	–	–	–	*Ps glumae*	NDA	NDA	7012
Laguna	–	–	–	*Ps glumae*	NDA	NDA	7018
Laguna	–	–	–	*Ps glumae*	NDA	NDA	7014
Laguna	–	–	–	*Ps glumae*	NDA	NDA	7010
Laguna	+	W	–	*Ps glumae*	NDA	NDA	7015

[a]OXI = oxidase, ADH = arginine dihydrolase, ST = starch hydrolysis, *Ps* = *Pseudomonas*, NDA = no data available



15 Frequency of detection of seedborne pathogens during routine seed health testing of outgoing rice seeds. Based on 1,703 seed lots sent out in 1989. IRRI Seed Health Unit, 1990.

yellow hairs laterally. Both are orange pink when mature. Figure 16 shows all the developmental stages of *A. saccharini*.

Injury on rice is similar to that due to thrips: feeding produces white, chlorotic, shallow, gall-like pustules. The long proboscis of the mite probing vertically into the leaf either in the upper or lower epidermis lacerates the tissues and ruptures both the epidermal and parenchymous tissue cells. Blisters vary in length (0.20 to 18 mm) and width (0.01 to 10 mm). Damage symptoms in the field can be confused with those from tungro.

We monitored densities in 14 irrigated fields at IRRI during wet season (WS) to determine mite abundance by plant age and distribution on the leaves. Three leaves each from the bottom, middle, and topmost portions of a plant were sampled at four growth stages: seedling, maximum tillering, panicle initiation, and ripening. Ten samples per growth stage were bagged separately or placed in vials with 80% alcohol. The mite population reached its peak

16. Developmental stages of *A. saccharini*: a) egg (30×), b) larva (60×), c) protonymph (54×), d) deutonymph (71×), and e) adult (94×).

(X = 2485 ± 306/3 leaves) during the premonsoon and was least common (X = 128 ± 42/3 leaves) at postmonsoon.

A. saccharini preferred relatively young and greenish foliage in the following order: maximum tillering > panicle initiation > seedling > ripening stage. It abounded most in the middle to apical one-third stratum of the dorsal leaf surface.

Annelid worm pest of rice

The oligochaete *Dichogaster* nr. *curgensis* Michaelsen (Annelida: Octochaetidae) is a small red earthworm (40-75 mm long and 1.50-2.00 mm wide). It is a newly recorded subterranean pest of irrigated lowland rice, infesting more than 20,000 ha in the Philippine rice terraces. We determined its relative abundance in three habitats in the most severely affected areas of Salapadan, Abra, in 1989 WS. Twenty-four hills (n = 12 hills/field) were randomly collected from lowland ricefields. Because we suspected that the earthworms came with the irrigation water, we took soil samples (30 ml) from the banks of Abra River and the irrigation canals. The samples were individually processed like those of rice hills. The high organic matter of the banks supported a high earthworm population year round. Flooding from heavy rains on a deforested watershed washed the banks, transporting the worms to the irrigation canal and ultimately to the ricefields. The earthworm did not feed on rice, but their burrowing in the field resulted in mechanical injury to the rice root system; as a result, plants less than 50 d old wilted and died. Infested fields exhibited reduced plant stand and uneven growth. Greenhouse studies confirmed the injury earthworms caused to rice plants. Germination was reduced by 16% at an infestation rate of 1 earthworm per seed (Table 43). One earthworm per 10 seeds had a perceptible effect on plant growth.

Biology of the rice ear-cutting caterpillar

Forty-one common ricefield plants belonging to 8 families — Poaceae (25), Cyperaceae (6), Commelinaceae (3), Leguminosae (3), Amaranthaceae (1), Pontederiaceae (1), Portulacaceae (1) and Onagraceae (1) — were evaluated as plant hosts to *Mythimna separata*. Ten neonate larvae were placed on a test plant within a 10-×72-cm cylindrical mylar cage. Host suitability was determined by four biological

Table 43. Effect of earthworm density on plant growth.[a] IRRI greenhouse, 1990.

Earthworm density (no./container)	Germination[b] (%)	Observed plant growth[c]
0	99.0 ± 0.9 b	Even growth and plant height
10	98.6 ± 1.2 a	Even growth and plant height
100	92.0 ± 7.2 a	Growth and height slightly uneven
1000	84.2 ± 6.0 b	Clumpy and uneven plant stand

[a]Av of 5 replications. [b]Determined from 1000 seeds sown in soil in a rectangular pan (34 x 24 x 12 cm) with varying earthworm densities. Values followed by the same letter are not significantly different at the 5% level by LSD. [c]Determined from 1000 seeds sown in soil in an aquarium (60 x 30 x 30 cm) with varying earthworm densities.

variables: life cycle, percent survival, growth index, and reproductive index.

In a separate setup, a pair of 3- to 5-d-old pupae (one male, one female) reared from rice was placed in a 65- x 110-cm rectangular mylar cage containing the same plant. The moths received honey solution (10%) as food. Ovipositional preference and fecundity were determined.

All 41 plants were accepted as ovipositional hosts (Table 44). Moths were reared from rice and caged over each plant host in a no-choice test. The descending order of ovipositional host was rice > *P. scrobiculatum* > *D. ciliaris* ≥ *P. paspalodes* ≥ *L. hexandra* ≥ *I. globosa*. All but 10 plant species supported complete development. The descending order of larval survival was *L. chinensis* (58) > *I. globosa* (54) > *P. paspalodes* (53) > rice (51), while the growth index was rice (3.2) > *L. chinensis* (3.1) > *P. paspalodes* (2.2) > *I. globosa* and *E. colona* (1.9) > *P. conjugatum* and *E. crus-galli* ssp. *hispidula* (1.6). Reproductive index potential was more favorable in rice (0.4) > *L. chinensis* (0.7) > *P. paspalodes* and *I. globosa* (1). The life cycle was shortest on rice (23d) followed by *L. chinensis* (33 d). Considering all five of the biological properties, rice is the most suitable host.

The female moth laid smooth, shiny yellowish-white spherical rows of egg masses (48 ± 40). On rice, incubation period was 3 d and the larva passed 5 stadia — I = 3.4 ± 0.7 d, II = 3.2 ± 0.4 d, III = 4.0 ± 0.7 d, IV = 4.4 ± 0.5 d, and V = 4.9 ± 0.3 d in 20 d. Prepupation and pupation periods were 2 and 8 d,

Table 44. Host plant range of *Mythimna separata* (Walker).[a] IRRI greenhouse, May-March 1990.

Host plant	Biological property				
	Eggs deposited (no./female)	Survival[b] (%)	Growth index[c]	Reproductive index[d]	Duration of life cycle[e] (d)
Oryza sativa L.	220 ± 60 a	51 ± 25 ab	3.2 ± 1.5 a	0.4 ± 0.1 a	29.2 ± 0.8 a
Leptochloa chinensis (L.) Nees	76 ± 4 def	58 ± 19 a	3.1 ± 1.0 a	0.7 ± 0.2 a	32.7 ± 0.8 b
Paspalum paspalodes (= *P. distichum* L.)	135 ± 17 bc	53 ± 19 ab	2.2 ± 0.8 b	1.1 ± 0.4 a	37.8 ± 2.6 c
Isachne globosa	121 ± 59 c	54 ± 19 a	1.9 ± 0.7 bc	1.1 ± 0.4 a	41.7 ± 1.2 e
Echinochloa colona (L.) Link	73 ± 86 d-g	47 ± 13 ab	1.9 ± 0.6 bc	1.6 ± 0.9 a	38.9 ± 0.7 c
Digitaria ciliaris (Retz.) Koel.	143 ± 53 bc	23 ± 22 d	0.9 ± 0.9 d	1.1 ± 0.5 a	38.7 ± 1.0 c
Paspalum conjugatum Berg	45 ± 9 f-l	31 ± 3 cd	1.6 ± 0.2 c	2.3 ± 0.9 a	33.2 ± 0.9 b
Paspalum scrobiculatum L.	154 ± 61 b	30 ± 17 d	0.9 ± 0.5 d	1.6 ± 0.6 a	47.4 ± 0.7 f
Echinochloa crus-galli (L.) Beauv. ssp. *hispidula* (Retz.) Honda	34 ± 13 h-o	42 ± 19 bc	1.6 ± 0.7 c	2.5 ± 1.4 a	40.2 ± 1.1 d

[a]Av of 10 replications. The 9 most suitable hosts of 41 plant species tested.

[b]Survival = $\frac{\text{larvae pupating (no.)}}{\text{total larvae (no.)}} \times 100$

[c]Growth index = $\frac{\text{survival (\%)}}{\text{growth period (d)}}$

[d]Reproductive index = $\frac{\text{female pupal weight (g)}}{\text{eggs produced (no.)}}$

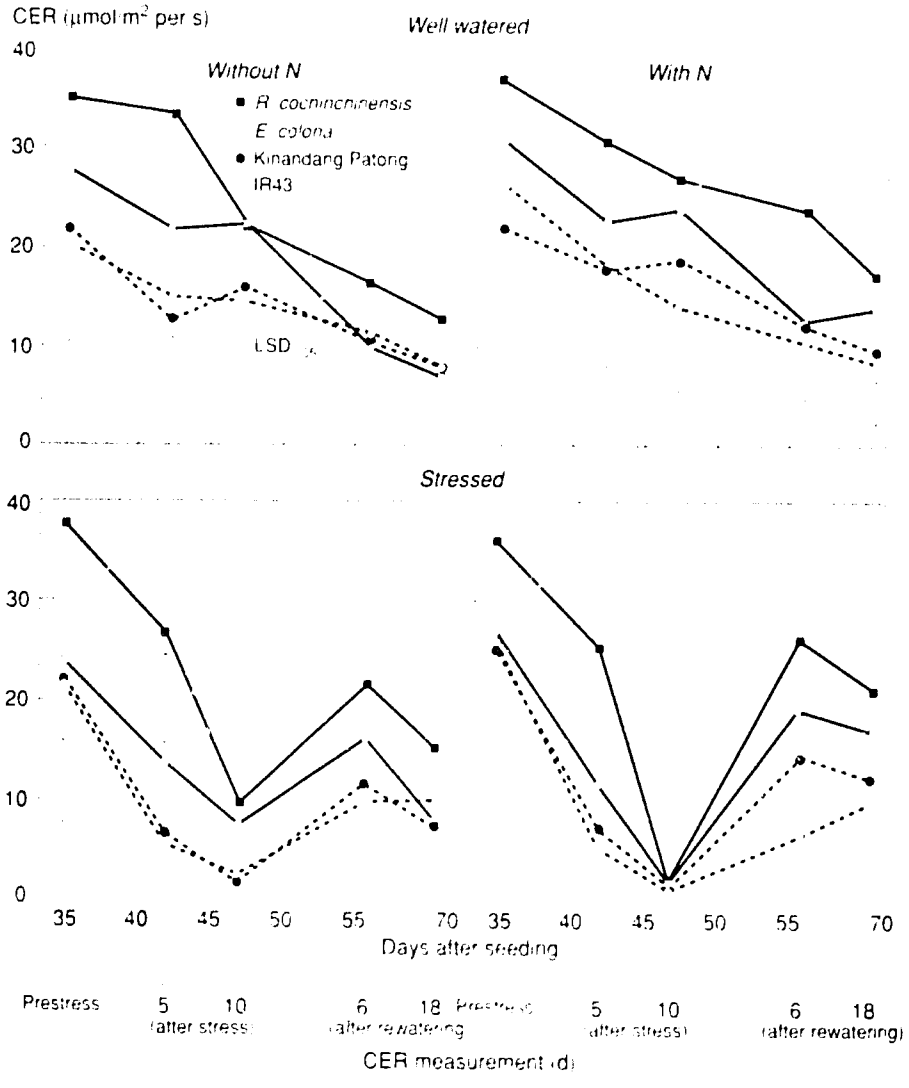
[e]n = 10

respectively. Total development from egg to adult emergence was 30 d and female longevity 11 d. Fecundity was 220 ± 60 eggs per female.

Effect of water stress and nitrogen application on photosynthesis of two upland rices and two upland weeds

A greenhouse experiment investigated the effects of increasing water stress and fertilizer N on the photosynthetic response of upland rices IR43 and Kinandang Patong (both C3 species), and upland weeds *Echinochloa colona* (L.) Link and *Rottboellia cochinchinensis* (Lour.) W.D. Clayton, both C4 species. Four pregerminated seeds of each species were seeded in drums containing 100 kg of air-dried soil. Treatments consisted of 2 water regimes (well-watered to field capacity, and water stress treatment imposed during the vegetative stage of the plants at 38 d after sowing [DAS]) and 2 N levels (no N and 100 kg N/ha, all applied basally) in a factorial combination with 4 replications. The study emphasized the influence of water regime and N resources on the leaf photosynthesis and resource use efficiencies of the plants while in competition.

In well-watered conditions, both *E. colona* and *R. cochinchinensis* had higher photosynthetic rates than IR43 and Kinandang Patong, with or without applied N (Fig. 17). *E. colona* maintained high rates

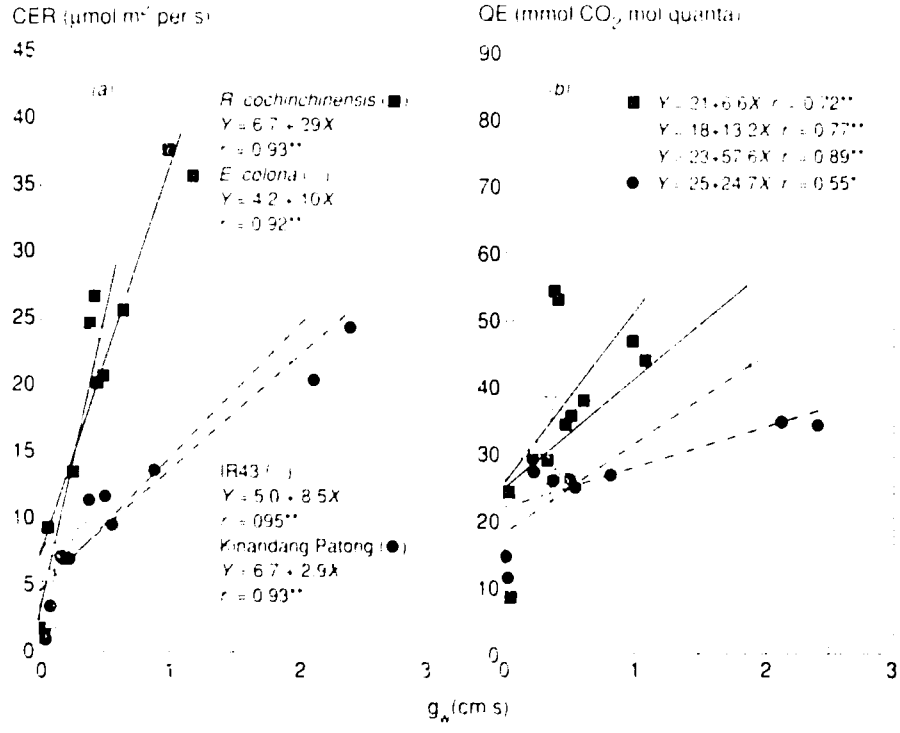


17. Effect of water regime and N application on net CO_2 assimilation or CO_2 exchange rate (CER) of 2 upland rices and 2 upland weeds, IRRI, 1990 wet season (WS).

up to three CO_2 exhange rate (CER) measurements, but was similar to the rices at 56 and 70 DAS measurements (recovery period). On the other hand, *R. cochinchinensis* had superior CER. It had about 24 and 40% higher rates than *E. colona* and the rices, respectively, even under water-stressed conditions except for the 10-d stress period. At 35 DAS, when CER measurement commenced, photosynthetic rates of *R. cochinchinensis* decreased with plant age. The 10-d water stress period decreased the average leaf water potential of the plants to −2.4 Pa from −0.45 Pa in well-watered condition. In the stressed treatment, without N, CER of *R. cochinchinensis* was 73% higher and that of *E. colona* 60% higher than that of the 2 rices, suggesting the high water use efficiency (WUE) of both weeds under this situation. In contrast, the photosynthetic rates averaged over all species decreased by 78% in the stressed treatment with high N resources, compared with no application of N, indicating strong water stress and N interactions. Even the highly efficient weeds were affected. In the field, high N enhances the effect of water stress on the physiological processes of plants. Water stress alone reduced the photosynthetic rates of the plants by 44% in 5-d and 82% in 10-d stress periods.

The high photosynthetic rates of the weeds (C4) were associated with higher quantum efficiency (QE, in mmol CO_2/mol quanta) and higher WUE (in mmol CO_2/mol H_2O) than in the C3 rices. QE was about 59 for *E. colona* and 48 for *R. cochinchinensis* under normal condition; that of IR43 was about 36 and Kinandang Patong, 34. The WUE of the weeds was two to three times higher than that of the rices. Moreover, the weeds maintained these efficiencies even under water-stressed conditions. As for CER, water stress and N resources had similar interactions for both QE and WUE.

The high photosynthetic rates of the weeds can also be attributed to their high CO_2 utilization efficiency. At the leaf level, the weeds maintained higher CER than did rice, although the stomatal conductance (g_s, unit is cm/s) of the weeds was 2-3 times lower than that of rice. Also, CER and QE were highly correlated with g_s even under water-stressed condition (Fig. 18). The slopes of the lines for both weeds were steeper, indicating high photosynthetic rates at low CO_2 level. Water stress apparently reduced the g_s of all species because of the induction of stomatal closure. The reductions were considerably higher in the two rices. The two way treatment



18. Effect of CO_2 stomatal conductance on a) leaf net CO_2 assimilation rate (CER), and b) quantum efficiency (QE), IRRI, 1990 WS. Data pooled over water stressed treatments and sampling time.

interactions, however, were more pronounced in the weeds than in the rices at 10-d stress periods. Under water stress and without applied N, g_s of the weeds was about 70% more than that under stress and with applied N.

Similarly, the N use efficiency of the weeds was higher than that of the two rices (Fig. 19), suggesting higher CO_2 fixed per unit N available than in rice. This linearity, however, was not as strong under stressed conditions possibly because of the highly significant water stress and N interaction.

Our results show the physiological advantages of the two upland weeds over the two upland rices and their ability to maintain their efficiencies over moderate water stress. *R. cochinchinensis* maintained its superiority almost throughout the growing season. We would expect the high aggressivity of these weeds over rice in the field, even under resource-scarce conditions. These results have serious implications for field conditions. Because most of the common upland weeds that compete with rice belong to the C4 species, the crop will encounter stiff competition with these species. We must adjust our weed control program in such a way that these weeds will be removed before they damage the rice crop.

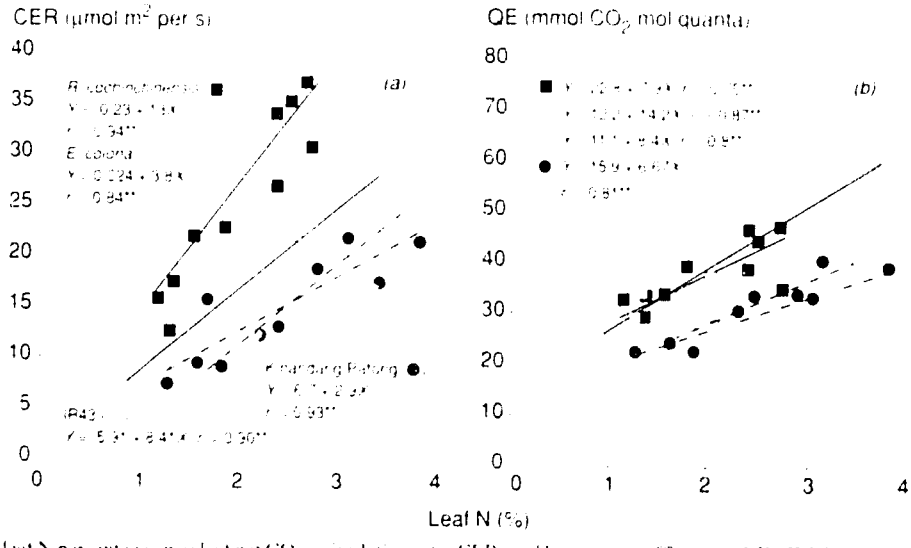
Physiological response of rice and *Rottboellia cochinchinensis* to applied nitrogen in monocultures and mixture

A field study in 1990 WS at the IRRI upland farm evaluated the response of IR43 rice and the weed *Rottboellia cochinchinensis* (Lour.) W.D. Clayton, in monoculture or in mixture, to increasing fertilizer N application. At 70 DAS, *R. cochinchinensis* had high dry matter (DM) production under most soil N conditions (Fig. 20). With no fertilizer N added, the weed in monoculture had higher DM than rice, suggesting weed insensitivity to low N supply. In mixture, both rice and weed produced similar DM. DM production of *R. cochinchinensis* sharply increased with increase in N fertilizer application. Dry biomass of this weed in monoculture and in competition with rice continued to respond to as high as 150 kg N/ha. Rice DM decreased in mixture, again indicating the high competitiveness of *R. cochinchinensis*, particularly at higher N levels. These DM responses were also reflected in the N uptake of the plants. The weed absorbed more N than did rice, the amount absorbed increasing as N levels increased.

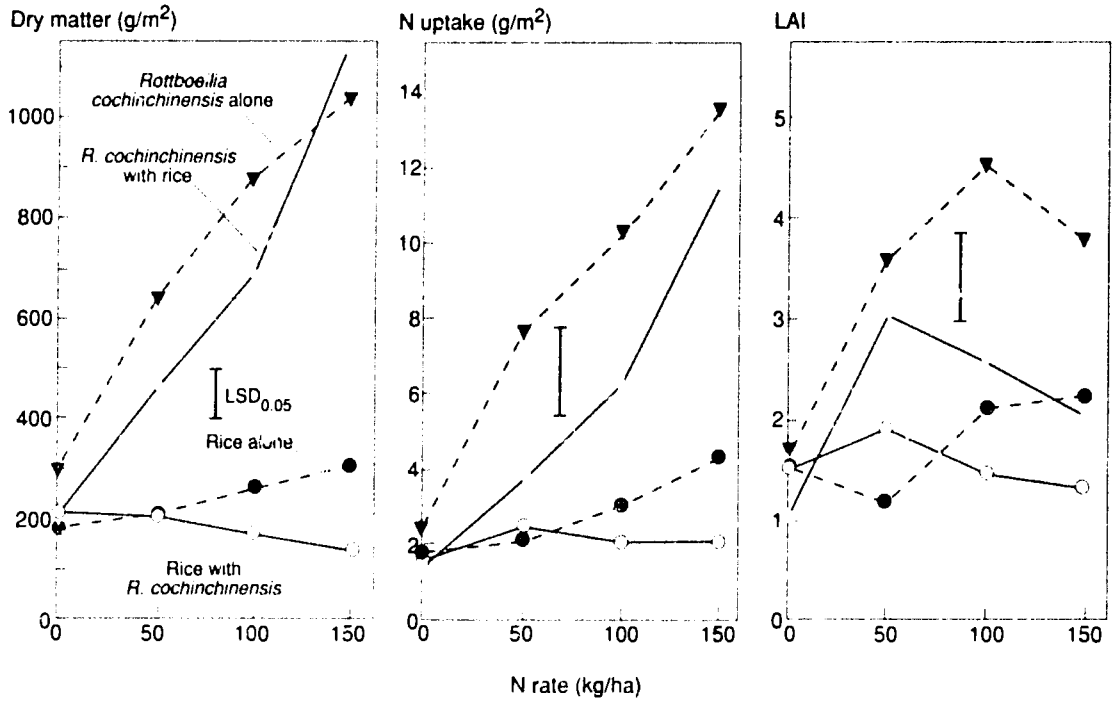
The high responsiveness of *R. cochinchinensis* to N, its higher accumulated LAI, and its height advantage over rice (*R. cochinchinensis* is more than twice as tall as rice) render this weed very competitive. For the rice plant to get maximum benefit from the applied fertilizer N, *R. cochinchinensis* should be controlled early or before any N application.

Next steps

We will continue to study the etiology of viruses and seedborne pathogens, the ecophysiology of major weeds, and the taxonomy of insect pests and natural enemies. The risk of seedborne pathogens will be



19. Effect of leaf N percentage on a) leaf net CO_2 assimilation rate (CER) and b) quantum efficiency (QE), IRRI, 1990 WS. Data pooled over well-stressed treatments and sampling time.



20. Dry matter accumulation, N uptake, and leaf area index (LAI) response of rice variety IR43 and *Rottboellia cochinchinensis* as monoculture and in mixture as affected by N application rates at 70 d after seeding. IRRI, 1990 WS.

analyzed. Methods to differentiate virus strains will be developed.

Pest population dynamics

Knowledge of factors that affect pest-population increase provides a basis for a pest management strategy. Such knowledge enables a crop protection specialist to select the best strategy for preserving and increasing a pest's natural enemies, preventing pest outbreaks, and reducing artificial pest control inputs.

This research project is studying the structure and dynamics of pests and natural enemies in selected rice ecosystems. Improving the pest monitoring techniques and deriving quantitative methods to describe the spatial and temporal spread of pests are important aspects of this research.

Pheromone interactions

The pheromone composition of the striped stem borer (SSB) *Chilo suppressalis* was determined. When the formulated mixture of three aldehydes (5 parts Z-11-16: ald, 1 part Z-9-16: ald, and 1 part Z-13-18: ald) is put in the field, the air over the rice canopy is continuously saturated by the pheromone and SSB mating ceases because males are unable to track a female odor gradient. It is also believed that females detect the pheromone emitted by other females and upon sensing it fly away. The result is that oviposition is prevented. This method of mating disruption has reached commercialization because of a technological breakthrough—the development of a low-cost solid polymer substrate in which the pheromone mixture is embedded. The pheromone is entrapped within the polymer matrix by premixing followed by heat fusion and the resin sheet is then cut into squares of desired sizes. The polymer resin not only releases the pheromone continuously over 100 d but prevents chemical degradation from UV radiation and weathering.

To determine if the formulated product can disrupt mating, a pheromone dispenser was made by stapling a 2.5- × 2.5-cm square of formulated product onto a bamboo stake. These stake dispensers were placed in rows 3 m apart in a lattice configuration, giving a dosage of 25 g ai pheromone/ha. Each dispenser contained the pheromone equivalent of 14 million virgin females. Mating disruption was measured by the catches in pheromone traps set in the centers of four pairs of fields, one set serving as a control. On the first night, the fields were tested for

uniformity in catches and no mating disruption was attempted. The mean catch between sets of paired fields was not significantly (P = 0.12) different (89 vs 69 males/trap). On the second night, the pheromone dispensers were placed in a 12- × 12-m block around the pheromone trap in one set of the paired fields. The catches recorded 98% disruption the next day, as significantly (p = 0.01) fewer (1.2 vs 40) males/trap were collected. On the third night, the pheromone dispensers were removed and the subsequent catch from both sets of traps was 48 vs 38 males/trap. The results clearly show mating disruption occurred.

USING MOLECULAR PROBES TO CHARACTERIZE PATHOGEN STRAINS AND POPULATION DIVERSITY

DNA typing of the bacterial blight pathogen. Transposable genetic elements can be useful as probes for DNA identification of pathogen strains. Several putative transposable elements were isolated from the genome of the bacterial blight (BB) pathogen *Xanthomonas oryzae* pv. *oryzae* (Xoo), using a transposon trapping vector.

From a collection of 95 isolates, 17 types were identified using pTnX1 and 27 types using pJEL101. For pTnX1, but not for pJEL101, isolates from more than one race shared a single DNA type in several cases. The overlap of DNA types between races gives a clear indication of evolutionary relationships among the races.

Identification of a new race of bacterial blight pathogen. The relationship between DNA type and pathogenic phenotype was examined for 16 strains of BB race 5. The strains were analyzed using the probes pJEL101 and pTnX1 and by *Pst*I digestion and were distinct from one another by one or more of these analyses. Differential reactions were observed for these isolates on accession 8106 from Ifugao, Philippines, and the differences in pathogenic phenotype corresponded to differences in DNA type as defined by pJEL101 and pTnX1.

By pJEL101, the strains incompatible with accession 8106 had DNA profiles with 95% similarity; compatible strains had DNA profiles with 92% similarity. The level of similarity between the compatible and incompatible strains was 85%. By pTnX1, the strains incompatible with accession 8106 had a level of similarity of 95%, the compatible strains were 86% similar, and the compatible and incompatible strains had a 74% similarity.

The group of strains defined as race 5 on the five differential cultivars used for race typing in the Philippines thus can be subdivided into two groups by DNA typing and into two races by inoculation to accession 8106. DNA fingerprinting of pathogen strains can be used to identify evolutionary lineages with differences in virulence phenotype. Other aspects of this study are reported under project IR90-1-3.

Competition between races 1 and 2 of the bacterial blight pathogen. One strategy for reducing the prevalence of virulent pathogen strains is to vary the genotype of the crop over time. After cultivars carrying the *Xa-4* gene for resistance to Xoo were introduced, race 1 was replaced by race 2 as the dominant pathotype in the Philippines. Both races 1 and 2 are compatible with cultivars lacking *Xa-4* and other genes for resistance to BB. If race 1 were more fit on susceptible cultivars, then rotation of varieties with and without *Xa-4* might provide alternating selection for the two races, thus reducing the level of inoculum virulent to any given genotype.

To examine the possibility that race 1 is more adapted to varieties susceptible to races 1 and 2, a field survey was conducted at a site where cultivars resistant and susceptible to race 1 were grown simultaneously, and greenhouse and field experiments were conducted to study competition between races 1 and 2 on a cultivar that is susceptible to both.

Intensive sampling was conducted in farmers' fields in Bayombong, Nueva Vizcaya, Philippines, at a site where cultivars with and without *Xa-4* were growing in adjacent fields. Five infected leaves were collected from each of seven 1.0-m^2 areas in each of 5 fields. Each strain was tested for virulence spectrum (race). Only race 2 was found on the cultivars containing *Xa-4*; race 1 was prevalent on the cultivars without *Xa-4*.

To examine the competition between races 1 and 2 directly, antibiotic resistant strains of races 1 and 2 (PXO61^{rif} and PXO86^{rif}, respectively) were inoculated to susceptible variety IR56 in greenhouse experiments, using single or mixed inocula. When inoculated singly, the strains grew at similar rates, reaching 10^{10} CFU/ml by day 12. When inoculated with another strain, growth of race 1 strain was unaffected while race 2 strain reached only 10^{7} CFU/ml.

To test the effect of competition between the two races under field conditions, seedlings of IR56 were

spray inoculated with PXO61[m], PXO86[m], a mixture of the two races, or with water alone. The inoculated seedlings were transplanted to 3- × 3-hills at the center of subplots containing 25 × 36 hills. In mixed inoculations, race 1 was consistently recovered at a much higher frequency than was race 2. Disease incidence and apparent infection rate were similar in all treatments. These results indicate that race 1 is more fit than race 2 on IR56.

Race 1 is more competitive than race 2 on cultivars susceptible to both races, and planting of resistant and susceptible cultivars within the same field or in succession could provide alternating selection for races 1 and 2, thereby lessening the level of each race.

Spatial scale of variation of the bacterial blight pathogens. IRRI's studies of genetic variability of BB have generally made use of relatively small sets of strains (about 95-200 isolates per study) collected within the Philippines over several years. Substantial variation was observed both within and between races. The diversity of the pathogen at any given site was not established. To determine the spatial scale of variation, intensive sampling was conducted in farmers' fields, and the bacterial isolates obtained were analyzed by DNA and race typing.

In 1990, 11 sites were sampled in 6 Philippine provinces. The isolates were analyzed for two sites: Bayombong in Nueva Vizcaya, and Batad in Ifugao. For each of 5 fields from site 1 and 4 fields from site 2, five infected leaves (if present) were sampled from each of seven 1.0-m^2 areas in a W-walk. DNA types were determined using *Pst*I analysis and restriction fragment length polymorphism analysis using the probe pJEL101 for the 240 isolates obtained. Pathogenic race was determined by testing on differential cultivars. Each field showed a high degree of diversity. For most of 1.0-m^2 areas sampled, more than one *Pst*I type was observed. A lower level of diversity was detected using the probe pJEL101. Two races were found in several 1.0-m^2 areas at site 1.

This variability may have implications for disease sampling and management.

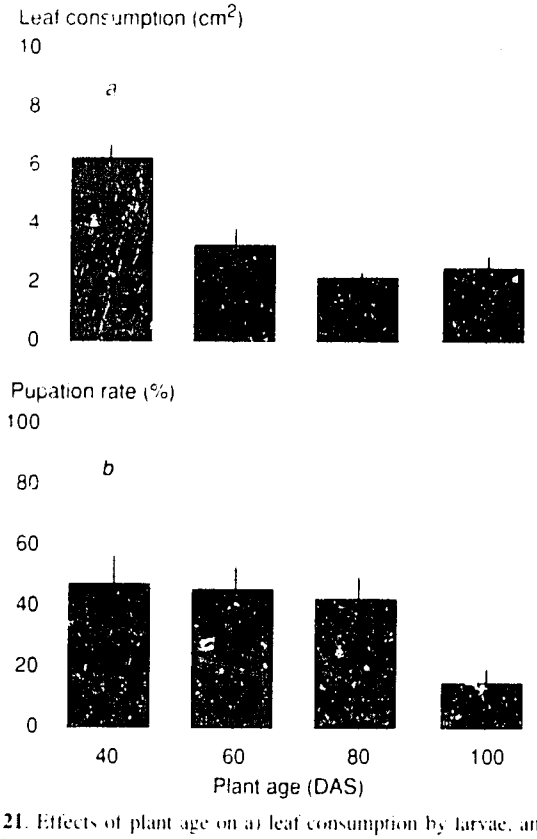
Influence of rice plant age on rice leaffolder survival and fitness

The survival and fitness of leaffolder LF *Cnaphalocrocis medinalis* depend on the stage of the rice plant at colonization. Mortality was significantly lower in larvae starting on 40-d-old plants than in larvae starting on 60-, 80-, or 100-d-old plants. The relationship between percent larval mortality (M) and plant age (A, in days), was described by a regression equation, $M = 0.54\ A + 36$. LF larvae starting on the younger plants consumed more leaf material (Fig. 21). Pupation rate was lower in larvae starting on the oldest plants. Pupal weight was inversely related to plant age. Larvae starting on the younger plants produced the largest pupae.

Since rice LF are generally less fit and survive less on older plants, their damage may only be important at early crop stages. At the younger stages, rice plants have the ability to compensate for leaf damage. These findings have implication for economic thresholds for LF management.

Community structure of arthropods in rice ecosystems

The objective of this study was to characterize the populations of insects and spiders inhabiting different rice ecosystems.



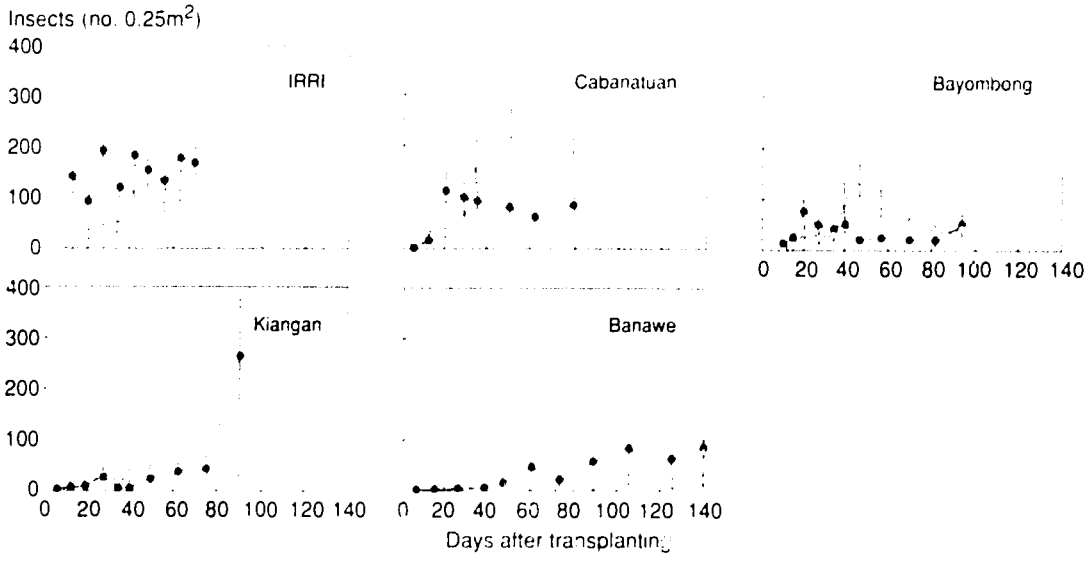
21. Effects of plant age on a) leaf consumption by larvae, and b) pupation rate of *Cnaphalocrocis medinalis*. Bars represent S.E. at 95% confidence.

Successional trends in arthropod guilds in rice ecosystems. Early colonizations at five rice-growing areas in Luzon, Philippines, were dominated by herbivores (plant feeding species) (Fig. 22). In Banaue and Kiangan (higher elevation), colonizations were slower, probably because of lower temperature. Monthly average temperature was between 20 and 23 °C in Banaue, and between 27 and 30 °C at IRRI and in Cabanatuan. At IRRI, colonization occurred throughout the season, probably because of the continuous presence of rice and heterogeneity of cultivars and crop phenology. In Cabanatuan and Bayombong, colonization of herbivores peaked about 3 wk after transplanting and then declined rapidly. The predators built up more gradually, reaching peak abundance at 50 d after transplanting (DT). This alternating abundance of herbivores and predators is typical of oscillations in predator-prey interactions. After 35 DT, predators were more abundant at all sites except IRRI and Banaue.

Relations between major predator and herbivore species in rice ecosystems. Counts of delphacid and cicadellid hoppers (herbivores) in each sample were aggregated and the linear relationships with the predators *Cyrtorhinus lividipennis*, spiders, and veliids + mesoveliids determined. Correlations were significant ($P<0.05$) and positive in all cases (Table 45). *C. lividipennis* exhibited a strong numerical response at Bayombong and Kiangan, but a negligible response at IRRI, Cabanatuan, and Banaue. Because *C. lividipennis* is an egg predator, a delayed instead of a direct numerical response is expected.

Serological techniques for virus disease monitoring

The RTBV, RTSV, RGSV, and rice ragged stunt virus (RRSV) depend on insect vectors for their transmission to the host plant and transfer to new sites. Epidemiology studies of the rice virus must



22. Abundance of herbivores (●) and predators (○), means per 9 hills ± 95% confidence limits, at 5 Philippine sites.

Table 45. Linear regression coefficients and SEs (in parentheses) of relationships between abundance of planthoppers and leafhoppers and associated predators at different sites in the Philippines.[a]

Insects	Regression coefficient				
	IRRI (90)	Cabanatuan (80)	Bayombong (110)	Kiangan (100)	Banaue (130)
Cyrtorhinus	0.02 (0.01)	0.03 (0.01)	0.29 (0.03)	0.48 (0.05)	0.11 (0.01)
Spiders	0.34 (0.04)	0.14 (0.05)	0.34 (0.05)	0.54 (0.09)	0.12 (0.01)
Veliids and mesoveliids	0.29 (0.14)	0.73 (0.25)	0.54 (0.23)	0.57 (0.13)	0.26 (0.02)

[a]In all occasions, data fitted the linear model, $y = mx + C$ at probability $p < 0.005$

monitor the movement of vectors and associated viruses.

From May 1990, two light traps—one in Laguna Lake, 3 km from the nearest rice, and the second in a farmer's field in Pila, Laguna—were checked weekly for insect vectors: *Nephotettix virescens* and *N. nigropictus*, *Recilia dorsalis*, and *Nilaparvata lugens*.

Brown planthoppers were removed from the trap cages and exposed individually to enzyme-linked immunosorbent assay (ELISA) for determining the presence of RGSV and RRSV. However, ELISA cannot detect tungro viruses in GLH, and infectivity in GLH was determined by placing 100 to 200 7-d-old TN1 seedlings in each trap, and testing by ELISA on 10 seedlings/trap when homogenized 3-4 wk later.

Tungro vectors were collected in the farmer's field throughout the trapping period, with peak catches in May and August 1990. Occasional catches were recorded in the lake with one peak catch in May (coinciding with the onset of rain). Some vectors collected at both sites were tungro-infective as shown by ELISA in the seedlings exposed to the vectors. Relatively fewer *N. lugens* than tungro vectors were collected at both sites. *N. lugens* carried only RRSV and at a very low number. This is the first report on the infectivity of migrating tungro vectors in the Philippines and showed that GLH can carry tungro viruses for at least 3 km.

Next steps

DNA probes and other techniques in biotechnology show considerable promise for characterizing and monitoring pathogen strains and populations. This research will receive increased emphasis and will be expanded to determine applications in population studies with insects as well. Use of insect pheromones as monitoring tools will also be emphasized.

Future work on insect pheromones will test the confusion technique in farmers' fields. If this is successful, then ways to reduce costs will be evaluated. A major portion of the cost of this technology goes to the synthesis of the pheromone. It may not be necessary to have all three chemicals in the pheromone and trials will test reducing the mixture to only 2 or 1 chemical. Without the Z-13-18: ald component, the cost can be reduced by half. Ultimately combining pheromones from other SB and LF will not be as daunting because pheromone components are often similar between species.

Population studies will continue with emphasis on quantifying the natural control of SB and LF and coupling predator and pest submodels. Community studies will quantify arthropod diversity in upland direct seeded rice and examine the dynamics of food web structure in different rice ecosystems. More rice genotypes will be evaluated to determine differences in attraction to natural enemies and the mechanisms involved.

The blast disease model BLASTSIM.2 will be validated in the field. In natural systems, plants have evolved diverse mechanisms to avoid, tolerate, or recover from attacks of other organisms. Plant breeders have used this natural process to their advantage by deliberate selection of modern crop varieties genetically resistant to or tolerant of pest organisms. Natural enemies of insects such as predators and parasitoids have also evolved diverse mechanisms for locating and regulating the pest organisms. Increasing evidence points to the importance of the pests' host in luring natural enemies to the pests, which the natural enemies use for food or hosts for reproduction. Plant color, shape, texture, infrared radiation, or odors may affect the natural enemies' success in colonizing crops and effectively controlling the pests. A potentially fruitful approach to rice pest management is to develop (through conventional breeding or genetic engineering) crop varieties that resist or tolerate insect pest, but which provide their natural enemies with more favorable plant habitat. Plant improvement efforts with such dual objectives could contribute significantly in achieving durable and sustainable systems of plant protection.

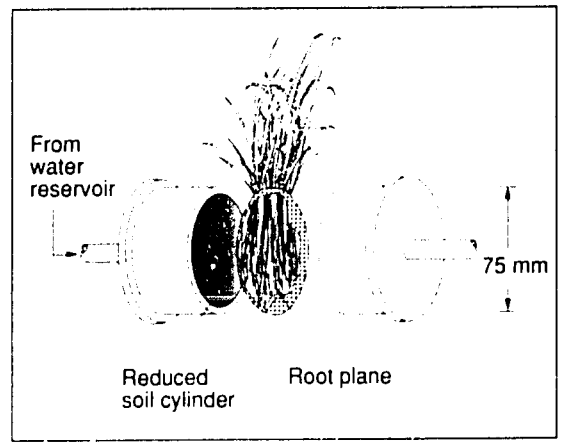
IRRI entomologists, plant breeders, and chemists have started a collaborative effort to measure the response of key natural enemies to different genotypes and determine if mechanisms that favor an increased response can be manipulated. Genotypes of rice representing diverse genetic backgrounds are being evaluated. Plant volatile chemicals are being extracted from the plants at different stages of growth and bioassayed (in an insect olfactometer and electroantennogram) to determine predator and parasitoid response. Preliminary results with the predators *Micraspis crocea* and *C. lividipennis* indicate that some rice genotypes elicit a positive response, some a negative response, and some no response. More

genotypes will be evaluated using bioassays with the two predators and the parasitoid *Telenomus rowani*. The specific volatile compounds in genotypes that elicit a positive olfactometer response from the natural enemies will be identified.

Subprogram V: Plant, soil, water, and nutrient processes

Advances in quantitative theory describing soil, water, and plant processes now allow mechanistic understanding of the ways in which soil conditions affect rice growth. With such understanding, we can predict the effect of the diverse treatments imposed upon rice crops growing in different ecosystems, and can help design rice ideotypes best suited to particular conditions. Continuing research is examining how nutrient uptake and tolerance for soil stresses are determined by the development and morphology of the root system and of individual roots, and by the chemistry and microbiology of the rhizosphere. In particular, this links with work in the Irrigated Program on efficient use of soil and fertilizer N, and in the Rainfed, and Deepwater and Tidal Wetlands Programs on P deficiency. Evaluation of soil microbial biomass as a ready measure of submerged-soil fertility, and the fate and management of organic materials in submerged soils are other crucial activities.

CHEMICAL PROCESSES IN THE RICE RHIZOSPHERE Rice roots can greatly influence nutrient and toxin transformations in the soil. For example, accumulation of insoluble ferric hydroxide in the rhizosphere as a result of O_2 release from roots may increase P sorption, but the acidification resulting from Fe oxidation and from other rhizosphere processes may release more P than is sorbed. Better understanding of such processes and how they are influenced by root characteristics can give a rational basis for improving management practices and for developing germplasm efficient at nutrient uptake and tolerant of soil stresses.



23. Exploded view of the root plane and soil cylinder apparatus used to study rhizosphere chemistry

To study rhizosphere processes experimentally, we needed a method that could separate soil samples at different distances close to root surfaces in quantities sufficient for analysis. We grew seedlings of IR36 in thin nylon mesh bags so that the roots formed a continuous planar layer (Fig. 23). Each root plane was then sandwiched between cylinders of thoroughly reduced Iloilo soil (Table 46) connected to water reservoirs, and the system sealed so that the only means of O_2 transfer between the atmosphere and soil was through the roots. The entire assembly was then placed in a plant growth chamber. After intervals of a few days, the cylinders were separated and the soil sectioned parallel to the root plane at 0.2-mm intervals. Each 0.2-mm section, which contained about 1 g of soil solid, was analyzed for pH, Fe(II) extractable with 1 M NH_4OAc at pH 2.8, and Fe(III) extractable with 2 M H_2SO_4. The widths of

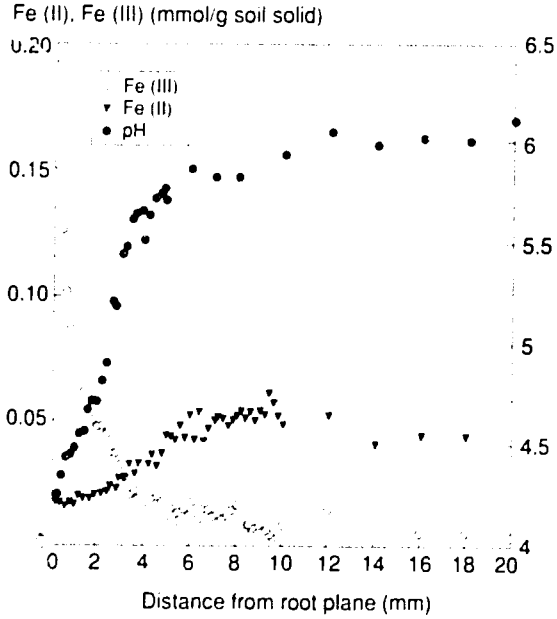
Table 46. Properties of Philippine soils used in experiments on rhizosphere chemistry, P reactions, and soil microbial biomass. pHs were measured in water.

Property	Tarlac	Maahas	Pila	San Manuel	Pangil	Iloilo
Aerobic pH (H_2O)	5.4	6.4	6.2	5.0	4.2	3.4
Anaerobic pH (H_2O)	6.5	6.9	6.9	6.6	6.6	6.6
C (%)	0.6	1.4	1.3	0.6	2.2	1.2
N (%)	0.06	0.15	0.17	0.06	0.23	0.1
CEC (meq/100 g)	7.8	24.6	39.9	10.0	22.8	16.0
Active Fe (%)	0.5	1.2	0.6	0.3	5.8	2.1
Active Mn (%)	0.02	0.12	0.09	0.01	0.04	Nil
Soil texture	Sandy loam	Clay	Clay loam	Silt loam	Silty clay	Sandy loam

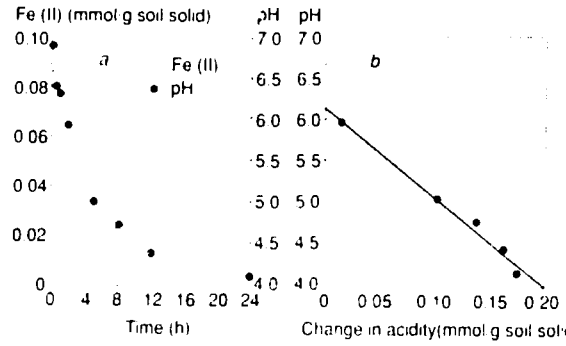
the sections were calculated accurately from their weights and the soil bulk density.

The roots appeared healthy throughout the experiment and their cortices remained largely intact. Profiles of pH and Fe near the root plane after 3 d are shown in Figure 24. A large quantity of Fe had been transferred toward the root plane and oxidized, producing a zone of Fe(III) accumulation; soil within 4 mm of the root plane was highly acidified. Control experiments with soil cylinders sealed together without roots indicated that the seals were good and that oxidation in cylinders with roots was indeed largely due to root-released O_2.

The total acidity generated in the soil—calculated from the pH profile using the pH buffer power of the reduced soil while undergoing oxidation, measured independently (Fig. 25)—was roughly twice the quantity of Fe(III) formed (3.37 vs 1.48 mmol). This is consistent with the Fe oxidation stoichiometry, indicating that acidification was due to Fe oxidation. The volume of O_2 required to oxidize this quantity of Fe is 8.3 ml at standard temperature and pressure. Additional acidity may be released from rice roots because, under flooded conditions, the roots receive N chiefly as NH_4^+ and therefore take up a considerable excess of cations over anions and release H^+ to



24. Profiles of Fe(II) (extracted with 1 M NH_4OAc at pH 2.8), Fe(III) (extracted with 2 M H_2SO_4), and pH in flooded soil exposed to a planar layer of rice roots for 3 d. The soil volumetric moisture content was 0.61 ml/ml (soil) and dry bulk density 1.16 g (soil solid)/ml (soil).



25. a) Changes in Fe(II) (extracted with 1 M NH_4OAc at pH 2.8) during oxidation of a reduced soil suspension shaken with O_2, and b) the pH buffer curve of the reduced soil while undergoing oxidation. The change in acidity required to produce a given pH change was calculated from the corresponding change in [Fe(II)] using the reaction stoichiometry $4Fe^{2+} + O_2 + 10H_2O = 4Fe(OH)_3 + 8H^+$. The pH buffer power—given by the inverse of the slope—is 0.093 mmol H^+/g (soil solid)/pH unit ($r^2 = 0.99$).

maintain electrical neutrality. However, we calculate that the resultant flux of acidity would be too small to cause a significant pH drop; at the high moisture contents and CO_2 pressures of flooded soils, pH changes tend to be propagated rapidly through the soil.

In experiments in which we exposed cylinders of the same reduced soil directly to air, greater oxidation took place, but the concentration of Fe(III) at the air-exposed surface was much smaller. This is because, in the root-plane experiments, the O_2 concentration maintained by the roots at their surfaces was less than that in air, and therefore the diffusion of O_2 into the soil was smaller and the movement of Fe^{2+} toward the roots greater. Movement of the soil solution due to water uptake by the roots will enhance this effect.

Acidification depends on the amount of Fe, or other soil constituent, oxidized. The Fe content of the experimental soil is not exceptional (Table 46). We expect similar degrees of acidification to occur in other soils, even calcareous ones, if they contain sufficient reducible materials. The effect of soil variables on the degree of acidification, predicted by theory, was reported in the 1989 IRRI program report.

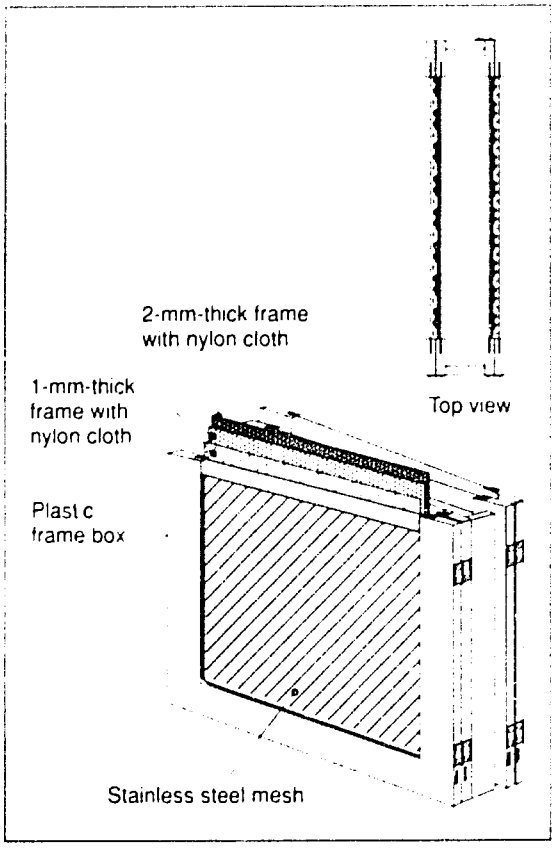
A large acidification will increase the availability of sparingly soluble nutrients such as P and Zn, but will also increase the concentrations of toxic acids such as Al—upland rice is tolerant of very high levels of acidity. The technique does not distinguish differences in root-induced changes and nutrient

uptake along the length of the root, whereas in practice such differences are large and important. Thus, the part of the root that releases O_2 most rapidly may not be the most active in nutrient uptake.

Screening rice varieties for ability to stimulate rhizosphere microbes

Rice roots release organic materials into the soil both by exudation and tissue decomposition. This may cause an increase in the size and activity of the microbial population near the roots, benefiting plant nutrition.

We grew rice plants in "rhizoboxes" (Fig. 26). These consist of 30-mm-wide (inner) and 50-mm-wide (outer) compartments separated by stainless steel mesh with 200-mm-diam holes. The outer compartment, which faces the roots, is divided into 2-mm sections by a nylon mesh with 50-mm-diam holes. Root penetration is thereby prevented. The soil microbial biomass, determined at flowering by chloroform fumigation, was slightly lower in the soil section adjacent to the roots than in control soil.



26. The rhizobox.

There was no increase in gram-negative bacteria in the rhizosphere soil, although they are generally abundant in the rhizosphere. We conclude that a thickness of 2 mm was too great for detecting rhizosphere effects.

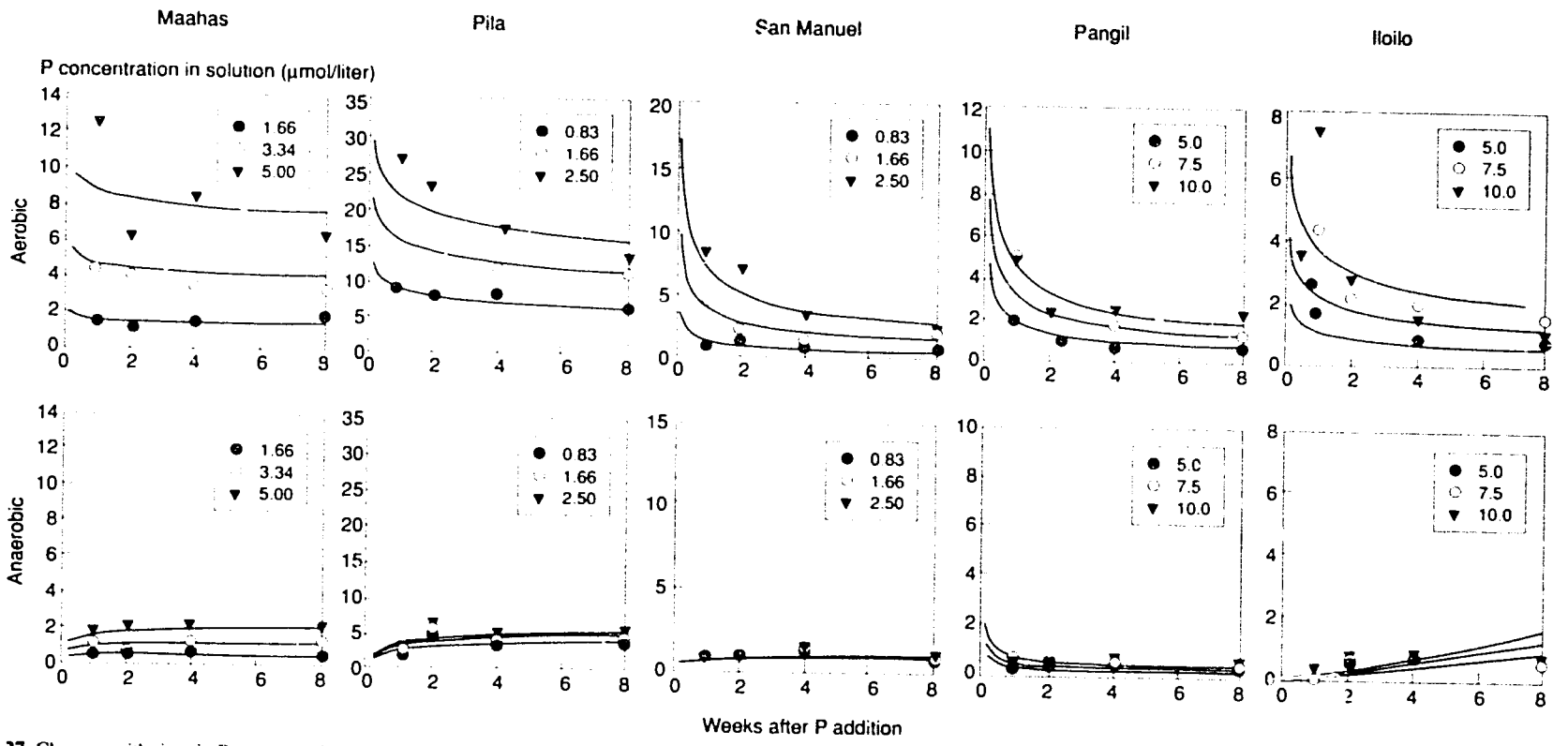
Precipitates of Fe oxide were formed on the nylon mesh facing the roots along the root paths. They give an indication of root oxidizing ability, and the imprinted nylon meshes can be conveniently stored as a record. Thus, the method may be a useful screening technique. The widths of the Fe precipitates ranged from 0.2 to 3 mm. Some precipitates formed along tiny lateral roots up to the tips of fine roots. Thus, the youngest parts of the roots appeared to be oxidizing the soil. Soil particles without visible Fe precipitates were attached to the nylon mesh along the roots, probably bound by secreted mucilages.

Reaction of phosphorus with submerged soil

The fate of P added to aerobic, nonsubmerged soils is reasonably well understood, but comparatively little is known about how the process is influenced by soil submergence. Such knowledge is important for developing germplasm efficient at P uptake, for improving P fertilizer management for rice and for crops grown in rotation with rice, and for predicting the long-term fate of P in the environment.

Generally, P in aerobic soils shows an initial fast reaction that is complete within a matter of hours, and a much slower reaction that can continue for many months. In laboratory experiments, we followed the changes in P concentrations in soil solutions after addition of soluble P to soils maintained under aerobic and anaerobic conditions at field capacity. Prior to P addition, the anaerobic soils were thoroughly reduced—chemically by submerged incubation—then dried anaerobically and remoistened to field capacity. They were stored in gastight bottles periodically flushed with N_2. Thus, for a given soil, the aerobic and anaerobic treatments differed only in redox status. P concentrations were measured periodically in solutions that underwent no net exchange of P with the soil. Results for five Philippine soils each with three levels of P addition are shown in Figure 27. Relevant soil properties are shown in Table 46.

The lines in Figure 27 were obtained by fitting the data to an equation that has been successfully used to



27. Changes with time in P concentrations in solution following P additions to soils under aerobic and anaerobic conditions. The numbers with the symbols are P additions in µmol/g.

describe P reactions in aerobic soils. The equation is useful because it summarizes the results in just a few numbers, and it can be used in quantitative soil-plant models. It was derived as follows. After the initial fast reaction, the distribution of P between the soil solution (concentration C_L) and rapidly equilibrating soil-solid P-sorption-sites (concentration C_S) is described by a Freundlich equation:

$$C_S = aC_L^{b1}$$

where a and $b1$ are coefficients. To allow for the slow reaction, the total concentration of P in the soil solid is described by

$$C_{St} = C_S t^{b2}$$

where t is the time following P addition and $b2$ a coefficient. $b2$ ranges from 0 (no slow reaction) to 1 (C_{St} proportional to time); a low value means the reaction is fast, a high value means it is slow but persistent. Thus, assuming the amount of P in solution is smaller than that in the soil solid, the overall equation is

$$C_L = [(C_T/a)t^{-b2}]^{1/b1}$$

where C_T is the total concentration added to the soil. The coefficients obtained for the different soils under aerobic and anaerobic conditions are shown in Table 47 (note that the coefficient values depend on the units chosen for concentration and time).

More P was sorbed by the anaerobic soils, resulting in much smaller P concentrations in solution for given P additions. Correspondingly, the Freundlich coefficients a and $b1$ are far higher. Also, there was little slow P reaction with the anaerobic soils; indeed, the concentrations in solution in most of the anaerobic soils increased slightly with time, resulting in negative values for the coefficient $b2$. The results can be explained in terms of the changes with submergence in the nature of Fe-containing soil constituents; these have a dominant role in soil-P reactions. The results are not due to physical changes in soil following submergence: experiments in which soils were submerged, puddled, and dried aerobically gave results similar to those in experiments with nonsubmerged aerobic soils. The gradual, slight increases in P in solution under anaerobic conditions are probably due to slow changes in the nature of the P-sorbing surfaces caused either by continuing soil reduction or by reoxidation due to experimental limitations. The increases are not due to slow desorption of P present in the unamended soils because the soils had very low initial P contents and the increases were greater with greater P addition.

The findings imply that more P must be added to anaerobic soils to produce a given increase in P in solution, but the sorbed P remains in rapid equilibrium with the solution and hence is "available" to plants. The rate of P diffusion to roots will be decreased by increased sorption, but this will be offset to some extent by higher moisture content under submerged conditions. Since P diffusion to roots is slow, processes that lead to efficient P uptake by the plant must operate in the rhizosphere.

Soil microbial biomass as an indicator of soil fertility. Soil microbial biomass mediates nutrient mineralization and is itself a labile nutrient pool. Its quantification could be a tool for gauging soil fertility. Microbial biomass has been widely measured in nonsubmerged soils, but the fumigation-incubation methods used are inappropriate for submerged rice soils or for soils recently disturbed by cultivation.

With the Natural Resources Institute, UK, we developed and tested a method for measuring microbial biomass in flooded soils. Soils are fumigated with chloroform to kill microorganisms; cell contents consequently released into the soil are then measured as N fractions in a 0.5 M K_2SO_4 soil extract and expressed relative to an unfumigated control. This "flush" reflects the size of the soil microbial biomass. The advantages of this procedure are that it

Table 47. Coefficients in the equation $C_L = [(C_T/a)t^{-b2}]^{1/b1}$ fitted to measured P concentrations in solution (C_L, mol/liter) after time t (s) following P addition C_T (mol/kg) to 5 Philippine soils.

Soil	Aerobic				Anaerobic			
	a	b_1	b_2	r^2	a	b_1	b_2	r^2
Maahas	5.39	0.655	0.048	0.95	$3.62 \times 10^{-}$	0.887	−0.126	0.93
Pila	1.31×10^{2}	1.257	0.196	0.91	$4.85 \times 10^{-}$	3.760	−0.845	0.44
San Manuel	0.21	0.670	0.316	0.94	3.01×10^{4}	6.060	−1.150	0.63
Pangil	1.38	0.801	0.369	0.93	7.55	0.821	0.371	0.61
Iloilo	1.12	0.564	0.175	0.62	$1.04 \times 10^{-}$	1.211	−1.341	0.57

requires simple equipment and allows large numbers of samples to be processed rapidly.

A greenhouse experiment investigated changes in soil microbial biomass due to green manure (equivalent to 160 kg N/ha), pesticide (carbamate equivalent to 3 kg/ha), and imposed differences in bulk density in 2 soils of contrasting physical and chemical characteristics (Table 46). Figure 28 shows the changes in biomass (given as flush of ammonium N after fumigation) and available ammonium. Biomass increased in the organic matter-amended treatments during 0-7 d, but not after 14 d. The pattern of biomass development was not affected by bulk density (Maahas soil) or by application of carbamate pesticide (Tarlac soil). Available ammonium decreased after 21-28 d, apparently because of immobilization in the biomass, which shows a corresponding increase. Although the levels of available ammonium differed between the two soils, the ammonium released through mineralization of added organic matter was similar.

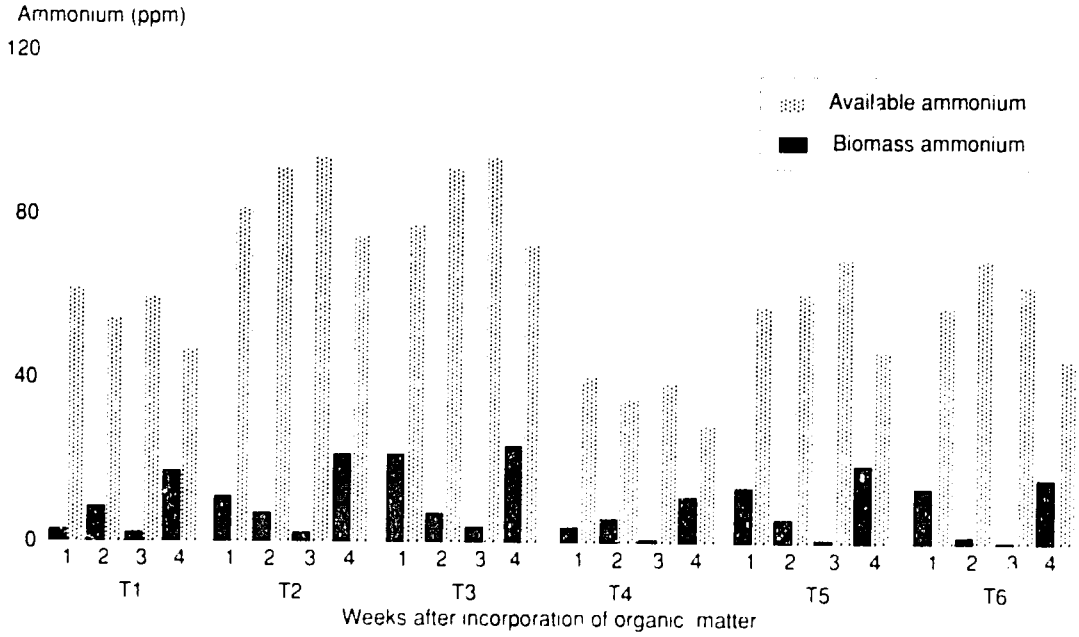
Field measurements at IRRI of the effect of green manure *Sesbania rostrata* and straw on the time course of soil biomass and available ammonium are shown in Figure 29. More N was mineralized in the sesbania-treated than in the straw-treated soil. Available N increased when inorganic N was added with sesbania; in straw treatments, available N decreased after an initial stimulation. The data indicate that to use soil biomass as an index of soil fertility, it is necessary to characterize both its size and its turnover rate.

Long-term straw management

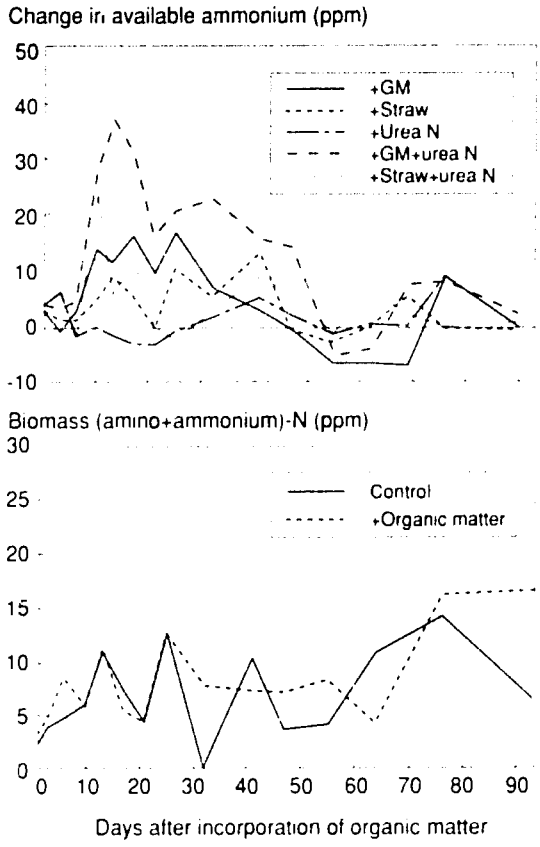
A series of field and drum experiments were started 10 to 20 yr ago to ascertain the long-term effects of straw management on soil fertility and rice yields.

Effect on soil fertility. In long-term drum experiments with various soils, straw increased organic C, total N, and exchangeable K (Fig. 30). The results were independent of water regime. In the early years of the experiment, a gradual change in the C:N ratio occurred in treatments both with and without straw as the soil adjusted to intensive lowland rice cultivation. This was superimposed on the changes in C and N due to the treatments. While C and N remained constant in the control, they increased in similar ways with straw amendment; they increased significantly in an acid and a neutral soil, but not in a calcareous soil. Field experiments showed the same trends, but seasonal and treatment variations were much greater.

Effect on rice yield. In long-term field experiments, straw incorporation generally produced higher



28. Changes with time in available ammonium and soil microbial biomass. Treatments T1, T2, and T3 are the control, organic matter amended, and organic matter amended with increased bulk density. Maahas soil; treatments T4, T5, and T6 are the control, organic matter amended, and organic matter and pesticide amended. Tarlac soil.

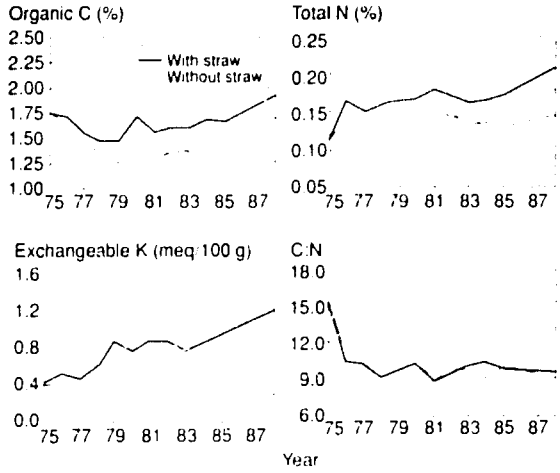


29. Effect of organic matter and inorganic N applications on time-courses of excess (flush) of ammonium concentration and soil microbial biomass as compared with unfumigated soil. GM = green manure.

rice yields than either burning or removal. The increase in yield per crop due to straw application compared with removal, averaged over 19 cropping years, was 0.4 t/ha; increases were 0.5 t/ha with compost application and zero for burning (Table 48). The highest increase in yield from straw (5 t/ha) was attained with no inorganic N fertilizer. Up to 120 kg N/ha, the higher the inorganic N addition, the smaller was the effect of straw addition. At each level of inorganic N, straw had a smaller impact on grain yield than either green manure or chicken manure (Table 49).

Irrigation water quality at IRRI

On the IRRI farm, differences in soil properties and rice yields have been linked to differences in irrigation water quality. IRRI farm has 15 reservoirs fed by 15 deep well pumps, 12 of which are currently operating. Since 1979, water from the pumps and reservoirs has been monitored for pH, temperature,



30. Changes in organic C, total N, exchangeable K, and C:N ratios in Maahas clay over time as affected by straw addition. Average of 15 cropping years and 3 replications.

Table 48. Increase in grain and straw yields per crop of rice due to straw management practices compared with straw removal. IRRI Farm, Block L3.[a]

Straw management practice	Increase (t/ha)	
	Grain yield	Straw yield
Straw burned	0.0 b	0.2 b
Long straw	0.4 a	0.5 a
Straw compost	0.5 a	0.6 a

[a]Av of 19 cropping years and 5 replications

Table 49. Increase in grain yield per crop due to organic matter addition at varying levels of fertilizer N. IRRI Farm, Block 422.[a]

N rate (kg/ha)	Increase (t/ha) in grain yield		
	Straw	*Sesbania rostrata*	Chicken manure
0	0.26	0.27	0.38
30	0.20	0.43	0.32
60	0.05	0.31	0.26
120	−0.18	0.01	−0.05

[a]Av of 4 cropping years and 4 replications

EC, Na, K, Ca, Mg, B, Cl, SO_4, and HCO_3. The values have been fairly consistent over the years. Concentrations of B are of continuing concern, but measurements of the other individual solutes were discontinued this year.

IRRI water contains nontoxic Na levels and adequate K levels for rice. In 1990, the generally high (pH 7-8) water pH may have contributed to occurrences of Zn, Fe, and Mn deficiencies. Based

on USDA salinity criteria, IRRI irrigation waters range from medium (.25-.75 dS/m) to high (.75-2.25 dS/m) salinity, but salinity has not been a problem for rice on the IRRI farm. Levels of B toxic to rice (>2 mg/liter) have been recorded in water from reservoirs 500 and L (Fig. 31)—consistent with B toxicity symptoms in areas irrigated from these reservoirs. Boron toxicity is a serious risk during long dry seasons when irrigation water is little diluted by rainwater. It can be alleviated by use of tolerant varieties, by diluting the irrigation water with low-B surface water, and by dry plowing.

Using the 1983-90 data, we grouped IRRI waters into 3 categories based on critical levels of EC (0.75 dS/m) and B (2 ppm). The reservoirs in the good and potentially hazardous groups are on one side of Buot Creek, and those in the injurious group are on the other side. This suggests that differences between reservoirs are related to gradients in the aquifer.

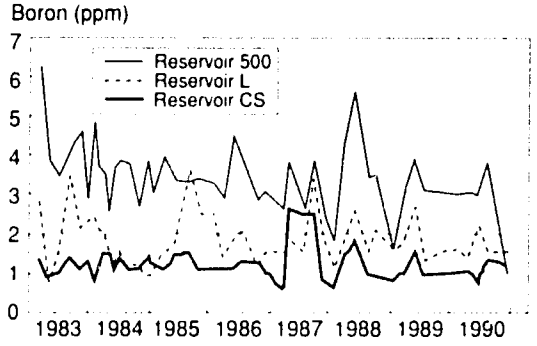
Next steps

Future activities will focus on 1) experimental and simulation work on soil nutrient dynamics and rhizosphere processes, and their relation to root characteristics; 2) experimental and simulation work on gas transport through rice roots in relation to O_2 supply to the root tip and the rhizosphere, root uptake of soil CO_2 as a C source for photosynthesis, and the release of soil CH_4 to the atmosphere; and 3) work on rice root morphology and development in relation to nutrient uptake.

Subprogram VI: Rice grain and seed quality, postharvest and biomass issues

Grain and seed quality, and improved nutritional value

The objectives of this project are to improve methods for evaluating rice grain quality and for identifying sources of improved nutritional value, and to incorporate seed vigor in modern varieties through a study of the genetic and biochemical aspects of seed vigor and related traits. Results are applicable to all ecosystems.



31. Boron concentrations of irrigation waters from reservoirs 500, L, and CS on the IRRI farm.

Effect of seed vigor on yield

Studies show that rate and duration of germination after accelerated aging are good indicators of seed vigor in rice. Within the same variety, plants from low-vigor seeds showed delayed flowering, fewer panicles and filled grains, and lower yield than those from high-vigor seeds.

Grain quality factors

Critical moisture content for crack susceptibility. Considerable variation in head rice recovery is obtained with selected IR rices between seasons. Unstressed grains give high head rice yields. In view of the importance of crack prevention during grain drying, and in the absence of data for heat-dried IR varieties, we determined for selected IR rices and CP/SLO 17 the critical moisture content (CMC) at which wet grains became susceptible to cracking. For IR rices, the CMC was 13-14% for crack-resistant IR60, 16% for crack-susceptible IR42, and 12% or less for CP/SLO 17. Thus, drying of wet grain to about 20% moisture to minimize deterioration may be accomplished rapidly without causing grain fissuring, but final drying to 14% moisture should be done more slowly.

Rationalization of cooked-rice hardness method. Breeding lines with similar starch properties cannot be differentiated by chemical means, and oftentimes even by cooked-rice texture measurements. The IRRI method for measuring cooked-rice hardness using an Ottawa Texture Measuring System (OTMS) 10-cm^2 cell on an Instron Model 1140 was evaluated with food rheologists at Cornell University. Extrusion hardness (x) in an OTMS cell with 0.32-cm holes correlated positively with hardness ratings (y) with an 11-member sensory panel (a =

−54, b = 0.010, r = 0.94**, n = 15) and with hardness by single-grain puncture (r = 0.97**) in rices cooked at water:rice ratio of 2.0. The OTMS cell was simpler to operate and cleaner than the Kramer shear cell. However, freshly cooked samples with similar starch properties were not differentiated by the sensory panel or Instron cell or even by the Rheolograph-micro at the National Food Research Institute, Japan.

Storage modulus G' (a measure of gel hardness) of fresh aqueous rice starch gels measured at the University of Manitoba with an oscillating rheometer increased exponentially with apparent amylose content. However, staling of selected aqueous starch gels at 7-8°C showed varietal differences in rate of increase in G', being faster for IR64 than for IR8. This was also confirmed from staling enthalpy by differential scanning calorimetry. Accelerated staling of cooked rice at IRRI by ≥4 h at 2-4°C followed by 4 h at 42°C also magnified the differences in Instron hardness in 3 pairs of low gelatinization temperature (GT) waxy rices. Thus, staling can improve the sensitivity of the Instron hardness test.

Waxy gene allele and glutelin α_1 molecular weight. We found the specific activity of granule-bound starch synthase in starch granules to be three times more in japonica than in indica rices. Hybrids showed intermediate synthase activities regardless of their *waxy gene allele*. Thus, the *waxy gene allele b* (japonica) produced a more active isozyme form of bound synthase than *allele a* (indica) to effect the synthesis of the same amount of amylose even at presumably lower enzyme level. The levels of *waxy gene* product in the starch granules of developing grain were higher than those in the mature grain starch granules.

Japanese scientists have reported that all japonica varieties have the endosperm glutelin α band (molecular wt 37 kD) on sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) at low concentration of cross-linker bisacrylamide. Absence of this glutelin band was observed only in indica rices. At IRRI it was verified that with normal SDS-PAGE, the glutelin α_1 band in rice endosperm proteins was present in all japonica rices, including waxy rices. Samples with known japonica genes, such as indica/japonica crosses, including IR36-based *amylose extender* mutants, showed the glutelin α_1 band. But when the SDS-PAGE was run at higher current, all rices showed the α_1 band: indicas had a low-mobility (higher molecular wt) α_1 band compared with japonicas. Apparently, the glutelin α_1 band of the indicas overlapped with the glutelin α_2 band under normal SDS-PAGE running conditions. In many varieties, the classification based on glutelin α_1 band coincided with the *waxy gene allele* as well as with Glaszmann's isozyme classification.

Near-infrared reflectance (NIR) spectroscopy of rice starch. In a cooperative study with scientists in Albany, California; Beaumont, Texas; and Beltsville, Maryland, NIR spectroscopy of milled rice flour for amylose content distinguished among long, medium, short, and waxy types with minimum overlap. Related studies suggested that altering the crystallinity of starch by acid corrosion or ball milling may influence NIR spectra.

Resistant starch of milled rice. Studies on resistant starch in nonrice cereals indicate that the fraction resistant to in vitro and in vivo enzymic digestion is amylose, with degree of polymerization (DP) of about 60 glucose units. Resistant starch may be related to cooked rice texture. Resistant starch prepared from various cooked milled rice and IR42 parboiled rice and IR42 extruded noodles by digestion with β-amylase-pullulanase was found to have an amylose-like structure with peak DP of 55-65 glucose units.

NUTRITIONAL VALUE

Amylose-extender mutants. The relative lysine content of bran and milled rice proteins of the 2064 *amylose extender* IR36-based mutant was compared with that of IR36. Lysine contents of bran protein were 5.6% for amylose extender and 5.3% for IR36; those of milled rice protein were 4.4% for amylose extender and 4.0% for IR36. Lysine in milled rice protein of the 2064 mutant's opaque grains was 4.6%; that in translucent grains 4.3%.

Nitrogen and amino acid digestibility of rice diets. FAO/WHO recently approved a new method for determining the protein quality of vegetable foods: amino acid score × protein digestibility in growing rats. Digestibility of individual amino acids is generally within ± 10% of protein digestibility; but in cooked rice, lysine digestibility can be more than 10% higher than protein digestibility. Nitrogen and amino acid balance in growing rats was determined in Denmark on cooked rice and on two cooked composite Filipino diets (adult and toddler). The

new method underestimated protein quality by 6-8% because of lower digestibility of protein than of lysine in the rice and rice-based diets.

Nutrient content and retention during milling. At the University of Nebraska, energy-dispersive X-ray fluorescence spectrometry of minerals in seven IR brown and milled rices showed the mineral values for IR rices to be similar to those of traditional rices. Silicon content was low at 0.015% in milled rice. Retention of brown-rice thiamine (13%) during milling (10% bran-polish removal) was less than that of riboflavin (46%). True prolamin content was 6.5% of total milled rice protein.

Next steps

The grain quality activities of this project will be completed by 1992. Dried grain of rices differing in crack resistance will be examined using NIR spectroscopy and CMC. Accelerated staling of cooked rice prior to Instron hardness measurement will be imposed to improve varietal differentiation. Collaborative studies on resistant starch and properties of *amylose extender* mutants will be completed in 1991. A data base on grain quality for about 2,900 rices sampled since 1963 will be published. The seed quality study will continue.

Postharvest technologies and biomass utilization

Harvesting

Development of low-cost, mixed-crop stripper harvesting systems. Shortage of labor at harvest results in untimely harvests, loss in crop yields, and increased vulnerability to storms; hence the need for a low-cost, compact, mixed-crop harvester that increases labor productivity and efficiency.

A feasibility study for a small-farm rice stripper-harvester was undertaken. Two prototype walk-behind units were developed, then evaluated in wet season rice. The stripper principle is relevant to any rice ecosystem that can bear the weight of a machine.

The small, hand-pushed, low-cost unit, with stripping width of 45 cm weighs 70 kg and has a theoretical field capacity of 0.5 ha/d. Grain recovery with the stripper proved superior to that with hand harvesting, with total losses below 2%. An average of 99% of the collected material in undamaged semidwarf varieties was threshed by the stripper rotor, which is powered by a 3-kW engine. Rethreshing of the collected material in such crops is, therefore, unnecessary. In taller, more vegetative Basmati, crop collection was excellent, but only 94% of the material from the stripper rotor was threshed. In a crop where stems had been damaged by pests, the percentage threshed fell to 80% and accordingly required rethreshing. Two people can lift this machine; hence it can quickly get the crop in from the field. It requires considerable labor to clean the grain; thus, significant labor displacement is avoided.

A self-propelling, walk-behind model with 60-cm stripping width has an on-board straw separator/rethresher attachment, which allows it to operate in a wide range of crop conditions and with considerably less labor than manual harvesting and mechanical threshing. Model S600, with 7.5 kW engine, is capable of 1.2 ha/d. An assessment of the benefits and costs of changes in rice straw utilization practices in Asia made necessary by stripper harvesting was commenced.

Multicrop threshing and straw flow analysis. A new multicrop axial-flow thresher was developed, utilizing a threshing drum with a staggered, easily fabricated rasp-type rotor arrangement; it is intended for handling long and damp straw. Tests with rice and maize indicate savings in power using the new drum compared with peg teeth. A built-in concave adjustor for the different crops and straw conditions will probably be needed. The design was assessed by instrumentation and magnetic pickups incorporated in the rig earlier by collaborators from the University of Hohenheim. This equipment has proven invaluable for research on straw flow characteristics and rotor-power demand.

Drying

Mobile dryers. Economics and farmer demand for drying were assessed through field visits and surveys of 35 farming communities in the Philippines. Contractor-operated mobile dryer services were simulated for economic viability based on a drying capacity of 1.0 and 0.4 t/h, matched to thresher throughput rates.

Fluidized bed dryer. A laboratory model Fluidized Bed Dryer was designed to operate on the principle of increasing the convection coefficient between the drying air and the grain for faster drying

and a net saving in fuel. Warm and cool air are alternately blown through the suspended grain.

Crop fed in to the inlet gate of the heating chamber can be transferred to the cooling chamber through a transfer valve. Recirculation of wet grains depends on the desired moisture level. The heating, cooling, transferring, and discharging of the grain are all accomplished by fluidization.

A 2-10% reduction in total moisture per pass was achievable, at rates equivalent to up to 50% moisture removal/h. Experiments to determine the optimum combination of drying air temperature, volume, velocity, and pressure that are consistent with cost-efficiency and minimal losses in quality continue along with the analysis of contractor-sized units.

Palay picker and bagger. A major bottleneck in pavement drying is how to bring in the grain quickly if storms threaten.

A prototype rice picker and bagger using a brush paddle-type of conveyor to collect and move grains to the bagging chute could collect about 250 kg/h. Further tests will be undertaken to determine the capacity, durability, and other pertinent specifications and to scale up potentiality.

Rice processing

Micromills. Low-cost small ricemills of three sizes are being developed to meet the milling needs of rice farmers. The smallest unit is designed particularly for use by women, who traditionally mill rice for home consumption. The medium size (household-type-MM 50) can mill 50 to 80 kg rice/h with a 0.7-kW motor and has been released for production. The village model with capacity of up to 180 kg rice/h with 3-kW diesel engine can be readily moved around on a hand cart. It had up to 69% milling recovery and 79% head rice recovery because of reduced dwell time and improved rotor design. This compares with 65 and 41%, respectively, for the traditional Engelberg ("kiskisan") mill. Initial on-farm trials have established the efficacy and acceptability of the micromills, which cost one-third to one-fifth the price of imported models of equivalent capacity.

Targeted throughput for the alternative "Friendly" design ricemills intended for small processor plants was 250 kg rice/h using a 3-kW motor. Two design principles were pursued, one using a series of inverted abrasive cones. The goal was a design for a mill that has very high milling recovery, does not overheat the grain, is simple and inexpensive, and provides separate discharges for milling coproducts. This unit had 70% milling and 85% head rice recovery in tests.

Both designs seek to encourage farmers to capture price incentives from better quality milled rice. Ownership of these mills would enable farmer groups to take part in processing and by-product preparation, where the greater profits from rice production are to be achieved.

Economic appraisal of these small mill designs confirmed that where village mills are not available, or where mills are so far that their use entails substantial transport cost and supervision time, small-scale mills will be profitable to operate. Grain quality improvement and by-product management offer good potential for adding value locally.

Investment in the MM 50 mill can be recouped in 3.2 yr (payback period [PBP]), the break-even point (BEP) being 265 h use/yr. Model MM 150 has a BEP of 315 h/yr and PBP of 2.0 yr, whereas a "Friendly" mill has a BEP of 386 h/yr and PBP of 2.5 yr.

Next steps

The new stripper harvester principle and prototypes show considerable promise across ecosystems, but the socioeconomic ramifications and the question of what to do with intact, standing rice straw (minus the grain) need to be addressed. In the Philippines and elsewhere in Asia, fuel wood critical for home cooking is becoming increasingly scarce. Rice straw, on the other hand, is often burnt in the field. Rice straw is bulky, has low calorific value, needs to be dried and has a high ash content, but it may nonetheless be used to produce a low-cost fuel.

Briquettes can be made from composted straw, and rice straw can be treated to enhance its nutritive value for livestock feed.

Ongoing multicrop thresher rotor development is also relevant to the stripper harvester, which needs a rethresher and cleaning system in any case. The straw flow research is relevant to improved thresher designs for which there is still a very large latent market in the rice world.

In response to demand, the fluidized and mobile dryer concepts will be pursued, as well as the upgrading of the in-bin flat bed drying technologies. Continuing the work on the micromills and on by-product utilization will benefit low-income people across all ecosystems.

International Programs

Previous Page Blank

International programs

Germplasm conservation and dissemination

SUBPROGRAM I: INTERNATIONAL RICE GERMPLASM CENTER 218
Germplasm collection, acquisition, and research 218
Field collection 218
Acquisition 218
Storage characteristics of *Oryza glaberrima* 219
Protocol for in vitro culture of rice germplasm 219
Chromosome races of *Oryza punctata* 219
Germplasm conservation, dissemination, and assistance to national agricultural research systems 220
Seed production and characterization 220
Data base management and development 220
Evaluation file 221
Passport information data base 221
Listing of special types 221
Medium- and long-term seed storage 221
Germplasm information and seed dissemination 221
Technical assistance to genebanks of NARS and other centers 221
Training of germplasm workers 221

SUBPROGRAM II: SEED HEALTH UNIT 221
Seed health standards 221

Previous Page Blank

Germplasm conservation and evaluation

Subprogram I: International rice germplasm center

Germplasm collection, acquisition, and research

FIELD COLLECTION

During 1990 wild relatives of rice were collected in remote areas and threatened habitats in Cambodia, Indonesia, Myanmar, Papua New Guinea, the Philippines, and Vietnam (Table 1). Notable finds were *Oryza rufipogon*, *O. ridleyi*, *O. schlechteri* from the inland river systems of Papua New Guinea; *Oryza officinalis* on the island of Samar, Philippines, and in the Ayeyawady division of Myanmar; and *O. meyeriana* from Indonesia.

We collected wild rice in the Mekong Delta, where changes in rice cultural practices—from growing traditional deepwater rices in the wet season to two crops of modern varieties in the dry season—and continued development of irrigation schemes are causing the disappearance of wild rice populations. In Myanmar, populations of *O. officinalis* and *O. rufipogon* recorded by an earlier collector had disappeared because of urban development, planting of eucalyptus stands, and overgrazing by cattle.

ACQUISITION

Of a total of 1,737 seed samples received from 23 countries, 1,450 were of *O. sativa* and 287 were of wild *Oryza* species; the latter were mainly from collaborative collection with national programs. The trend in germplasm acquisition over the past decade is shown in Figure 1. Major donors of germplasm in 1990 were China (500), Malaysia (145), Bangladesh (142), Republic of Korea (100), West Africa Rice Development Association (77), and Taiwan, China (38).

The total holdings of the germplasm bank at year's end totaled 84,592.

Registered *O. sativa* accessions	77,175
O. glaberrima	2,398
Wild species	2,606
Genetic testers and mutants	676
Newly received *O. sativa* samples	1,450
Newly received wild *Oryza* samples	287

Table 1. Species and origin of field-collected germplasm, 1990.

Species	Species (no.)							
	Cambodia	Indonesia	Myanmar	Papua New Guinea	Philippines	Thailand	Vietnam	Total
O. sativa		24	37				13	74
O. nivara	22		17					39
O. rufipogon	17		35	44			56	152
O. spontanea	1		18				2	21
O. officinalis		17	26		5	4	2	54
O. minuta					12			12
O. meyeriana		1			2			3
O. ridleyi				3		1		4
O. schlechteri				1				1
Total	40	42	133	48	19	5	73	360

Storage characteristics of *Oryza glaberrima*

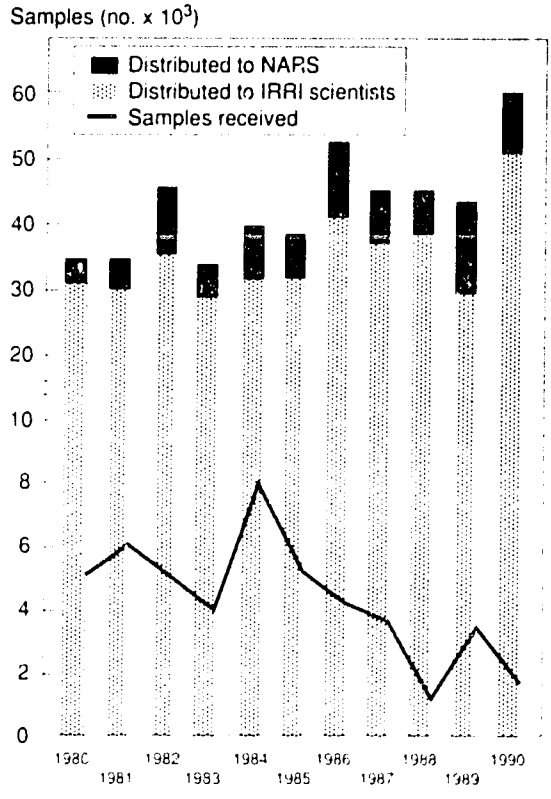
There are 2,398 accessions of *Oryza glaberrima*, the West African cultivated rice, conserved in the International Rice Germplasm Center (IRGC). We compared five accessions of *Oryza glaberrima* (100136, 103330, 103453, 103475, and 102377) with indica variety IR36 and japonica variety Taipei 309, using standard accelerated aging methods. After 13 wk of accelerated aging, all accessions except *O. glaberrima* (102377) from Liberia had lost their viability. The loss of viability was fastest for Taipei 309. Three accessions of *O. glaberrima* had a slower decline of viability than IR36. Two accessions showed a decline similar to that of IR36. These results, which affect conservation management decisions, suggest that *O. glaberrima* will have good storage characteristics similar to those of the tropical indica varieties of Asia.

Protocol for in vitro culture of rice germplasm

Among the conserved rices of IRGC are a few sterile populations, accessions that produce few seeds, and accessions for which viable seed stocks are very low. We have started to investigate methods of generating multiple plants from a single seed or callus and of maintaining germplasm in vitro under slow growth conditions.

In one experiment, a single-shoot explant was obtained from seeds of the following rices: *O. sativa* race indica (Acc. 7887, 5811), *O. sativa* race japonica (Acc. 7520, 74365), *O. glaberrima* (Acc. 102486, 103616), *O. rhizomatis* (Acc. 103410, 103417), and *O. punctata* (Acc. 103897, 101409). Shoot multiplication followed the Finch method using Murashige-Skoog's (MS) medium plus 6.0% sucrose, 2 mg BAP/liter, and 0.8% agar (MS2BAgar) with modified protocol.

Two weeks after transfer to MS2BAgar media, all the cultivated rices responded with an average 8 of 20 explants showing multiple shoots. The wild rices *O. rhizomatis* and diploid *O. punctata* remained in the single-shoot stage. However, one tetraploid accession of *O. punctata* produced multiple shoots in hormone-free MS medium. The multiple shoots will later be separated and transferred to rooting media and finally to pots in the greenhouse to permit the plants to grow to maturity. It is hoped that using the methods developed will enable us to produce many plants when seed stocks are very limited.



1. Germplasm samples received and distributed to national agricultural research systems (NARS) and IRRI scientists, 1980-90.

We successfully induced callus from the immature inflorescence of a Rayada variety from Bangladesh (Acc. 27588), for which seed production in Los Baños is problematic. The callus was transferred to plant regeneration media and allowed to produce multiple shoots. The shoots were then separated and transferred to MS2BAgar media for further shoot production. We intend to vary conditions to determine which conditions best permit multiplication and slow growth of low seed-producing germplasm.

Chromosome races of *Oryza punctata*

We recently received accessions of *O. punctata* from East Africa. Since *O. punctata* has two chromosome races, diploid and tetraploid, it is necessary to make chromosome counts of these new accessions. We found that all were diploid. We also found that we can distinguish morphologically diploid and tetraploid races by using characteristics described by

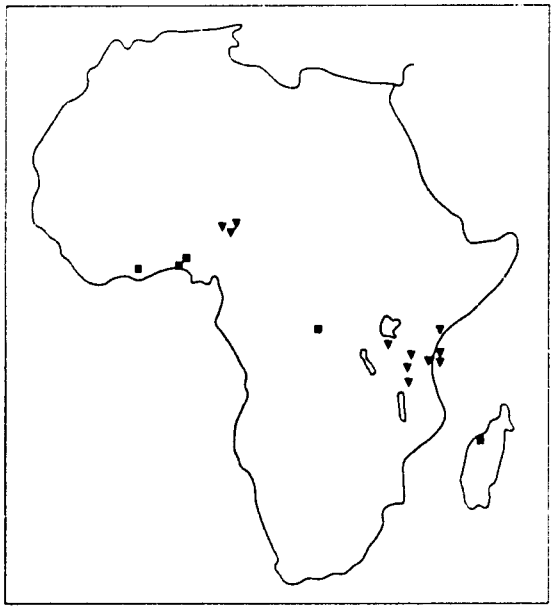
earlier workers such as spikelet size and annual or perennial life cycles. The tetraploid will be called *Oryza schweinfurthiana*, to prevent confusion when we supply seeds to rice workers. Our continuing herbarium studies confirm that the type specimen of *O. schweinfurthiana* collected in central Africa has smaller spikelets than the type specimen of *O. punctata* collected in Ethiopia. The distribution of these two chromosome races of *O. punctata* conserved in IRGC is shown in Figure 2.

Germplasm conservation, dissemination, and assistance to national agricultural research systems

Seed production and characterization

During 1990, 17,601 plots in 16 ha on the IRRI research farm and 11 ha at an off-station site in Dayap, Calauan, Laguna, were planted. Efforts to completely characterize accessions for which characterization had previously been incomplete were intensified. A total of 2,480 accessions were completely characterized in the field during the year.

A total of 163 accessions were compared with incoming seed samples; 84 of these accessions were considered duplicates. We substantially increased our efforts to rejuvenate accessions for which viability was low or seeds were few. Some 2,319 accessions were planted either in sterile agar media (928) or in petri dishes (1,391). About 38% of the accessions germinated and were grown to maturity in either the phytotron or a screened nursery area. This is a lower rate of success than in earlier years and highlights the need to devote more resources to this germplasm.



2. Distribution of the diploid (▼) race of *O. punctata* and the tetraploid (■) race, also known as *O. schweinfurthiana*

A total of 2,140 accessions of rice with few seeds were grown in our contained nursery area. In this area, we also grew 371 accessions of wild rice; 221 were to rejuvenate our seed stocks and 150 were newly received wild populations for growth under quarantine control. These wild rice accessions were all partly characterized during the year.

We rejuvenated 322 accessions of *O. glaberrima* in the dry season and grew 296 *O. glaberrima* accessions in the wet season for characterization.

Data base management and development

In mid-1990, three microcomputers in IRGC were linked directly to the VAX, which permitted expanded use of our data base management system on the ORACLE DBMS. We were able to improve efficiency in operations, such as record keeping for newly received seed samples; printing of data sheets, field books, summary reports; and information retrieval. The improved, single-step, information retrieval system helped us furnish required information and increase the number of rice samples we distributed from IRGC to evaluators.

We developed a system to improve our monitoring of accessions with few seed stocks. This monitoring system covers accessions to be planted in the protected nursery area and accessions requiring seed rescue technique.

IRRIGEN. The IRGC staff, in collaboration with the former Statistics Department staff, revised and completed the microcomputer-based IRRIGEN software. This software will assist in the processing of newly received seed samples; selection of materials to be planted for initial seed increase, characterization, or rejuvenation; generation of field plot and accession numbers and printing of planting plan, field books, and data sheets for field operations; processing of the 45 morphoagronomic characteristics, which includes data entry, data editing, and information retrieval; and in keeping track of the amount of seed stocks in the medium- and long-term storage rooms.

Seven sets of IRRIGEN were released in 1990 to Liberia, Peru, North Korea, the Philippines, and

China. In addition, two copies of the Seed Inventory System (SIS), a module of IRRIGEN, were released to Malaysia and Taiwan. This software is subject to further revisions based on the comments and suggestions of users in national centers.

Evaluation file

During the year, IRGC with support from the Computer Center initiated the development of a GEU file for wild relatives of rice and *O. glaberrima*. In cooperation with evaluators and the Project Management Services and Biometrics Department, we now have a GEU file for wild species containing screening results on 10 insect pests, 3 viral diseases, and 2 bacterial diseases. For *O. glaberrima*, the evaluation file covers only four insect pests. The number of accessions for which information is available varies from trait to trait for both *O. glaberrima* and wild species.

Passport information data base

During 1990, we further sought out information in old records and from data obtained in the field by collectors for germplasm conserved in IRGC. Much of this information is fragmentary, but identification of the exact origin of germplasm, elevation, and cultural type adds to our ability to conserve germplasm appropriately and to distribute it to evaluators more logically. Passport information on a total of 11,639 accessions was added to the passport data file.

Listings of special types

We continue to compile and update the list of special types in a core collection of *O. sativa* germplasm. Recent additions to the list are accessions with fine quality, aromatic rices, and the "widely compatible" varieties reported by Japanese breeders.

Medium- and long-term seed storage

A total of 4,474 accessions of *O. sativa* and 392 accessions of *O. glaberrima* were processed for long- and medium-term storage. This was a 13% increase over the previous 2 yr's, achieved with the help of extra contractual workers. Samples of the accessions were prepared for shipment to a duplicate storage site at the National Seed Storage Laboratory, Fort Collins, USA. A total of 211 accessions of wild rice were added to stocks of these materials in long-term storage. Accessions now in long-term storage number 46,201.

Germplasm information and seed dissemination

IRGC staff provided scientists working in six national centers with the entire set of GB-basic data for their country. We responded to 26 requests for GB-basic information within IRRI and 32 requests from countries worldwide (Table 2).

Increasing requests from national agricultural research systems (NARS) for special types such as cold-tolerant accessions, high-altitude rices, preferred grain quality, and widely compatible accessions were received during the year. A total of 8,219 samples of both cultivated and wild rice germplasm were distributed during the year. One of IRGC's tasks is to assure sufficient seed stocks of these special types to meet the increasing demands from NARS.

In response to 260 requests, we distributed within IRRI 49,993 samples of *O. sativa* in addition to 1,328 samples of wild species and *O. glaberrima*. This was the highest number of samples distributed within IRRI over the past 10 yr (Fig. 1).

Technical assistance to genebanks of NARS and other centers

The head of IRGC visited China to advise the China National Rice Research Institute in Hangzhou and the Agriculture Research Institute in Taichung on genebank design and operations. IRGC's associate geneticist presented a seminar on germplasm conservation for scientists in the Philippines, Cambodia, and Vietnam.

Training of germplasm workers

Ms. Fadhila H. Ali from Tanzania spent 6 wk at IRGC, learning different facets of the work of conserving rice germplasm. The head of IRGC also participated as a lecturer in the International Plant Genetic Resources Conservation Short Course conducted by the University of California, Davis, in June.

Subprogram II: Seed health unit

Seed health standards

Phytosanitary certificates were issued for 611 rice seed shipments covering 114,225 seed lots sent to cooperators in 61 countries around the world (Table 3). Most of the outgoing seeds originated from the

Table 2. Worldwide dissemination of information on IRRI's conserved germplasm, 1990.

Requests (no.)	Country	Total no. of accessions		
		Basic[a]	Characterization[b]	Characterization/GEU[c]
2	USA		14	24
7	Philippines	2,772	448	303
1	Korea	9,033		
3	India	45,821	8	
1	Myanmar			1,601
1	Nepal			1,491
1	Madagascar			881
3	Japan	5		20
1	France	2,892		
1	UK		9	
1	Australia		56	1,208
2	Bangladesh		2	1
1	Thailand			915
1	Colombia	77,175		
1	Laos	1,451		
1	Guinea-Conakry			560
1	Malaysia	2,785		
1	Zanzibar			797
1	Canada			1
1	Sri Lanka			2,170
32		141,935	537	9,972

[a]Information on accession number, seed source, origin, variety name, and former designation. [b]Information on morphoagronomic characters of the germplasm. [c]Information on evaluation of germplasm.

Division of Plant Breeding, Genetics, and Biochemistry (Table 4). Incoming rice seed from 29 countries were processed for post-entry certification in 1990 (Table 5).

Intercepted quarantine objects included weed seeds belonging to nine species (*Echinochloa* spp., *Scirpus* sp., etc.), storage insects belonging to six species (*Sitotroga cerealella*, *Sitophilus* spp., etc.), seeds infected with false smut, and seeds with soil (Table 6). Routine seed health test (RSHT) of seeds also revealed nine pathogens (Table 7). Infection

Table 3. Seed lots with phytosanitary certificates sent by IRRI to different regions, January-December 1990.

Region[a]	Shipments (no.)	Seed lots (no.)	Total weight (kg)
East Asia (4)	110	22,333	1090.46
Europe (11)	79	2,441	101.85
Latin America (9)	29	7,103	138.54
North America (2)	43	1,001	34.38
Oceania (3)	12	828	31.10
South Asia (6)	137	36,970	1,270.12
Southeast Asia (8)	154	33,632	1,114.77
Sub-Saharan Africa (14)	29	4,611	192.60
West Asia and North Africa (4)	18	5,306	121.50
Total	611	114,225	4,095.32

[a]Number of countries in parentheses.

Table 4. Seed lots sent by IRRI to different countries through the Seed Health Unit, January-December 1990.

Source of seeds	Shipments (no.)	Seed lots (no.)
Plant Breeding	233	26,470
INGER	122	76,556
IRGC	207	8,618
Cereal Chemistry	1	6
Training Center	2	12
Plant Physiology	2	20
Agronomy	3	27
Plant Pathology	36	875
Entomology	5	38
Total	611	112,622

Table 5. Countries of origin of imported seeds received from January to December 1990.

Origin[a]	Shipments (no.)	Seed lots (no.)	Total weight (kg)
East Asia (4)	22	2424	150.79
Europe (3)	6	438	2.30
Latin America (3)	6	299	19.82
North America (1)	4	151	1.15
Oceania (2)	2	44	0.39
South Asia (5)	28	527	44.67
Southeast Asia (6)	20	766	25.80
Sub-Saharan Africa (3)	6	175	23.81
West Asia and North Africa (2)	2	8	5.21
Total	96	4832	282.94

[a]Number of countries in parentheses.

Table 6. Quarantine objects identified from incoming seeds, 1990.

Quarantine objects	Infested seed lots (no.)	Percent[a]
Weeds		
Echinochloa sp.	25	0.52
Fimbristylis sp.	2	0.04
Rottboellia exaltata	3	0.06
Paspalum conjugatum	1	0.02
Paspalum dilatatum	1	0.02
Scirpus sp.	4	0.08
Paspalum sp.	2	0.04
Cyperus difformis	1	0.02
Unidentified	6	0.12
Insects		
Sitophilus sp.	89	1.84
Rhizopertha dominica	48	0.99
Sitotroga cerealella	90	2.05
Tribolium sp.	23	0.48
Cryptolestes ferrugineus	25	0.52
Oryzaephilus surinamensis	1	0.02
Smut (false smut)		
Ustilaginoidea virens	8	0.17
Soil or seed with soil	114	2.36

[a]Based on a total of 4,832 seed lots.

ranged from 89% (*Curvularia* spp.) to 0.8% (*Pyricularia grisea*). Shipments with storage insects were fumigated before processing. All incoming seed lots were given the recommended hot-water and fungicidal seed treatments before release of the IRRI consignee.

Table 8. Rice pathogens detected with RSHT (blotter method) of outgoing seeds, 1990.

Pathogen	Affected seed lots[a] (%)	Detection level (%)	Mean value (%)
Trichoconis padwickii	95.4	1-98	40.6
Curvularia spp.	88.5	1-79	7.9
Sarocladium oryzae	68.5	1-66	4.5
Gerlachia oryzae	61.2	1-24	3.3
Fusarium moniliforme	32.5	1-17	1.6
Drechslera oryzae	18.5	1-14	1.7
Pyricularia grisea	0.5	1	1.0
Tilletia barclayana	4.8	1-57	4.4
Aphelenchoides besseyi[b]	6.4	1-73	6.5

[a]Based on 200 seeds seed lot of 2,373 seed lots. [b]Actual nematode count, using modified Baerman funnel method.

RSHT of outgoing seeds revealed that a high percentage of seed lots are also infected with pathogens (Table 8). All outgoing seeds were given the recommended seed treatments, except those sent to countries that do not allow treatments.

Crop health inspection was done on 2,069 incoming seeds planted during the year in designated post-entry areas. Diseases observed on incoming materials were not of the introduced type. Pre-export crop health inspection was also done on 24,529 entries planted for seed increase by the International Network for Genetic Evaluation of Rice, IRGC, and the

Table 7. Rice pathogens detected with routine seed health test (RSHT) of incoming seeds received without[a] and with[b] treatment, 1990.

Pathogen	Without treatment			With treatment		
	Affected seed lots (%)	Detection level (%)	Mean value (%)	Affected seed lots (%)	Detection level (%)	Mean value (%)
Trichoconis padwickii	78.9	1-88	28.1	24.2	1-21	3.1
Curvularia spp.	88.9	1-80	7.2	44.7	1-66	10.8
Sarocladium oryzae	39.5	1-24	3.3	0.8	1	1.0
Gerlachia oryzae	45.2	1-68	4.4	2.3	1	1.0
Fusarium moniliforme	28.0	1-10	1.7	1.5	1	1.0
Drechslera oryzae	64.0	1-52	6.7	35.6	1-31	2.5
Pyricularia grisea	0.8	1-2	1.5	0	0	–
Tilletia barclayana[c]	14.9	1-88	20.3	41.7	1-83	18.0
Aphelenchoides besseyi[d]	23.4	1-58	7.6	31.1	1-54	10.9

[a]Based on 200 seeds seed lot of 261 seed lots. [b]Based on 200 seeds seed lot of 132 seed lots. Declared treatments were benomyl and thiram, carboxin, benlate, and mancozeb. [c]Seeds contaminated with *Tilletia barclayana* were rejected for certification. [d]Actual nematode count.

Table 9. Entries in multiplication plots of IRGC, INGER, and Plant Breeding Division inspected for crop health and found infected with rice diseases of incoming[a] and outgoing seed in 1990 dry and wet seasons.

Disease	Entries (%)			
	Incoming[b]		Outgoing[c]	
	Dry season	Wet season	Dry season	Wet season
Without disease	86.39	0.38	77.5	4.60
Rice tungro	1.44	0	2.27	3.99
Grassy stunt	0	0	0	0.02
Ragged stunt	0	0	0.01	0
Sheath rot	7.85	18.01	12.14	14.29
Sheath blight	0	0.76	0.08	1.97
Stem rot	0	0	0	0
Narrow brown leaf spot	0.72	0	0.28	3.08
Leaf scald	0.06	1.14	0	59.26
White leaf streak	0	0	0	0.01
Blast	0.28	0.38	0.14	0.76
Brown spot	0	0	0.01	0
Bakanae	1.55	0	1.22	0
Bacterial leaf streak	0.11	76.24	6.90	68.89
Bacterial blight	0	1.14	0.07	1.18
Leaf smut	0	0	0	1.98
False smut	0.06	0	0.04	0.28
Bacterial stripe[d]	1.33	0	0.01	0.01
Sclerotium seedling blight	0.33	0	0.02	0

[a]Diseases observed on plants originating from incoming seeds were not of introduced nature. [b]Based on 1,808 entries in dry season (DS) and 261 entries in wet season (WS). [c]Based on 14,148 entries in DS and 10,381 entries in WS. [d]Bacterial stripe and sclerotium seedling blight observed at seedbed stage.

Plant Breeding Division during the dry and wet seasons. The major diseases observed in both seasons were bacterial leaf streak and sheath rot. In addition, leaf scald infected more than 50% in the wet season (Table 9).

All incoming and outgoing seeds were processed and monitored for crop health by SHU under the supervision of the Philippine Bureau of Plant Industry plant quarantine personnel assigned at IRRI. Monthly reports of phytosanitary certification activities were submitted and payments of phytosanitary certificates or import permit fees made to the Plant Quarantine Service.

International programs

Information and knowledge exchange

Library and documentation 226
Improving research communication 226
Service to research 226
Conferences and workshops 227
Improving public awareness 227
Rice data bases and computer services 228

Information and knowledge exchange

Library and documentation

Rice literature update is a new publication that lists the latest rice publications added to the IRRI Library collection. It replaces the selective routing of tables of contents to IRRI scientists, and extends the same service to rice workers of national agricultural research systems (NARS) worldwide. In 1990, we published 6 issues averaging 1,500 citations each, and distributed them to 10,500 addresses. This generated more than 300 requests from 39 countries, that we filled with 23,300 pages of rice literature.

The Rice Literature Search System (LSS) is essentially a computerized card catalog that now has about 170,000 entries. All of the original documents are in the IRRI collection. We filled 351 LSS requests.

We acquired the CAB-International abstracts on CD-ROM and use it, along with AGRICOLA, LSS, and other data bases for computer literature searches.

Our monograph collection, the world's largest for rice, now totals more than 93,000 titles. Serial titles reached a maximum of 4,022, but 50 subscriptions were discontinued to cut costs.

Improving research communication

We published 11 new books in English in 1990, and distributed almost 83,000 copies of major IRRI publications. About 34,000 were in English; the remainder were translations copublished by NARS cooperators.

Four hundred key NARS rice libraries received one complimentary copy of each new English-language book. Sales of IRRI books financed publication of the English titles. NARS or donors sponsored printing and distribution of the translations.

Almost 250,000 copies of IRRI periodicals were distributed to 12,000 addresses in 146 countries. These included the *International Rice Research newsletter*, the *IRRI reporter*, *the IRRI research paper series*, and *Rice literature update*.

We changed the traditional *Annual report* to a *Program report*, and altered its format to reflect the Institute's new ecosystem-based program structure.

IRRI and the International Center for Living Aquatic Resources Management organized the International Agricultural Research Center Book Exhibition at the 1990 Beijing Book Fair in China.

IRRI also published, on behalf of all centers, a 730-page 1989 catalog *Publications of the international agricultural research and development centers*, and a *1990 supplement*. The catalogs are probably the largest compilation of titles on agricultural science and production in the developing countries. The combined catalogs will be made available on computer disc in 1991.

Nine translations of IRRI books were copublished in 1990. At least 139 editions of 33 IRRI books have now been copublished in 44 languages in 29 countries.

A farmer's primer on growing upland rice was published in Hindi, Vietnamese, and Spanish. *A farmer's primer on growing rice* is now available in 38 languages.

One new IRRI book, designed for copublication, was released: *Seeds and seedlings of weeds in rice in South and Southeast Asia*.

Service to research

We made about 30,000 slides in 1990, and reproduced about 120,000 copies for research and training programs. We provided 14,000 black-and-white photo prints, and printed more than 20 million pages on in-house presses (all books and the IRRN are printed at commercial plants in Manila). IRRI artists produced 6,000 pieces of B&W and 600 color figures and artwork.

Conferences and workshops

Collaborative research planning meetings help to strengthen national programs and workshops help to strengthen research focus and methodology on specific program areas.

Conferences have the larger purpose of enabling scientists, administrators, policymakers, extension experts, and farmers to interact and sharpen their focus. Recommendations from conferences serve to guide research planning and funding.

IRRI was host to or the cosponsor of 28 conferences and workshops, including the 2d International Rice Genetics Symposium, which attracted 300 participants, and the 1990 International Rice Research Conference held in Suweon, Republic of Korea. Other conferences and workshops covered such diverse topics as rodent control in rice and gender analysis in farming systems research. The complete list of conferences and workshops is given here.

February

15-10 SARP international workshop on cropping systems

13-17 Training workshop on the participatory design of on-farm experiments

March

11-14 Regional steering committee meeting of INGER-Latin America

12-14 Biological control of rice diseases planning workshop

24 Planning workshop: Rice demand and supply project

26-28 Differential impact of the modern rice technology across production environments

26-30 Knowledge acquisition workshop

28-30 Workshop on environmental and health impact of pesticide use

May

9-12 Biotechnology meeting

10-13 Rice germplasm workshop

14-18 The 2d international rice genetics symposium

22-25 Ecosystem analysis for extrapolation of agricultural technologies planning workshop

June

4-8 Gender analysis in farming systems: Does it make a difference?

11-22 Agroecosystem analysis and farming systems research methodology

13-14 Problems of irrigation management for rice-based farming systems workshop

18-23 Prosperity through rice-phase III

August

12-16 Third crop-animal farming systems workshop

24-31 International rice research conference 1990

September

10-14 Expert panel meeting on rice rodent control

November

12-14 IRRI-IIMI workshop on irrigation management for rice-based farming systems

12-16 Fifth meeting of the cooperative research on problem soils

12-17 SARP workshop on production potential

13-17 21st ARFSN working group meeting

19-21 EPA-IRRI-SARP workshop

23-29 Impact of farming systems research review meeting

26-29 Regional workshop on rice research and production in SADCC and neighboring countries

December

6-9 INGER global advisory committee meeting

17-19 Review meeting of ADB-funded project on strengthening research on IPM in DWR farming systems

Improving public awareness

IRRI produced 37 press releases in 1990, and disseminated them to about 1,000 addresses worldwide. The releases were published in newspapers and magazines at least 200 times. We also received 108 visiting journalists.

IRRI cooperated with WNET/Thirteen, a pubic television station in the USA, in producing a 1-h feature, *Seeds of Hope*, for the series INNOVATION. The subject is IRRI's strategies for promoting sustainable agricultural productivity in developing countries, IRRI programs in Cambodia, and cooperative programs with Cornell University.

At least 26 U.S. public television stations will air *Seeds of Hope*. It will also be shown on Australian television. WNET has given IRRI permission to share the film with TV stations in developing countries.

We published individual brochures on *Facts About Cooperation*: IRRI and Germany, India, Italy, Japan, Korea, the Netherlands, Thailand, the U.K., and the USA in English and the language of each country. The brochures were mailed to all individuals and organizations in the appropriate countries, and to all who indicate Thai, German, etc. as their primary language.

This Week at IRRI is a weekly newsletter, initiated in 1989, to increase communication of events at IRRI and in the Los Baños community. Almost 1,000 copies of each issue are distributed.

Rice data bases and computer services

We completed renovation of the Computer Services facilities in 1990, with funds from the Japanese Government.

We began installation of a campus-wide Local Area Network that will give us electronic "paperless" communication within IRRI 24 h a day. A Wide Area Network (WAN) connection was installed, allowing scientists to communicate with colleagues around the globe. The WAN will give IRRI staff and, later, NARS cooperators, access to information stored in IRRI data bases.

The *rice virus data base* was completed in 1990. We will use the data model developed for this application for other subject areas. Scientists enter their observations on viruses or other data into a subject-specific "table" that links to other tables (for viruses, to the germplasm table of the Genetic Evaluation Unit).

This allows scientists to manipulate and analyze data from several disciplines.

The *rice workers data base* contains information about 10,000 people: IRRI's worldwide clients. Its primary data were gathered through our computerized mailing list access system. It can be merged with other data bases such as the *International bibliography of rice research* to give a clearer picture of IRRI clients and their research interests and needs.

International programs
Networks

SUBPROGRAM I: INTERNATIONAL NETWORK FOR GENETIC EVALUATION OF RICE **230**
International Network for Genetic Evaluation of Rice (INGER) **230**
1989 nursery results **230**
1990 nursery distribution **234**
Monitoring visits and planning meetings **234**
INGER and related activities in Africa **235**
INGER and related activities in Latin America and the Caribbean **235**

SUBPROGRAM II: CROP AND RESOURCE MANAGEMENT NETWORKS **236**
International Network on Soil Fertility and Sustainable Rice Farming (INSURF) **2**
Integrated use of inorganic and organic nitrogen **237**
Upland (soil pH <5) trial **237**
Long-term fertility trials in irrigated rice **238**
Soil fertility management for strongly acid upland soils (pH <5) **239**
Management of other nutrients **241**
Asian Rice Farming Systems Network **242**
Cropping systems testing **242**
Crop-animal farming systems **244**
Women in rice farming **246**
Rice-fish farming systems research **248**
Impact of farming systems research **249**
Directions **251**

Networks

Networks link institutions concerned primarily with knowledge and technology exchange and field testing of technologies. They essentially function as continuing channels for different countries to access new knowledge and technologies developed in other countries or research institutions. The growing strength of national agricultural research systems (NARS), new technological developments in advanced laboratories, and increasing concerns for the less favorable rice environments have increased the need and opportunities for networking for mutual benefit.

The goal of the program is expanded spillover of the effects of new rice technologies from regions where research is conducted to regions with similar agroecosystems. Collaboration among network members involves the exchange of expertise, research methodologies, and knowledge between NARS and IRRI, and among NARS themselves.

IRRI is the headquarters for three operational networks: the International Network for Genetic Evaluation of Rice (INGER), the International Network on Soil Fertility and Sustainable Rice Farming (INSURF), and the Asian Rice Farming Systems Network (ARFSN). Network in 1975 as means of disseminating IRRI-developed technologies, evolved into a true network, with significant contributions from participating NARS. In 1990, a fourth network, the Integrated Pest Management Network (IPMN), was organized with support from the Swiss Development Cooperation.

Subprogram I: International Network for Genetic Evaluation of Rice

International Network for Genetic Evaluation of Rice (INGER)

INGER is a global rice improvement network funded by the United Nations Development Programme. Active collaboration among the national rice research systems and the international agricultural research systems is the key feature of this network. Its objectives are to facilitate genetic improvement of rice and to promote genetic diversity for different ecosystems through global exchange, evaluation, and utilization of improved breeding materials originating from sources worldwide.

1989 NURSERY RESULTS

INGER composed 959 sets of 25 types of nurseries—13 for ecosystem and 12 for stress tolerance—and distributed them to 41 countries. A new nursery, the International Rice Drought Tolerance Nursery (IRDTN), was started during the year to evaluate the performance of promising upland and rainfed lowland varieties and breeding lines under severe moisture stress conditions. An additional goal was to identify gene sources for drought resistance for use in breeding programs.

Ecosystem-oriented nurseries. Top entries for the three maturity groups of irrigated rice —the International Irrigated Rice Yield Nursery - Very Early (IIRYN-VE), -Early (IIRYN-E), and -Medium (IIRYN-M)—are listed in Tables 1, 2, and 3. Tables 4 and 5 present details of the best performing entries in the two rainfed lowland yield nurseries of early (IRLYN-E) and medium (IRLYN-M) maturity. The highest yielding entries in the nurseries for the two

Table 1. Best performing entries in the 10th International Irrigated Rice Yield Nursery-Very Early (IIRYN-VE) based on overall mean yield (28 trials), 1989.

Designation	Origin	Days to flowering	Yield (t/ha)
IR66[a]	IRRI	93	4.7
IR50404-57-2-2-3	IRRI	87	4.5
AT77-1[a]	Sri Lanka	90	4.3
BG1203[a]	Sri Lanka	89	4.3
C1136-3	Philippines	82	4.3

[a]Also highlighted in previous years' tests.

Table 2. Best performing entries in the 17th International Irrigated Rice Yield Nursery-Early (IIRYN-E) based on overall mean yield (23 trials), 1989.

Designation	Origin	Days to flowering	Yield (t/ha)
IR35366-40-3-3-2-2[a]	IRRI	95	5.0
IR35546-17-3-1-3[a]	IRRI	95	5.0
IR44595-70-2-2-3[a]	IRRI	90	5.0
IR31805-20-1-3-3[a]	IRRI	98	4.9
SPRLR75001-68-2-2[a]	Thailand	94	4.9
S818b-10-2	Indonesia	98	4.9

[a]Also highlighted in previous years' tests

Table 3. Best performing entries in the 17th International Irrigated Rice Yield Nursery-Medium (IIRYN-M) based on overall mean yield (12 trials), 1989.

Designation	Origin	Days to flowering	Yield (t/ha)
B3894-22C-78-5[a]	Indonesia	99	5.0
BR203-70-B-2[a]	Bangladesh	97	4.8
Intan Gawri	India	109	4.8
IR68[a]	IRRI	98	4.8

[a]Also highlighted in previous years' tests.

Table 4. Best performing entries in the 9th International Rainfed Lowland Rice Yield Nursery-Early (IRLYN-E) based on overall mean yield (5 trials), 1989.

Designation	Origin	Days to flowering	Yield (t/ha)
IR33380-60-1-2-2[a]	IRRI	105	2.8
BR51-315-4[a]	Bangladesh	102	2.7
IR21567-16-3[a]	IRRI	98	2.7
IR46[a]	IRRI	100	2.7

[a]Also highlighted in previous years' tests.

maturity groups of upland rice, early (IURYN-E) and medium (IURYN-M), are given in Tables 6 and 7, respectively; those for IDRYN are in Table 8.

Nurseries for resistance or tolerance screening. Tables 9 and 10 list the best performing entries in nurseries established for specific stresses. Insect

Table 5. Best performing entries in the 9th International Rainfed Lowland Rice Yield Nursery-Medium (IRLYN-M) based on overall mean yield (11 trials), 1989.

Designation	Origin	Days to flowering	Yield (t/ha)
RP1057-393-1	India	113	3.3
BR850-9-1-1	Bangladesh	103	3.1
IR21141-24-2	IRRI	102	3.1
IR28526-44-1-1	IRRI	109	3.1
IR9884-54-3-1E-P1[a]	IRRI	107	3.1
MTU7633	India	113	3.1
RP1045-23-1	India	112	3.1

[a]Also highlighted in previous years' tests

Table 6. Best performing entries in the 15th International Upland Rice Yield Nursery-Early (IURYN-E) based on overall mean yield (17 trials), 1989.

Designation	Origin	Days to flowering	Yield (t/ha)
BR20 (BR201-193-1)	Bangladesh	84	2.4
ADT31	India	80	2.3
UPR103-80-1-2[a]	India	77	2.3
IET1444 (international check)[a]	India	79	2.2
IR3646-9-3-1	IRRI	91	2.2
NDR97[a]	India	71	2.2

[a]Also highlighted in previous years' tests.

Table 7. Best performing entries in the 15th International Upland Rice Yield Nursery-Medium (IURYN-M) based on overall mean yield (12 trials), 1989.

Designation	Origin	Days to flowering	Yield (t/ha)
B3016b-Tb-260-3-2-1-1-3[a]	Indonesia	91	2.5
IR27078-3-6	IRRI	100	2.4
IR5931-113-1	IRRI	94	2.3
IR43 (international check)[a]	IRRI	101	2.3
IR13260-100-1E-P2	IRRI	99	2.2
IR29429-B-3-B-1-4	IRRI	95	2.2
IR6023-10-1-1[a]	IRRI	99	2.2

[a]Also highlighted in previous years' tests.

Table 8. Best performing entries in the 2d International Deepwater Rice Yield Nursery (IDRYN), 1989 at 2 locations in India.

Designation	Origin	Days to flowering	Yield (t/ha)
BR222-B-358	Bangladesh	157	1.6
NC492	India	158	1.6
BKNFR76109-1-2-1	Thailand	141	1.5
IR21038-77-P2-5-2-3-1-1	IRRI	153	1.4
DWCB-B-110-H3	Bangladesh	158	1.3
Tilakkachari	India	159	1.3

nurseries were for brown planthopper (IRBPHN), whitebacked planthopper (IRWBPHN), and stem borer (IRSBN). Disease nurseries were for rice blast (IRBN), bacterial blight (IRBBN), and rice tungro (IRTN). Nurseries for other stresses were for salinity and alkalinity (IRSTON), acid upland soils (IRAUSN), acid lowland soils (IRALSN), cold tolerance (IRCTN), and drought tolerance (IRDTN).

Detailed results and analysis of the various yield and stress-oriented nurseries are given in INGER annual nursery reports, published separately.

Table 9. Best performing entries in the 1989 INGER insect and disease nurseries.

Nursery[a]	Trials (no.)	Entries[b]
IRBPHN	25	IR13146-45-2-3, IR21567-9-2-2-3-1-3, RP1579-1863-73-32-53, **BG367-2**, IR74, **PTB33**, RP1579-52
IRWBPHN	14	**BG379-2, IR15527-21-2-3, IR27316-6-2-2**, IR29692-99-3-2-1, IR29723-143-3-2-1
IRSBN		
• Greenhouse	4	**IR13475-7-3-2**, IR39385-124-3-3-2-3, **IR8608-75-3-1-3, TKM6 (Acc. 237)**
• Field	6	IR10198-66-2, **IR13475-7-3-2**, IR21567-9-2-2-3-1-3, **IR25587-133-3-2-2-2**, IR8608-75-3-1-3, IR25588-7-3-1, IR29658-43-3-2-1, **IR29692-99-3-2-1**, IR74
IRBN		
• Leaf blast	45	**IR42**, B5583C-19-ST-70-8, Suweon 360, B363H-ST-2-16-2, Cheolweon 44, Salumpikit, Suweon 352, Suweon 354, B5526F-ST-17, IR28228-96-3-2-1-3, IR31775-30-3-2-2-2
• Panicle blast	9	**Carreon**, Cheolweon 44, C711327, C722336, C731110, C731135, IRAT132, Iri 387, **IR25587-133-3-2-2-2, IR28228-119-2-3-1-1, IR37721-3-3-3-3-1, Milyang 82**, TNAU 80030, Unborig 5
IRBBN		
• Field	19	BR168-2B-23, **BR51-49-6-HR63, IR17494-32-1-1-3-2, IR35454-18-1-2-2, IR4442-46-3-3-3, Kalimekri 77-5 (Acc. 6613)**, PDR76-D10-D8-D1, **RP2151-224-4**
• Greenhouse	7	**AC19-1-1 (Acc. 32753), IR22082-91-1-2-2-2, RP2151-192-2-5, RP2151-224-4**, RP2151-32-2-11-3
IRTN		
• Greenhouse	3	**ARC11554, DWA8**, B3622e-Tb-5-4-4, **Utri Merah (Acc. 16682), Utri Rajapan (Acc. 16684), Pankhari 203**, BRC16-127-4-2, BR425-110-2-1-1-6-1
• Field	4	BRC16-127-4-1, BRC16-127-4-2, RP2263-934-592-5, BR1045-193-2-1, BR153-2B-10-1-3, IR19083-22-2-2

[a]IRBPHN = International Rice Brown Planthopper Nursery, IRWBPHN = International Rice Whitebacked Planthopper Nursery, IRSBN = International Rice Stem Borer Nursery, IRBN = International Rice Blast Nursery, IRBBN = International Rice Bacterial Blight Nursery, IRTN = International Rice Tungro Nursery. [b]Entries in boldface were also highlighted in previous years' tests.

Table 10. Best performing entries in the 1989 INGER stress nurseries.

Nursery[a]	Trials (no.)	Entries[b]
• Soils		
IRSTON		
Salinity Vegetative	8	CN540, Intan Gawri, **Nona Bokra**, IR19743-25-2-2-3-1, IR5931-110-1, **Pokkali**, OR142-99
Maturity	7	BR11, BR4, IR19083-22-2-2, IR22083-105-3-3-3-3, IR31361-8-3-2-2
Alkalinity Vegetative	4	IR13149-43-2-P1, IR18152-CN [illegible]-3-3, **IR29723-143-3-2-1**, IR32809-26-3-3, OR142-99
Maturity	4	**Nona Bokra**, IR14753-49-2, IR19431-72-2, IR26916-13-1-1-2-1-1, **Pokkali**, IR32809-26-3-3, X73-12-8
IRAUSN		
0 P	4	Aus 454, IAC165, IRAT170
60-P	4	Aus 454, IAC165, IRAT170, IR29429-B-3-B-2-3
IRALSN		
0-P	4	C22, **IR9764-45-2**
60-P	4	C171-120, **C22, ITA249, IR9764-45-2**
• Temperature		
IRCTN	26	IR15569-22-2-3-2-2-3-1-1-3, IR18482-PLP3-2-3-4-1-1, IR18482-PLP3-1-2-1-1-1, B4190E-CW-139-29-176, IR13105-60-30-3-1-2-1, **JKAU(K)450-126-2**, IR18482-PLP-1-2B
• Moisture		
IRDTN	5	B2992b-Tb-73-4-2-3-3-3-2, IR42583-34-1-2-2-1

[a]IRSTON = International Rice Salinity Tolerance Observational Nursery, IRAUSN = International Rice Acid Upland Screening Nursery, IRALSN = International Rice Acid Lowland Screening Nursery, IRCTN = International Rice Cold Tolerance Nursery, IRDTN = International Rice Drought Tolerance Nursery. [b]Entries in boldface were also highlighted in previous years' tests.

Table 11. Utilization of 1989 INGER nursery entries.

Region and country	Entries (no.) used for				Region and country	Entries (no.) used for			
	Hybridization	Yield testing				Hybridization	Yield testing		
		Local	State	National			Local	State	National
East Asia					North Africa				
China	33	-	-	-	Egypt	25	-	-	42
Korea	15	-	-	-	Sub-Saharan Africa				
Taiwan	29	-	-	-	Cameroon	3	10	-	-
Southeast Asia					Mozambique	-	2	-	-
Indonesia	2	15	-	-	Nigeria	-	35	-	-
Malaysia	23	-	-	56	Rwanda	-	19	-	-
Myanmar	39	14	4	30	South Africa	-	-	5	5
Philippines	27	30	-	-	Tanzania	9	78	-	-
Thailand	150	110	-	8	Zaire	-	14	-	14
Vietnam	45	89	8	1	Zimbabwe	-	6	-	-
South Asia					Latin America				
Bangladesh	85	319	-	3	Colombia	2	-	-	-
India	139	221	29	-	Dominican Republic	-	-	-	144
Nepal	-	13	16	10	Mexico	38	14	46	-
Pakistan	50	140	23	23	Europe				
Sri Lanka	83	27	-	10	Spain	6	6	-	-
					Total	803	1162	131	352

Utilization of 1989 nursery entries. National rice improvement programs are actively utilizing INGER entries either for follow-up trials or in hybridization programs. A total of 626 entries from the 1989 INGER trials were utilized for further yield testing in 20 countries, whereas 456 entries were used as parents in the breeding programs of 19 countries. Utilization of 1989 INGER nursery entries by country is shown in Table 11. The most frequently utilized entries are listed in Table 12.

Because of their outstanding performance, four INGER entries were released in 1990. IR10781-75-3-2 from IRRI and B2983b-Sr-85-3-2-4 from Indonesia were released in India; Suweon 287 from Korea, released in Guatemala; and IR10147-113-5-1-1-5 from IRRI, released in the Philippines.

Table 12. 1989 INGER entries most frequently included in national follow-up trials.

Entry	Origin	Nursery[a]
IR29670-52-3-2	IRRI	IIRON
IR32429-47-3-2-2	IRRI	IIRYN-VE, IRBN
IR51009-62-3-3-3	IRRI	IIRON
IR5629-64-3	IRRI	IRSTON
IR66	IRRI	IIRYN-VE, IIRON, IRBBN
RP1897-3790-30-1	India	IIRYN-VE

[a]IIRON = International Irrigated Rice Observational Nursery, IIRYN-VE = International Irrigated Rice Yield Nursery-Very Early, IRBN = International Rice Blast Nursery, IRSTON = International Rice Salinity Tolerance Observational Nursery, IRBBN = International Rice Bacterial Blight Nursery.

1990 NURSERY DISTRIBUTION

A total of 921 sets of 23 types of INGER nurseries (13 for ecosystem types and 10 for stress tolerance) were composed and distributed to 35 countries: 788 nursery sets were distributed to 18 countries in Asia, 29 to 2 countries in West Asia and North Africa, 56 to 5 countries in Sub-Saharan Africa, 38 to 6 countries in Latin America, 5 to 3 countries in Europe, and 5 to Oceania. A total of 1,716 nursery entries were distributed around the world (Table 13).

MONITORING VISITS AND PLANNING MEETINGS

The 1990 disease resistance monitoring tour to China and the Philippines organized by INGER further strengthened linkages among rice scientists. The INGER advisory committee, composed of rice scientists from 15 countries, met in Bogor, Indonesia, 6-12 Dec 1990 to review the results of the 1989-90 trials and formulate the network plans for 1991.

Table 13. Origin and types of entries in the 1990 INGER nurseries dispatched from IRRI.

Nursery	Sets dispatched (no.)	Entries (no.)	National program (no.)	IRRI (no.)	CIAT (no.)	IITA (no.)	IRGC (no.)
IIRYN-VE	60	15	7	8	0	0	0
IIRYN-E	53	22	14	8	0	0	0
IIRYN-M	42	25	17	8	0	0	0
IURYN-E	36	16	13	3	0	0	0
IURYN-M	25	19	13	5	0	1	0
IRLYN-E	16	10	7	3	0	0	0
IRLYN-M	21	17	15	2	0	0	0
IDRYN	12	14	7	7	0	0	0
IIRON	97	307	166	115	25	0	[illegible]
IURON	67	187	101	43	11	11	21
IRLON	38	146	86	51	0	1	8
IDRON	25	106	54	51	0	0	1
ITRON	9	19	8	10	0	0	1
IRCTN	64	79	43	23	3	0	10
IRSTON	54	43	24	18	0	1	0
IRALON	24	22	10	8	1	1	2
IRDTN	31	61	26	30	0	4	1
IRBN	83	246	179	46	16	1	4
IRBBN	38	96	66	20	0	0	10
IRTN	24	80	58	19	0	0	3
IRBPHN	41	107	81	21	0	0	5
IRWBPHN	25	42	24	17	0	0	1
IRSBN	36	37	20	15	0	1	1
Total	921	1716	1039	531	56	21	69

The observations and recommendations relative to the monitoring tour and meeting are published separately.

INGER and related activities in Africa

INGER-Africa, a collaborative program of IRRI, the International Institute of Tropical Agriculture (IITA), the West Africa Rice Development Association (WARDA), and African national programs, continued to consolidate its programs and introduce new ones. New nurseries were formed and monitoring tours were undertaken in some countries not previously covered by INGER.

Ten INGER-Africa nurseries were composed in 1990. In 1989, the African Mangrove Swamp Rice Observational Nursery (AMSRON) was added. In the last 2 yr, INGER-Africa nursery trials have been increased. The promising entries from 1989 INGER-Africa are listed in Table 14.

INGER-Africa also organized the following monitoring visits and workshops to strengthen collaboration among African scientists.

- Mid-altitude irrigated rice tour to Rwanda, 25-29 June
- Rice gall midge monitoring tour to Burkina Faso, 10-14 September
- Monitoring tour to Guinea, 23 September-3 October
- Mangrove swamp monitoring tour to Guinea Bissau, November

One of the major objectives of INGER-Africa in the immediate future is to ensure the effective continuity of IRRI/INGER activities in Africa.

INGER and related activities in Latin America and the Caribbean

For 1990, 102 nursery sets were distributed, and 83 lines nominated by national programs were included (Table 15).

The following new operational features of INGER-Latin America were adopted during 1989-90.

- Additional evaluation of F_2 materials from the CIAT Rice Program in order to include CIAT lines at F_3 generation.
- Full characterization of materials nominated by national programs.

Nine varieties were released in five Latin American countries during 1989-90 (Table 16).

Table 14. Promising entries in Africa, 1989 INGER-Africa nurseries.

Nursery[a]	Entries
AIRAT	ITA304, BW348-1, IR19670-263-3-2-2-1, IR22082-41-2, ITA302
AURAT	IDSA16, IRAT147, IRAT144, IDSA10, ITA321, TOX1012-12-28
AIRON	IR31837-11-2-2-1-2, IR64, IR65, IR68, CP3-C2, DR33-PD5-PD2-PD4-PD1, ITA312, TOX312, TOX3093-10-2-3-2, Vijaya
AURON	IR14632-2-3, ITA116, ITA183, TOX1010-21-5-12-4, TOX1768-3-1-101-1, TOX1780-7-1-201-1, TOX1889-3-102-1-1-2, TOX1889-4-101-1-1-2, TOX1889-3-104-3-1-1, TOX1889-7-105-2-1, TOX1945-8-101-2-1-3, Wabis 550
AIRPSS	Bouake 189, TOX3098-12-1-1-1, FAROX317-8-2, MRC2668-2483, P2015F4-128-5-4-1B, TOX2078-1-2-3, TOX3084-143-1-4-3, TOX3118-12-1-3-1, TOX3133-59-1-2-4, TOX981-10-3-2, TOX981-11-2-3
AURPSS	IRAT291 (GA4393), ITA130, ITA132, FAROx299, IRAT239 (IREM779), IRAT284 (GA4475), ITA257, TGR68, TOX1889-3-104-3-1-1, TOX1889-13-14-1-1, TOX1889-22-101-1
ALRESS	IR21170-43-12-2-2, IR28941-1-3-5-1-2, IR33461-39-3, BR51-282-8-HR83, IR33238-25-2-3-2, IR43506-CPA-513-2-1-1, ITA230, SPT7106-2-3-3-1, TOX3098-9-1-2-3-3
ARBN	ITA116, IRAT104, IDSA13 (IRAT265), ITA183, Milyang 82, TOX3108-43-1-5-3-6, IRAT13, IRAT124, ITA130, TOX955-208-2-102, TOX3108-17-2-1-2-6, TOX3118-73-2-1-1-1

[a]AIRAT = African Irrigated Rice Advanced Trial; AURAT = African Upland Rice Advanced Trial; AIRON = African Irrigated Rice Observational Nursery; AURON = African Upland Rice Observational Nursery; AIRPSS = African Irrigated Rice Preliminary Screening Set; AURPSS = African Upland Rice Preliminary Screening Set; ALRESS = African Lowland Rice Evaluation and Screening Set; ARBN = African Rice Blast Nursery

The following workshop and meeting were organized by INGER-Latin America in 1990.

- Second Steering Committee Meeting, Concepcion del Uruguay, Argentina, 11-17 March.
- Third Germplasm Evaluation and Selection Workshop, Villavicencio and Palmira, Colombia, 29 July-1 August.

To create a communication tool for Latin American rice researchers, INGER-Latin America is preparing a data base on rice workers. A data base on the Rice Crossing Programs in Latin America has also

Table 15. Characterized germplasm in observational nurseries distributed in Latin America, 1990.

Tolerance of germplasm	1st semester		2d semester		Total	
	Lines (no.)	Sets (no.)	Lines (no.)	Sets (no.)	Lines (no.)	Sets (no.)
			Favorable conditions			
Blast						
Blast only	52	9	52	2	52	11
Sogata/hoja blanca	9	10	9	0	9	10
Earliness	9	5	9	6	9	11
Fe toxicity	41	0	41	2	41	2
Earliness/ Fe toxicity	7	0	7	3	7	3
Fungal diseases						
Fungal diseases only[a]	43	32	43	4	43	36
Sogata/hoja blanca	8	18	8	0	8	18
Subtotal	-	74	-	17	-	91
			Unfavorable conditions			
Acid soils	42	4	42	7	42	11
Total	-	78	-	24	-	102

[a]Blast, neck blast, leaf scald, and glume discoloration

Table 16. Rice varieties released in Latin America, 1989-90.

Entry	Cross	Name given	Institution and country
P2020	Cica 8/BG90-2/Tetep	Aliança	CNPAF, Brazil
Taebaegbyeo (Suweon 287)	IR24*2/IR747B2-6-3	ICTA-CRISPO	ICTA, Guatemala
P4382F3-70	17330/7152/Metica 1	CARDI-70	CARDI, Belize
J276-43-1-15	J212/Mingolo	Juma 63	CEDIA, Dominican Rep.
P3831F3-RH38-8-1M-J182	Oryzica 1/7152/Costa Rica	Juma 64	CEDIA, Dominican Rep.
ECIA67-148-S1-1-5-3-2	CP1C8/ECIA22-8-163	IIAC-14	IIA, Cuba
ECIA179-S-13	CP3C2/ECIA13-31-1/CP1C8/C-4-10-1	IIAC-15	IIA, Cuba
P2030	Cica 4//4440/Cica 7	Pericuma	CNPAF and EMBRAPA, Brazil
IR10120-7-2-1	IR9538/IR9575	Sureste	INIFAP, Mexico

been prepared. Crosses from Argentina, Brazil, Colombia, Chile and the Dominican Republic, and Mexico and Peru have been compiled.

Subprogram II: Crop and resource management networks

International Network on Soil Fertility and Sustainable Rice Farming (INSURF)

The International Network on Soil Fertility and Sustainable Rice Farming (INSURF) was organized in 1987 to address increasing concern for sustainable rice-based farming systems and to develop an integrated and holistic approach to soil nutrient management in rice. Maintaining soil health and increasing productivity at a minimum cost without adverse effects on the environment together with socioeconomic and equity issues are the most pressing challenges faced by the network.

During the 1989-90 cropping seasons, about 30 collaborating scientists from 7 countries participated in the main network collaborative research trials. Research efforts have recently been directed toward managing adverse soil types such as the acid upland soil prevalent in the humid tropics. Acid uplands are

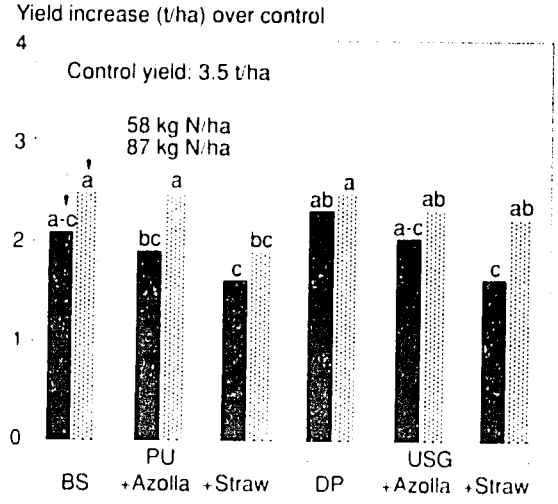
gaining importance as more and more of these harsh soils are cultivated as a result of decreasing traditional ricelands and increasing population pressures.

In addition, research trials focused on generating appropriate and economically feasible technologies that involve inorganic N combinations with azolla, green manure, compost, and other biofertilizers. Stability of yields and their long-term effects on soil properties are primarily considered when evaluating the technologies. The fertility trials seek to generate information on the long-term consequences of continuous application of NPK fertilizers and other limiting nutrients, such as S and Zn, on soil health and productivity.

Integrated use of inorganic and organic nitrogen

First trial. The significant findings from 63 trials at 17 sites during 1984-89 cropping seasons were reported in *Program report 1989*. Results of the ongoing trials at eight sites in China, India, Indonesia, and the Philippines for 1990 cropping seasons have not been collated, except for those on the IRRI experimental farm, Los Baños, Philippines. This trial consisted of 13 treatments involving 2 N levels with the N from organic sources equivalent to 29 kg N/ha. The inorganic N sources prilled urea (PU) and urea supergranule (USG) were tested alone or combined with organic N source azolla or rice straw. Changes in soil characteristics at this site were monitored after 5 and 10 consecutive crops to determine the long-term effects of the fertilizer treatments on the fertility status of the soil. Exchangeable K increased, more apparently in treatments involving rice straw as N source as did organic matter and total N contents. Available P and Zn substantially increased at 0 to 20-cm soil depth. At 20- to 40-cm soil depth, however, a gradual decrease in available Zn was apparent after 5 and 10 crops.

Results indicate that the combined inorganic and organic N sources were as effective as the inorganic fertilizer. Figure 1 shows a significant crop yield response to N when the organic N source was applied in combination with an inorganic N source. In general, yield increases over the control for the fertilizer treatments were comparable. Azolla proved to be a slightly better source of N than rice straw. Materials with high C:N like rice straw may depress yield because of partial immobilization of N.



1. Mean rice grain yield responses (av of 7 trials, 1984-90 dry season [DS]) of treatments involving inorganic N source, alone or combined with organic fertilizers, at 2 N rates in Los Baños, Philippines. PU BS = best split prilled urea, USG DP = deep placed urea supergranule. Bars with a common letter are not statistically different at the 5% level by DMRT.

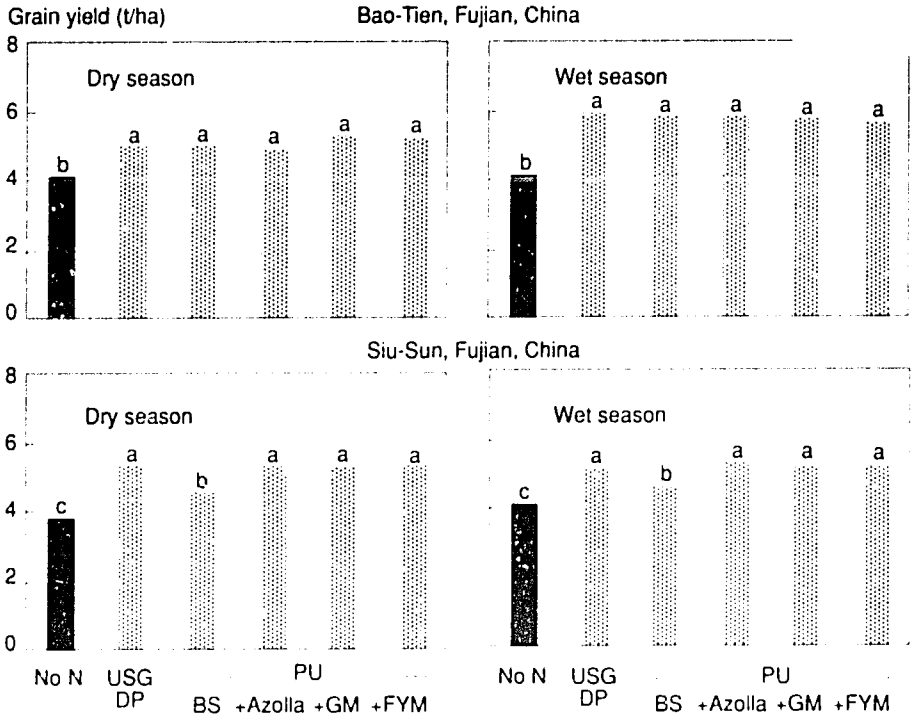
Second trial. In the second integrated nutrient management trial in irrigated rice, the performance of azolla, green manure (GM), and farmyard manure (FYM) combined with inorganic N fertilizers was evaluated.

Results from 29 trials conducted at 16 sites in 5 countries indicate that moderate amounts of organic material (equivalent to 43.5 kg N/ha) combined with inorganic fertilizers are equally effective if not better than inorganic fertilizer alone (Fig. 2). A variety of alternative N sources can be used to supplement the expensive chemical fertilizer used in rice production.

Azolla, *Sesbania rostrata*, and poultry manure were evaluated as potential sources of supplementary N in rainfed lowland rice in six trials (1987-90 wet season [WS]) in two rainfed farmers' fields in Nueva Ecija, Philippines. Results suggest that inorganic and organic N source combinations were as effective as inorganic fertilizers applied alone (Fig. 3).

Upland (soil pH<5) trial

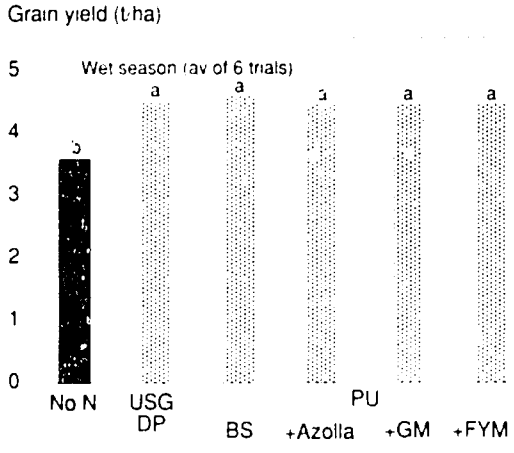
Ammonium sulfate (AS) and PU combinations with organic materials, namely, *Casia* spp., *Glyricidia sepium*, and *Helianthus annuus* as green leaf manures (GLM) and poultry manure as FYM were evaluated. The organic sources contributed 30 kg of



2. Mean grain yield of rice (av of 3-4 trials, 1987-90) as affected by inorganic and organic N fertilizer combinations at 2 sites in China and 1 site in India. GM = green manure: bean straw for wet season (WS) trial and *Sesbania rostrata* for DS trial. FYM = farmyard manure: hog or cattle manure. N rate = 87 kg N/ha. Bars with a common letter are not statistically different at the 5% level by DMRT.

the total N requirement of 60 kg/ha. Six trials were conducted at two Philippine sites, one with soil pH 4.6 and the other with pH 5.0.

No significant differences in grain yield of the fertilizer treatments including control were observed,



3. Mean grain yield of rainfed lowland rice (av of 6 trials, 1988-90 WS) as affected by inorganic and organic N fertilizer combinations across 2 farmers' fields in Guimba, Nueva Ecija Province, Philippines. GM = *S. rostrata*. FYM = poultry manure. Bars with a common letter are not statistically different at the 5% level by DMRT.

except in 1988 WS at soil pH 4.6, where response to N was significant. PU combined with organic materials produced grain yields (about 3 t/ha) comparable to that with inorganic fertilizers alone (about 3.4 t/ha). The poor N response in most of the trials could be due to drought and incidence of rice blast disease during the reproductive growth stages of the crops. It is expected that under normal growing conditions, the integrated use of inorganic and organic N fertilizers in acid upland rice soils should be beneficial on both short- and long-term basis.

Long-term fertility trials in irrigated rice

First trial. The objective of the first trial was to monitor the effects of continuous chemical fertilizer application and intensive cropping on soil health and productivity. By 1990, a total of 242 trials had been conducted at 24 sites in 13 countries. However, only 9 sites—four in China, two each in Indonesia and the Philippines, and one in India—are on-going.

Grain yields from 1976 to 1990 on an acidic Aquic Troporthent soil in Luisiana, Philippines, and on a calcareous Vertic Tropaquept soil in Tanay, Philippines, gradually declined in nonfertilized and

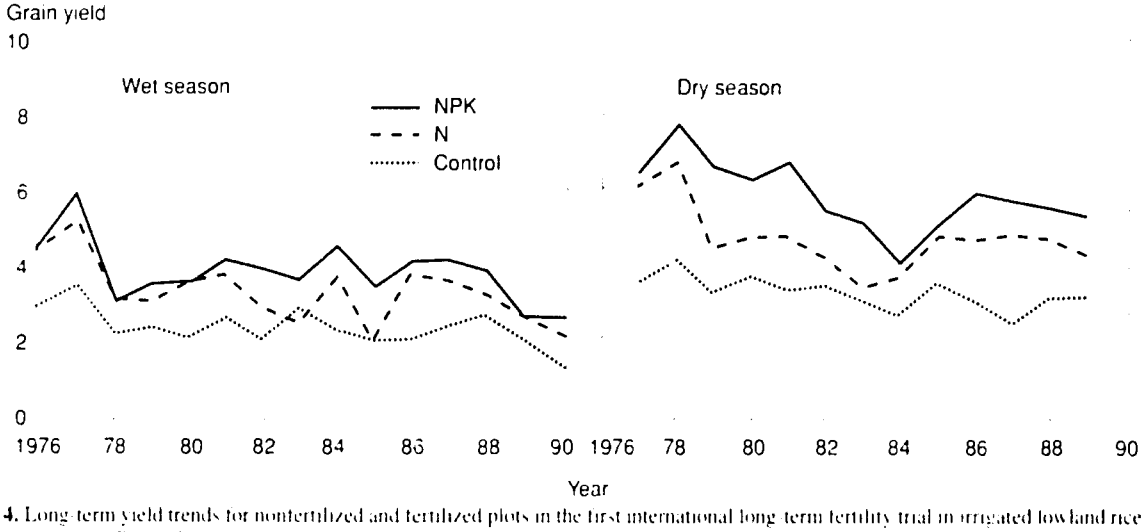
fertilized plots (Fig. 4,5). The observed fluctuations may be due to cultivars used, adverse weather conditions, and prevalent pests and diseases. Nitrogen continues to be the major limiting nutrient in both soils. However, the addition of P and K to N enhanced yield, especially during dry season (DS).

Second trial. The second long-term fertility trial for the irrigated rice ecosystem, initiated in 1987, includes treatments on inorganic and organic fertilizer combination and site-specific problems. As of 1990, trials had been conducted at 10 sites: 3 in India; 2 each in Indonesia, Myanmar, and Pakistan; and 1 in Malaysia. Preliminary results showed that the use of FYM in combination with NPK enhanced grain yield. Nutrients such as Zn and S added to NPK can further increase yields at sites where these elements are limiting.

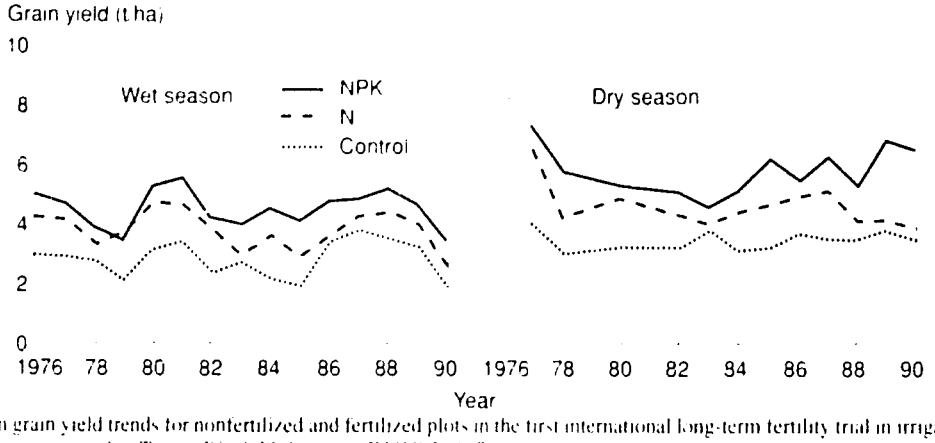
Soil fertility management for strongly acid upland soils (pH<5)

Upland rice was initially more responsive to applied P than to lime at sites in the Philippines. However, grain yields from plots treated with lime alone improved with time, except during droughty crop seasons. At the Cavinti site, fused magnesium phosphate alone and triple superphosphate at 36 kg P/ha combined with either 0.75 or 1.50 t lime/ha were consistently the best treatments, as shown by the high average grain yields data for 7 yr (Fig. 6).

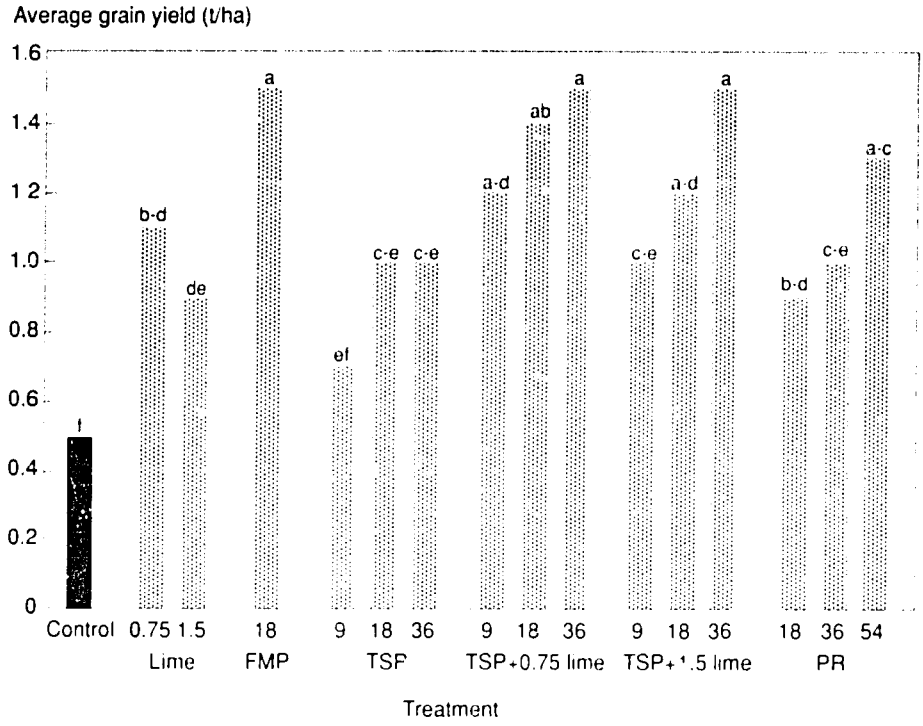
At the Claveria site, specifically Minsacuba, yields in plots treated with either 0.75 or 1.50 t lime/ha did not differ from that in the control. Other treatments, however, gave better yield than the control, but with only slight differences among treated plots (Fig. 7). Results in the Plaridel trial were similar to those in



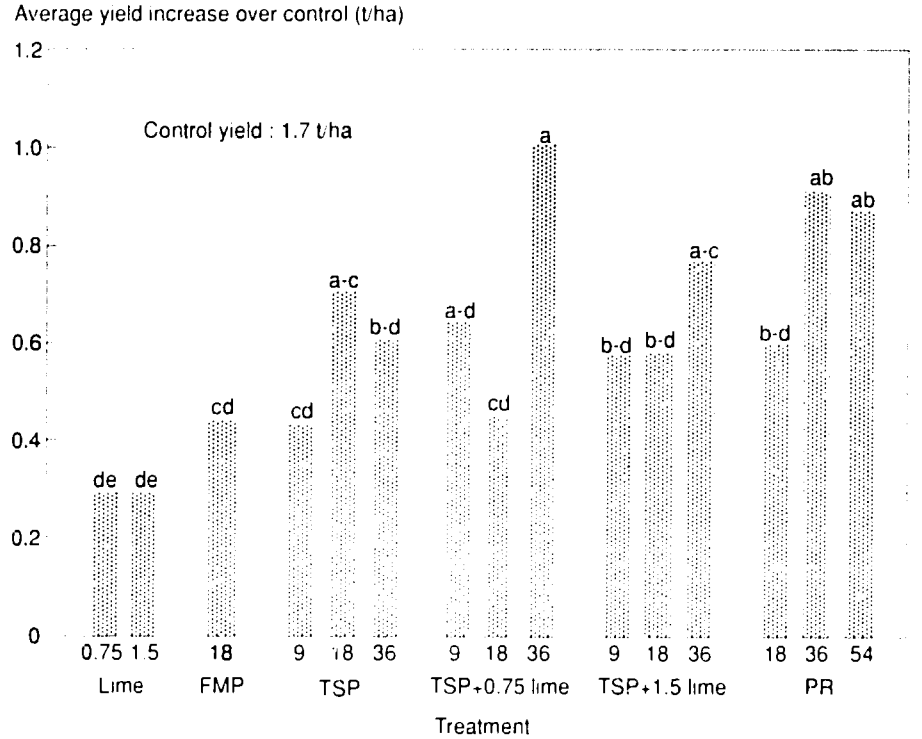
4. Long-term yield trends for nonfertilized and fertilized plots in the first international long-term fertility trial in irrigated lowland rice on an Aquic Troporthent soil in Luisiana, Lagana, Philippines. INSURE, 1976-90.



5. Long-term grain yield trends for nonfertilized and fertilized plots in the first international long-term fertility trial in irrigated rice on an Aquic Tropaquept soil in Tanay, Rizal, Philippines. INSURE, 1976-90.



6. Average grain yield of different treatments over 7 yr of continuous rice cropping, Cavinti, Laguna, Philippines, 1990. FMP = fused magnesium phosphate, TSP = triple superphosphate, PR = phosphate rock. Lime rate in t/ha, P rate in kg/ha. Bars with common letters are not significantly different at the 5% level by DMRT.



7. Average yield increase of different treatments over the control for the first P × lime trials in Minsacuba, Misamis Oriental, Philippines, 1986-90. Bars with common letters are not significantly different at the 5% level by DMRT.

Minsacuba. Because little differences were observed among treatments, the economics of each will have to be considered to assess their applicability.

Yield increase associated with phosphate rock application became evident only after several trials. Soil properties, such as pH and available P, changed only slightly even after several years of continuous lime and P fertilization. Results show that lime together with P fertilizer must be applied in optimum amounts to significantly increase rice grain yield in acid upland soils. Once P deficiency and soil acidity are corrected, proper management of other nutrients becomes important to increase grain yield.

Management of other nutrients

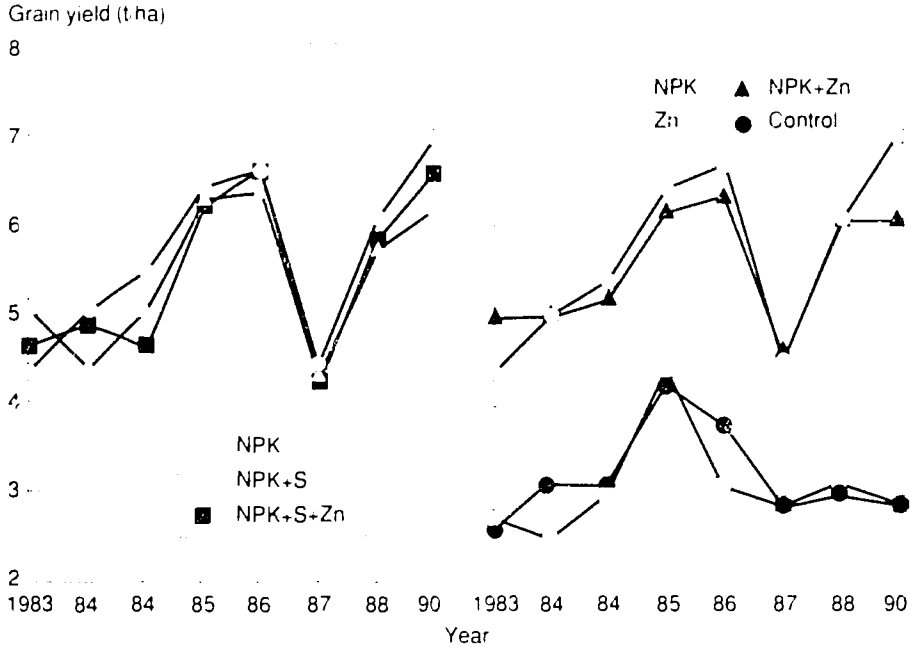
Long-term sulfur fertility trial. The effect of continuous application of high analysis fertilizers—urea, triple superphosphate, and potassium chloride—on rice grown in a clay soil at IRRI farm was evaluated in a long-term fertility trial. In its 17th cropping season, yield responses to NPK alone were comparable to those to NPK + Zn, NPK + S, and NPK + S + Zn and significantly higher than those to Zn alone in all DS trials (Fig. 8). Despite application of high-analysis fertilizers containing almost no S, S deficiency was not apparent.

In 1990 DS (16th crop), N combined with other nutrients and organic manure significantly increased yield, whereas Zn fertilizer applied alone or with P, K, or both gave no response (Table 17). Nitrogen continued to be the major limiting nutrient during DS.

Varietal reactions of lowland rice to sulfur deficiency. A trial in a S-deficient site in Batangas, Philippines, was conducted in 1990 DS to identify rice varieties with relatively greater tolerance for low S in irrigated lowland soils. Nine varieties of different maturity periods were tested using ammonium sulfate as S source at 20 kg S/ha. With or without S, IR34 produced significantly lower yield than did the other varieties (Table 18). IR54 gave the highest yield with no S, whereas IR20 gave the highest yield at 20 kg S/ha. Yields of IR42 and IR64 increased significantly when S was added (Fig. 9). The 1990 WS residual trial was established late because floods recurred at the site. The trial is still in progress.

Effect of combined sulfur and zinc application on lowland rice. A trial in 1990 DS at an adjacent site in Batangas, Philippines, determined the effect of combined S and Zn application on yield and yield components of IR72 lowland rice.

Addition of Zn had no significant positive effect on tiller number and plant height at 30 d after transplanting (DT), and on grain yield of IR72 at any S rate (Table 19). With or without Zn, addition of S



8. Grain yield trends over 8 yr of 7 treatments during dry season in Block 421-A, IRRI farm. Long-term S fertility trial in irrigated rice, 1983-90.

Table 17. Yield of 15 treatments in the long-term S fertility trial in irrigated lowland rice. IRRI, 1990.

Treatments	Yield (t/ha)	
	DS	WS
Control	2.9 d	3.0 c
Zn alone	2.9 d	3.4 bc
P + Zn	2.7 d	3.6 abc
K + Zn	2.9 d	3.3 bc
PK + Zn	2.8 d	3.5 abc
N + Zn	6.5 ab	3.7 ab
NP + Zn	6.9 a	3.8 ab
NK + Zn	6.5 ab	3.6 abc
NPK	7.0 a	4.0 a
NPK + Zn	6.1 b	3.8 ab
NPK + S	6.2 b	3.6 ab
NPK + Zn + S	6.6 ab	3.8 ab
NPK + Azolla + Zn	6.1 b	3.3 bc
NPK + Straw + Zn	5.4 c	3.6 abc
NPK (*S. rostrata*)	6.6 ab	3.5 abc

significantly enhanced tiller number and plant height at 30 DT. Tiller number and plant height at 30 DT and grain yield average across all Zn levels were significantly higher at 20 kg S/ha than at 0 and 10 kg S/ha.

Asian Rice Farming Systems Network

The objective of the Asian Rice Farming Systems Network (ARFSN) is to identify more productive

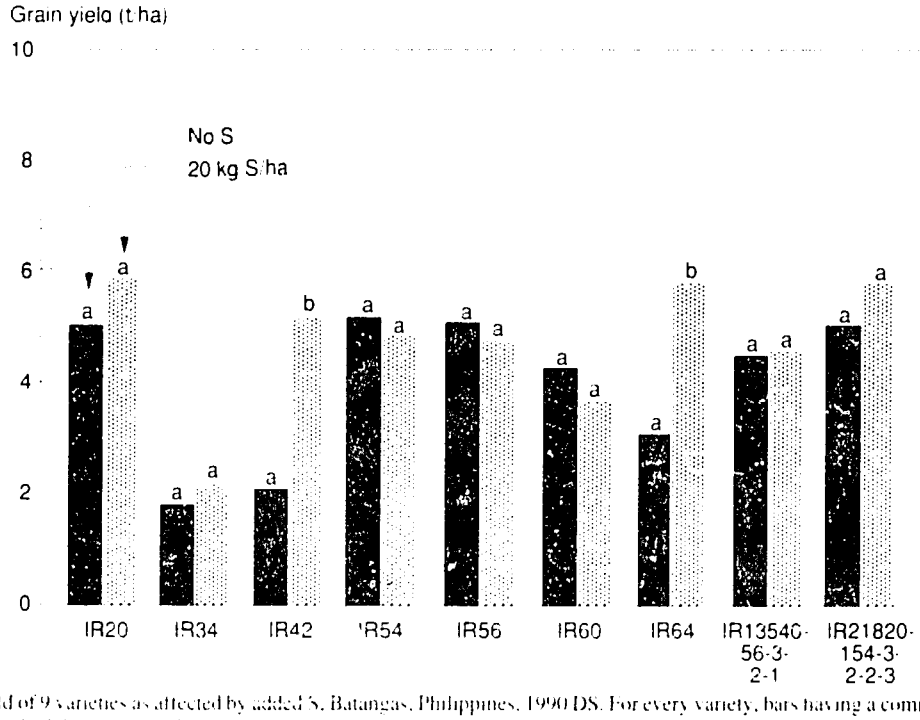
Table 18. Effect of S added S on grain yield (t/ha) of 9 varieties. Batangas, Philippines, 1990 DS.

Variety	S rate (kg/ha)		Mean
	0	20	
IR20	4951 a	5860 a	5406 a
IR34	1755 c	2174 e	1965 e
IR42	2060 bc	5169 abc	3614 d
IR54	5159 a	4801 abc	4980 ab
IR56	5001 a	4737 bc	4869 ab
IR60	4249 a	3700 d	3975 cd
IR64	3029 b	5815 ab	4422 bc
IR13540-56-3-2-1	4439 a	4446 cd	4443 bc
IR21820-154-3-2-2-3	5037 a	5768 ab	5402 a

rice-based farming systems in different rice environments. At present there are 17 collaborating countries: Bangladesh, Bhutan, Cambodia, China (including Taiwan), India, Indonesia, Laos, Madagascar, Malaysia, Myanmar, Nepal, Pakistan, the Philippines, South Korea, Sri Lanka, Thailand, and Vietnam. Several research activities on production systems and component research are on-going.

Cropping systems testing

Most of the sites focus on cropping pattern testing in different rice ecologies: rainfed lowland, irrigated, upland, and deep water. At most sites, component technology research (adaptive or applied) is con-



9. Grain yield of 9 varieties as affected by added S. Batangas, Philippines, 1990 DS. For every variety, bars having a common letter are not significantly different at the 5% level by DMRT.

Table 19. Effect of S and Zn on tiller number and plant height at 30 DT, and grain yield of IR72, Batangas, Philippines, 1990 DS.

Zn rate (kg/ha)	S rate (kg/ha)[a] 0		10		20		Mean	
	Tiller number/m²							
0	337	a	515	a	677	ab	510	a
20	344	a	523	a	563	b	477	a
40	342	a	589	a	594	ab	508	a
2% ZnO	492	a	432	a	754	a	559	a
Mean	379		515		647			
	Panicle height (cm)							
0	34	a	40	a	43	a	39	a
20	34	a	38	a	41	a	37	a
40	33	a	38	a	41	a	38	a
2% ZnO	37	a	36	a	45	a	39	a
Mean	35		38		42			
	Grain yield (t/ha)							
0	6.1	a	6.2	a	6.8	a	6.3	a
20	5.9	a	6.0	a	6.1	a	6.0	a
40	6.2	a	6.1	a	6.3	a	6.2	a
2% ZnO	5.9	a	6.0	a	6.4	a	6.1	a
Mean	6.0		6.1		6.4			

[a]In a column under each parameter, treatment means having a common letter are not significantly different at the 5% level by DMRT

ducted on major problems such as varietal, fertilizer, and crop management trials in addition to cropping pattern testing. In cropping pattern trials, two or more experimental cropping patterns are evaluated and compared with the farmers' existing dominant cropping pattern. The major objective is to increase production, income, and cropping intensity, taking into consideration the farmers' resources. Some findings from selected countries are presented here.

In Guangdong, China, two rice crops under irrigated condition is the most common cropping pattern. A long-term cropping pattern trial at the Xinhua site involved green manure - rice - rice, rice - rice, and vegetable - rice - rice. All the vegetable - rice - rice cropping patterns (cauliflower, broccoli, and Xiaobaicai) showed much higher net returns ($4,154 - $5,609) than green manure - rice - rice ($1,641) and rice - rice ($1,534). There was an increase in organic matter, N, P, and potash content in the vegetable - rice - rice cropping patterns compared to pretrial soil test and rice - rice (check).

In Sichuan, China, the traditional cropping pattern is wheat/maize/sweet potato. The lowland rice hybrid Shanyou 63 was evaluated under upland conditions in different cropping patterns: wheat/maize - rice, wheat - rice, wheat/maize/rice, wheat - sweet potato + rice, wheat/maize/sweet potato + rice, and wheat/maize/sweet potato (check). Shanyou 63 yielded 5.19 t/ha in the wheat - rice cropping pattern but only 2.8 t/ha when relay cropped or intercropped with maize or sweet potato. The highest production was from wheat/maize/sweet potato + rice.

In Taiwan, research focused on planting maize, sorghum, and soybean in ricefields instead of a second rice crop. Since 1984, when the conversion plan started, superior maize, soybean, and vegetable varieties have been developed for this purpose. Long-term trials on different cropping patterns were conducted in Hualien and Tainan under irrigated conditions. In Hualien, four cropping patterns were evaluated: rice - rice, peanut - rice, rice - soybean, and maize - soybean. The most promising in terms of yield and net return are peanut - rice and maize - soybean compared with rice - rice. Two years of continuous maize - soybean pattern improved soybean yield significantly. In Tainan, six cropping patterns were evaluated in a long-term trial since 1986: rice - rice, rice - soybean - maize, rice - green manure - maize, soybean - rice - maize, sorghum - ratoon sorghum - maize, and sorghum - soybean - maize. Net return was highest from rice - soybean - maize and sorghum - soybean - maize, 68 and 65% higher than rice - rice, respectively.

In Myanmar, rice-based cropping pattern trials were conducted at four key sites of the network: Yezin—partly irrigated, Shwelaungkyun—deepwater, Patheingyi—fully irrigated, and Taikhyi—rainfed lowland. In Yezin, peanut - transplanted rice (TPR), TPR - chickpea, dry seeded rice (DSR) - chickpea, and DSR - cowpea were evaluated in farmers' fields and compared with the farmers' existing cropping pattern sesame - TPR. Net return was highest from peanut - TPR followed by TPR - chickpea. In the station, TPR - chickpea showed higher net return, whereas the net return of peanut - TPR was 95% better than the farmer's sesame - rice. Two cropping patterns were evaluated at Shwelaungkyun deepwater rice (DWR) site using different rice seeding techniques. The rice - sunflower showed higher net return than monocrop DWR. DSR - sunflower showed higher net return than transplanted rice - sunflower. In Taikhyi, the most promising cropping pattern was rice - sunflower from previous trials.

In the Philippines, the four key sites in irrigated rice ecosystems are Guimba, Nueva Ecija; Pototan, Iloilo; Iriga, Camarines Sur; and Campostela, Davao del Norte. In Nueva Ecija the rice - maize cropping pattern gave higher net return ($1,525) than the farmer's practice of rice - rice ($1,407) especially in medium-textured soils. In Davao del Sur and Camarines, the improved rice - mungbean - rice gave higher net return than the farmer's rice - rice. Mungbean gave additional income in Camarines Sur and improved the soil. In Davao del Norte, rice yield increased when mungbean was incorporated as green manure.

The rainfed rice sites in the Philippines are in Tumauini, Isabela and Carmen, Bohol. In Isabela, about 388 farmers with 153 ha in 8 locations adopted the mungbean - rice where before only monocrop rice was grown. The average net income from rice - rice - mungbean was two times higher than that from rice - rice.

Cropping systems testing in Thailand is conducted at different sites, both rainfed lowland and irrigated. In the former, farmers grow only one rice crop. In 1987, mungbean was tested before rice. The results after 2 yr of evaluation showed the very promising performance of mungbean before rice. In 1989, multilocation testing of mungbean - rice involved 80 households with an area of 50.8 ha. The net return from mungbean - rice was 141% better than that from monocrop rice. In Ampoe Borabu, Mahasarakhan, where rice cultivation in the upper fields is risky, results indicate that 3 cropping patterns can be grown; sesame - peanut showed 296% more net income than the farmer's monocrop rice. Three cropping patterns evaluated in Khuan Khanun, Phattalung—mungbean - sweet maize - rice, peanut - sweet maize - rice, and peanut - potato - rice—gave higher net returns than peanut - rice, which is the farmers' traditional cropping pattern. Peanut - sweet maize - rice was 195% better.

In Sisaket, representing irrigated ecology, the planting of soybean after rice was introduced. Soybean yield was 2.11 t/ha, whereas the farmers' practice with peanut had been 0.92 t/ha, the net return from soybean was 81% better.

At the research site representing rainfed lowland rice ecology in Malaysia, the use of improved rice varieties (MR84, MR77, and MR71) and good agronomic practices increased farm family rice production from 3 t (pre-project yield) to 5.2 t. Net income increased from $483 to $989 and farmers were able to grow short-season crops after rice.

In Nepal, cropping pattern testing was continued in Khandbari and Kotahari, representing rainfed rice ecology. Evaluation focused on improving the crop variety, nutrient management, and other agronomic practices. In Khandbari, the improved cropping pattern of rice/lentil - maize with good management showed 40% higher net return than the farmers' practice. In Kotahari, rice+maize - wheat+mustard was comparable with the improved cropping pattern but with improved varieties and fertilizer, it yielded 45% higher net return than the farmers' practice.

In Korea, six cropping patterns were evaluated in a 2-yr rotation: rice - barley - rice - barley, sesame - garlic - rice, peanut - potato - rice, red pepper - sweet maize - rice, cucumber - Chinese cabbage - pea - rice, taro - kidney bean - rice. The most profitable cropping patterns were sesame - garlic - rice and cucumber - Chinese cabbage - pea - rice, which were 65 and 81% better than rice - barley.

Crop-animal farming systems

The number of farming systems sites studying crop-animal systems has increased since the start of this collaboration in 1984. The main objectives of this activity are to identify and refine technologies that will improve crop and animal productivity, thereby increasing farm income; identify constraints for strategic research; and develop on-farm research methodologies.

Philippines. Rice-food/forage legume + cattle fattening and draft animal power were studied in Santa Barbara, Pangasinan, Philippines; and rice/root crop + pig fattening and native chicken production in Trece Martires, Cavite.

In Pangasinan, siratro showed favorable effect on the yield of mungbean, but not crotalaria, which shaded the food crops. Both forage legumes had similar herbage yield of 4.8 t/ha, although only 2 cuttings were possible with crotalaria and 3 for siratro. The yield of 5.7 t rice grain/ha and 5.8 t straw/ha in plots with siratro green manure was higher than in monocrop plots (4.6 and 4.9 t/ha, respectively). The study of draft animal power involves refinement of a simple in-field draft measurement and determination of the effect of rice bran supplementation at 0.5% of liveweight on some draft and physiological parameters. Although rice bran supplementation did not have any effect on liveweight, there were indica-

tions that it improved the draft performance of the animals as manifested by their slower pulse and respiration rate than those in the control group. Another component of draft animal power was whole-farm economic analysis. Results showed that among 12 cooperators, the average cash and noncash returns from crops were 40% while those from animals accounted for 60%. On the other hand, crop enterprises accounted for 48% of the total cost, while costs due to animals were 52%.

A cattle feeding trial lasting 8 mo showed that an optimum growth rate of 0.58 kg/d for cattle can be sustained with a diet consisting of 30% rice straw soaked in urea solution, 30% rice bran, and 40% weeds. However, the low supply of forage legume was a major feed problem in rainfed lowland farming systems.

In Cavite, the cowpea/cassava for pig feed initiative was continued. A trial involving 6 experimental and 5 control pigs showed that while the growth rate of both groups was similar, the experimental animals were more efficient in converting feeds into meat (4.22 kg/head) than the control animals (5.39 kg/head). Likewise, the lean meat yield of the experimental animals was higher.

China. In Changping, Beijing, a new fodder crop triticale grown after rice to produce silage for the dairy cow yielded an average of 30 t/ha. A trial of nine triticale varieties after rice was conducted. Four varieties (8-Forage-6, WOH 813-F4, 8-Forage-5, and WOH 59) were better than check variety H-1990 in terms of yield and maturity. Early cutting of triticale is very important for the establishment of the following rice. Triticale - rice showed the highest net returns ($1,025 per ha) followed by wheat - maize for silage ($553). The grain - grain cropping pattern of wheat - maize and wheat - rice and monocrop maize showed much lower net returns.

In Zhenjiang, Jiangsu, maize was introduced in the rice-based cropping pattern to increase the feed supply for swine. The upper ricefields were grown to wheat - maize, rapeseed - maize, and barley/maize - mungbean or radish or Chinese cabbage instead of rice - wheat or rice - barley. In 1989, the spring maize yielded 5.47 t/ha and the maize after barley and wheat yielded 4.95 t/ha. Feeding trials on improved and traditional feeds given to different swine breeds showed that improved breed (Yorkshire Taihu) fed with mixed feed gave the highest feed efficiency, shortest feeding duration, and highest net return followed by improved breed fed with traditional feed. In a demonstration involving 75 heads of 2- to 3-way-cross hybrid pigs, improved management resulted in shortening the growth duration by 20 d and saving 40 kg/head of mixed concentrates.

At the cooperative dairy farm at the Zhenjiang site, the average yield per hectare of dual-purpose maize hybrid was 4.54 t grain and 18.8 t silage. Rye cultivar Dongmu 70 and triticale Oh 1194 were evaluated with wheat as silage. Dongmu 70 gave the highest fodder yield (71 t/ha), crude protein (1.41 t/ha), and net energy for milking (20,250 Mcal).

Indonesia. The preproduction trials in Indonesia were conducted in six village units and carried out on five farms per village in Batumarta. The technologies promoted are improved rice-based cropping pattern (rice+maize/cassava/peanut or soybean), improved housing facilities for goats and chickens, brooder box systems for young chicks to reduce mortality, vaccination against Newcastle disease, improvement of feed quality, soil conservation, and introduction of small-scale machinery.

The yield of the food crops was high during the wet season but low during the dry season because of drought. Upland rice yielded 2.0 t/ha; maize, 2.2 t/ha in WS and only 0.2 t/ha in DS; cassava, 6.4 t/ha; legumes (soybean, peanut, mungbean, and cowpea), less than 1 t/ha; and lowland rice, 2.9 t/ha.

The cattle raised by farmers were local breeds Ongole and Bali. The average daily gain of Bali was higher at post-rearing. There was no mortality. Cattle provided higher income than that from goat and chicken. The goats had high mortality of offspring (40%). Chicken performance was very good.

An experiment on grazing goat under rubber plants was conducted in a block of land planted to 4-yr-old plants. Five goats grazed day and night in about 2,075 m^2. More than enough herbage was available. About 37% of the potential production was consumed. The trees showed no damage. Weight gain of the bucks was low—3 kg over 5 mo.

Nepal. The research activities at the crop-animal key sites in Naldung, Nepal, are focused on varietal trial of grain crops (rice, maize, and wheat), planting of forage grass on the bunds for use during the dry season, and planting of fodder trees not only for feed but also for fuelwood and timber. Five maize varieties were evaluated on four farms. The local check produced the highest grain mean yield (4.83 t/ha) and biomass (4.87 t/ha). However, farmers also like

Manakamana-2 maize variety because it resists lodging, is good for making pudding, and has a yield comparable to that of the local variety. Napier, guinea grass, and setaria forage grasses were introduced. Farmers preferred napier (NB21) because it is palatable and easy to grow, and can be fed as green grass during the DS. NB21 evaluated on 5 farms produced an average yield of 0.19 kg/linear meter with a survival rate of 61% and 5.2 tillers in 6 mo.

Agroforestry is an important feature of Nepalese farming systems in the hills. From 1987 to 1989, 13 species of fodder trees were planted in 63 sets of terraces belonging to 40 farmers. Studies indicate that food crops close to the trees yielded less because of shading. In an observation block of mixed species, several species had died and regrowth was observed in some. The most promising species at the early stage is *Quercus leucotricophera*. A community silvipasture forest was established at Chiyandranda in 1987 on a total area of 5 ha. Patula pine and Utis (*Alnus nepalensis*) were the choice of the farmers. In addition, other species such as painyu, crytomerica, callestemon, *Acacia*, and ghangaru were also planted. The broadleaf species are now well established and there is some natural regeneration of cholaune (*Schima wallichi*), katus, and other forest species.

Women in rice farming

Bangladesh. A survey of 248 households in the Gazipur district was conducted to determine gender roles in agriculture, differential access to resources, and income-generating activities. Constraints to productivity and potential technology options were also identified. This was followed by an in-depth study of 42 households from 3 household categories (landless, marginal, small). Results revealed that most women are involved in seed storage and management, rice processing, collecting animal manure for fuel, kitchen gardening, and poultry and goat raising. Because of the nonavailability of jobs, and lack of capital and marketable skills, only 5% of the women are involved in income-generating activities. All agricultural decisions are made by the principal male of the family, decisions on seed storage and homestead production are exclusively done by the principal female, and decisions regarding goats and poultry are made by both. Among the activities carried out by women, rice processing, homestead gardening, poultry and goat raising were considered major activities in which better technologies could improve women's productivity and income.

Indonesia. In the Batumarta (upland rice ecosystem) transmigration area, South Sumatra, Indonesia, a study on the role of women is being conducted to enhance women's livelihood. In food production, female labor contributes 42.6% of the total labor with the bulk coming from family labor. Female family members contribute 32.6% to total off-farm income and 47% to nonfarm income. An innovative approach with women as the target was tested in 4 village units where women's groups of 30 members each were organized. Some of the potential technologies identified during the meetings of women's groups are 1) improved varieties of food crops such as cowpea, cassava, peanut, and mungbean; and 2) testing of production and postharvest tools/equipment, such as the jab seeder, weeder, furrower, equipment for applying fertilizer, serrated cycle, maize sheller, peanut sheller, rice thresher, and soybean thresher.

Women's role in upland farming systems was studied in Gunungsari village, Wonosegoro district, Boyolali. The households were stratified into three groups: stratum I, > 1 ha (18 households); stratum II, 1-2 ha (16 households); and stratum III, >2 ha (16 households). Labor input by gender and by stratum shows that women's contribution in rice production was higher in strata I (42.6%) and II (46.9%) than in stratum III (11.3%). For maize, female labor input is almost equal to that of male labor in both strata II and III. In animal production (cattle, goat, and poultry), female labor contributes significantly in all strata: 31.8% in stratum I, 48.7% in stratum II, and 61.0% in stratum III for cattle; 65.9% in stratum I, 68.3% in stratum II, and 80.6% in stratum III for poultry. Women's contribution increased as landholdings increased. Goat management is equally shared by men and women. In terms of total income, upland and rainfed crops are the major sources of income. Off-farm income (wages from land preparation, transplanting, and harvesting) comprised 26.4, 20, and 23.4% in each stratum and female earnings from off-farm employment comprised 4-6% of the total off-farm income. Women's nonfarm income is from the making of charcoal and pounding of *sambiroto* leaves.

Nepal. Studies at Naldung, Nepal, revealed a high contribution of female labor: 58% of total labor use in rice production. Transplanting and weeding

are their major tasks. Female labor contribution for other crops is as follows: wheat, 65%; maize, 79%; finger millet, 78%; vegetable production, 73%; and livestock management, 51%.

In recognition of the crucial role of women in agriculture, the farming systems research program has initiated experiments in crop production, horticulture and livestock, and forestry which might directly or indirectly address some of the concerns of women. Training for women will include crop production, kitchen gardening, fruit production, production of fodder/firewood/timber tree and forage grasses, and animal health.

Thailand. In Ban Pai, Khon Kaen, a gender-disaggregated reanalysis of household recordkeeping data revealed high out-migration of young men and women during the dry season, leaving older women as sole producers. The introduction of improved sericulture has provided a modest increase in income to women with few other viable alternatives. However, several constraints were encountered during the research period: 1) low productivity of mulberry leaves because of drought; 2) the preference of women farmers for the traditional silkworm breeds over the improved ones as the former are easier to hatch at the household level; and 3) competition between the mulberry garden and the animal grazing area. Given these constraints, productivity in silkworm production will be reassessed by improving the existing practice rather than changing it. One potential solution is the introduction of a reeling machine that will save spinning time and increase the volume of production of local silkworm breeds.

The project sites in Phattalung Province are located in Village 2 of Ban Sai-Kham and Village 5 of Ban Khao Fand-It of Phraek-oha subdistrict. An analysis of labor in rice production shows that women have higher labor input than men. In Village 2, female labor (family and hired) is higher than the male's in seedbed preparation (66%), transplanting (94%), pulling of seedlings (92%), and harvesting (77%). Pulling of seedlings and harvesting are predominantly women's tasks whereas land preparation, irrigating, and hauling are men's responsibilities. In Village 2, men spend more time in the rubber plantation, leaving women to manage the ricefields.

Men have greater access to banks and cooperatives; women have greater access to informal sources of credit. In general, women keep most of the household income, particularly income from swine and poultry. Men and women share decisions with regard to agricultural matters such as the choice of crops to grow and when to apply fertilizers, pesticides, and chemicals. Decisions to purchase agricultural equipment, to join a cooperative, and to borrow money for investments are dominated by men; hiring of labor is the domain of women. More than 50% of the female respondents expressed a need to learn more about crop production techniques, animal management, and labor-saving devices, particularly in transplanting rice. Women farmers obtain their main source of information regarding agricultural matters from the agricultural extension officers.

Philippines. The application of gender analysis to the activities and sources of income for men and women in Carosucan, Santa Barbara, Pangasinan, revealed that processing of glutinous rice provided a significant (13%) source of income. Subsequently, researchers introduced improved varieties of glutinous rice, which were subjected to evaluation for production characteristics by male farmers and for processing and eating qualities by men and women. Agricultural engineers developed, tested, and evaluated postharvest equipment to increase efficiency in processing glutinous rice. The equipment reduced women's time in processing, increased the volume processed, and enabled women to spend their time in marketing.

To give more attention to poultry production, a survey sought to understand the existing poultry management and constraints that women face. The findings will form the bases of experiments by the Institute of Animal Science, University of the Philippines at Los Baños.

Involvement of women and men cooperators in verification of integrated pest management (IPM) in rice and vegetable production was assessed in Calamba, Laguna, Philippines. The men are responsible for spraying the rice crop while women play a predominant role in deciding about household expenditures. Women were included with men in subsequent training. Subsequently, women asked for IPM verification in vegetable production. Levels are still being determined, but on vegetables meant for their own consumption, women have all but eliminated the use of pesticides. The inclusion of women in IPM verification trials has been expanded to four other locations.

Rice-fish farming systems research

The ARFSN has several key farming sites for rice-fish farming systems research in Asia. The main objective of this collaboration is to identify more productive rice-fish farming in rainfed, deepwater, and irrigated rice ecosystems.

Bangladesh. On-farm research activities on rice-fish farming in the DWR environment with fishpen and cage fish culture was initiated by the Bangladesh Rice Research Institute (BRRI) in Mirzapur in 1989 in water depth of 90-150 cm. Fishpens (large size approximately 1 ha, small size 10×10 m^2) were made of bamboo and nylon netting materials (mesh size 1.5 cm, 20×25 m). Fish cages measured $1 \times 1.5 \times 1$ m. Fish species were silver barb and carp (silver, mirror, grass, rohu, mrigal, and catla) for the fishpen and Nile tilapia for the cage. The fishes grew better in the net pen than in the bamboo pen. The increase in body weight and length was 400% in 3 mo.

Thailand. There is a steady increase in area devoted to rice-fish farming in Ubon, Yusothorn, and Sisaket, in Thailand.

On-farm research on rice-fish farming was conducted by different units of Farming Systems Research Institute. In Phon Sawan subdistrict in Nakhon Phanom, representing rainfed lowland rice ecosystem, the experiments involving five farmer cooperators showed that the average rice yield was not affected by fish: the net return was $245, 74% higher than for the farmer's monocrop rice. However, the yield of fish was only 144 kg/ha. In another high-potential rainfed lowland site with shallow water table at Muang, Yasothon, three patterns were evaluated: rice+fish, rice+fish - peanut, and rice - peanut. The yield of fish was 187 kg/ha. Rice+fish - peanut had the highest net return of $673, followed by rice+peanut with $520. The return from the farmer's monocrop rice was only $281.

In Yangtalad, Kalasin, representing irrigated rice ecology, two patterns (peanut - rice+fish - rice and rice+fish - rice+fish) were compared with the former practice of rice - rice. Yield of fish was only 138 kg/ha. Highest net return was observed with the peanut - rice+fish - rice+fish ($1,130), which was 129% higher than rice - rice and 61% higher than rice+fish - rice+fish.

China. Rice-fish farming in Sichuan and Hunan is in 0.33 million ha and 0.227 million ha, respectively. In Sichuan, the average fish production was 157.5 kg/ha with a high 2,250 kg/ha from an area of 112.2 ha. In Hunan, average production was 900 kg/ha from a 63-ha area.

Rice-fish research at the Huaihua site by the Hunan Academy of Agricultural Sciences aimed to refine and expand rice-azolla-fish in ridged fields in low-lying areas. The ridge width trial showed higher rice yield in the nonridged than in the ridged fields. The fish yield decreased as ridge width became narrower. However, the fish yield was much higher with ridges than without. Fish yield (1.13 t/ha) was highest with 53-cm wide ridges.

To maximize the fish yield in the rice-azolla-fish farming system, a trial on high-yielding techniques for fish was conducted. Double stocking multiple catching with supplementary feeding gave the highest fish yield of 1.58 t/ha, followed by single stocking and with feeding (1.36 t/ha). Rice yield was also higher with double stocking and multiple catching with feeding. Supplementary feeding is necessary for higher fish yields because the temperature in Hunan is high from July to September. With high temperature, fish grows more rapidly and requires more feed, but azolla grows poorly.

The rice-azolla-fish system spread to 10,213 ha in 1989 in Hunan with two crops of rice, one crop of fish and azolla. Average rice yield was 8% higher with fish than without fish. The average net return from 2 crops of rice and 1 crop of fish and azolla was $1,965, 76% higher than that from rice - rice with azolla. The pattern 1 rice crop with azolla and fish spread to 7,040 ha in 1990. Average rice yield (8.48 t/ha) was also 8% higher with fish. The net return of rice-fish-azolla was $1,444/ha, 104% better than that from rice with azolla.

Philippines. The on-farm research at Guimba, Nueva Ecija, showed that the pond refuge is better than the trench. Average production of rice+fish-rice+fish with the pond refuge was 9.8 t rice/ha and 388 kg fish/ha, whereas the average with the trench refuge was 9.21 t rice/ha and 379 kg fish/ha. The pond refuge gave a net return 8% higher than that with the trench refuge and 22% higher than that from rice - rice.

Initial results of ricefield floodwater ecology indicate that during midway in rice growth (i.e., after all fertilizer has been applied and the rice canopy inhibits light penetration), the available natural food

for fish declines drastically; hence, supplementary feed is needed.

Pilot production programs on rice-fish were organized in two regions in the Philippines. In the Cordillera Autonomous Region, the pilot production program covered 67.78 ha and involved 310 farmer cooperators. The average rice yield (local variety) was 1.5 t/ha and fish was 218 kg/ha. In the Bicol region, fish yield in 11.5 ha involving 37 farmer cooperators was 135.6 kg/ha.

Vietnam. Cantho University is currently conducting experiments on the rice-fish/shrimp system in rainfed, irrigated, and deepwater rice ecosystems. A network of canals was excavated in the ricefields to provide the shrimps with shelter during the growth period. A total yield of 7 t/ha from 2 rice crops and an average of 140 kg of shrimps/ha (equivalent to rice yield from 2 ha) were obtained. Intensification of the system can increase production of both shrimp and rice components.

One experiment in Cuu Long Province showed that by excavating a large ring canal and a checkered smaller canal system across the field, a surrounding dike, high enough for fruit trees to be planted, was formed. In the inside field, one rice crop with a traditional medium-term rice variety was grown simultaneously with shrimp and fish. Two upland crops (soybean or mungbean) followed from December to May. The rice yield ranged from 3 to 4.5 t/ha; the rough rice equivalent for the 2 upland crops was 10-12 t/ha. About 200 kg of fish and shrimp were obtained. In addition, various fruits for home consumption were obtained from the surrounding dike.

Korea. Weed is a major problem in Korea, and rice yield is much lower without herbicide application. Studies were conducted to see the effect of herbicide on the yield of rice and fish. Rice yield in rice-catfish and rice-tilapia farming was comparable with that from rice monoculture, even if 14% was taken out by the pond and trench. Rice yield was significantly reduced by 46% without herbicide. After 4 mo in the field, fish yield was 1.26 t/ha for catfish and 2.72 t/ha for tilapia. Herbicide did not affect fish yield. Survival rate was 50% for catfish and 92% for tilapia.

The number of farm households practicing rice-fish farming increased to 621 in 1990, an increase of 27% from 1989. The fish species are loach, catfish, and carp. The rice-loach average net income in 621 households was $17,295/ha.

Impact of farming systems research

Studies on the impact of farming systems research (FSR) continued in the six collaborating countries: Bangladesh (Bangladesh Rice Research Institute), Indonesia (Central Research Institute for Food Crops), Nepal (National Agricultural Research and Service Center), Philippines (Farming Systems and Soil Resources Institute), Sri Lanka (Department of Agriculture), and Thailand (Farming Systems Research Institute of the Department of Agriculture and Chiang Mai University). In addition, IRRI is conducting a study in Ilagan, Isabela.

We sought to determine the extent of adoption of the rainfed lowland favorable rice cropping systems technologies and their impact on resource use, productivity, and income and expenditure patterns of the farming community at two sites in Bangladesh. The extent of adoption was determined on the basis of planting time, varietal sequence, cropping intensity, and fertilizer use. Preliminary results showed that at both sites, households have adopted the technology, and productivity of land and other resources varied positively according to the extent of adoption. One site has more adopters who have invested in the extra inputs required for the new production process. In contrast, regular off-farm employment at the other site has meant that absolute land owned is not as critical to determine economic position; hence, the impact of extra income on the family through the adoption of the rice technology is not as marked. The study suggests that infrastructural development at the grassroot level and the diversity of income source, both farm and nonfarm, are essential to provide enough income to maintain and improve the standard of living of the farming community in the study areas.

In Indonesia, the study concentrates on the degree to which rice-fish farming systems have increased real income and purchasing power of the farm families, and tries to determine the level to which this increased purchasing power has helped improve the quality of consumption. The study also attempts to measure the extent to which introduced technology has affected the marketable surplus of rice.

Results from the first year indicate that introduction of fish to rice production in irrigated land increases the per capita on-farm income by about 34% relative to existing farming systems. There is not much change in expenditure for food. However, expenditure for assets increases almost three times

(284%) that of farmers in the existing farming systems.

A significant variability in the elasticities was found between the two groups of consumers. The demands of subgroups within the food sector are price-inelastic in farmers adopting the introduced farming system but vary in farmers practicing existing systems. Similar figures were found in the nonfood sector. The marketed surplus of farm families belonging to the new technology was determined by the rice yield only. In the existing system, however, this surplus was determined by rice yield, nonfarm income, and planting season.

In Nepal, a study among hill farmers seeks to determine the degree of adoption of the recommended FSR technologies. Results indicate that farmers adopted researcher-recommended cropping patterns both in upland and lowland areas and that most farmers adopted improved varieties of major crops and their cultural practices. Vegetable growing became very popular among interviewed farmers who improved their nutritional status by consuming vegetables and also generated cash income by the sale of excess vegetables. Farmers also adopted recommended species of fodder trees and grasses because of their highly nutritive value. Milk production and sale increased substantially because of increase in animal numbers and availability of suitable livestock fodder.

In the Philippines the study at two sites specifically seeks to refine impact assessment methodology in the operational definitions of adopters and non-adopters and to develop and institutionalize a cost-effective impact monitoring methodology that can be used by national programs. An analytical technique using cluster analysis was adopted with the data available from one site; dry seeded and wet seeded rice plots appeared to have no significant differences in productivity and profitability.

The study showed the application of cluster analysis in classifying technology adopters, particularly when dealing with the adoption of a package of technology. It also showed that management of farm plots depends on the physical and socioeconomic characteristics of farmers.

At another site, nonadopters showed higher average rice yields than did adopters of all cropping patterns except fallow - rice. However, adopters had higher net benefits primarily because nonadopters had other obligations that they paid in kind.

In Sri Lanka, a more in-depth analysis of the data already collected was made to ascertain a suitable methodology. Additionally, a close monitoring field survey was conducted in Katupotha among selected farmers, both adopters and nonadopters. The survey revealed that lack of support services especially seed supply and marketing, has inhibited the adoption of new technology.

In Thailand, a preliminary conclusion is that while new technology exhibits positive effects on the communities under study, it needs to be seen in the context of changes taking place in the area. In Dok Kham Thai where the study is being conducted, other socioeconomic changes are gaining force in the communities while changes due to FSR technology are suffering from instability and discontinuity of technology development. Income effect from the new technology seems inadequate to slow down migration of the young. Much of the wealth in the district is a result of other socioeconomic factors. Mungbean before rice and dry seeded rice had positive effects on productivity, income, and security of the farm household. However, these positive effects were not large enough for the farmers to feel substantially upgraded by the new technology. Moreover, when rainfall was not enough or was excessive, the new technology was a new source of risks to the farmers.

The IRRI study considers the importance of nutritional aspects in FSR. The two sites have two distinct landforms: the rice-based area is rainfed wetland while the maize-based area is rainfed dryland. The average farm household cultivates about 3 ha distributed almost equally between the two landforms. All households therefore have the opportunity to grow wetland and dryland crops.

For the purpose of comparison, the sample farmers were divided into three categories based on the degree of adoption of the introduced technology. Group I, LCII >150; Group II, 100≤LCII≥150; and Group III <100. Lowland cropping intensity index was used as a substitute for the level of technology adoption, as the basis for farm classification.

The initial findings indicate that adoption of FSR technology allows households to produce energy and protein food in excess of their requirements. However, after deduction of landlord share or land rent, hired labor payments in kind, and sales receipts, there is barely enough food left to meet the household's nutrient requirements.

Actual nutrient consumption did not vary across degrees of technology adoption. Furthermore, all farm groups exhibited declining nutrient adequacy over time.

The observation that nonadopters of lowland technology are earning more from their maize and other income-generating activities suggests that the technology introduced may not be as profitable as has been presumed by the proponents. In a resource-poor site where farmers have a relatively vast choice of investment opportunities, they are likely to invest in a more secure activity. The present lowland technology is probably not one of these. This could be the reason why nonadopters are at par with technology adopters as far as nutritional standard of the household is concerned. Nonadopters supplement their diet through higher earnings from other enterprises.

Directions

Research and extension systems are a continuum of closely related activities, from knowledge generation through research, technology development, technology evaluation, and dissemination, and technology adaptation to specific environments or conditions. Since IRRI has shifted its research programs from a predominantly discipline-based to an ecosystem-oriented strategy, networks must likewise adjust.

The INGER, ARESN, and INSURE have exerted efforts to strengthen their ecosystem-based multilocation testing programs. This shift will continue as national systems also strengthen their research programs on the less favorable rice environments. The anticipated organization of rice research consortia for rainfed lowland, upland, and deepwater rice ecosystems will increase the participation of NARS in ecosystems-oriented rice research, and will speed the shift of network activities.

Integration of the ARESN, INSURE, and IPMN under Crop and Resource Management Networks, as indicated in IRRI's 5-year work plan, will also be pursued vigorously. This will be done with consideration of existing procedures in national programs. An essential step is creation of a Crop and Resource Networks Advisory Committee, which will provide a forum for discussing the transition to ecosystems-oriented activities as well as integration of the three networks.

International programs
Training

SUBPROGRAM I: DEGREE AND POSTDEGREE TRAINING 254
Management of degree and postdegree training 254
Postdoctoral research and midcareer training 254
Fellows, scholars, and nondegree trainees who completed training in 1990 255

SUBPROGRAM II: GROUP TRAINING 257
Short-term courses 257
Regular courses 257
Special courses 259
Participants in group training courses in 1990 260
Courseware development 263
Collaborative in-country training programs 264
Conclusion 264

Previous Page Blank

Training

The newly established IRRI Training Center completed its first year of operations in 1990. After a major internal reorganization within the center, a Training Policies and Guidelines document was developed and approved by the Board of Trustees during the September 1990 meeting. This working document will enable the Training Center to accomplish the objectives of IRRI's work plan and to meet the evolving needs of the national agricultural research systems (NARS).

The IRRI Training Program, the goal of which is to develop human resources in national rice research systems, is composed of two subprogram areas: degree and postdegree training and short-term group training.

Subprogram I: Degree and postdegree training

Management of degree and postdegree training

The objectives of this project are twofold: to assist national systems by increasing trained professionals at key, strategic national institutions and to strengthen collaboration among IRRI scientists, university professors, and national scientists.

IRRI has formal memoranda of agreement with more than 30 selected universities worldwide for collaborative MS and Ph D degree programs. IRRI awards degree scholarships for thesis or dissertation research (Type I scholar) and for course work and thesis or dissertation research (Type II scholar). IRRI Type III scholarships are awarded to trainees from developing countries for in-service, on-the-job training at IRRI for durations of less than 1 yr. IRRI provides research accommodations only to Type IV, collaborative research scholars who come to IRRI from institutions in developed countries.

During 1990, 169 scholars from 28 countries and 5 continents participated in IRRI degree and nondegree research training programs. Among them were 8 MS and 32 Ph D Type I scholars, 31 MS and 54 Ph D Type II scholars, 39 Type III trainees, and 1 MS and 4 Ph D Type IV scholars. Types I-IV scholars or trainees are listed by country in Table 1.

Postdoctoral research and midcareer training

During the year, 73 scientists participated in IRRI's research fellowship programs. Five were visiting scientists who spent their sabbatical year at IRRI; 51, postdoctoral research fellows; 5, collaborative research scientists; and 12, collaborative research fellows. Distribution of scientists and fellows by region and country and by division or center is shown in Tables 2 and 3, respectively.

In 1990, IRRI assigned four research fellows to key sites in Kenya, Indonesia, Thailand, and Cambodia, to strengthen collaboration with national programs in irrigated, rainfed lowland, and upland rice. Two more fellows will be assigned at key deepwater and tidal wetland rice and upland rice sites. During the year, 27 scientists completed their fellowship and returned to their country where they are expected to continue their research in collaboration with IRRI scientists.

Nine new positions for postdoctoral research fellowships were approved effective 1991: six are core-funded and three are special project-funded. The new positions will supplement the work on

Table 1. Research scholars by region, country, and type. IRRI, 1990.

Region and country	Scholars (no.)								
	Type I		Type II		Type III	Type IV			Total
	MS	Ph D	MS	Ph D		MS	Ph D	ND[a]	
Asia									
Bangladesh	-	4	1	11	1	-	-	-	17
Bhutan	-	-	1	-	1	-	-	-	2
Cambodia	-	-	1	-	1	-	-	-	2
China	-	-	4	13	5	-	-	-	22
India	-	4	-	-	2	-	-	-	6
Indonesia	-	2	1	1	4	-	-	-	8
Iran	-	-	-	1	1	-	-	-	2
Japan	-	3	-	-	-	-	-	-	3
Korea	-	2	-	6	4	-	-	-	12
Malaysia	-	-	-	-	1	-	-	-	1
Myanmar	-	-	3	2	2	-	-	-	7
Nepal	5	3	-	5	1	-	-	-	14
Pakistan	-	4	-	2	-	-	-	-	6
Philippines	2	5	-	1	1	-	-	-	9
Sri Lanka	1	-	1	2	2	-	-	-	6
Thailand	-	-	3	3	1	-	-		7
Vietnam	-	-	7	2	9	-	-	-	18
Subtotal	8	27	22	49	36	-	-		142
Africa									
Ghana			1	1	-	-	-	-	2
Madagascar			6	2	-	-	-	-	8
Somalia		1	-	-	-	-	-	-	1
Tanzania	-	-	1	2	1	-	-	-	4
Subtotal	-	1	8	5	1	-	-	-	15
The Americas									
Canada	-	-	-	-	-	-	2	-	2
Mexico	-	-	1	-	-	-	-	-	1
United States	-	3	-	-	-	1	-	-	4
Subtotal	-	3	1	-	-	1	2	-	7
Europe									
France	-	-	-	-	-	-	1	-	1
Germany	-	-	-	-	-	-	1	-	1
Italy	-	-	-	-	2	-	-	-	2
United Kingdom	-	1	-	-	-	-	-	-	1
Subtotal	-	1	-	-	2	-	2	-	5
Grand total	8	32	31	54	39	1	4	-	169

[a]Nondegree

characterization of strains of rice tungro and grassy stunt viruses, upland rice (to be based in Hazaribagh, India), phytohormonal basis of nutrient uptake, global warming, biological pesticides, economics of deep-water and tidal wetland management, and identification of audiences of IRRI publications. IRRI continues to search for appropriate candidates to work on site characterization, wide hybridization work, and research related to women in rice farming systems.

Fellows, scholars, and nondegree trainees who completed training in 1990

The following research fellows, degree scholars, and nondegree trainees completed training in 1990. One

Table 2. Distribution of scientists and fellows by region and country.[a] IRRI, 1990.

Country	Scientists and fellows (no.)				
	VS	RF	CRS	CRF	Total
Asia					
Afghanistan	-	1	-	-	1
Bangladesh	-	3	1	-	4
China	-	3	-	-	3
India	-	21	1	-	22
Indonesia	-	3	-	-	3
Korea	-	2	-	-	2
Nepal	-	2	-	-	2
Pakistan	-	1	-	-	1
Philippines	-	9	-	-	8
Sri Lanka	-	1	-	-	1
Thailand	-	2	-	-	2
Vietnam	-	1	-	-	1
Subtotal	-	48	2	-	50
The Americas					
Canada	2	-	-	-	2
USA	3	1	-	-	4
Subtotal	5	1	-	-	6
Europe					
Belgium	-	1	-	2	3
France	-	1	-	-	1
Germany	-	-	3	2	5
Netherlands	-	-	-	4	4
United Kingdom	-	-	-	4	4
Subtotal	-	2	3	12	17
Total	5	51	5	12	73

[a]VS = visiting scientist, RF = research fellow, CRS = collaborative research scientist, CRF = collaborative research fellow

asterisk (*) indicates the MS degree; two asterisks (**), completion of the Ph D degree. Universities of those who completed degrees are noted after their countries.

Visiting scientists

James S. Townsend, Canada
Alan K. Watson, Canada

Postdoctoral scientists

Anil Kumar Chowdhury, India
Vijai Pal Singh, India
Asuncion K. Raymundo, Philippines
Rezaul Karim, Bangladesh
Hari K. Upadhyaya, Nepal
Mohammad F. Masyhudi, Indonesia
Ganesh Thapa, Nepal
Kyung Hee Ree, Republic of Korea

Table 3. Distribution of scientists and fellows by division or center. IRRI, 1990.

Division or center	Scientists and fellows (no.)				
	VS	RF	CRS	CRF	Total
Agricultural Engineering	1	2	-	3	6
Agronomy Physiology Agroecology	1	14	1	1	17
Entomology	-	3	-	1	4
Plant Breeding Genetics and Biochemistry	-	14	-	-	14
Plant Pathology	-	6	2	2	10
Social Sciences	-	4	-	1	5
Soils and Water Sciences	1	3	-	1	5
Soil Microbiology	-	1	2	2	5
Project Management Systems and Biometrics	1	1	-	-	2
Training Center	1	-	-	-	1
INGER	-	2	-	-	2
Seed Health Unit	-	1	-	-	1
ARFSN	-	-	-	1	1
Total	5	51	5	12	73

Moon Hee Lee, Republic of Korea
Mai Van Quyen, Vietnam
M. B. Kalode, India
Iswandi Hasan Basri, Indonesia
Natarajan Sakthivel, India
B. Mishra, India
Jitendra Kumar Mishra, India
Ma. Francisca Van Outryve, Belgium
Michael Dingkuhn, Germany
Muhammad Rashid, Pakistan
Nathalie Boissot, France
Lin Jin Tian, China
Dayanidhi Mahapatra, India
Mahesh P. Janoria, India
Azucena L. Carpena, Philippines
Nurul Islam Faridi, Bangladesh

Degree scholars

Ma. Gabrielle Rerivoson*, Madagascar, University of Madagascar
Randriamananoro Jean Joseph*, Madagascar, UPLB
Razafinjara Aime Lala*, Madagascar, UPLB
F. Canizales*, Mexico, Colegio de Postgrad
Bai Jianfa*, China, UPLB
Sun Haoxun*, China, UPLB
Teng Shibiao*, China, UPLB
Nirmal P. Gyalang*, Nepal, UPLB
Vishwa Ranjan Amatya*, Nepal, UPLB[1]
N. P. Adhikari*, Nepal, UPLB

Gemma Encarnacion*, Philippines, Araneta University
Victoria M. De Vera*, Philippines, UPLB
J. D. K. M. Jayawardena*, Sri Lanka, UPLB
A. Auyamathiti*, Thailand, UPLB
Wantana Thevapuchom*, Thailand, Kasetsart University
V. D. Pien*, Vietnam, UPLB
Ferdous Ara Zapata**, Bangladesh, UPLB
Nur-E-Elahi**, Bangladesh, Cornell University
Dai Qunjie**, China, UPLB
Guo Yujie**, China, UPLB
Huang Jikun**, China, UPLB
Jin Can Chen**, China, UPLB
Zhang Jiabao**, China, UPLB
Geetha Nagarajan**, India, Ohio University
P. S. Reddy**, India, APAU
Rusnadi Padjung**, Indonesia, UPLB
Hajrial Aswidinnoor**, Indonesia, University of Missouri
Hideshi Yasui**, Japan, Kyushu University
Dong Jin Lee**, Korea, UPLB
Jae Duk Kim**, Korea, UPLB
K. Sik Jin**, Korea, UPLB
Hla Than**, Myanmar, UPLB
Pye Tin**, Myanmar, UPLB
Pius Raj Mishra**, Nepal, UPLB
R. A. Mann**, Pakistan, UPLB
U. Mustafa**, Pakistan, UPLB
M. A. Gill**, Pakistan, UPLB
Anwar Aram**, Pakistan, UPLB
Jacinto Fabiosa**, Philippines, UPLB
N. Nabheerong**, Thailand, UPLB
R. H. Diekmann**, Germany, University of Giessen
Aurora Garcia**, United Kingdom, University of Sussex
Edmund Russel**, USA, University of Michigan
Julie Leones**, USA, Cornell University

Nondegree trainees

Fadhila Ali, Tanzania
Qayum Parvez, Bangladesh
Chan Phaloeun, Cambodia
Tan Dong-fei, China
Zhong Jihong, China
B. S. Sandhu, India
Sudir, Indonesia
Widianto, Indonesia
Moh Hadi Nassiriian, Iran
Gwang Su Li, Korea
Jong Hu Choi, Korea
Jong Su Ryu, Korea
Ul Byong Li, Korea
Lee Aw Kaw, Malaysia
Arthur Mundt, Myanmar
Tin Maung Shwe, Myanmar
Nirmal Joshee, Nepal
Raul J. Lara, Philippines
D. D. B. Dodanwela, Sri Lanka
Kalaya Kupkanchanakul, Thailand
Cong Doan Sat, Vietnam
Le Thu Thuy, Vietnam
Le Van Du, Vietnam
Le Van Thinh, Vietnam
Nguyen Van Dan, Vietnam
Claudia Piatti, Italy
Clelia Moroni, Italy

* Died during the year.

Subprogram II: Group training

The subprogram comprises short-term group training courses conducted at IRRI, extensive courseware development efforts that support and complement group courses, and collaborative in-country training activities in national systems.

Short-term courses

The objectives of IRRI's group training courses are to assist NARS scientists in developing research expertise and in transferring technology to national systems. Regular and special short-term courses are offered to address specific needs of national research systems. IRRI's training methodology is a blend of theoretical and problem-solving exercises. IRRI adheres to the training philosophy of "learning by doing"; thus, at least 50% of group training activities are of a practical nature.

During 1990, 282 trainees attended 17 IRRI short-term group training courses, which were oriented to research methodology and rice production technology and included specialized courses on rice biotechnology, biological control, geographic information systems and simulation and systems analysis. The number of participants by course and country is indicated in Tables 4 and 5.

Regular courses

Agricultural Engineering Course (AEC). This 3-wk course supplements IRRI's on-farm machinery development program and introduces all facets of design, manufacture, and field testing of IRRI-designed machines.

Table 4. Participants in regular short-term courses. IRRI, 1990.

Country	Participants (no.)						
	AEC	FSRC	GEU	IWMT	T3C I	T3C II	Total
Africa							
Liberia	-	-	1	-	-	-	1
Madagascar	-	2	-	-	-	-	2
Nigeria	1	-	-	-	-	1	2
Subtotal	1	2	1			1	5
Asia							
Bangladesh	1	4	3	-	-	-	8
Bhutan	-	-	1	1	-	-	2
Cambodia	-	2	2	-	-	-	4
China	3	2	-	-	-	-	5
India	2	1	-	1	-	3	7
Indonesia	1	-	1	4	-	-	6
Laos	-	2	-	-	-	-	2
Malaysia	1	-	1	-	-	-	2
Myanmar	2	5	2	-	3	-	12
Nepal	-	3	-	1	-	3	7
Philippines	2	2	1	6	-	-	11
Sri Lanka	2	-	1	-	-	-	3
Thailand	1	2	1	2	6	-	12
Vietnam	2	-	3	2	2	7	16
Subtotal	17	23	13	20	11	13	97
The Americas							
Dominican Republic	1	-	-	-	-	-	1
Mexico	-	-	1	-	-	-	1
Subtotal	1	-	1	-	-	-	2
Oceania							
Papua New Guinea	1	-	-	-	-	-	1
Subtotal	1	-	-		-	-	1
Total	20	25	15	20	11	14	105

Farming Systems Research Course (FSRC). This 17-wk course develops knowledge and skills in conducting farming systems research (FSR) and extension as it relates to research in rice production and sustainability of rice ecosystems. With the Training and Technology Transfer Course component added to its curriculum, it also adheres to the training team concept.

Genetic Evaluation and Utilization (GEU). This 16-wk course emphasizes rice germplasm improvement and management. This course, which is supported by UNDP as part of the seed improvement network, is structured around IRRI's GEU program.

Irrigation Water Management Training Course (IWMTC). This 6-wk course strengthens participants' concepts, understanding, knowledge, and skills for effective management of irrigation water. It emphasizes engineering, agronomic, economic, socioinstitutional, and communication factors associated with efficient management of irrigation water.

Training and Technology Transfer Course (T3C). This 12-wk course teaches educational technology and adaptive design process, and provides theory and practical expertise for training and technology transfer. It aims to develop proficiency and competence in needs assessment and curriculum development, training media, methodologies, and the evaluation of training programs. This course initiated the concept of team training where participants are required to reside in the same institution. Two sessions were offered in 1990.

Table 5. Participants in special short-term courses, by country. IRRI, 1990.

Country	Participants (no.)												
	AZOL	BPCR	GEUP	GIS	OFTV	PALM	RFFS	RBTW	RSHT	SARP	SRPT	VTUC	Total
Africa													
Madagascar	-	-	-	-	-	-	-	-	-	-	3	-	3
Mozambique	-	-	-	-	-	-	-	-	-	-	1	-	1
Sierra Leone	1	-	-	-	-	-	-	-	-	-	-	-	1
Tanzania	-	-	-	-	-	-	-	-	-	-	1	-	1
Subtotal	1	-	-	-	-	-	-	-	-	-	5	-	6
Asia													
Bangladesh	-	2	2	-	-	2	1	-	-	2	-	-	9
Bhutan	-	1	-	-	-	-	-	-	1	-	-	-	2
Cambodia	-	-	-	-	-	-	-	-	-	-	6	-	6
China	5	1	-	-	-	-	-	-	-	1	-	-	7
India	1	5	5	-	-	-	-	2	-	10	-	-	23
Indonesia	-	3	2	-	6	1	-	2	-	4	-	1	19
Iran	2	-	-	-	-	-	-	-	-	-	-	-	2
Korea	-	-	2	-	-	-	-	-	1	-	-	-	3
Laos	-	1	-	-	-	-	-	-	1	-	-	-	2
Malaysia	-	2	1	-	3	-	-	2	-	2	-	-	10
Myanmar	-	-	1	-	-	-	-	-	-	-	3	-	4
Nepal	-	1	-	-	-	-	1	-	1	-	-	1	4
Pakistan	-	-	-	-	-	-	-	2	-	-	-	-	2
Philippine	3	3	3	12	6	1	5	3	1	2	-	4	43
Sri Lanka	-	-	1	-	-	1	-	-	-	2	-	-	4
Thailand	2	4	3	-	6	1	3	2	-	2	1	-	24
Vietnam	-	2	2	-	-	1	1	-	-	-	-	-	6
Subtotal	13	25	22	12	21	7	11	13	5	25	9	7	170
Oceania													
Fiji	-	-	-	-	-	-	-	-	1	-	-	-	1
Subtotal	-	-	-	-	-	-	-	-	1	-	-	-	1
Total	14	25	22	12	21	7	11	13	6	25	14	7	177

SPECIAL COURSES

International Azolla Training Course. Funded by the Australian International Development Assistance Bureau (AIDAB), this 2-wk course aims to make a nucleus for forming national and regional networks of agricultural research systems for dissemination of azolla culture. Scientists were trained in the technical and practical aspects of azolla utilization in rice and rice-azolla-fish systems. The second offering of this course was in Fuzhou, Fujian, China, 19 Jun-1 Jul.

Biological Pest Control in Rice-Based Cropping Systems (BPCRBCS). Jointly organized by CAB International Institute of Biological Control (CIBC) and IRRI, this 4-wk course addresses new concepts and methods for research into the biological control component of pest management in rice. It will enable scientists to make valuable contributions to their national systems by expanding their knowledge of biological research methods.

Genetic Evaluation and Utilization - Problem Soils (GEU-Problem Soils). This 14-wk course is designed for plant breeders and soil scientists involved in analysis and utilization of rice germplasm for problem soils. It enhances participants' germplasm evaluation and selection skills and acquaints them with the types of rice culture, various screening and hybridization methods, and evaluation of progenies.

Geographic Information Systems (GIS) Training on Extrapolation of Agricultural Technologies. This 2-wk course is intended to measure the impact of environmental parameters to increased food production, income, and livelihood. Participants are provided with knowledge and skills in extrapolation of agricultural technologies. Three sessions were conducted.

Physical Aspects of Land Management in Rice-based Cropping Systems (PALMIRCS). This 9-wk course replaced the Soil-Physical Manage-

ment in Rice-Based Cropping Systems (SPMRCS). It offers tutorial instruction and practical experience in field experimentation for riceland management and for land management of dry season wheat and legumes following rice. It focuses on soil-physical measurement techniques and geostatistical methods to determine required sample sizes and sampling densities for effective characterization of physical properties of rice soils.

On-Farm Trials for Technology Verification (OFTTV). Conducted in collaboration with SEARCA, this 4-wk course provides basic concepts, philosophies, principles, practices, issues, and concerns related to on-farm trials for technology verification. It emphasizes knowledge and skills on data management using compater-based analytical techniques.

Rice-Fish Farming Systems Training Course (RFFS). This 3-wk course in Central Luzon State University (CLSU), Muñoz, Nueva Ecija, will enable trainees to acquire practical experience in different cultural and management aspects of various rice, fish, and rice-fish culture systems.

Rice Biotechnology Training Workshop (RBTW). Supported by the Rockefeller Foundation, this 8-wk course familiarizes rice scientists from developing countries with new biotechnology tools and their potential to solve problems encountered in modern rice improvement programs.

Simulation and Systems Analysis in Rice Production (SARP). This 8-wk course develops expertise and capabilities to implement systems analysis and simulation of rice production. It emphasizes modeling as a tool to improve research and extension work in rice production.

Special Rice Production Training Course (SRPTC). This 16-wk course provides theory and practical experience in rice production and experimentation, irrigation, training and technology transfer, and farming systems extension. It exposes participants to participatory management in irrigation systems through a 1-mo training by the College of Engineering, CLSU.

Varietal Testing of Upland Crops (VTUC). This 4-wk course exposes participants to different techniques of varietal improvement screening and selection of upland crops for rice farming systems, and to methodologies on the establishment and management of trials, data collection, analysis, and interpretation.

PARTICIPANTS IN GROUP TRAINING COURSES IN 1990

Regular courses

Agricultural Engineering (AEC)

Md. Abdur Rahman (Bangladesh)
Liu Hong (China)
Cao Hongguo (China)
Liu Yundong (China)
Lopez Julio Grullion (Dominican Republic)
Suresh Narang (India)
Er. Mansha Ram Varma (India)
Harnel (Indonesia)
Abd. Rahim Hassan (Malaysia)
U Mya Thein (Myanmar)
U Thein Swe Myint (Myanmar)
Philip Vandi Kwaya (Nigeria)
Yowat Pulas (Papua New Guinea)
Eden C. Gagelonia (Philippines)
Virgilio Flores Muyot (Philippines)
H.P.N.S. Fernando (Sri Lanka)
Karunasena Thrikawela (Sri Lanka)
Amnuay Cheirchart (Thailand)
Quang Thu Nguyen (Vietnam)
Vo Van Than (Vietnam)

Farming Systems Research (FSRC)

Md. Abdul Hafiz (Bangladesh)
Abdul Quayum (Bangladesh)
Abhijit Saha (Bangladesh)
Zahidul Alam Zahid (Bangladesh)
Sum Sahak (Cambodia)
Mak Soeun (Cambodia)
Guoliang Zhou (China)
Wang Deren (China)
Sivanantham Mhalingam (India)
Bounphasouk Phanthavong (Lao PDR)
Bounthiam Phommasay (Lao PDR)
Nirina Rabemanantsoa (Madagascar)
Rolland Razafindraibe (Madagascar)
Aye Swe (Myanmar)
Myint Zaw (Myanmar)
U Htun Aye (Myanmar)
U Maung Myint (Myanmar)
U Myint Oo (Myanmar)
Chiranjibi Adhikari (Nepal)
Janmejai Tripathi (Nepal)
Mina Nath Paudel (Nepal)
Alberto J. Pajarito (Philippines)
Digna Lopez Sandoval (Philippines)
Som Sam Ath (Thailand)
Teav Kim Yee (Thailand)

Genetic Evaluation and Utilization (GEU)
Men Saron (Cambodia)
Sok Sophal (Cambodia)
M. Nasri (Indonesia)
Johansen T. Voker (Liberia)
Teo Gien Kheng (Malaysia)
U Zaw Myint (Myanmar)
U Khin Shwe (Myanmar)
Leticia Tavitas (Mexico)
Van Hong Nguyen (Vietnam)
Yolanda Dimaano (Philippines)
Sangay Duba (Bhutan)
Ekasith Skulkhu (Thailand)
A. H. Gunadasa (Sri Lanka)
Huynh Quang Tin (Vietnam)
Tran Van Chien (Vietnam)

Irrigation Water Management (IWMT)
Md. Abdul Hashem (Bangladesh)
Towfiqul Islam (Bangladesh)
Nafis Jahan Joarder (Bangladesh)
Tempha Gyeltshen (Bhutan)
B. R. Yadav (India)
Amur Farid (Indonesia)
Dodi Rusadi Sunandaka (Indonesia)
I. Putu Wardana (Indonesia)
Sofyan Arsyad (Indonesia)
Madhusudan Singh Basnyat (Nepal)
Herminio A. Fabros (Philippines)
Reynold Julian Gumtang (Philippines)
Marciano M. Llandado (Philippines)
Victorio D. Nera (Philippines)
Cesar M. Pobre (Philippines)
Emmanuel V. Sicat (Philippines)
Preecha Sukklam (Thailand)
Manoch Watanachote (Thailand)
Thanh Can Nguyen (Vietnam)
Cong Thien Tran (Vietnam)

Training and Technology Transfer (T3CI)
U Sein Lwin (Myanmar)
U Tint Lwin (Myanmar)
U Chit Ko Ko (Myanmar)
Arayaphong Uholwan (Thailand)
Charsayan Saranan (Thailand)
Poonsak Mekwatanakarn (Thailand)
Suthep Nuchsawadi (Thailand)
Supeluck Phonyiearn (Thailand)
Nida Sakkatatiyakul (Thailand)
Van Chuong Do (Vietnam)
Thi Vien Nguyen (Vietnam)

Training and Technology Transfer (T3CII)
Mouneshwar K. Chandrakar (India)
Rajiv Joshi (India)
Brijendra Kumar Tyagi (India)
Bahuri P. Chaudhary (Nepal)
Devendra Kumar Choudhary (Nepal)
Madhav Joshi (Nepal)
Izonebi Rodger Obubo (Nigeria)
Thanh Be Tran (Vietnam)
Nguyen Van Cong (Vietnam)
Tran Dac Dan (Vietnam)
Ha Trien Hiep (Vietnam)
Le Hieu Huu (Vietnam)
Nguyen Thanh Nghiep (Vietnam)
Le Ngoc Thach (Vietnam)

Special courses

International Azolla Training
Yang Yong Duan (China)
Tang Jian Yang (China)
Xu Guo Zhong (China)
Zheng Guo Lu (China)
Zhang Xiao Lin (China)
P. Subramanian (India)
Mohammed Hadi Nassirian (Iran)
B. Ghareyazhie (Iran)
Visitacion P. Lawas (Philippines)
Lydia J. Querubin (Philippines)
Arsenia G. Cagauan (Philippines)
Charles Ayodeshi-Dixon (Sierra Leone)
Vithaya Thananusont (Thailand)
Chirasak Arunsri (Thailand)

Biological Pest Control in Rice-Based Cropping Systems (BPCRBCS)
Mohibul Hasan (Bangladesh)
Anwaral Islam (Bangladesh)
Narendra Kumar Pradhan (Bhutan)
Zhang Kanghua (China)
M. A. Ansari (India)
Jagpal Singh (India)
Jagadish Sanmallapa Bentur (India)
Vaghasia Balubhai Nathubai (India)
Tejpal Singh (India)
Mappagangang S. Pabbage (Indonesia)
Firdaus Natanegara (Indonesia)
Agus Salim Yahya (Indonesia)
Kongsay Sivathat (Lao PDR)
Md. Nasir Kushari (Malaysia)
Mohamed Salleh (Malaysia)
Samudra Lal Joshi (Nepal)

Alejandra T. Burdeos (Philippines)
Gilely C. Santiago (Philippines)
Alex Corpuz Pulmano (Philippines)
Popaitoon Narongsak (Thailand)
Sopapun Botpibul (Thailand)
Nusaya Na Songkla (Thailand)
Raywat Pattrasudhi (Thailand)
Vu Thi Thang (Vietnam)
Le Thi Tuyet (Vietnam)

GEU-Problem Soils (GEU-P)
Md. Shafiqul Alam (Bangladesh)
Md. Hanif Miah (Bangladesh)
Amalendu Bikash Mandal (India)
K. S. Shylaraj (India)
Indra Bhanu Singh (India)
Rakesh Kumar Singh (India)
Vinauak Ganpat Sodayer (India)
Muhrizal Sarwani (Indonesia)
Hadis Siregar (Indonesia)
Kyu Seong Lee (Republic of Korea)
Yeon-Gyu Kim (Republic of Korea)
Omar Bin Taib (Malaysia)
Tin Tin Myint Daw (Myanmar)
Thelma F. Padolina (Philippines)
Joselito Quan Quizon (Philippines)
Evelyn B. Tabelin (Philippines)
Nimala Kanthe Setunge (Sri Lanka)
Somsak Boondown (Thailand)
Bunjirtluk Jinatarıdth (Thailand)
Rangsit Senghaphan (Thailand)
Nguyen Van Tao (Vietnam)
Le Thu Thuy (Vietnam)

Geographic Information Systems Training (GIS)
Mar A. Adame (Philippines)
Jecela A. Demegillo (Philippines)
Cheryl L. Hernandez (Philippines)
Russell D. Jumagdao (Philippines)
Tomasita A. Cadungog (Philippines)
Emma C. Caspillo (Philippines)
Ma. A. Geraldine M. Franza (Philippines)
Helen J. Maquiling (Philippines)
Luis Alejandre I. Tamani (Philippines)
Andres B. Diamsay, Jr. (Philippines)
Rodolfo S. De la Cruz (Philippines)
Anita Asuncion (Philippines)

On-Farm Trials for Technology Verification (OFTTV)
Adiwirman (Indonesia)
Wahyudi Dyarkasih (Indonesia)
Anischan Gani (Indonesia)
Agus Hermawan (Indonesia)
I. Putu Wardana (Indonesia)
Zubachtirodin (Indonesia)
Mustaffer Bin Abdullah (Malaysia)
Mohd Nizam Khamis (Malaysia)
Fauzi Bin Mamat (Malaysia)
Lilia C. Barbonio (Philippines)
Vilma E. Constante (Philippines)
Reynaldo C. Patricio, Jr. (Philippines)
Elizabeth M. Reyes (Philippines)
Leonardo D. Sureta (Philippines)
Arlene L. Vibar (Philippines)
Komsat Amnueysit (Thailand)
Suntariporn Duanyai (Thailand)
Weena Mekwaianakarn (Thailand)
Boonrawd Thongdonphun (Thailand)
Satit Kerdsomboon (Thailand)
Manoon Boonputaraksa (Thailand)

Physical Aspects of Land Management in Rice-Based Cropping Systems (PALMIRCS)
A.K.M. Azmal (Bangladesh)
Md. Nuruzzaman (Bangladesh)
Syahrial Abdullah (Indonesia)
Wilfredo Sanidad (Philippines)
Priyantha Weerasinghe (Sri Lanka)
Suthat Prosayakul (Thailand)
Van Tinh Nguyen (Vietnam)

Rice-Fish Farming Systems (RFFS)
Muhammad Nasim (Bangladesh)
Hirar Lal Bhusal (Nepal)
Wilfredo H. Libunao (Philippines)
Henry P. Amparado (Philippines)
Rene L. Limosinero (Philippines)
Mary Agnes S. Sastrillo (Philippines)
Nestor D. Verdeflor (Philippines)
Thitima Chitkasikorn (Thailand)
Kachon Petchrit (Thailand)
Phat Viboonchaoenphol (Thailand)
Nguyen Duy Can (Vietnam)

Rice Biotechnology Training Workshop (RBTW)
Ayyanar Manickam (India)
Arunava Pattanayak (India)

Masdiar Bustamam (Indonesia)
Ida Hanarida Somantri (Indonesia)
Latifah Bt Ahmad (Malaysia)
Naziah Bt Basirun (Malaysia)
Muhammad Ilyas (Pakistan)
Alim Said (Pakistan)
Antonio A. Alfenso (Philippines)
Loida C. Malijan (Philippines)
Ma. Teresa Bantilan Peralta (Philippines)
Monton Poonyarit (Thailand)
Siravit Ruangsook (Thailand)

Rice Seed Health Testing (RSHT)
Thinlay (Bhutan)
Suraj Kumar (Fiji)
Hyeong Jin Jee (Republic of Korea)
Namkham Phouysangieme (Lao PDR)
Gyanu Devi (Manadhar) Gurung (Nepal)
Josephine G. Aguinaldo (Philippines)

Simulation and Systems Analysis in Rice Production (SARP)
M. Aminul Haque (Bangladesh)
Md. Musherraf Husain (Bangladesh)
Wu Yunying (China)
Rabidra Nath Dash (India)
Naveen Kalra (India)
Sendass Mohandass (India)
M.V.R. Murty (India)
Selvarajan Muruhesan (India)
Pradyumna Kumar Pathak (India)
Ramasamy Sakkarai (India)
R. A. Singh (India)
T. M. Thiyagarajan (India)
Narasimhan Varadarajan (India)
Aan Andang Daradjat (Indonesia)
Rahayu Tejasarwana (Indonesia)
Susanto Tirtowirjono (Indonesia)
Sutoro (Indonesia)
Mohd Norowi Hamid (Malaysia)
Rajan (Malaysia)
Jesusita L. Orno (Philippines)
Lyndo G. Villacorta (Philippines)
Vithanage Pemajayantha (Sri Lanka)
Dalmie Lalantha Wickremasingha (Sri Lanka)
Sirichi Kanlanarat (Thailand)
Krirk Pannangpetch (Thailand)

Special Rice Production (SRPTC)
Tho Chea (Cambodia)
Sokchea Hieng (Cambodia)
Mao Monyratana (Cambodia)
Seang Chhoeurth (Cambodia)
Tea Neang (Cambodia)
Ung Sopheap (Cambodia)
Justin Rakotonjanahary (Madagascar)
Joseph Randrianampy (Madagascar)
Iarinivo Razanakiniary (Madagascar)
Daw Win Win (Myanmar)
U Kyaw Thaung (Myanmar)
Than Tun (Myanmar)
Antonio Semente Gaspar (Mozambique)
Julius Magesa Magoti (Tanzania)

Varietal Testing in Upland Crops (VTUC)
Rudy Soehendi (Indonesia)
Tufail Akhtar (Nepal)
Vilma A. Cristobal (Philippines)
Emilia D. Llabores (Philippines)
Lorenzo B. Palaca (Philippines)
Braulio B. Tamayo (Philippines)
Buddhachard Chuenchit (Thailand)

Courseware development

Courseware documents technical information in a manner that can be readily transferred, adapted, and, if necessary, translated. Objectives of the Training Center courseware development project are to design and produce training materials in multimedia format to support and complement group training courses and thereby facilitate learning. IRRI courseware has proved an invaluable asset in resolving language problems in information dissemination. IRRI courseware lines that were completed or are in different stages of production (Table 6) are in the following formats:

- Print on paper (POP)—printed instructional materials
- Slide tape modules (STM)—learner-driven programs consisting of a slide set, taped instruction, and self-learning and self-test booklets
- Interactive computer-based instruction (ICAI)—interactive computer program modules with graphic text displays
- Video instruction (VI)—modules documented in 8-mm videotapes.

Knowledge-based expert systems programs can potentially assist in problem analysis and decision-making. The International Development Research Centre supported an IRRI project on knowledge

Table 6. Courseware materials produced.[a] IRRI, 1990.

Courseware lines	Titles (no.)
Print on paper	
Basic skills series:	
T3C	8
GEU	4
Objectives manual	
T3C	1
Guidebooks/brochures	
T3C	1
General (training)	1
Slide/tape modules	
FSR	13[b]
RP	7
SARP	5
Interactive computer-aided instruction	
RP modules	1
Video instruction	
T3C	2

[a]In various phases of completion as of 31 Dec 1990 were 2 T3C basic skills booklets, 2 T3C guidebooks, 1 RP objectives manual, 2 RP slide/tape modules, 1 RP ICAI, 5 SARP slide tape modules. [b]Revisions.

acquisition as a prelude to development of expert systems. A workshop was conducted during 26-30 Mar, to introduce concepts, principles, tools, and techniques of knowledge acquisition. Eight participants from diverse fields of psychology, education, computer science, and human-computer interaction attended the workshop. Participants from six institutions in Indonesia, Malaysia, and the Philippines were involved in the development of expert systems programs ranging from identification and management of Southeast Asian weeds, beekeeping, and rice maladies in irrigated environments, to the identification of constraints to farm productivity.

Collaborative in-country training programs

In assisting NARS to develop and strengthen human resource capabilities, IRRI adopts two approaches. One is the collaborative training program or "course transfer" approach, whereby a version of a traditional IRRI course is adapted to training needs of a particular national system. Expertise and resources are shared among participating IRRI and national program scientists. The second approach is to provide training specialists who can conduct in-country courses. During 1990, IRRI assisted in conducting the following:

- Training on rice production/irrigation water management/extension course. This 4-wk training course was conducted in Kilimanjaro Agricultural Development Project (KADP) at Chekereni, Moshi, Tanzania, 25 Mar-20 Apr. Held in collaboration with FAO, this course was attended by 30 participants.
- Training workshop on agroecosystems. This 2-wk training workshop, focusing on FRS/E methodologies, agroecosystem, and economic analysis, was a collaborative program between IRRI and ICAR. The training was held in Hazaribagh, Bihar, India, with 28 Indian and 2 Bangladeshi researchers in attendance.
- Training on computer applications in FSR. This 2-wk course provided skills to 16 FSR practitioners from 11 institutions on data base management and analysis, graphic presentation of results, and report writing using computers. This training was conducted at the Chinese Academy of Agricultural Sciences (CAAS), Beijing, China 15-30 Oct.
- Training on problem diagnosis in rice. This course stressed principles and concepts of integrated pest management, particularly methods of problem diagnosis in rice; identification of diseases caused by bacteria, fungi, virus, and nematodes; and sampling for insect damage and diseases. Eighty-six agricultural officers and extension staff participated in three training sessions 15 Oct-3 Nov in Cambodia.

Conclusion

The year 1990 saw internal reorganization in the Training Center. Adjustments were made to better accomplish the objectives of IRRI's work plan and to meet the changing needs of NARS. Future training activities will be linked to IRRI's ecosystem-based research programs through research consortia involving collaborating institutions. IRRI will continue its efforts to strengthen in-country training capabilities through collaborative training activities with national systems that demonstrate the interest, capacity, and commitment to conduct training programs.

With IRRI moving upstream in its research focus, priority will be given to awarding scholarships for Ph D research while gradually reducing the number of candidates in the MS program, particularly since

more national systems are strengthening their capabilities to offer graduate programs at the MS level.

Six explicit objectives of IRRI's training programs were identified in the Training Policies and Guidelines document. These are to

- plan jointly with NARS rice-related training needs and define IRRI's role in training activities that are linked to ecosystem-based research programs;
- focus training efforts on strategic national institutions selected by NARS so that a group of core scientists can be formed in key research institutions;
- involve IRRI alumni, agricultural universities, and advanced laboratories in strengthening training in their respective systems;
- redirect short-term training to areas where IRRI has comparative advantage such as biotechnology, sustainability, and integrated pest management, as well as to refresher and midcareer courses that will supplement the training program;
- transfer short-term courses to national and regional institutions, wherever feasible, and develop training methods and appropriate courseware materials, in cooperation with NARS, to eliminate communication barriers that impede learning; and
- maintain sensitivity to client needs through a feedback mechanism, which evaluates the relevance of IRRI's training activities to changing and emerging needs.

International programs
Country and regional projects

Bangladesh 269
Bhutan 270
Cambodia 270
  Varietal improvement 270
  Integrated nutrient management 271
  Rice ecosystem analysis 271
  Training 272
Eastern, Central, and Southern Africa 272
Egypt 272
  Research 272
  Training 273
  International collaboration 273
India 273
  ICAR-IRRI collaborative programs 273
Indonesia and Malaysia 274
Lao PDR 274
  Rice in the Lao PDR 274
  The Lao-IRRI research and training project 275
  Training 275
Latin America 275
  Palmira as a yield selection site for Latin America 276
  Genetic base of Latin American irrigated rice 276
Madagascar 277
  Central highlands 277
  Coastal areas 278
Myanmar 279
Sri Lanka 280
Thailand 280
Vietnam 280
  De-collectivization and rice productivity growth 280

Previous Page Blank

Country and regional projects

The broad and interrelated objectives of this component of IRRI's international program are to

- facilitate research aimed at generating and disseminating rice-related knowledge and technology; and
- help strengthen the rice research capacity and capabilities of national agricultural research systems (NARS).

Country and regional projects emphasize collaborative research and training as the principal means of strengthening national rice programs.

Our firm commitment to research-driven country and regional projects is demonstrated in our 1) project formulation process, 2) recruitment policies, 3) personnel evaluation procedures, and 4) reporting system. Related efforts include an annual meeting of IRRI staff posted in Los Baños and in other countries and increased opportunities for the latter to visit IRRI, Los Baños. We also aim to strengthen links between country projects and advanced research institutions, where the latter can complement expertise available at IRRI and the concerned NARS.

Recognizing IRRI's mandate and comparative advantage, country projects do not incorporate extension, seed production, or development activities, although we accept the need to ensure that research findings are communicated to our target groups through

- participation of IRRI scientists in national workshops and conferences;
- documentation and, in some cases, translation of relevant information and research results into local languages; and
- inclusion of extension and development personnel (including those from nongovernment organizations [NGOs]) in in-country training programs and adaptive research activities.

In January, 1990 IRRI established the International Programs Management Office (IPMO) with the following responsibilities in relation to country and regional projects:

- ensuring high quality and relevance of research and training activities;
- coordination of technical and administrative support from IRRI Los Baños;
- project design, appraisal, and review;
- recruitment and personnel management for outposted scientists;
- liaison with NARS officials and scientists; and
- liaison with donors and related international organizations in coordination with IRRI's Liaison, Coordination, and Planning Unit.

IRRI continued to work closely with national rice programs through the implementation of several country and regional projects. Currently we have scientists in Bangladesh, Cambodia, Colombia (for Latin America), Egypt, India, Indonesia, Lao PDR, Madagascar, Myanmar, Nigeria (for Africa), and Thailand. IRRI also collaborates closely with Bhutan, Sri Lanka, and Vietnam, with the support of donor-funded projects. Collaboration with China is supported through appropriate core-funded research projects.

All country and regional projects are executed jointly with NARS scientists and

therefore represent collaborative efforts. The following selected highlights from country and regional projects illustrate the range of collaborative research and training activities in 1990. In some cases more detailed reports are found in other sections of the *Program report*.

Bangladesh

Collaboration with Bangladesh is primarily through the Bangladesh Rice Research Institute (BRRI) - IRRI Rice Research and Training Project, which is supported by the Canadian International Development Agency (CIDA) and the United States Agency for International Development (USAID). A major complementary project on rainfed lowland rice is supported by the International Fund for Agricultural Development (IFAD).

Research into varietal improvement for the IFAD-supported Rainfed Rice Project is now in full operation. Four BRRI staff participated in a workshop on rainfed rice farming systems and environmental analysis 11 to 22 Jun 1990 in Hazaribagh, India. We expect this project will accelerate cross-border exchange of germplasm and rainfed rice technology.

Surveys on varietal requirements in Rajshahi, Chittagong, and Khulna Districts revealed the preference of farmers in Chittagong and Rajshahi areas for high-yielding varieties with intermediate plant height, early maturity, and medium-fine grain. Farmers in Khulna District prefer high-yielding varieties with tall plant height, tolerance for tidal submergence, medium-late maturity, and medium-coarse grain.

After a 1989 survey, 20 local varieties were grown in Joydebpur to evaluate specific traits responsible for their good adaptation under diverse environments. Promising varieties will be utilized in a crossing program for development of new varieties for rainfed lowland ecosystems. In addition, environmental data collection from different rice ecosystems will be started soon.

For the favorable rainfed lowland and drought-prone environments, extrapolation areas for cropping system research technologies have been determined (900,000 ha for each). For the drought-prone analysis, the Bangladesh Agricultural Research Institute (BARI) and BRRI worked jointly and it is expected that the BRRI Environmental Unit will draw strongly on the excellent computerized agroecological data base that Bangladesh has for identifying research priorities.

The botanical pest control project is an important part of BRRI's research program. It is funded from BRRI's core fund as well as through a collaborative program between IRRI and BRRI with support from the Asian Development Bank (ADB). In recent years, commercial bioactive products have been developed from neem in different countries. Some are being used by farmers against crop pests. The second phase of the BRRI-IRRI collaborative research program, which commenced in 1990, will test the neem-based commercial products against major rice insect pests in farmers' fields.

In deepwater rice (DWR) entomology studies, 36 rice cultivars were screened in 2 experiments. One strip of each experiment was kept free of yellow stem borers (YSB) by collection and destruction of female moths and egg masses and by application of insecticides when necessary. Natural infestation was allowed in the other strip and artificial inoculation by first-instar larvae was made in September. A pot experiment was also set up to evaluate the effect of hispa beetle damage at different crop growth stages on grain yield. DWR plants were exposed to adult hispa beetle at maximum (basal) tillering, early elongation, and late elongation stages.

In DWR pathology studies, 150 breeding lines and progeny lines from BRRI and 29 breeding lines from IRRI were screened for ufra nematode resistance. Scores were recorded at the vegetative stage. Some data on the inheritance of ufra nematode resistance have been taken and will be analyzed in collaboration with the Plant Breeding Division of BRRI. The breeding program to develop ufra-resistant varieties is also in progress. Silicon and protein contents in the leaf sheath and stem of ufra-resistant and -susceptible varieties under different silicon treatments are being analyzed. Ufra reaction and yield of five ufra-resistant and two -susceptible entries under artificially inoculated conditions in deepwater tanks have been studied.

The regional Prosperity Through Rice Phase 2 (PTR-2) Project completed all field studies and a final workshop was held at IRRI 18-23 Jun 1990. The results of the impact study of PTR-2 indicated adoption of modern varieties (MVs) (BR11 and BR14) increased by 59% in Kismat and 38% in Tatisotha. Rice yield increases were 13-24% over

3 yr in Kismat and 2-19% in Tatisotha. Income due to increased rice yields increased by about 56% in Kismat and 43% in Tatisotha during the project period. Labor use in rice production increased by 11% in Kismat and 8% in Tatisotha because of MV adoption.

Farmers' knowledge of modern crop management practices increased. Cooperators used higher doses of fertilizer compared to benchmark survey rates and their knowledge of proper seedling age, time of planting, and intercultural operations also increased. Demonstrations of small agricultural equipment such as weeders, sprayers, winnowers, and threshers exposed the technology to farmers but also provided researchers opportunity to field-test equipment.

Demonstrations of making and using urea-treated straw for cattle feed and the fuel-efficient stove created an awareness among farmers of the potential use of these technologies. However, the added costs and changes in traditions constrained adoption.

A training program on irrigation and water management was organized at BRRI and conducted from 14 Jul to 2 Aug 1990. Twenty-three participants from seven government agencies participated in the training program. It was decided that, based on research results from the Ganges-Kobadak and the North Bangladesh Tubewell Project areas, recommendations should be formulated separately for the researchers, extension personnel, and irrigation engineers. Strategies should be developed for each group for implementing the recommendations.

Research on women in rice farming systems (WIRFS) was initiated in an upland area near Joydebpur. BRRI staff have found clearly demarcated gender roles among family members, and have identified opportunities for women to improve their productivity and income. In this regard, poultry raising seems most promising as an intervention; hence, a research program on this has been initiated.

A kitchen gardening demonstration for winter vegetables and high-yielding guava plantations have been established. Informal discussions were carried out with the cooperators concerning layout, land preparation, use of fertilizers, sowing, and other management practices to improve their plans and technical knowledge.

Socioeconomic studies are conducted with marginal and small farmers at four sites representing favorable rainfed lowland, deepwater, and upland ecosystems. These studies have indicated that farmers with less than 0.6 ha, even in a favorable two-rice-crop rainfed environment, are vulnerable to losing land; however, adoption of innovative local technology along with recommended rice technology can greatly increase production and cash income. Interventions were initiated with 16-30 farmers at each site to test these strategies.

Bhutan

After the conclusion of Phase 1 of the International Development Research Centre (IDRC)-funded Bhutan-IRRI Rice Farming Systems Project, Phase 2 began in April 1990; support in the amount of US$340,000 again came from IDRC. One of the key thrusts of Phase 2 is to develop national capacity in conducting baseline and diagnostic surveys for the dual purposes of impact assessment and research priority setting. Surveys were undertaken during March-April 1990 in Gaylegphug District in southern Bhutan, which represents the low-altitude, rice-growing zone. A range of rice research needs were identified based on the causes of low rice yields and low farm productivity.

A 1-yr ethnographic study of rice farming in medium (1000-1500 m) and high (>1500 m) altitudes of Bhutan was started in October 1990. The study is a collaborative effort of Bhutan's Ministry of Agriculture and IRRI to improve knowledge of farming practices and resource allocation in strongly seasonal irrigated rice ecosystem and to strengthen social science research capacity in Bhutan through training and guidance from IRRI.

Cambodia

Activities under the IRRI-Cambodia Project gathered considerable momentum during 1990. Significant progress was made in the areas of varietal improvement, integrated nutrient management, rice ecosystem analysis, and training.

Varietal improvement

More than 3,000 traditional and modern varieties were tested during 1990 in 278 locations in upland, rainfed lowland (early, medium, late, and aromatic varieties), floating/deepwater, and dry season irrigated environments. From trials conducted in 126 farmers' fields during the year, promising varieties

for upland, irrigated, favorable rainfed lowland, and deepwater situations were identified. Sita (ITA257) and Rimke (ITA150) outyielded local varieties in the upland; IR66, IR72, and Kru (IR13429-150-3-2-1-2) were superior in the irrigated and favorable rainfed lowland while Teweda, Khao Tah Petch, and Don (HTAFR 77022-45-3-2-1) performed well in the deepwater environments.

A large-scale evaluation of the Cambodian rice germplasm was also started during 1990. With the support of local agricultural officers, a collection of 1,358 accessions from 11 provinces in Cambodia was made. All varieties were grown during the wet season and evaluated for 42 characters in an effort to field-test, catalogue, and conserve the collection. The classified collection will be shared with IRGC, Los Baños. Some germplasm was used immediately for the development of 19 F$_1$ hybrids and 37 new crosses during the year.

A seed production program for these varieties was started by provincial farmers and development projects, resulting in more than 2,000 ha of IR66, the most preferred variety, planned for seed multiplication during the 1990-91 dry season. The higher yield of these varieties, once grown over a large area, will almost eliminate the rice deficit of Cambodia.

Integrated nutrient management

Integrated nutrient management research trials concentrated on evaluation of cropping systems and use of locally available phosphate rock (PR), imported fertilizers, and organic manures.

Sesbania rostrata was compared with three local legumes cultivated before transplanted rice. Biomass production was extremely variable because of drought prevailing in Cambodia during 1990. Fresh weight yields were between 0 and 501 ha^{-1}. Across 18 sites, rice yields after *S. rostrata* increased by an average of 40% compared with the control. Although several of the on-farm experiments were abandoned because of poor growth of green manure some farmers perceived the system as one which assists plowing and weed control in addition to having a positive effect on rice yields.

Finely ground PR is a potential source of P for the acid soils of Cambodia. Replicated experiments compared PR with triple superphosphate (TSP) across 12 sites. Many of the tested soils responded significantly to both sources. Doubling of the grain yield with 25 kg of TSP or 100 kg of PR was common and residual effect was also considerable after 1 yr, particularly with PR.

The effects of P and N applications were greatly improved with organic matter additions.

Rice ecosystem analysis

Mapping of the rice ecosystems in Cambodia using Landsat Thematic Mapper (TM) data and 1:50,000 topographical maps was started in 1990. The rice areas of the country were divided into deepwater or floating, wet season, and dry season rice ecosystems. Separate maps for each of the 12 rice-producing provinces will be prepared to assist in estimating crop area and national rice production.

Baseline surveys for the deepwater, rainfed lowland, and irrigated rice ecosystems were completed in 1990. Beginning in early December, a comprehensive set of crop cuts of 29 varieties of rainfed lowland rice were taken. In conjunction with these, a short interview was conducted with farmers concerning crop timing and care, appraisal of grain and cooking quality of the variety, and farmers' reasons for its yearly cultivation.

Early varieties are grown primarily for their early maturity in the higher fields, good yielding characteristics, and the fact that this was subsistence rice. Yield and agronomic characteristics such as panicle size, number of seeds per panicle, or other matters such as milling recovery were the most frequently mentioned reasons for growing medium-duration varieties. Long-duration varieties are generally grown for their adaptation to lower fields on the farm and their flood tolerance.

The frequency with which eating quality, specifically, and associated attributes such as volume expansion and sale price were mentioned bears out the generalization that medium-duration varieties tend to have the best eating quality followed by early and late varieties, and late varieties have the best volume expansion.

The report generated from these data and survey has provided the plant breeding program with useful guidance concerning farmers' agronomic and culinary preferences and cropping problems, which govern their decisionmaking in relation to varietal choice in the complex and difficult rainfed lowland rice environment.

Training

Cambodian researchers are severely handicapped by lack of training and poor facilities. To improve the capacity to conduct field trials, in-country training included courses on experiment management (4 courses of 60 participants), English for agriculturists (1 course of 20 participants), and field problem diagnosis (3 courses of 30 participants each). Eleven Cambodians also attended nondegree training courses at IRRI, Los Baños, while another commenced a masteral program at the Central Luzon State University.

Eastern, Central, and Southern Africa

The Southern African Centre for Cooperation in Agricultural Research (SACCAR) and IRRI jointly organized a regional workshop on "Rice Research and Production in the SADCC Region and Neighboring Countries" in Lusaka, Zambia, 26-29 Nov 1990. The workshop was attended by national scientists from Burundi, Kenya, Madagascar, Swaziland, Tanzania, Zambia, and Zimbabwe, as well as representatives of SACCAR and IRRI.

Participants highlighted the rapidly increasing demand for rice in the Eastern, Central, and Southern Africa region. While current production and rice area are low (except for Madagascar and Tanzania), there exists great potential for the development of hydromorphic depressions (known as *dambo* or *vlei*) for rice production. The workshop participants recommended more of collaborative research and training, and requested support of SACCAR and IRRI in strengthening the scientific and technical capabilities of rice scientists in the region.

Egypt

Preliminary estimates for Egypt show that rice was grown in 435,000 ha with a record production of 3.2 million t of rough rice. National average yield exceeded 7.2 t/ha. In two of the rice-growing governorates, average yield reached 8.0 t/ha.

During the past 3 yr, the Egypt-IRRI Project, supported by a grant from USAID, has emphasized the strengthening of the Rice Research and Training Center (RRTC) at Sakha, Kafr El Sheikh. The project helped operationalize the RRTC as an effective national institute. Aside from research, RRTC trains extension workers and supports demonstration of more productive rice technology.

Research

The varietal improvement program aimed to develop high-yielding varieties for normal and saline soils. Desired agronomic characters included early maturity and resistance to blast (Bl) and stem borer.

Two promising breeding lines were registered for commercial cultivation as varieties Giza 175 and Giza 176. Giza 175 was the breeding line GZ1394-10-1, a derivative of the cross IR28/IR1541//Giza/Giza 14. It matures in 140 d and has short grain, high level of Bl resistance, and high yield potential (8.7-11.5 t/ha). Giza 176 is the breeding line GZ2175-5-6, a japonica type derived from the cross Calrose 76/Giza 172//GZ242. Because of its early maturity (145 d), yield potential (8.7-13.3 t/ha) higher than that of local cultivar Giza 172, and good grain quality, it occupied about 20% of the rice area in 1990.

In multilocation yield trials, 182 advanced breeding lines were evaluated. Among them the most promising cultures were IR25571-31-1, EICA 31-104, and GZ1368-S-5-4. They were comparable to high-yielding checks Giza 175, Giza 176, and Giza 181. These highly Bl-resistant varieties demonstrated a yield potential of 9.8-10.4 t/ha in normal soils and 5.3-6.5 t/ha in saline soils.

Six international trials (IRYN-VE, IRYN-E, IRON, IRSATON, IRBN, IRCTN), consisting of 469 test entries, were evaluated at Sakha and Sirw locations. The most promising entries were IR39357-45-3-2-3, IR53970-100-3-3-2, and IR25898-69-2.

In an area of 1,000 ha, commercial cultivars (Giza 171, Giza 172, IR28, Giza 175, Giza 181) and promising breeding lines (GZ2175-5-6 and IR25571-31-1) were grown by RRTC for seed production in collaboration with the Seed Board and the Department of Agriculture. Distributed to farmers were 4,464 t of pure seed comprising 8 t of breeder seed, 335 t of foundation seed, and 4,119 t of registered seed.

In the agronomy program, methods to improve fertilizer and water use efficiency were evaluated. For direct seeded rice, a seeding rate of 110 kg/ha and application of 96 kg N/ha in 3 split doses (basal, at tillering, and at panicle initiation) resulted in maximum yields (10.0-11.0 t/ha). Water manage-

ment experiments showed that grain yield was affected when the interval between irrigations was prolonged (6-d interval), especially at the reproductive stage. IET1444 and Giza 181 were more drought tolerant than the other evaluated cultivars.

Weed management studies showed that preplant application of thiobencarb at 3.6 kg/ha or oxadiazon at 0.6 kg/ha was effective in controlling weed flora in broadcast seeded rice. In drill seeded rice, preemergence application of oxadiazon at 0.75 kg/ha or thiobencarb + propanil at 3.6 + 1.8 kg/ha and postflooding treatment of 5.2 kg molinate/ha provided good weed control.

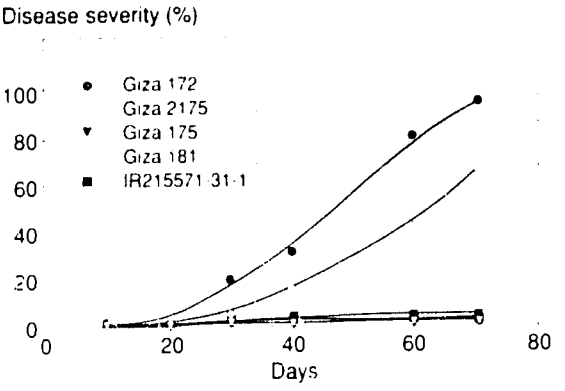
To develop BI-resistant cultivars, exotic and indigenous germplasm, breeding lines, and segregating populations were evaluated in BI nurseries in Sakha and three other representative locations. The following cultivars and breeding lines had low disease incidence (low AC DPC values) and were highly resistant: Giza 175, Giza 181, Giza 1368-S-64, GZ2447-S11, GZ2611-1-6-4, GZ4120-2-5-2, GZ 4196-36-2, IR28, IR215571-31-1, IR19743-46-2-3, IR54017-2-3, IR54017-49-2. At the multilocation, on-farm test sites (20), the cultivars IR28 and Giza 181 and the breeding lines IR25571-31-1, IR54017-49, GZ1365-S-4, GZ2447-S-17, and GZ4196-36-2 were resistant; they were also resistant in glasshouse tests against the prevailing BI races (IC 17, IC 25, IC 29, ID 13, ID 15) of the Nile delta. The reaction patterns of newly released varieties Giza 175 and Giza 2175 against prevailing virulences of the pathogen on the Nile delta are presented in Figure 1.

Training

One Egyptian scientist completed his postdoctoral studies at IRRI on the use of anther culture techniques for japonica rice improvement. Another scientist worked at IRRI for 2 mo on a N collaborative project. In the in-country training program, local scientific staff at RRTC trained 70 senior extension workers.

International collaboration

IRRI assisted the Egyptian rice program through rapid advance of generations of breeding lines. Nearly 250 crosses were planted in a winter nursery in collaboration with the IRRI Plant Breeding Division. Egyptian administrators and scientists participated in several IRRI organized technical conferences and workshops.



1. Blast disease progress in 5 rice varieties.

India

ICAR-IRRI collaborative programs

During 1987 two special Indian Council of Agricultural Research (ICAR-IRRI) collaborative projects for development of rainfed rice production in eastern India were initiated with funding by ADB and IFAD. The first project is "Pest Management in Deepwater Rice" and the second "Development of Rainfed Rice Production in Eastern India."

Major achievements of the former are the mapping of the deepwater areas in East India, detailed studies on the population dynamics of major insect pests, rice-fish culture ecology, breeding for ufra resistance, nematode surveys, crop loss assessment for diseases, chemical control of YSB, sequential monitoring of insects, diseases, nematodes, weeds; screening for tolerance for YSB, sheath rot, BI, bacterial blight (BB), brown spot (BS); flooding pattern studies in West Bengal, identification of weeds, and effects of pesticides on fish.

In the second project, work is being carried out in 15 centers and through on-farm trials with the cooperation of more than 1,500 farmers. The centers represent specific agroecological environments of rainfed upland, shallow, stagnant, and deepwater conditions.

Environment characterization and classification of dominant rice ecosystems provide guidelines for selecting the representative field sites for evaluation of production technology, and allow more effective dissemination of the research results. Another outcome is the methodology for extrapolating research findings from experimental sites to production regions.

Agroecosystem analysis has provided an ecology-based framework for understanding farming systems and identifying problems by land type. The interactions between biophysical causes and socioeconomic constraints to farmers' problems were identified and problems ranked considering the number of farmers affected, the importance of the enterprise involved, and the losses in production and income entailed.

On-farm research sites include several villages at each of the 15 centers. Agroecosystem analysis, problem ranking, and systems diagnosis have been carried out as sample case studies involving a few villages. The project plan is to continue similar studies in other villages at each project site and the outcome of the study would form part of a future project report. Socioeconomic analysis indicates that farmers adopt varieties found to be high yielding at the on-farm research sites, resulting in high yields in farmers' fields. The productivity of rice by farm size appears to be related to input use, in particular to fertilizer and labor. The yield of rice per hectare, however, does not show any trend with increase in farm size. Participation of female labor in rice cultivation is quite high in all rice ecosystems. The average size of holdings is considerably higher in the deepwater ecosystem than in the two other ecosystems.

Under different ICAR-IRRI collaborative research projects, four workshops, nine planning or review meetings, and one symposium took place during the year.

Indonesia and Malaysia

Indonesia remains self-sufficient in rice despite severe drought in some parts of the country during 1990 and the conversion of some irrigated ricelands to other economic uses. The government continues to emphasize agricultural development, especially to maintain food self-sufficiency and increase farmers' income.

Malaysia likewise continues its program to achieve 65-80% self-sufficiency in rice production. With increasing production cost and the government's concern for food security, the rice research program of the Malaysian Agricultural Research and Development Institute (MARDI) focuses on cost reduction through direct seeding and mechanization.

An important activity in the Indonesia-Malaysia-IRRI program is the visit by internationally recruited staff (IRS) from IRRI headquarters to discuss collaborative research and exchange information. In 1990, 29 IRS spent a total of 166 person-days in Indonesia, while 7 nationally recruited staff spent 67 person-days. Five IRS, including the liaison scientist, visited Malaysia for a total of 28 person-days.

Training of national program research staff continues to be a very important activity. Twenty-five research staff from Indonesia and 3 from Malaysia participated in 14 training activities at IRRI.

Seed exchange and collection are two important activities being undertaken by the collaborative program. Twenty shipments of seeds were received by 17 Indonesian researchers. Of the 20, 16 were INGER nurseries. One germplasm collection mission to North Sumatra was undertaken jointly by Central Research Institute for Food Crops during the year. Of the 24 accessions collected, 17 were *O. sativa*, 6 were *O. officinalis*, and one was *O. meyeriana*.

Collaborative research activities in Indonesia during the year were related to the international networks: INGER, INSURF, ARFSN, and IPMN. Specific research activities were varietal testing for tolerance for problem soils, N fertilizer efficiency, P sources in lowland rice, soil and water management, hybrid rice, rice stem borer, biological control of rice diseases, rice blast, upland rice, rice modeling and collection of wild rice germplasm. Core-funded experiments on upland and rainfed lowland rice, initiated during the year, are managed jointly by Indonesian scientists and IRRI staff stationed in the country.

Key sites for research consortia have been identified: they are Sitiung Station in West Sumatra for upland rice and Jakenan Station in Central Java for rainfed lowland rice.

Malaysia continues to participate in the activities of the international networks being coordinated by IRRI, as well as in hybrid rice, anther culture, biological control of rice diseases, and the collection of wild rices.

Lao PDR

Rice in the Lao PDR

Rice, the single most important crop in the Lao PDR is planted in 596,000 ha representing approximately

84% of the country's cultivated land area. Less than 2% (10,200 ha) of the area is irrigated; about 62% is rainfed lowland, and 36% is upland. Yields are low, varying from less than 1 t/ha in the uplands to about 2 t/ha in the rainfed lowlands. Total production in an average year is 1.4-1.5 million t.

The rice varieties currently grown are largely glutinous (86% of the area) and traditional (more than 90%). The national rice production program has two broad objectives: 1) increased and more stable production to ensure self-sufficiency, and 2) stabilization of areas of production based on shifting cultivation.

The Lao-IRRI Research and Training Project

The Lao-IRRI Research and Training Project formally began in August 1990 with initial funding by the Swiss Development Cooperation (SDC). The project has two major components: 1) research program development, and 2) training.

The project has three long-term IRS positions: lowland agronomist/team leader, responsible for the development of research skills and technology for rice-based ecosystems in the rainfed lowlands and, to a more limited extent, the irrigated lowlands; upland agronomist, responsible for the development of research skills and technology for the upland rice ecosystem; and plant breeder, responsible for training and development to systematically evaluate rice varieties for each of the major rice ecosystems in the Lao PDR.

Rainfed lowland research. The project will conduct on-farm and on-station research in the 1991 wet season in the main rainfed lowland rice producing provinces of Savannakhet, Champassak, and Vientiane. Research on varietal evaluation, the use of organic and inorganic fertilizers and green manure crops, and the measurement of yield loss due to pests and diseases will involve close collaboration with the Thai-IRRI research program on rainfed lowland rice in Northeast Thailand.

Upland research. Two broad types of shifting cultivation are recognized in the Lao PDR, one destructive and exploitative and the other potentially stable. The former is commonly practiced by the Lao Sung, in which the main ethnic group is the Hmong who usually occupy hill slopes above 1,000 m and have a system of cultivation based on migrating every 15-20 yr. Forest cover in new areas is completely destroyed and the area intensively cropped until the soils are exhausted. Regeneration of an area is believed to take decades and, in some cases where serious soil erosion has occurred, regeneration will never be complete. This system has to be completely abandoned if the affected areas are to be stabilized.

The second type features a managed cycle of annual cropping: after one or two crops on the slash-and-burn system for a given area, the area is left to regenerate before being cropped again. When cropping is based on an 8- to 15-yr cycle, this system can often be stable. However, in areas of the Lao PDR the cropping cycle has been reduced to 3-4 yr.

In late 1990, a diagnostic survey of areas of shifting cultivation in the provinces of Oudomsay and Luang Prabang defined future research priorities. Research will be directed at obtaining a better understanding of factors affecting the relative stability of the slash-and-burn upland rice cropping systems. At the same time, collections of the diverse range of local upland glutinous rice varieties were undertaken.

Irrigated lowland research. Apart from some varietal evaluation, fertilizer response studies, and insect pest yield loss studies, research in the irrigated areas will receive less emphasis than in areas of rainfed lowland and rainfed upland rice production.

Cooperative research links. Cooperative research links are being developed with other national and international research agencies such as ACIAR (Australian Centre for International Agricultural Research) and the FAO-IPM networks and programs. Arrangements have been made for Lao PDR to participate actively in INSURF.

Training

A major constraint to participation of Lao research scientists in IRRI nondegree training courses is the low level of proficiency in English. In the short term, training courses will be arranged using the pool of IRRI-developed expertise in Thailand. The first Basic Rice Production Course in Thai language for Lao scientists is scheduled in February-April 1991.

Latin America

IRRI contributes one research scientist to the Latin American rice research team, coordinated by the Centro Internacional de Agricultura Tropical (CIAT). The scientist serves as liaison with the Latin Ameri-

can region, coordinates the regional International Network for Genetic Evaluation of Rice (INGER) network, and provides the regional team with direct research backstopping in germplasm enhancement. Only the results of the research activities are highlighted here; the other activities are summarized elsewhere in the *Program report*.

Palmira as a yield selection site for Latin America

Yield data generated in replicated trials in Latin America during 1977-84 were used to evaluate Palmira, Colombia, as a yield selection site for Latin America. Locations were classified as tropical, arid, and temperate irrigated, and favored upland according to planting system and climate. Lines were classified as discarded and selected as their yields were statistically less than, equal to, or more than that of the best check. Proportions of coincidence in selection and divergence in rejection were defined as the proportion of lines selected in Palmira that were also selected in the rest of the region and the proportion of lines discarded in Palmira that were selected by the region, respectively. The difference between the two proportions was calculated as an estimate of the ability to discriminate among the lines for yield.

Those years in which more than 75% of the lines were selected in Palmira showed better discriminating power, suggesting that selection at the site should be mild if materials useful to the region are to be saved.

Genetic base of Latin American irrigated rice

The pedigree of 143 Latin American rice cultivars released during 1971-89, was followed back to the original land races. The contribution of each land race was estimated, assuming that each parent provided 50% of its genes to its descendants in each biparental cross. A group of 14 land races were found to contribute to cultivars released in all periods (Table 1), and was defined as the core for the genetic constitution of the Latin American irrigated rice. The data show that parents of the cultivars were increasingly more related—a simple way of making sure segregants accumulated the basic genes for adaptation. Thus, when incorporating new genes, breeders put them in the core background acting as a carrier.

Not all land races had the same level of contribution. Land races Cina, Latisail, and Dee-Geo-Woo-

Table 1. Land races contributing to rice varieties released in Latin America through 4 periods, 1971-89.[a]

Land race	Origin	1971-75		1976-80		1981-85		1986-89		Mean	
		Cultivars participating (%)	Contribution (%)	Cultivars participating (%)	Contribution (%)	Cultivars participating (%)	Contribution (%)	Cultivars participating (%)	Contribution (%)	Cultivars participating (%)	Contribution (%)
Blue Rose	USA (Japan)	32.25	3.44	29.6	3.46	18.5	0.16	39.6	1.68	32.2	2.11
Bruinmissie	USA	6.45	0.30	7.4	0.40	3.7	0.01	10.3	0.30	7.8	0.26
Cina	China	67.74	9.68	74.1	11.73	96.3	13.82	91.4	12.42	83.9	11.96
Dee-Geo-Woo-Gen	China	70.96	13.36	85.2	16.46	96.3	15.54	91.4	14.76	86.7	14.93
Hill Selection	USA	12.90	0.30	33.3	0.68	37.0	0.05	62.1	0.54	41.2	0.42
I Geo Tse	China	19.35	4.43	44.4	5.03	70.4	6.70	62.1	4.14	51.0	4.80
Khao Dawk Mali 105	Thailand	3.22	1.61	7.4	0.93	18.5	2.89	31.0	1.76	18.2	1.78
Latisail	India	67.74	9.68	74.1	11.70	96.3	13.82	91.4	12.48	83.9	11.98
Marong Paroc	Philippines	38.71	6.16	77.7	9.37	65.2	2.54	87.9	4.49	74.8	5.41
Mong Chim Vang A	Vietnam	19.35	4.43	44.4	5.03	70.4	6.71	62.1	4.14	51.0	4.86
Pa Chiam	China	41.93	5.02	66.6	5.03	85.1	3.40	89.6	2.61	74.1	3.74
Sinawpagh	Philippines	6.45	0.13	18.5	0.94	11.1	0.10	17.2	0.74	14.0	0.52
Tadukan	Philippines	9.67	4.84	18.5	4.17	44.4	5.44	58.1	6.32	37.7	5.42
Tsai Yuan Chon	China	25.80	1.76	25.9	0.90	51.8	0.66	51.7	0.55	41.2	0.90
Total		-	65.14	-	75.82	-	71.84	-	66.93		68.19

[a]Assuming 50% contribution of each parent in a single cross.

Gen contributed the most. They had been used to develop IR8, the cultivar that triggered the Green Revolution in rice. Lines introduced from IRRI were found to be a very important vehicle for the core land races. The most important cross was IR8, found in 76% of the cultivars released (Table 2).

Madagascar

The Third Phase of the USAID-funded Madagascar-IRRI Rice Research Project began 1 Jan 1990 with financial assistance of $5.6 million over the next 5 yr.

Training, particularly degree training, remained a high priority. During 1990, two Malagasy scientists began MS or Ph D programs; at present a total of 2 scientists are studying for the Ph D and 5 for the MS degrees. In addition, two scientists participated in short-term training. Since the beginning of the project in 1984, 43 Malagasy research scientists have participated in short-term training programs.

Central Highlands

Early rice crop (Antananarivo area). On the Central Highlands (1,000-1,800 m), about 180,000 ha are grown to the main or rainy season crop transplanted in November-December and harvested at the end of the rainy season March-April. However, in about 18,000 ha early season rice is transplanted in poorly drained plains that may flood during December-February. Even with early transplanting in August-September, farmers can expect to lose their rice crop once every 4 or 5 yr.

Rice scientists consider two strategies to reduce the risk of flood-induced crop losses: 1) growing early-maturing varieties to escape flooding, and 2) growing elongating varieties that can "ride out" the flooding. Trials conducted over the past 4 yr have identified several varieties that yielded at least as high as the local varieties and also matured early (Table 3).

Main rice crop. *Varietal improvement.* In 81 farmer-managed trials conducted in Manjakandriana and Mahitsy, 4 of FOFIFA's advanced varieties (2067, 2822, 2787, and 2509) were tested against the farmers' preferred variety. We also asked participating farmers to complete a questionnaire that would provide us information to explain varietal performance, identify research issues, and provide a data base of farmers' management practices. The new varieties were superior to the local varieties; 2067 and 2822 in Manjakandriana and 2787 and 2822 in Mahitsy were the best performers.

Because farmer participatory trials permit widespread testing but require minimum researcher management and resources FOFIFA's rice program is testing 14 new wetland varieties in about 100 farmers' fields on the High Plateau in the 1990-91 rice season.

Phosphorus efficiency trials. At two locations, we tested the efficiency of different sources of P when applied at 13 kg P/ha as a seedling root dip or when broadcast and incorporated. Results indicate no difference between sources as root dip or broadcast and incorporated, thus cost per unit P should determine the fertilizer of choice. However, dipping in single element P materials was more effective than broadcast and incorporation. At Ambatomafana, dipping plant roots in complete fertilizer 16-16-16 retarded seedling growth and reduced yields whereas at Soanierana, 16-16-16 applied by the 2 methods gave equivalent yields.

We tested the value of applying the more commonly available compound fertilizer 11-22-16 as root dip because previous research had indicated that this could cause seedling mortality, probably be-

Table 2. IR crosses most frequently found in the parentage of Latin American irrigated rice cultivars, 1971-89.

Cross	Cultivars participating (%)	Genetic contribution cultivar	
		Mean	Maximum
IR8	76.2	0.36	0.75
IR262	26.6	0.5	0.50
IR579	36.4	0.29	1.00
IR661	9.1	0.22	0.50
IR665	34.3	0.28	1.0
IR841	16.8	0.17	1.0
IR930	51.0	0.38	1.0

Table 3. Yield and duration of deepwater rice varieties grown in farmers' fields,[a] Betsimitatatra Plain, Antananarivo, Madagascar, 1989-90.

Variety	Duration[b] (d)	Yield (t/ha)
IR13146-13-3-3	156	6.7
IR21188-87-3-3-2-2	149	6.6
IR6370-k-23-1	156	6.3
IR21363-13-2-2-11	139	5.7
Rojomena 271-10 (check)	156	5.2
SPR7297-432-1-2-1	143	5.2
IR9763-11-2-2-3	143	5.2

[a]Seeded 15 April, transplanted 28 August, fertilized with 60-26-37 kg NPK/ha. [b]Days from transplanting.

cause of the soluble urea-KCl component of the fertilizer mixture. At P rates of 0, 6.4, 8.6, and 10.8 kg/ha, we found no seedling mortality; as P rates increased, yields increased proportionately (Table 4). At 8.6 kg P/ha, dipping roots in 11-22-16 was about 17% more efficient than broadcast and incorporation of the fertilizer.

Technology verification trials. Nine farmers, under their own management, tested the researchers' technology package consisting of improved varieties, application of low P rates as root dip, and shallow (3 cm) transplanting. Yield increase from the researchers' package was 0.1-2.0 t/ha (mean 0.8 t/ha) compared with the farmers' practice.

In 1990-91, 15 farmers will follow the researcher package, which has been amended to include dipping of roots in complete fertilizer 11-22-16 and transplanting 35- to 50-d-old seedlings.

Based on on-farm research and experience over the past 5 yr, we wrote a detailed technical bulletin on growing rice on low-fertility, P-fixing soils. In 1991, we plan to write an abridged bulletin in Malagasy for dissemination to farmers.

Effect of silicon on rice yield. We tested the effect of silicon in the form of burned rice hulls on the Fe-toxic, P-fixing soils in Manjakandriana. In the trial, roots were dipped in 13 kg P/ha. The application of 0.48 t Si/ha increased yields by 0.6 t/ha, or 18%, over the no Si treatment, but there was no difference between broadcast/incorporation and the root dip.

Effect of sulfur on rice yield. Many farmers in the Mahitsy region have not found NPK application profitable; consequently fertilizer use is low. In previous trials we found that soils were deficient in S. Therefore, a trial was conducted to determine the best source and rate of S. Sulfur at 40 kg/ha produced higher yields than did 20 kg/ha (Table 5). At 20 kg S, $CaSO_4$ was more efficacious than ammonium sulfate but equivalent to elemental S and S powder. At 40 kg S/ha, all sources were equivalent in value.

Rice-forage legumes. During the dry, cold season, most fields are fallow. During the dry season, cattle lose weight, produce less milk, and often become sick or die for lack of forage. Two years ago, we introduced a number of cold-season forage or green manure legumes to test after wetland rice. Certain varieties of crimson clover (*Trifolium incarnatum*), red clover (*T. pratense*), white clover (*T. repens*), and common vetch (*Vicia sativa*) from the southeast U.S. were very productive. Berseem clover (*T. alexandrinum*) from Egypt and hairy vetch (*V. villosa*) from China were also very promising. Crimson and red clover were adapted to production with no tillage. Seeding as early as possible (April-May) before temperatures became too cold or the surface soil too dry was important for establishing a good stand.

Coastal areas

On the northwest coast, varietal trials over the past several years have identified a number of varieties having higher yield, earlier maturity, and acceptable grain characteristics. Trials this year have identified varieties that yield 40-80% more than the local varieties (Table 6). IR21015-80-3-3-1-2 and IR38 were widely tested in farmers' fields. In 1991, these varieties and IR36 and IR9830-26-3-3 will be placed in multilocation, farmer-managed trials.

At Tanandava in the southwest, varieties IR36, IR396, IR50, IR64, and 2787 (B54/bka/112/2) have been found superior to the farmer's variety Taichung 178 (known as IR8). These improved varieties are being more widely tested in farmer-managed trials.

Table 4. Effect of applying different rates of 11-22-16 compound fertilizer as root dip or broadcast and incorporated (B&I) on the yield of 2067 (Chianan 2 Sel.). Farmer's field, Ambatomatana, Sambaina, Manjakandriana, Madagascar, 1989-90.

Fertilizer	Rate (kg NPK/ha)	Method of application	Yield (t/ha)
Urea + KCl	12.5-0-15	B&I	1.3 c
11-22-16	7.5-6.4-9	Root dip	2.2 ab
11-22-16	10-8.6-13	Root dip	2.4 ab
11-22-16	12.5-10.8-15	Root dip	2.8 a
11-22-16	10-8.6-13	B&I	2.1 ab
CV (%)			14

Table 5. Effect of S rates and sources on yields of 2787. Farmer's field, Soanierana, Mahitsy, Madagascar, 1989-90.

Fertilizer rate (NPK + S, kg/ha)	S source	Yield (t/ha)
0-0-0 + 0		2.45 d
60-26-50 + 0		3.14 d
60-26-50 + 20	Ammonium sulfate	3.40 c
60-26-50 + 40	Ammonium sulfate	4.28 ab
60-26-50 + 20	Elemental S	3.68 bc
60-26-50 + 40	Elemental S	4.45 a
60-26-50 + 20	S powder	3.65 bc
60-26-50 + 40	S powder	4.65 a
60-26-50 + 20	$CaSO_4$	4.12 ab
60-26-50 + 40	$CaSO_4$	4.60 a

Table 6. Yield of early- and medium-early maturing varieties when grown at two levels of fertilization. Tsararano Station, Marovoay Plain, Madagascar, 1989 dry season.

Variety	Maturity (d)	Yield (t/ha)		% of check
		No NPK	3-13-25 kg NPK/ha	
Early-maturing				
IR9830-26-3-3	120	4.3	4.8	140
Kaohsiung-sen-yu 254	120	3.5	4.3	119
IR34	115	3.1	3.9	107
Boina 1329 (check)	135	2.9	3.6	100
Medium early				
IR21015-80-3-3-1-2	136	4.9	5.8	183
Taichung Sen 10	136	4.9	5.0	169
IR54	136	4.9	4.5	161
IR38	145	4.0	4.7	149
Tsipala A (check)	136	2.7	3.0	100

Myanmar

Technical collaboration with Myanmar involves rice farming systems research, varietal improvement, development of farm implements, and technical manpower development through degree and nondegree training. An agronomist/IRRI representative stationed in Myanmar works closely with the Myanmar Agricultural Service (MAS). Research programs are coordinated through the Agricultural Research Institute (ARI) in Pyinmana. IDRC provides financial support.

Computer analysis of 30-yr daily rainfall data for Pathein, Hmawbi, Taungoo, Pyinmana, and Mandalay townships predicted the onset and termination of monsoon and was the basis for testing crop establishment and rice-based cropping patterns. The models predicted that rice double cropping is possible in Pathein, Hmawbi, and Taungoo, but not in Pyinmana and Mandalay where the onset and termination of monsoon are erratic.

A diagnostic survey indicated that head rice yield and milling recovery are not correlated to ambient relative humidity and temperature but are affected by the practices at stages of harvest in some locations. The current practice of threshing by animal treading on the threshing floor may be improved to minimize losses and prevent grain quality deterioration.

MAS started a pilot program on *Sesbania rostrata* use in four rice townships. Results in Hlegu and Daik-U sites were encouraging, but those in Letpadan and Thongwa failed because of poor sesbania stand, attributed to poor seed germination. Sesbania seeds are sensitive to waterlogging; therefore, they must be sown before heavy rains. Average rice yields were 3.74 t/ha in fields with green manure (GM) and 3.31 t/ha in fields with 60 kg N/ha. Fields with GM and 30 kg N/ha sidedressed at panicle initiation yielded an average of 4.01 t/ha. MAS embarked on a rainfed rice pilot production program using sesbania as GM. Availability of sesbania seed is a constraint to expanded production but, to overcome that, ARI propagates sesbania with stem cuttings.

Our research work on the establishment of black gram, chickpea, cowpea, and mungbean after rice indicated that the farmers' presowing practice of one plowing followed by two harrowings to cover the broadcast upland crop seeds gave better crop stand than using the slit seeder and deep seed placement by dibbling.

ARI staff and the IRRI rice germplasm collector undertook collection in 12 Myanmar townships in December 1990. The collection yielded 31 traditional varieties and 23 samples of 3 wild rice species.

Rice varietal improvement studies identified IBP3146-45-1 and Yn-63-1 for rainfed lowland, Yn-114-47 for irrigated lowland, X71-1-1 and BR-118-38-17 for deepwater ecosystem. The varieties recommended for release in 1990 were B91203 from Sri Lanka and IR13240-180-2-2-3 from IRRI, both for lowland; and ARI-developed Yar 8 for upland.

ARI researchers and engineers from the Agricultural Mechanization Department (AMD) carried out research and development on rice farming systems mechanization at ARI-Yezin. The AMD research team focused on improving the Ingon maize sheller, construction of a prototype hydrotiller using local materials, and evaluation of the drum seeder for rice wet seeding. The ARI team developed an efficient single-animal drawn, wooden-frame plow and adapted the IRRI drum seeder for upland crops sowing. Ongoing work includes collection and improvement of indigenous farm implements, development of an efficient work animal harness, a low-lift irrigation pump, a rice stubble cutter, and popularizing the use of the slit seeder.

The Myanmar-IRRI Farming Systems (MIFS) Project was reviewed in February 1990 and a proposal to extend it was submitted to IDRC in December 1990. The proposed extension calls for the following outputs over a 15-mo period to June 1992:

- Revision and characterization of key sites for the major rice ecosystems, with emphasis on less favorable environments.
- Identification of technical and socioeconomic constraints to rice production and riceland productivity, also with emphasis on less favorable environments.
- Continuation of research collaboration between Myanmar and IRRI scientists, with increased emphasis on agricultural economics, social science, and rice-fish and rice-forage research.
- A proposal for establishment of the Myanmar Rice Research Institute.

Sri Lanka

During 1990, research and training cooperation between IRRI and the Department of Agriculture, Sri Lanka (DOASL), continued to be strengthened with financial assistance totaling US$313,900 from the Swedish Agency for Research Cooperation with Developing Countries (SAREC). Under the project, IRRI scientists will undertake short-term consultative visits in areas of mutual interest. Sri Lankan scientists, on the other hand, will have increased opportunities to undertake degree and nondegree training at IRRI and elsewhere, and to participate in relevant conferences, symposia, and workshops.

In September 1990, the DOASL organized a major rice congress in Kandy. The congress, which was attended by the IRRI director-general, discussed challenges and strategies for rice research and development in Sri Lanka over the next decade.

Thailand

Exports of Thai rice dropped to 3.9 million t in 1990 from more than 6 million t in 1989. Production was reduced by pest outbreaks and a shortage of water in the major catchments. In September a severe brown planthopper (BPH) infestation devastated 250,000 ha of rice in 26 central provinces, affecting 80,000 farmers. Most damage was to variety Suphanburi 60. This highlights the need for integrated pest management in farmers' fields, which is one of our collaborative research activities. An IRRI entomologist assisted in designing a strategy for dealing with the BPH outbreak. Plans for follow-up research were made at an IPM Network Meeting in Lopburi, November 1990.

The first International Deepwater Rice Farming Systems Research planning meeting held at Ayutthaya in July was followed by a farmers' field day to demonstrate collaborative research on mixed deepwater rice (DWR) and upland crops at the Huntra Experiment Station. Farmers were keen to adopt the use of sesame mixed with deepwater rice as a preflood crop.

DWR breeding experiments were expanded by mechanized sowing of experimental plots. High floods gave intense selection pressures. Short lines with poor elongation were destroyed, but many with good response will continue to be in the breeding program.

For rainfed lowland rice the collaborative shuttle breeding project on varietal improvement has produced some promising lines. Soil fertility studies have shown the effectiveness of green manure crops such as sesbania. Nitrogen use efficiency is being evaluated by experiments using ^{15}N.

In November, an international workshop examined progress in research on problem soils. Two new tolerant rice lines selected in Thailand were ready for yield testing.

Throughout 1990, the IRRI office in Bangkok provided important logistic and administrative support services to our country projects in Cambodia, Lao PDR, and Vietnam.

Vietnam

De-collectivization and rice productivity growth

Vietnam's re-emergence in 1989 as a rice exporter after two decades of being a net importer can be attributed at least partly to the de-collectivization policies pursued since 1981. In 1981, Vietnam started to allow individual households to cultivate land independently, rather than as members of collective work groups, and to be responsible for providing a contracted amount of output to the state.

The productivity impact of the contract system was empirically estimated. Separate production functions were fit for the northern and southern provinces to capture the differential effects of policy reform in the former North and former South Vietnam. A data set consisting of provincial data for the years 1976, 1980, and 1985 was analyzed, using a variant of the Cobb-Douglas production

function, presented below. This function is similar to the one used by Lin (1988) for China.

$$q = \alpha_0 x_1^{(\alpha_1 + \alpha_{1z} Z_1)} x_2^{(\alpha_2 + \alpha_{2z} Z_2)} x_3^{(\alpha_3 + \alpha_{3z} Z_3)}$$
$$\exp(\beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \theta_1 T_1 + \theta_2 T_2 + \gamma R)$$

Total rice output per province per year (q) is related to production inputs, provincial characteristics, time, and regional dummies. Production inputs considered are total rice cultivated area by province (x_1); rural population by province (x_2), used as a proxy for agricultural labor force; and buffalo population by province (x_3), used as a proxy for draft animal power. Provincial characteristics are proportion of rice area under modern varieties (Z_1), proportion of rice area irrigated (Z_2) and proportion of farmers who are members of cooperatives (Z_3).

With 1976 as base year, year dummies for 1980 (T_1) and 1985 (T_2) were used to measure the impact of two distinct policy regimes. Since all three years were normal-weather years and showed no unusual deviations in rainfall or temperature patterns, the year dummies were designed to capture the impact of collectivization and de-collectivization policies, which are not captured by the ratio of cooperative farmers. The percentage change in output for years 1980 and 1985 relative to the base year 1976 is measured by $[\exp(\theta_1) - 1]$ and $[\exp(\theta_2) - 1]$, respectively.

The Northern uplands and the Central coastal region were used as base regions for comparison for the North and South, respectively. The percentage difference in output for region (R) relative to the base region is measured by $[\exp(\theta) - 1]$.

Regression results are presented separately for the North and the South in Table 7. This analysis underscored the significant negative impact of collectivization on productivity in rice production. The productivity difference between cooperative and non-cooperative farmers is measured by $[\exp(\beta_3 - 1)]$. When evaluated for the northern provinces, this leads us to conclude that cooperative farmers had 52% lower productivity than non-cooperative farmers. The ratio of cooperative to total farmers in the northern provinces was 0.93; hence, collectivization accounted for a total productivity decline of about 48%.

The coefficient on cooperative farmers was not significant for the southern provinces because less than 30% of all southern farmers belong to cooperatives. The cooperative movement was more successful in the less productive, upland rice production areas of the Central coastal and Western Plateau regions of the South.

Table 7. Rice production functions for northern and southern Vietnam.

	Northern	Southern
Intercept	0.0492	-0.7466
	(0.7297)	(0.4556)
Log of area (X_1)	1.5260***	0.9702***
	(0.3108)	(0.0723)
Prop. of area under MV Log (area)	-1.0290	-0.5774**
	(0.6779)	(0.2214)
Log of rural pop'n. (X_2)	-0.2315	0.1533
	(0.2283)	(0.0962)
Prop. of area under MV Log of rural pop'n.	0.4539	0.1236
	(0.5411)	(0.2441)
Log of no. of buffaloes (X_3)	0.1109	0.1105**
	(0.1588)	(0.0427)
Prop. of area under MV Log of no. of buffaloes	-0.2900	-0.3891***
	(0.3779)	(0.1235)
Prop. of area under MV (Z_1)	2.7438	3.1191***
	(1.8888)	(1.1126)
Proportion of area under irrigation (Z_2)	0.2722	0.2893***
	(0.2918)	(0.1063)
Proportion of farmers membership in cooperatives (Z_3)	-0.7336**	0.1292
	(0.3600)	(0.0869)
Dummy for year 1980 (T_1)	-0.1420***	-0.0187
	(0.0428)	(0.0455)
Dummy for year 1985 (T_2)	0.1116**	0.1503**
	(0.0477)	(0.0571)
Regional dummy 1	0.1685**	0.0421
	(0.0754)	(0.0788)
Regional dummy 2	-0.1643**	0.0186
	(0.0724)	(0.0801)
Regional dummy 3	-	0.1990**
		(0.0853)
R^2	98.20%	98.46%
DFE	40	44

The year dummy for 1980 had a significant negative effect on rice output for the northern provinces. Rice output was lower than the 1976 level by 13%. The productivity decline during 1976-80 can be attributed to the high degree of centralized control of rice production in the north. The year dummy for 1980 was not significant in the south although it had the expected negative sign. There are two reasons for the relative stability of southern agriculture during this period: 1) southern farmers had inputs and equipment left over from before the reunification period, 2) centralization and collectivization efforts were not made in earnest till almost the end of the 1970s.

The time dummy for 1985 was significantly positive for both the northern and the southern provinces. Relative to 1976, rice output was higher in 1985 by 11.8 and 16.25% for the northern and the southern provinces, respectively. The contract system of production, introduced at the end of 1981, rewarded individual effort by incremental output that the farmer could keep or sell. The productivity gain between the two time periods across the northern and southern regions can be attributed, at least to some extent, to this de-collectivization policy.

Research support services

Analytical Service Laboratories 284
Communications support 284
Integrated Experimental Farm and Grounds 285
Pesticide Residue Laboratory 286
Phytotron 286

Publications and seminars

Publications 288
Seminars 298

Staff changes 301

Finances 303

Weather summary 304

Research support services

Analytical service laboratories

The Analytical Service Laboratories (ASL) with its three component laboratories—the Chemical Analysis Laboratory (CAL), the Mass Spectrometry Laboratory (MSL), and the Radioisotope Laboratory (RIL)—continued to provide analytical services and special laboratory (radioisotope) facilities to the IRRI research projects.

Analytical services. The analyses completed in 1990 totaled 99,378. The samples were generated by 39 core projects and 19 special projects. Of this total, nearly 90% were performed on soil, plant, water, and some fertilizer samples in the Chemical Analysis Laboratory (Table 1).

The average rate was 2.8 analyses/man-hour, or 21.34 man-minutes/analysis. This year's average is slightly better than last year's, probably because of the implementation of the computerized data acquisition and processing system, which was designed in-house and used with the autoanalyzers.

Other services. Special laboratory and other support services were provided to the following activities that involved the use of radiotracers:

- Uptake and distribution of sucrose through the vascular bundle of detached panicles of rice (C-14).
- Effect of fertilizer application method on the fate of N and S from urea-elemental S and urea-ammonium sulfate mixtures (S-35).
- Assay of soluble starch synthase (C-14).

Table 1. Analyses completed in 1990.

	Determinations (no.)
Chemical Analysis Laboratory	89,356
Mass Spectrometry Laboratory	8,348
Radioisotope Laboratory	1,674
Total	99,378

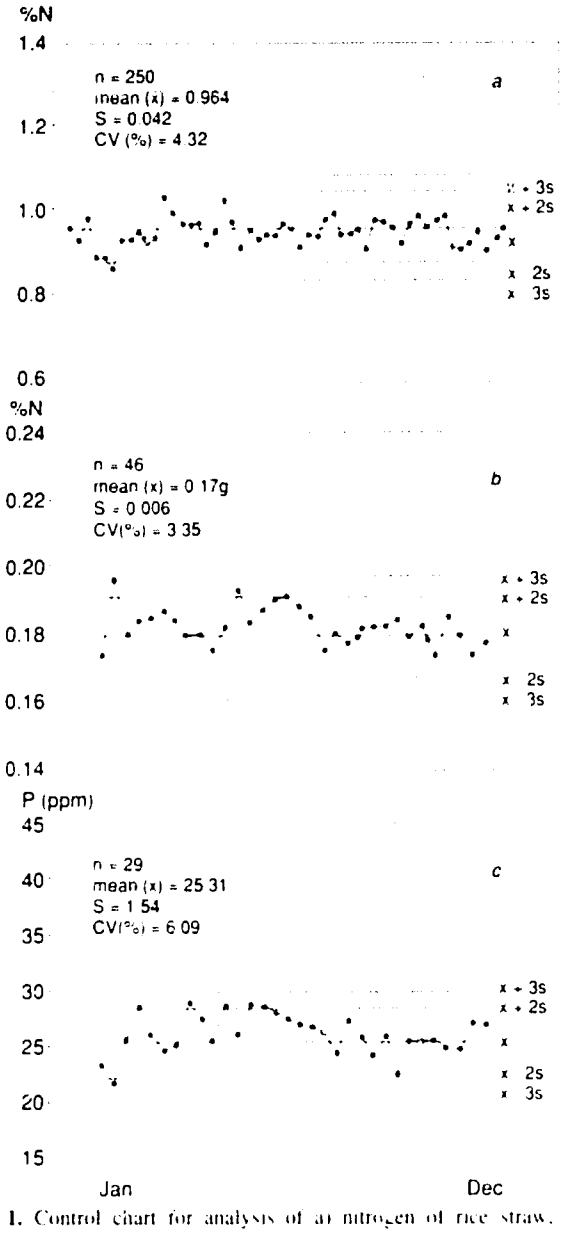
- Restriction fragment length polymorphism mapping of quantitative resistance to blast (P-32).
- Analysis of DNA introgression from *Oryza minuta* to *Oryza sativa* (P-32).
- Restriction fragment length polymorphism of *Xanthomonas oryzae* pv. *oryzae* population (P-32).
- Association of phytopathogenic and nonphytopathogenic bacteria in rice seed (P-32).

Quality assurance. A useful tool in a quality assurance program is control charting. Control charting indicates whether a measurement process is in statistical control or out of it. We set up control charts for the methods of analysis routinely employed in the ASL.

Bulk samples of Maahas clay and IR42 rice straw were obtained for use as control samples. Those were prepared, homogenized, and analyzed. At least 25 measurements for any one parameter for each sample were taken. The mean of the measurements ($\bar{X}$) and the standard deviation (s) were calculated. Then the following were plotted on graph paper: mean, mean ± 2s, and mean ± 3s. Warning limits were marked at +2 and −2 standard deviations and rejection limits were marked at +3 and −3 standard deviations. Subsequently, one control sample was included in the analysis of each batch of 50 samples. Each value obtained for the control sample was plotted on the appropriate control chart. Three of the resulting charts obtained in 1990 are shown in Figure 1.

Communications support

The Information Center provides in-house communications support services to IRRI programs, administration, and other entities. This support includes editorial, typesetting, art, design, printing, photography, and audiovisual services.



1. Control chart for analysis of a) nitrogen of rice straw, b) nitrogen of soil, and c) Bray P in soil, 1990.

The Information Center printed 18 million pages of text in-house in 1990 (not including IRRI books and periodicals, which are contracted out). More than 12,000 original slides were produced, and 40,000 slides were duplicated. About 4,500 pieces of black-and-white artwork were drawn, and about 7,500 pages were laid out. We developed about 52,000 black-and-white photographs and prepared 50 posters.

In addition, we edited 135 journal and miscellaneous papers (conference papers, proposals, etc.) totaling more than 3,000 pages (tables and figures included).

The other work of the Information Center— library services, scientific publication, data bases, conferences and workshops, and public awareness—is program-driven and is reported under the Information and Knowledge Exchange Program.

Integrated experimental farm and grounds

Installation of culverts in the main drainage canals has been completed in the old lowland areas and is in progress in the new lowland areas and the upland. This should allow easier maintenance of levees where rats build their nests and should help destroy breeding places of golden snails.

The administrative, threshing/drying, and chemical storage buildings in block F were completed and fully operational in November when the Centralized Research Farm offices were transferred. Five officers were appointed, one each for mechanical operations, labor and seed processing, plant protection and surveillance, plant growth facilities, and grounds development and maintenance.

Centralization of farm labor on the farm began with the transfer of laborers from Entomology, Agronomy, and Soils. Space was provided to different divisions like Agronomy Physiology, and Agroecology (APA), Plant Breeding, International Network for Evaluation of Rice (INGER), Plant Pathology, and Entomology; laborers in the threshing and drying buildings were provided with lockers.

All vacant plots which were formerly utilized for seed production are now planted to green manure crops: sesbania in the lowland and crotalaria in the upland. A total of 57.78 ha were planted to different varieties for milling. Of that area, 7.92 ha were planted to IR22, IR26, IR42, IR60, IR64, IR66, IR72, IR74, IR41985-111-3, and Makiling for seed increase.

During the y 7,381 rats were killed with the use of electric fence, baiting, trapping, and flame throwing.

Contract labor in 1990 cost $337,438.65: 69.35% was paid to planters/weeders, 28.18% to birdboys, and 2.47% for land preparation.

We realized ₱1,361,384.14 from the sale of palay for seeds, palay for milling, milled rice, and other farm produce (Table 2).

Table 2. Farm income for 1990.

Item	Quantity (kg)	Value	
		₱	$
Seed			
IR60	620	5,374.08	191.93
IR64	1,503	11,629.13	415.33
IR65	289	2,210.85	78.96
IR66	1,644	10,727.55	383.13
IR68	556	4,575.78	163.42
IR70	4,918	46,205.96	1,650.21
IR72	8,506	69,000.24	2,464.29
IR74	9,838	82,350.21	2,941.78
IR841	106	761.50	27.20
Milled rice	100,741	645,252.85	23,044.74
Palay for milling	41,251	182,008.00	6,500.28
Glutinous rice	26,287	247,455.07	8,837.68
Sesbania seeds	87	1,305.00	46.61
Pole sitao	151	1,300.60	46.45
Supersweet corn		26,666.00	952.36
Supersweet corn seeds	6	120.00	4.28
Rice bran	263 cans	1,052.00	37.57
Soybean discard	359	897.50	32.05
Tomatoes	329	1,530.66	54.67
Cucumber	238	4,118.50	147.09
Cabbage	45	3,965.20	141.61
Eggplant	43	269.46	9.62
Gabi	15	129.00	4.61
Patola	625	150.00	5.36
Jute sacks		12,779.00	456.39
Total		1,361,834.14	48,636.93

As of December 31, 1990, we had in our seed room 5,534 kg of seeds valued at $1,778.78.

Pesticide residue laboratory

The Pesticide Residue Laboratory (PRL) received 351 samples for complete analysis in 1990; 192 water samples were for residues of typical insecticides and herbicides (azinphos-methyl, butachlor, carbaryl, carbofuran, chlorpyrifos, cypermethrin, 2,4-D, DDT, deltamethrin, diazinon, endosulfan, endrin, isoprocarb, lindane, malathion, MCPA, methomyl, monocrotophos, parathion-methyl, and piperophos) applied by Luzon farmers, 114 water samples for the IRRI waterways pesticides (acephate, BPMC, butachlor, carbaryl, carbofuran, chlorpyrifos, diazinon, and isoprocarb) runoff monitoring project, and 22 paddy water samples for carbofuran. Pingali's Agricultural Chemicals Environmental Impact Assessment Project submitted 23 well water samples for identification and confirmation of residues of chlorpyrifos, endosulfan, and monocrotophos by mass spectrometry.

Five hundred and three extracts were submitted for chromatographic analysis only: 128 fatty acid methyl ester extracts submitted by INGER for gas chromatography and 375 extracts submitted by Weed Science for fractionation by high performance liquid chromatography, followed by infrared spectroscopy and mass spectrometry.

Table 3 summarizes the work of PRL in 1990.

Phytotron

The phytotron provided services for 42 experiments: 16 new studies and 26 continuing projects. The experiments lasted from 14 to 320 d and involved 65 research staff users from 7 divisions. The major users were Plant Breeding (Plant Breeding, Genetics, and Biotechnology Division) and Plant Physiology Unit (APA Division). Other users were INGER, Soil Microbiology, Agroecology, Agronomy, Plant Pathology, Soils, and IRGC.

Most of the experiments were on the effect of temperature in combination with various subjects: direct seeding, seedling vigor, root and nutrition, water stress, salinity, anther culture, genetic mapping, plant growth regulators, nitrogen fixation (azolla), seed dormancy and fatty acids, pollen grain germination, embryo rescue, low light intensity,

Table 3. Summary of analyses performed by PRL, 1990.

	Complete analyses (no.)	GLC[a] injections only (no.)
Acephate	114	
Azinphos-methyl	192	
BPMC	114	
Butachlor	306	
Carbaryl	306	
Carbofuran	328	
Chlorpyrifos	329	
Cypermethrin	192	
2,4-D	192	
DDT	192	
Deltamethrin	192	
Diazinon	306	
Endosulfan	215	
Endrin	192	
Isoprocarb	306	
Malathion	192	
MCPA	192	
Methomyl	192	
Monocrotophos	215	
Parathion-methyl	192	
Piperophos	192	
Others		503
Total	4651	503

[a]Gas liquid chromatography

Table 4. Growth rooms and occupancy rates. IRRI phytotron, 1990.

Growth rooms	Total floor area (m^2)	Mean monthly occupancy (%)
6 glasshouses (naturally lighted)	240.00	97
12 SA-L cabinets (naturally lighted)	18.72	77
4 KB cabinets (naturally lighted)	1.76	53
11 KG cabinets (artificially lighted)	15.84	82
1 Conviron bench (artificially lighted)	4.46	99
1 HNL cabinet (artificially lighted)	3.08	98
5 darkrooms	32.50	55

hybrid rice, bacterial blight, chlorophyll fluorescence, photosynthesis, and ultraviolet-B (UV-B) radiation.

The glasshouses are the most used facilities (Table 4). They have fixed settings of 2 units with 27/21 °C and 4 units with 29/21 °C day/night temperatures and 70% relative humidity. Requests for differential temperature settings ranging from 17-41 °C day and 15-33 °C night temperatures were done in all the growth cabinets. Relative humidity settings ranged from 55 to 80% and lighting ranged from 10 to 25 klux. A total of 216 requests for drying oven, cold room, and leaf area meter were received from 6 divisions. The aeroponic setup was used by the Agronomy Unit and IRGC. The Plant Physiology Unit continuously used the UV-B setup occupying the whole glasshouse 1 to determine changes in the rice plant as induced by UV-B radiation.

No major technical problems were encountered during the 1990 operations despite 14 scheduled and unscheduled power interruptions, which were serviced by two 500-KVA standby generators. Most of the power interruptions lasted 1 h, but the longest was 9 h on 14 July during the peak of summer. The total power interruptions lasted 43 h and 13 min.

The growing period for experiments lasted 11.5 mo. The phytotron was shut down 1 Nov to 15 Dec 1990 for regular annual maintenance for all motors, cooling units, generators, and control units.

Information and orientation services were given to new research staff users, graduate students, and visitors.

Publications and seminars

Under **Institute publications** are listed the 10 major books in English, 9 translations of 5 books in 5 languages, 6 monographs in the IRRI Research paper series, and 5 periodicals published by IRRI in 1990. All translations were produced by other organizations with assistance from the Institute.

Subsequent sections list the output of individual scientists by division and additional bibliographies produced by the Library and Documentation Center.

Institute publications

Books

Climate and food security. 602 p.

Crop loss assessment in rice. 334 p.

Dibble sticks, donkeys, and diesels: machines in crop production. 329 p.

IRRI 1989: planning for the 1990s. 72 p.

Phosphorus requirements for sustainable agriculture in Asia and Oceania. 478 p.

Program report for 1989. 306 p.

Publications of the international agricultural research and development centers: supplement 1990. 332 p.

Rice: then and now. 44 p.

Seeds and seedlings of weeds in rice in South and Southeast Asia. 63 p.

Sharing innovation: global perspective on food, agriculture, and rural development. 265 p.

Translations

A farmer's primer on growing rice [Vietnamese edition], by B. S. Vergara. 221 p.

A farmer's primer on growing upland rice [Vietnamese, Hindi, and Spanish editions], by M. A. Arraudeau and B. S. Vergara. 284 p.

Field problems of tropical rice [Myanmar edition], by K. E. Mueller. 172 p.

Helpful insects, spiders, and pathogens: friends of the rice farmer [B. Malaysia, Myanmar, and Vietnamese editions], by B. M. Shepard, A. T. Barrion, and J. A. Litsinger. 136 p.

Illustrated guide to integrated pest management in rice in tropical Asia [Myanmar edition], by W. H. Reissig, E. A. Heinrichs, J. A. Litsinger, K. Moody, L. Fiedler, T. W. Mew, and A. T. Barrion. 411 p.

Research paper series

139. Choice of rice crop establishment technique: transplanting vs wet seeding, by A. Erguiza, B. Duff, and C. Khan. 10 p.
140. Rice production in the Wangdiphodrang-Punakha Valley of Bhutan, by N. Dorji, J. C. Flinn, and C. Maranan. 21 p.
141. Myanmar's experience in rice improvement, 1830-1985, by Khin Win and Kyi Win. 10 p.
142. Transformation of a Laguna Village in the two decades of green revolution, by Y. Hayami, M. Kikuchi, L. M. Bambo, and E. B. Marciano. 21 p.
143. Agroecosystem and farmer practices and knowledge in Madagascar's Central Highland: toward improved rice-based systems research, by S. Fujisaka. 15 p.
144. Rice research priorities for Madagascar's Middle West, by S. Fujisaka and the FOFIFA team. 15 p.

Periodicals

Deepwater rice. No. 17

Hybrid rice newsletter. Vol. 4, nos. 1 and 2

International rice research newsletter. Vol. 15, nos. 1-6

IRRI reporter. 1/90, 2/90, 3/90/, 4/90

Rice literature update. Feb, Apr, Jun, Aug, Oct, Dec

Agricultural Engineering

Bonifacio E P, Duff B (1990) The impact of postharvest operations on paddy and milled rice quality. Philipp. Agric. Eng. J. 21(1):19-24.

Bonifacio E P, Quick G R, Pingali P L (1990) Deriving design specifications for mobile dryers: an end-user perspective. Proceedings of the International Agricultural Engineering Conference and Exhibition, December 3-6, 1990, Bangkok, Thailand. Vol. 2. V. M. Salokhe and S. G. Ilangantileke, eds. Asian Institute of Technology, Thailand.

Bregt A K, Wopereis M C S (1990) Comparison of complexity measures for chloropleth maps. Cartographic J. 27:85-91.

Diestro M S, Salazar G C (1990) Factors affecting belt and chain drive durability on a hydrotiller. Proceedings of the International Agricultural Engineering Conference and Exhibition, December 3-6, 1990, Bangkok, Thailand. Vol. 2. V. M. Salokhe and S. G. Ilangantileke, eds. Asian Institute of Technology, Thailand.

Douthwaite M B, Quick G R (1990) The feasibility of developing a small-scale stripper harvester for rice based on a novel rotor design. Proceedings of the International Agricultural Engineering Conference and Exhibition, December 3-6, 1990, Bangkok, Thailand. Vol. 2. V. M. Salokhe and S. G. Ilangantileke, eds. Asian Institute of Technology, Thailand.

Fyfield T P, Gregory P J, Woodhead T, Pasuquin E M (1990) Effect of tillage, seeding methods and time of sowing on the establishment of mungbean in drying, previously puddled soil. Soil Tillage Res. 18:333-346.

Padilla J L, Buresh R J, De Datta S K, Bautista E U (1990) *See* **Agronomy, Physiology, and Agroecology**.

Paglia M, Painuli D K, Woodhead T (1990) Microstructure and porosity in rice fields under different management practices and their relation to post-rice cultivation. Trans. XIV ISSS Congr. Kyoto 6:192-196.

Pingali P L, Awadhwal N K, Quick G R (1990) *See* **Social Sciences**.

Posmentier H (1990) Management of rodent populations at the International Rice Research Institute. IRRI special publication. 40 p.

Quick G R (1990) Lessons for the Asian farm equipment market from an analysis of the Australian tractor industry. Proceedings of the International Agricultural Engineering Conference and Exhibition, December 3-6, 1990, Bangkok, Thailand. Vol. 2. V. M. Salokhe and S. G. Ilangantileke, eds. Asian Institute of Technology, Thailand.

Recel M R, Woodhead T, Ingram K T, Moody K, Pasuquin E M, Dacanay E V (1990) Interactions of water shortage and weed stress on the growth of lowland rice on two Philippine soils. Trans. XIV ISSS Congr. Kyoto 4:461-462. (abstr.)

Woodhead T (1990) Problems and opportunities in soil-physical management in rice-based cropping systems. Trans. XIV ISSS Congr. Kyoto 1:140-145.

Wopereis M C S, Wosten J H M, Stein A, Bouma J, Woodhead T (1990) Spatial patterns of physical properties in rice soils. Trans. XIV ISSS Congr. Kyoto 1:239-240. (abstr.)

1990 patent applications

Awadhwal N K, Quick G R. A pesticide dispenser and application (Ref. 2.92-1358).

Bautista E U, Salazar G C, Quick G R. Micromill for farmer households.

Bautista E U, Townsend J S. Slit seeding machine.

Douthwaite M B. Straw separator/rethresher for a stripper-harvester.

Kiamco L C, Quick G R. Multiple-cone rice mill.

Quick G R. A cultivator assembly with seeding and fertilizing means (Ref. 2.92-1357).

Quick G R, Bautista E U. Wheelbarrow transport modality for transplanting machines and other field equipment.

Agronomy, Physiology, and Agroecology

Ahn J K, Fateña G F, Vergara B S, Visperas R M (1989) Relationship between grain filling and some morphoanatomical characters of the panicle. Abstr. Philipp. J. Crop Sci. 14 (suppl. 1):S42.

Akita S, Blanco L, Katayama K (1990) Physiological mechanism of heterosis in seedling growth of indica F. rice hybrids. Jpn. J. Crop Sci. 59(3):548-556.

Basri I H, Mercado A Jr., Garrity D P (1990) Upland rice cultivation using leguminous tree hedgerows on strongly acid soils. Agron. Abstr. p. 53.

Bekhasut P, Puckridge D W, Wiengweera A, Kupkanchanakul T (1990) Sequential elongation of internodes of deepwater rice at different water depths. Field Crops. Res. 24(3,4):195-209.

Buresh R J, De Datta S K (1990) Denitrification losses from puddled rice soils in the tropics. Biol. Fert. Soils 9:1-13.

Buresh R J, Vlek P L G, Harmsen K (1990) Fate of fertilizer nitrogen applied to wheat under simulated Mediterranean environmental conditions. Fert. Res. 23:25-36.

Chauhan J S, Lopez F S S, Vergara B S (1989) Genetic analysis of ratooning ability of rice (*Oryza sativa* L.). Euphytica 40:97-102.

Chauhan J S, Lopez F S S, Vergara B S (1990) Heritability and genetic advance in early segregating populations of rice. Oryza 27:15-20.

Chauhan J S, Lopez F S S, Vergara B S (1990) Ratoon growth and development in rice (*Oryza sativa* L.) under various temperature regimes. J. Agron. Crop Sci. 165:202-206.

Chauhan J S, Lopez F S S, Vergara B S (1989) Regeneration time and pattern of ratoon-tiller development in 'IR44' rice (*Oryza sativa*). Indian J. Agric. Sci. 59(3):172-174.

Chauhan J S, Vergara B S, Virmani S S, Lopez F S S, Chauhan V S (1987) Inheritance of regeneration ability in rice. Oryza 24:371-373.

Coronel V, Akita S, Yoshida S (1990) Aluminum toxicity tolerance in rice (*Oryza sativa*) seedlings. Pages 357-363 *in* Plant nutrition - physiology and application. M. L. van Beusichem, ed. Kluwer Academic Publishers. Dordrecht, The Netherlands.

De Datta S K, Broadbent F E (1990) Nitrogen use efficiency of 24 rice genotypes on an N-deficient soil. Field Crops Res. 23:81-92.

De Datta S K, Buresh R J, Obcemea W N, Castillo E G (1990) Nitrogen-15 balances and nitrogen fertilizer use efficiency in upland rice. Fert. Res. 26:179-187.

Dingkuhn M, Schnier H F, De Datta S K, Dorffling K, Javellana C, Pamplona R (1990) Nitrogen fertilization of direct-seeded flooded vs. transplanted rice. II. Interactions among canopy properties. Crop Sci. 30:1284-1292.

Dingkuhn M, Schnier H F, De Datta S K, Wijangco E, Dorffling K (1990) Diurnal and developmental changes in canopy gas exchange in relation to growth in transplanted and direct seeded flooded rice. Aust. J. Plant Physiol. 17:119-134.

Dua A B, Penning de Vries F W T, Seshu D V (1990) Simulation to support evaluation to the production potential of rice varieties in tropical climates. Pages 1185-1194 *in* Transaction of the American Society of Agricultural Engineering. Vol. 33. American Society of Agricultural Engineering. Michigan, USA.

Ekanayake I J, Steponkus P L, De Datta S K (1990) Sensitivity of pollination to water deficits at anthesis in upland rice. Crop Sci. 30:310-315.

Elazegui F A, Seriano J, Bandong J, Estorninos L, Jonson I, Teng P S, Shepard B M, Litsinger J A, Moody K, Hibino H (1990) *See* **Plant Pathology**.

Freney F R, Trevitt A C F, De Datta S K, Obcemea W N, Real J G (1990) The interdependence of ammonia volatilization and denitrification as nitrogen loss processes in flooded rice in the Philippines. Biol. Fert. Soils 9:31-36.

Fujisaka S, Vejpas C (1990) *See* **Social Sciences**.

Furoc R E, Manguiat I J (1990) State of the art of green manuring. Pages 210-220 *in* Proceedings of the National Symposium on Bio- and Organic Fertilizers, October 9-12, 1989, University of the Philippines at Los Baños, Philippines. National Azolla Action Program, UP at Los Baños, Laguna, Philippines.

Garrity D P (1990) Agronomic research on biofertilizers at IRRI: overcoming system-level constraints. Pages 309-320 *in* Proceedings of the National Symposium on Bio- and Organic Fertilizers, University of the Philippines at Los Baños, October 9-12, 1989. National Azolla Action Program, UP at Los Baños, Laguna, Philippines.

Garrity D P (1990) Hedgerow systems for sustainable food crop production on sloping lands. Contour Newsl. 2(2):18-20.

Garrity D P (1990) Sustainable land use systems for the sloping uplands of Southeast Asia: solutions for resource stewardship in small-scale farming. Agron. Abstr. p. 57.

Garrity D P, Bantilan R T (1990) *Indigofera tinctoria*: farmer-proven green manure for rainfed ricelands. Pages 261-284 *in* Proceedings of the National Symposium on Bio- and Organic Fertilizers, University of the Philippines at Los Baños, October 9-12, 1989. National Azolla Action Program, UP at Los Baños, Laguna, Philippines.

Garrity D P, Bantilan R, Bantilan C, Pye Tin, Mann R (1990) The potential of *Indigofera tinctoria* as a legume green manure for tropical rice. Agron. Abstr. p. 143.

Garrity D P, Gines H (1990) The development of rice-corn rotations in tropical lowland environments: a systems research approach. Food and Fertilizer Technology Center. Extension Bulletin No. 316, December 1990.

Herrera C H, Penning de Vries F W T (1990) Evaluation of a model for simulating the potential production of rice. Philipp. J. Crop Sci.

Hill J E, De Datta S K, Real J G (1990) *Echinochloa* competition in rice: a comparison of studies from direct-seeded and transplanted flooded rice. *In* Proceedings of the Symposium on Weed Management, Bogor, Indonesia, 7-9 June 1989. V. A. Auld, R. C. Unaly, and Sitti Soetarni Tjitrosomo, eds. BIOTROP Spec. Publ. No. 38. SEAMEO-BIOTROP, P.O. Box 17, Bogor, Indonesia.

Ingram K T, Real J G, Maguling M A, Obien M A, Loresto G C (1990) Comparison of selection indices to screen lowland rice for drought resistance. Euphytica 48:253-260.

Jamarun N, Robles A Y, Palo L P, Lapinid R R, Lopez F S S, Vergara B S (1988) Enhancement of the feeding value of rice straw with rice forage silage. Pages 183-187 *in* Ruminant feeding systems utilizing fibrous agricultural residues - 1987. R. M. Dizon, ed. International Development Program of Australian University and Colleges, Ltd., Australia.

Kim S Y, De Datta S K, Mercado B L (1990) The effect of chemical and heat treatments on germination of *Commelina benghalensis* L. aerial seeds. Weed Res. 30:109-116.

Kim S C, Moody K (1989) Adaptation strategy in dry matter and seed production of rice and weed species. Korean J. Weed Sci. 9(3):183-200.

Kim S C, Moody K (1989) Germination and seedling development of rice and *Echinochloa* species. Korean J. Weed Sci. 9(2):108-115.

Kim S C, Moody K (1989) Germination of two rice cultivars and several weed species. Korean J. Weed Sci. 9(2):116-122.

Kim J K, Vergara B S (1989) Contribution of different tillers within a hill to grain yield of rice. Abstr. Philipp. J. Crop Sci. 14 (suppl. 1):S35.

Mambani B, De Datta S K, Redulla C A (1990) Soil physical behavior and crop responses to tillage in lowland rice soils of varying clay content. Plant Soil 126:227-235.

Mercado B L, De Datta S K, Migo T R, Baltazar A M (1990) Growth behavior and leaf morphology of Philippine strains of *Spheneoclea zeylanica* showing differential response to 2,4-D. Weed Res. 30:245-250.

Moody K (1990) Pest interactions in rice in the Philippines. Pages 269-299 *in* Pest management in rice. B. T. Grayson, M. B. Green, and L. G. Copping, eds. Elsevier Science Publishers Ltd., England.

Moody K (1990) Weeds and their control in rice and rice-based cropping systems. Pages 32-37 *in* 11th International Congress of Plant Protection Proceedings, Manila, Philippines.

Moody K (1990) Yield losses due to weeds in rice in the Philippines. Pages 193-202 *in* Crop loss assessment in rice. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Morris R A, Siri-Udompas C, Centeno H S (1990) Effects of crop proportion on intercropped upland rice and cowpea. I. Grain yields. Field Crops Res. 24(1,2):33-49.

Morris R A, Villegas A N, Polthance A, Centeno H S (1990) Water use by monocropped and intercropped cowpea and sorghum growth after rice. Agron. J. 82(4):664-668.

Muirhead W A, De Datta S K, Roger P A, Gusto R M (1990) Effect of algicides in reducing NH_3 loss from urea applied to transplanted rice. I. Floodwater chemistry and biota. Fert. Res. 21:95-107.

Nartsomboon Chumnong, Moody K (1988) Effect of weeding and green manure on the yield of transplanted rice. Pages 53-77 *in* Proceedings of the Second Tropical Weed Science Conference. Vol. 2. Phuket, Thailand.

Nartsomboon Chumnong, Moody K (1988) The effect of seeding rate and weeding on growth and nitrogen accumulation of *Sesbania rostrata*. Pages 78-86 *in* Proceedings of the Second Tropical Weed Science Conference. Vol. 2. Phuket, Thailand.

Olszyk D M, Bachelet D M, Barnes F W, Brown D, Holman S R, Bonman J M, Penning de Vries F W T, Heong K L, Ingram K T, Neue H U, Vergara B S (1990) The EPA/IRRI Rice Research Project: impacts of global climate change on Asian rice production. Agronomy Abstracts. 1990 Annual Meetings, ASA, CSSA, SCSA. San Antonio, Texas.

Padilla J L, Buresh R J, De Datta S K, Bautista E U (1990) Incorporation of urea in puddled rice soils as affected by tillage implements. Fert. Res. 26:169-178.

Pandey R K, Garrity D P, Ranaweera N F C (1990) Diversity and convergence in on-farm research and methodology. *In* Proceedings of the Second International Workshop on Chickpea Improvement, 4-8 December 1989, ICRISAT. International Crops Research Institute for the Semi-Arid Tropics, Center, Patancheru, A. P. 502 324, India.

Penning de Vries F W T (1990) Can crop models contain economic factor? *In* Theoretical production ecology, hindsight and perspectives. Simulation Monograph, PUDOC, Wageningen.

Penning de Vries F W T, Spitters C J T (1990) The potential for improvement in crop yield simulation. Proceedings of a symposium on climatic risk in crop production: models and management for the semi-arid tropics and subtropics. Commonwealth Scientific and Industrial Research Organization, Australia.

Perez C M, Juliano B O, De Datta S K, Amarante S T (1990) *See* **Plant Breeding, Genetics, and Biochemistry**.

Rao A N, Moody K (1990) Weed seed contamination in rice seed. Seed Sci. Technol. 18:139-146.

Recel M R, Woodhead T, Ingram K T, Moody K, Pasuquin E M, Dacanay E V (1990) *See* **Agricultural Engineering**.

Rubia E G, Penning de Vries F W T (1990) Simulation of yield reduction caused by stem borer in the rice. J. Plant Prot. Trop. 7(2):87-102.

Samson M I, Buresh R J, De Datta S K (1990) Evolution and soil entrapment of nitrogen gases formed by denitrification in flooded soil. Soil Sci. Plant Nutr. 36(2):299-307.

Schmier H F, Dingkuhn M, De Datta S K, Marqueses E P, Faromilo J E (1990) Nitrogen-15 balance in transplanted and direct-seeded flooded rice as affected by different methods of urea application. Biol. Fert. Soils 10:89-96.

Schmier H F, Dingkuhn M, De Datta S K, Mengel K, Faromilo J E (1990) Nitrogen fertilization of direct-seeded flooded vs. transplanted rice. I. Nitrogen uptake, photosynthesis, growth, and yield. Crop Sci. 30:1276-1284.

Schmier H F, Dingkuhn M, De Datta S K, Mengel K, Wijangco E, Javellana C (1990) Nitrogen economy and canopy carbon dioxide assimilation of tropical lowland rice. Agron. J. 82:451-459.

Takahashi K, Aguilar A M, Mazaredo A M, Vergara B S (1988) Analysis of the internode elongation of deepwater rice. Changes in the number of cells and cell length during phase change. Jpn. J. Crop Sci. 57 (extra issue 2):197-200.

Takahashi K, Mazaredo A M, Aguilar A M, Vergara B S (1988) Analysis of the internode growth during primary elongation phase and secondary elongation phase of stem development in shoots of deepwater rice. Jpn. J. Crop Sci. 57 (extra issue 1):111-112.

Takahashi K, Mazaredo A M, Aguilar A M, Vergara B S (1988) Analysis of the effect of gibberellin on the initiation of internode elongation in deepwater rice. Jpn. J. Crop Sci. 57 (extra issue 2):201-202.

Takahashi K, Mazaredo A M, Aguilar A M, Vergara B S (1988) Hormonal regulation of internodal elongation in rice. Abstracts in the 13th International Conference of Plant Growth Substances, July 17-22, 1988, Calgary, Canada.

Takanashi K, Mazaredo A M, Aguilar A M, Vergara B S (1989) Mechanism of hormonal regulation of internode elongation of rice. Model experiment in the seedling internodes. Jpn. J. Crop Sci. 58 (extra issue 2):189-190.

Takahashi K, Mazaredo A M, Vergara B S (1988) Initiation of "floating ability" in non-deepwater rice. Jpn. J. Crop Sci. 57 (extra issue 1):113-114.

Takahashi K, Mazaredo A M, Vergara B S (1989) Mechanism of growth regulation of internode elongation of deepwater rice - analysis of varietal difference. Jpn. J. Crop Sci. 58 (extra issue 2):229-230.

Takahashi K, Mazaredo A M, Vergara B S (1989) Mechanism of growth regulation of internode elongation of deepwater rice - varietal difference in the growth response of internode to gibberellin. Jpn. J. Crop Sci. 58 (extra issue 2):231-232

Thangaraj M, O'Toole J C, De Datta S K (1990) Root response to water stress in rainfed lowland rice. Exp. Agric. 26:287-296.

Vergara B S, De Datta S K (1989) *Oryza sativa* L. Pages 206-213 *in* Plant resources of Southeast Asia: a selection. E. Westphal and P. C. M. Jansen, eds. PUDOC, Wageningen.

Wada G, Sta. Cruz P (1989) Varietal difference in nitrogen response of rice plants with special reference to growth duration. Jpn. J. Crop Sci. 58(4):730-739.

Wada G, Sta. Cruz P (1990) Nitrogen response of rice varieties with reference to nitrogen absorption at early growth stage. Jpn. J. Crop Sci. 59(3):540-547

Zimdahl R L, Labigan R T, Moody K, Mabbayad M O (1989) Seeds and seedlings of weeds in rice in South and Southeast Asia. International Rice Research Institute, P.O. Box 933, Manila, Philippines. 63 p.

Entomology

Barrion A T, Litsinger J A (1990) *Lathromeromyia baltazarae* sp. n. (Hymenoptera: Trichogrammatidae) parasitic on the eggs of *Nisia carolinensis* Fennah (Hemiptera: Meenoplidae) in the Philippines. Philipp. Entomol. 8(1):689-695.

Bottenberg H, Litsinger J A, Kenmore P E (1990) Presence of tungro vectors and their natural enemies in different rice habitats in Malaysia. Agric. Ecosyst. Environ. 31:1-5.

Dahal G, Hibino H, Saxena R C (1990) *See* **Plant Pathology**.

Elazegui F A, Soriano J, Bandong J, Estorninos L, Jonson I, Teng P S, Shepard B M, Litsinger J A, Moody K, Hibino H (1990) *See* **Plant Pathology**.

Heong K L (1990) Computer expert systems for improving insect pest management. Rev. Agric. Entomol. 78:1-11.

Heong K L (1990) Feeding rates of the rice leaffolder, *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae), on different plant stages. J. Agric. Entomol. 7:81-90.

Heong K L (1990) Systems analysis and modeling in pest management. Pages 215-228 *in* Crop loss assessment in rice. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Heong K L (1990) Information management systems in rice pest surveillance. Pages 273-279 *in* Crop loss assessment in rice. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Heong K L, Saad Bleih, Lazaro A A (1990) Predation of *Cyrtorhinus lividipennis* Reuter on eggs of the green leafhopper and brown planthopper in rice. Res. Popul. Ecol. 32:1-90.

Khan Z R, Joshi R C (1990) Varietal resistance to *Cnaphalocrocis medinalis* (Guenée) in rice. Crop Prot. 9:243-251.

Khan Z R, Saxena R C (1990) Purification of biotype-1 population of brown planthopper *Nilaparvata lugens* (Homoptera: Delphacidae). Insect Sci. Appl. 11(1):55-62.

Olszyk D M, Bachelet D M, Barnes P W, Brown D, Holman S R, Bonman J M, Penning de Vries F W T, Heong K L, Ingram K T, Neue H U, Vergara B S (1990) *See* **Agronomy, Physiology, and Agroecology**.

Palis F G, Pingali P L, Litsinger J A (1990) *See* **Social Sciences.**

Ramachandran R, Khan Z R, Caballero P, Juliano B O (1990) Olfactory sensitivity of two sympatric species of rice leaffolders (Lepidoptera:Pyralidae) to plant volatiles. J. Chem. Ecol. 16:2647-2666.

Salim M, Saxena R C, Akbar M A (1990) Salinity stress and varietal resistance in rice: effects on whitebacked planthopper, *Sogatella furcifera* (Horvath). Crop Sci. 30(3):654-659.

Saxena R C, Barrion A A, Caoile A S (1990) Morphology and reproduction of yeast-like endosymbiotes of the whitebacked planthopper *Sogatella furcifera* (Horvath) (Homoptera: Delphacidae). Philipp. Entomol. 8(2):727-730.

Saxena R C, Khan Z R (1990) Genetics of insect-host plant interactions - concepts, old and new. Pages 111-120 *in* Advances in plant breeding methods. Biswa Bharati University, Santiniketan, West Bengal, India.

Teng P S, Elazegui F A, Shepard B M (1990) *See* **Plant Pathology**.

Ye Z H, Saxena R C (1990) Resistance to whitebacked planthopper in elite lines of cultivated × wild rice crosses. Crop Sci. 30(6):1178-1181.

Plant Breeding, Genetics, and Biochemistry

Abansi C, Duff B, Lantican F, Juliano B O (1990) *See* **Social Sciences**.

Adriantlana F, Rasolo F, Rakotonjanahary R, Juliano B O, Perez C M, Flinn J C, Shahi B B (1990) *See* **Social Sciences**.

Batalla M L, Zapata F J (1990) Effecto de la combinacion de varias hormonas en la formacion de colonias de *Oryza ridleyi* Hook. F. Page 35 *in* Proc. XIII Congreso Nacional de Fitogenetica, Escuela Superior de Agricultura "Hermanos Hescobar," Mexico.

Bonman J M, Mackill A O, Glaszmann J C (1990) *See* **Plant Pathology**.

Brar D S (1990) Isolation and culture of higher plant protoplasts. Pages 95-100 *in* Handbook of plant tissue and cell cultures. A R. Mehta and P. N. Bhatt, eds. Academic Book Centre, Allahabad, India.

Brar D S (1990) Protoplast fusion and regeneration of somatic hybrid plants. Pages 101-107 *in* Handbook of plant tissue and cell cultures. A. R. Mehta and P. N. Bhatt, eds. Academic Book Centre, Allahabad, India.

Brar D S, Uchimiya H (1990) Genetic engineering of crop plants. Pages 346-365 *in* Plant tissue culture: applications and limitations. S. S. Bhojwani, ed. Elsevier Science Publications, Amsterdam, Netherlands.

Brar D S, Vidhyasekaran P (1990) Tissue culture—a tool to develop disease resistant plants. Pages 19-25 *in* Basic research for crop disease management. P. Vidhyasekaran, ed. Daya Publishing House, New Delhi, India.

Chauhan J S, Vergara B S, Virmani S S, Lopez F S S, Chauhan V S (1987) *See* **Agronomy, Physiology, and Agroecology**.

Cho M S, Zapata F J (1990) Plant regeneration from isolated microspore of indica rice. Plant Cell Physiol. 31(6):881-885.

Cordesse F, Second G, Delseny M (1990) Ribosomal gene spacer length variability in cultivated and wild rice species. Theor. Appl. Genet. 79:81-88.

Dally A M, Second G (1990) Chloroplast DNA diversity in wild and cultivated species of rice (Genus *Oryza*, section Oryza). Cladistic-mutation and genetic-distance analysis. Theor. Appl. Genet. 80:209-222.

Ghosh Biswas G C, Zapata F J (1990) Callus formation and plant regeneration from protoplasts derived from suspension culture of rice (*Oryza sativa* L. cv. Taipei 177). Plant Breed. 105:95-100.

Glaszmann J C, Kaw R N, Khush G S (1990) Genetic divergence among cold tolerant rices (*Oryza sativa* L.). Euphytica 45:95-104.

Huebner F R, Bietz J A, Webb B D, Juliano B O (1990) Rice cultivar identification by high-performance liquid chromatography. Cereal Chem. 67:129-135.

Ishii T, Panaud O, Brar D S, Khush G S (1990) Use of non-radioactive digoxigenin DNA labeled probes for RFLP analysis in rice. Plant Mol. Biol. Rep. 8:157-161.

Islam-Faridi M N, Ishii T, Kumar V, Sitch L A, Brar D S (1990) Chromosomal location of ribosomal RNA genes in rice by in-situ hybridization. Rice Genet. Newsl. 7:143-144.

Jena K K, Khush G S (1990) Introgression of genes from *Oryza officinalis* Well ex Watt to cultivated rice, *O. sativa* L. Theor. Appl. Genet. 80:737-745.

Juliano B O (1990) Chemical basis of rice quality and palatability. Pages 39-41 *in* Abstract Asian Symposium on Rice Nutrition, Taipei, 22-23 June 1990. Taipei Dietitians Association, Taipei.

Juliano B O (1990) Recent rice starch research at IRRI. Page 17 *in* Abstract International Symposium on Cereal and Other Plant Carbohydrates, 7-9 Aug 1990, Kagoshima, Japan.

Juliano B O (1990) Rice grain quality, problems and challenges. Cereal Foods World 35:245-253.

Juliano B O, Perez C M (1990) Crystallinity of raw rice starch granules as indexed by corrosion with HCl and amylose. Starch 42:49-52.

Juliano B O, Perez C M, Chang T T (1990) Varietal differences in longevity of tropical rough rice stored under ambient conditions. Seed Sci. Technol. 18(2):361-369.

Juliano B O, Perez C M, Kaushik R, Khush G S (1990) Grain properties of IR36-based starch mutants. Starch 42:256-260.

Juliano B O, Perez C M, Kaushik R, Khush G S (1990) Some grain properties of IR36-based starch mutants. Starch/Starke 42:256-260.

Juliano B O, Perez C M, Villareal C P (1988) Varietal differences in the quality of processed rice products: a review. Pages 437-445 *in* Food science and technology in industrial development. S. Maneepun, P. Varangoon, and B. Phithakpol, eds. Institute of Food Research and Product Development, Kasetsart University, Bangkok.

Khush G S (1990) Rice breeding—accomplishments and challenges. Plant Breed. Abstr. 60:463-469.

Khush G S, Multani D S, Vergara G, Brar D S (1990) Taxonomic status of *Oryza indandamanica*. Rice Genet. Newsl. 7:88-89.

Khush G S, Virmani S S, Brar D S (1990) Expectations of plant breeders from tissue culture. Pages 412-423 *in* Plant tissue culture: applications and limitations. S. S. Bhojwani, ed. Elsevier Science Publications, Amsterdam.

Kobayashi N, Ikeda R, Vaughan D A, Shigenaga S (1990) Resistance to tungro in wild species of rice. Jpn. J. Breed. 40 (suppl. 2):176-177.

Ogawa T, Yamamoto T, Khush G S, Mew T W (1990a) Genetics of resistance in rice cultivars, Zenith and Cempo Selak to Philippine and Japanese races of bacterial blight pathogen. Jpn. J. Breed. 40:183-192.

Ogawa T, Yamamoto T, Khush G S, Mew T W (1990b) Genetics of resistance in rice cultivars Sateng to Philippine and Japanese races of bacterial blight pathogen. Jpn. J. Breed. 40:329-338.

Ohtsubo K, Siscar J J H, Juliano B O, Iwasaki T, Yokoo M (1990) Texturometer and Instron texture measurements on cooked Japanese milled rices. Rep. Nat. Food. Res. Inst. 54:1-9.

Peng J Y, Virmani S S (1990) Combining ability for yield and four related traits in relation to breeding in rice. Oryza 27:1-10.

Perez C M, Juliano B O, De Datta S K, Amarante S T (1990) Effect of nitrogen fertilizer treatment and source and season on grain quality of IR64 rice. Plant Foods Hum. Nutr. 40:123-130.

Pham J L, Glaszmann J C, Sano R, Barbier P, Ghesquiere A, Second G (1990) Isozyme markers in rice: genetic analysis and linkage relationships. Genome 33:348-359.

Quimio C A, Zapata F J (1990) Diallel analysis of callus induction and green-plant regeneration in rice anther culture. Crop Sci. 30(1):188-192.

Ramachandran R, Khan Z R, Caballero P, Juliano B O (1990) *See* **Entomology**

Sanchez A, Khush G S, Brar D S (1990) Linkage relations between Adh-1 and two morphological markers. Rice Genet. Newsl. 7:110-111.

Second G, Charrier A (1990) The purpose of genetic evaluation of germplasm. Pages 2-6 *in* Proceedings of a workshop on the genetic evaluation of plant genetic resources. B. Fraleigh, ed. Research Branch, Agriculture Canada. 19 p.

Siscar-Lee J J H, Juliano B O, Qureshi R, Akbar M (1990) Effect of saline soil on grain quality of rices differing in salinity tolerance. Plant Foods Hum. Nutr. 40:31-36.

Villareal C P, Juliano B O, Sauphanor B (1990) Grain quality of rices grown in irrigated and upland cultures. Plant Foods Hum. Nutr. 40:37-47.

Wang M-S, Zapata F J, de Castro D C (1990) Somatic embryogenesis and plant regeneration in long term callus culture of Indica rice variety IR40. Chin. J. Bot. 2(1):51-56.

Young J B, Virmani S S (1990) Effects of cytoplasm on heterosis and combining ability for agronomic traits in rice (*Oryza sativa* L.). Euphytica 48:177-188.

Young J B, Virmani S S (1990) Heterosis in rice over environment. Euphytica 51:87-93.

Young J B, Virmani S S (1990) Stability analysis for agronomic traits in rice hybrids and their parents. Oryza 27:109-121.

Yuan L P, Virmani S S, Mao C X (1989) Hybrid rice: achievements and outlook. Pages 219-235 *in* Progress in irrigated rice research. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Plant Pathology

Aung T, Prot J-C (1990) Effect of crop rotations on *Pratylenchus zeae* and the yield of the rice cultivar UPLRi-5. Rev. Nematol. 13(4):445-447.

Bonman J M, Mackill A O, Glaszmann J C (1990) Resistance to *Gerlachia oryzae* in rice. Plant Dis. 74(4):306-309.

Bonman J M, Mew T W, Koganezawa H, Vergel de Dios-Mew T I, Vera Cruz C M, Medalla E S, Kim C K, Notteghem J L, Glaszmann J C (1990) Resistance to key diseases in sub-specific groups of rice. Phytopathology 80(10):999. (abstr.)

Borromeo E S, Nelson R, Bonman J M, Leung H (1990) Population structure of the rice blast fungus in the Philippines. Phytopathology 80(10):981. (abstr.)

Dahal G, Hibino H, Cabunagan H, Tiongco E R, Flores Z M, Aguiero V M (1990) Changes in cultivar reactions to tungro due to changes in virulence of the leafhopper vector. Phytopathology 80:659-665.

Dahal G, Hibino H, Saxena R C (1990) Association of leafhopper feeding behavior with transmission of rice tungro to susceptible and resistant rice cultivars. Phytopathology 80:371-377.

Elazegui F A, Soriano J, Bandong J, Estorninos L, Jonson I, Teng P S, Shepard B M, Litsinger J A, Moody K, Hibino H (1990) Methodology used in the IRRI Integrated Pest Survey. Pages 243-271 *in* Crop loss assessment in rice. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Hsu H T, Hibino H, Cabauatan P Q (1990) Development of serological procedures for rapid, sensitive, and reliable detection of rice grassy stunt virus. Plant Dis. 74:695-698.

Johnson K B, Teng P S (1990) Coupling a disease progress model for early blight to a model of potato growth. Phytopathology 80:416-425.

Mew T W (1989) Disease management in rice. Pages 279-299 *in* CRC handbook of pest management in agriculture. D. Pimentel, ed. CRC Press Inc., Boca Raton, Ann Arbor, Boston.

Mew T W, Gergon E B, Merca S D (1990) Impact of seedborne pathogens in rice germplasm exchange. Seed Sci. Technol. 18:441-450.

Mew T W, Vera Cruz C M, Medalla E S (1990) An anatomy of bacterial blight epidemics in the Philippines. Proceedings of the 3d National Conference in Plant Protection in the Tropics, June 1990, Kuala Lumpur, Malaysia.

Ogawa T, Yamamoto T, Khush G S, Mew T W (1990a) *See* **Plant Breeding, Genetics, and Biochemistry**.

Ogawa T, Yamamoto T, Khush G S, Mew T W (1990b) *See* **Plant Breeding, Genetics, and Biochemistry**.

Olszyk D M, Bachelet D M, Barnes P W, Brown D, Holman S R, Bonman J M, Penning de Vries F W T, Heong K L, Ingram K T, Neue H U, Vergara B S (1990) *See* **Agronomy, Physiology, and Agroecology**.

Prot J-C (1989) Is *Aphelenchoides besseyi* an important plant quarantine subject? Rice Seed Health Newsl. 1:1.

Raymundo A K, Nelson R (1989) Application of genetic engineering to pest management (a review). Philipp. Agric. 72(4):444-457.

Swings J, Van den Mooter M, Vauterin L, Hoste B, Gillis M, Mew T W, Kersters K (1990) Reclassification of the causal agents of bacterial blight (*Xanthomonas campestris* pv. *oryzae*) and bacterial leaf streak (*Xanthomonas campestris* pv. *oryzicola*) of rice as pathovars of *Xanthomonas oryzae* (ex Ishiyama 1922) sp. nov., nom. rev. Int. J. Syst. Bacteriol. 40:309-311.

Teng P S (1990) Crop loss assessment: a review of representative approaches and current technology. Pages 19-37 *in* Crop loss assessment in rice. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Teng P S, Elazegui F A, Shepard B M (1989) Defining the bioeconomic environment for IPM. Phytopathology 79:1137. (abstr.)

Teng P S, Hibino H, Leung H (1989) Yield loss due to rice virus diseases in Asian tropics. Pages 93-100 *in* Crop losses due to disease outbreaks in the tropics and countermeasures. Tropical Agriculture Research Series No. 22. TARC, Ministry of Agriculture, Forestry and Fisheries, Tsukuba, Ibaraki, 305 Japan.

Teng P S, Mew T W, Bonman J M, Leung H (1989) Methods for estimating yield loss in tropical rice diseases. Pages 141-152 *in* Crop losses due to disease outbreaks in the tropics and countermeasures. Tropical Agriculture Research Series 22. TARC, Ministry of Agriculture, Forestry and Fisheries, Tsukuba, Ibaraki, 305 Japan.

Teng P S, Torres C Q, Nuque F L, Calvero S B (1990) Current knowledge on crop losses in tropical rice. Pages 38-53 *in* Crop loss assessment in rice. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Teng P S, Yuen J E (1990) Epidemics models: lessons from plant pathology. Pages 211-220 *in* Risk assessment in genetic engineering: environmental release of organisms. M. Levin and H. Strauss, eds. McGraw-Hill Book Co., New York, USA.

Teng P S, Yuen J E, eds. (1990) Proceedings of the Workshop on Modeling Pest-Crop Interactions. IBSNAT, University of Hawaii. 59 p.

Vauterin L, Swings J, Kersters K, Gillis M, Mew T W, Schroth M N, Palleroni N J, Hildebrand D C, Stead D E, Civerolo E L, Hayward A C, Marate H, Stall R E, Vidaver A K, Bradbury J F (1990) Towards an improved taxonomy of *Xanthomonas*. Int. J. Syst. Bacteriol. 40:312-316.

Soil Sciences

Abansi C, Duff B, Lantican F, Juliano B O (1990) Consumer demand for rice grain quality in selected rural and urban markets in the Philippines. University of the Philippines at Los Baños Regional Training Programme on Food and Nutrition Planning Monograph Series 13. College, Laguna. 30 p.

Andriamilana F, Rasolo F, Rakotonjanahary R, Juliano B O, Perez C M, Flinn J C, Shahi B B (1990) Grain quality characteristics of rice in Madagascar retail markets. Plant Foods Hum. Nutr. 40:21-30.

Asuming-Brempong S, Flinn J C (1990) Rice self-sufficiency and rice research priorities in Ghana. Q. J. Int. Agric. 29(2):173-191.

Bonifacio E P, Duff B (1990) *See* **Agricultural Engineering**.

Bonifacio E P, Quick G R, Pingali P L (1990) *See* **Agricultural Engineering**.

David C C (1989) Asean economic structure and changes in agricultural protection. Philipp. Rev. Econ. Bus. 26(1):47-66.

David C C, Otsuka K (1990) The modern seed-fertilizer technology and adoption of labor-saving technologies: the Philippine case. Aust. J. Agric. Econ. 34(2):132-146.

Fujisaka S (1989) The need to build upon farmer practice and knowledge: reminders from selected upland conservation projects and policies. Agrofor. Syst. Res. 9:141-153.

Fujisaka S (1990) Rainfed lowland rice: building research on farmer practice and technical knowledge. Agric. Ecosyst. Environ. 33:57-74.

Fujisaka S, Vejpas C (1990) Capture and cultured paddy fisheries in Khu Khat, NE Thailand. Thai J. Agric. Sci. 23:167-176.

Harrington L, Hobbs P, Pokhrel T, Sharma B, Fujisaka S, Lightfoot C (1990) The rice-wheat pattern in the Nepal Terai: issues in the identification and definition of sustainability problems. J. Farming Syst. Res. Ext. 1(2):1-28.

Huke R E, Huke E H (1990) Human geography of rice in Southeast Asia. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Huke R E, Huke E H (1990) Rice: then and now. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Otsuka K, Cordova V G, David C C (1990) Modern rice technology and regional wage differentials in the Philippines. Agric. Econ. 4(3/4):297-314.

Palis F G, Pingali P L, Litsinger J A (1990) A multiple-pest economic threshold for rice (a case study in the Philippines). Pages 229-242 *in* Crop loss assessment in rice. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Pingali P L, Awadhwal N K, Quick G R (1990) Environmental and health effects of pesticides in Philippine rice production: implications for equipment design. Proceedings of the First International Agricultural Engineering Conference for Asia-Pacific, December 3-6, 1990. Asian Institute of Technology, Bangkok, Thailand.

Upadhyaya Hari, Otsuka K, David C C (1990) Differential adoption of modern rice technology and regional wage differential in Nepal. J. Dev. Stud. 26(3):450-468.

Soil Microbiology

Becker M, Ladha J K, Ottow J C G (1990) Einflub von NPK auf die Biomasseproduktion und Stickstoffbindung der stengelknollchenbildenden Grundungungslegumnosen *Sesbania rostrata* und *Aeschynomene afraspera* im NaBreisanbau. Z. Pflanzenernahr. Bodenk. 153:333-339.

Becker M, Ladha J K, Ottow J C G (1990) Growth and N_2-fixation of two stem-nodulating legumes and their effect as green manure on lowland rice. Soil. Biol. Biochem. 22:1109-1119.

Chiu C Y, Watanabe I, Yoshida T (1990) Estimation of N_2 fixation of soybean by comparison of different ^{15}N labeling methods. Soil Sci. Plant Nutr. 36(3):383-388.

Kimura M, Watanabe I, Patcharapreecha P, Panichsakpatana S, Wada H, Takai Y (1990) Quantitative estimation of decomposition process of plant debris in paddy field. II. Amounts and C/N ratios of plant debris in tropical paddy soils. Soil Sci. Plant Nutr. 36(1):33-42.

Ladha J K, Pareek R P, So R, Becker M (1990) Stem-nodule symbiosis and its unusual properties. *In* Nitrogen fixation: achievements and objectives. Gresshoff, Roth, Stacey, and Newton, eds. Chapman and Hall, New York and London.

Lightfoot C, Roger P A, Cagauan A G, De la Cruz C R (1990) *See* **Rice Farming Systems Program**.

Muirhead W A, De Datta S K, Roger P A, Gusto R M (1990) *See* **Agronomy, Physiology, and Agroecology**.

Pareek R P, Ladha J K, Watanabe I (1990) Estimating N_2 fixation by *Sesbania rostrata* and *S. cannabina* (syn. *S. aculeata*) in lowland rice soil by the ^{15}N dilution method. Biol. Fert. Soils 10:77-88.

Roger P A (1990) International Symposium of Microbial Ecology 5. Round table: microbial processes in paddy fields. Bull. Jpn. Soc. Microb. Ecol. 5(1):25-27.

Roger P A, Bhuiyan S I (1990) Ricefield ecosystem management and its impact on disease vectors. Water Resour. Dev. 6(1):1-18.

Roger P A, Ladha J K (1990) Estimation of biological nitrogen fixation and its contribution to nitrogen balance in wetland ricefields. Pages III-128-133 *in* Transactions of the 14th International Congress of Soil Science, 12-18 August 1990, Kyoto, Japan.

Tang L F, Watanabe I, Liu C C (1990) Limited multiplication of symbiotic cyanobacteria of *Azolla* spp. on artificial media. Appl. Environ. Microbiol. 56:3623-3626.

Ventura W, Watanabe I (1990) Azolla and sesbania: organic fertilizers. Pages 171-180 *in* The Philippine environment. Proceedings of the Philippine Environment Opportunities in Conservation and Rehabilitation, 14-16 June 1990, Manila, Philippines. The Philippine Futuristics Society, Manila, Philippines.

Watanabe I, Chiu C Y, Yoshida T (1990) Estimation of N_2 fixation in soybean and cowpea by using soil residual ^{15}N. Soil Sci. Plant Nutr. 36(3):375-381.

Watanabe I, Cholitkul W (1990) Phosphorus as a factor limiting nitrogen fixation in flooded rice soils. Pages 281-293 *in* Phosphorus requirements for sustainable agriculture in Asia and Oceania. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Watanabe I, Ramirez C (1990) Phosphorus and nitrogen contents of Azolla grown in the Philippines. Soil Sci. Plant Nutr. 36(2):319-331.

Soil and Water Sciences

Galang A L, Bhuiyan S I (1990) Simulation model use for analyzing decision variables in multipump rice irrigation system. Agric. Water Manage. 17(4):339-350.

Guerra L C, Watson P G, Bhuiyan S I (1990) Hydrological analysis of farm reservoirs in rainfed rice areas. Agric. Water Manage. 17(4):351-366.

Kirk G J D (1990) Diffusion of inorganic materials in soil. Philos. Trans. R. Soc. London B 239:331-342.

Kirk G J D, Ahmad A R, Nye P H (1990) Coupled diffusion and oxidation of ferrous iron in soils. II. A model of the diffusion and reaction of O_2, Fe^{2+}, H^+ and HCO_3^- in soils and a sensitivity analysis of the model. J. Soil Sci. 41:411-431.

Kirk G J D, Nye P H, Ahmad A R (1990) Diffusion and oxidation of iron in the rice rhizosphere. Pages 153-158 *in* Proceedings of the 14th International Congress of Soil Science, Kyoto, Japan. International Society of Soil Science, Japan.

Kirk G J D, Yu Tian-Ren, Choudhury E A (1990) Phosphorus chemistry in relation to water regime. Pages 211-223 *in* Phosphorus requirements for sustainable agriculture in Asia and Oceania. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Neue H U, Becker-Heidmann P, Scharpenseel H W (1990) Organic matter dynamics, soil properties, and cultural practices in ricelands and their relationship to methane production. Pages 457-466 *in* Soils and the greenhouse effect. A. F. Bouwman, ed. John Wiley and Sons, Chichester.

Neue H U, El-Naggar M I A, Rashid (.990) Responses and tolerance mechanisms of rice to saline soil conditions. Pages 50-55 *in* Proceedings of the 14th International Congress of Soil Science, Kyoto, Japan, 12-18 August 1990. Vol. 4. International Society of Soil Science, Japan.

Neue H U, Lantin R S, Cayton M T C, Autor N U (1990) Screening of rices for adverse soil tolerance. Pages 523-531 *in* Genetic aspects of plant mineral nutrition. N. El Bassam et al, eds. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Neue H U, Zhu Zhong-Lin (1990) Chemistry of adverse flooded soils. Pages 225-242 *in* Phosphorus requirements for sustainable agriculture in Asia and Oceania. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Olszyk D M, Bachelet D M, Barnes P W, Brown D, Holman S R, Bonman J M, Penning de Vries F W T, Heong K L, Ingram K T, Neue H U, Vergara B S (1990) *See* **Agronomy, Physiology, and Agroecology**.

Roger P A, Bhuiyan S I (1990) *See* **Soil Microbiology**.

Scharpenseel H W, Neue H U, Mutze B (1990) Biological activities and soil physical properties. *In* Organic matter management and tillage in humid and sub-humid Africa. IBSRAM Proceedings No. 10. Africaland-Regional Workshop, January 1990, Antananarivo, Madagascar.

Analytical Service Laboratories

Diocares R R, Castro R U (1990) A data acquisition system for autoanalyzers. Comm. Soil Sci Plant Anal. 21(13-16):1541-1557.

International Rice Germplasm Center

Chang T T (1990) Report on Rice Germplasm Conservation Workshop. Rice Genet. Newsl. 7:67

Chang T T (1990) Rice germplasm researchers discuss future conservation strategies. Diversity 6(2):11.

Chang T T, Loresto G C (1990) The conservation of rice genetic resources for the future generations. Pages 303-311 *in* Proceedings of the 2d Conference of the Philippine Environment: opportunities in conservation and rehabilitation. Philippine Futuristic Society, Manila.

Ingram K T, Real J G, Maguling M A, Obien M A, Loresto G C (1990) *See* **Agronomy, Physiology, and Agroecology**.

Juliano B O, Perez C M, Chang T T (1990) *See* **Plant Breeding, Genetics, and Biochemistry**.

Kobayashi N, Ikeda R, Vaughan D A, Shigenaga S (1990) *See* **Plant Breeding, Genetics, and Biochemistry**.

Vaughan D A (1990) A new rhizomatous *Oryza* species (Poaceae) from Sri Lanka. Bot. J. Linn. Soc. 103:159-163.

Vaughan D A (1990) Recent additions to wild rice germplasm conserved at IRRI. Rice Genet. Newsl. 7:64-66.

Vaughan D A (1990) *In-situ* conservation of wild rices in Asia. Rice Genet. Newsl. 7:90-91.

Information Center

Cabanilla V L, Hargrove T R (1990) The role of Asian women in rice science—an overview. *In* Women in agriculture—a technological perspective International Federation for Women in Agriculture, Indian Council of Agricultural Research, New Delhi.

Cabanilla V L, Hargrove T R (1990) Technology transfer to farmers: a study of the effectiveness of *A farmer's primer on growing rice* in two Philippine dialects. J. Agron. Educ. 19(1):59-63.

A list of Japanese rice literature (quarterly).

International bibliography of rice research. 1989 supplement.

Library list of recent accessions (January-December 1990) (12 issues).

Theses and dissertations on rice available in the Library of the International Rice Research Institute. 1989 supplement.

Training Center

Frio A (1990) Gender analysis: the farming systems research-extension training experience. 10th International Symposium on Farming Systems Research Extension, 1990, East Lansing, Michigan, USA.

Frio A (1990) A Collaborative Training Program on FSR/E Skills for the 1990s. 1st Asian AFSRE Symposium, 1990, Bangkok, Thailand.

Gementiza R, Tipa E (1990) A guide to evaluating cognitive learning (a guidebook).

Minnick D R (1990) Some paradigms and perspectives of training and technology transfer (a guidebook).

Minnick D R, Tipa E (1990) Dimensions of the microrevolution in learning. *In* Development communication for agriculture. B R Publishing Corporation, Delhi, India.

Training Center (1990) Rice production slide/tape modules (print, slideset, and taped audio components). 5 modules.

Training Center (1990) Rice production interactive computer-aided instruction.

Training Center (1990) Training and Technology Transfer performance objectives manual (a manual).

Training Center (1990) Training and Technology Transfer skills booklets. 7 booklets.

Training Center (1990) Training and Technology Transfer video instructions. 2 video instructions.

Rice Farming Systems Program

Harrington L, Hobbs P, Pokhrel T, Sharma S, Fujisaka S, Lightfoot C (1990) *See* **Social Sciences**.

Lightfoot C, Roger P A, Cagauan A G, De la Cruz C R (1990) A fish crop may improve rice yields and ricefields. ICLARM Q. 13(4):12-13.

International Network for Genetic Evaluation of Rice

Krishnasamy V, Seshu D V (1990) Germination after accelerated aging and associated characters in rice varieties. Seed Sci. Technol. 18:147-156.

Krishnasamy V, Seshu D V (1990) Phosphine fumigation influence on rice seed germination and vigor. Crop Sci. 30(1):82-85.

Salim M, Saxena R C, Akbar M (1990) *See* **Entomology**.

Shenoy V V, Seshu D V, Sachan J K S (1990) Shikimate dehydrogenase-1 allozyme as a marker for high seed protein content in rice. Crop Sci. 30(4):937-940.

Siscar-Lee J J H, Jahano B O, Qureshi R H, Akbar M (1990) *See* **Plant Breeding, Genetics, and Biochemistry**.

SPECIAL SEMINARS

Regional demand for dryland technologies in India and West Africa's semi-arid tropics. Dr. T. Walker, principal economist, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India.

Phylogenetic studies in Oryzeae: evidence for "recent" origin of some wild species and recombination between indica and japonica rices prior to the advent of modern plant breeding. Dr. G. Second, visiting scientist, Cornell University.

Regulation of bacterial and plant genes involved in nitrogen fixation. Dr. F. de Bruijn, Max Planck Institute for Plant Breeding.

On the use and application of models for crop-weed interactions. Dr. M. J. Kropff, Department of Theoretical Production Ecology, The Netherlands.

Biological control of bacterial blight of rice with bacteriocinogenic strains of *Xanthomonas campestris* pv. *oryzae*. Dr. N. Sakthivel, collaborative research scientist, Plant Pathology Division.

Thoughts on the role of socioeconomic analysis in biological research. Dr. G. Norton, resource economist, Imperial College, London.

On-farm research and farmers' seasonal food shortages: developing a maize variety in western Ethiopia. Dr. S. Franzel, agricultural economist, World Bank, Addis Ababa, Ethiopia.

Beyond Mendel's garden: biotechnology in the service of world agriculture. Dr. G. Persley, associate director, Australian Center for International Agricultural Research, Australia.

Microbial biomass: measurement, properties, and functions in soils. P. Brookes, Rothamsted Experimental Station, UK.

Integrating FPR with conventional on-farm research programs: one example from Botswana. G. M. Hemrich, ATIP, Francistown, Botswana.

Trends in the global seed industry. Dr. S. M. Sehgal, president, Biogenetic Technologies, Inc., Des Moines, Iowa, USA.

Layman's guide to molecular biology. Dr. S. McCouch.

Agriculture and agricultural research in Switzerland: an overview with emphasis on plant pathology. J. Ruegg, Swiss Federal Research Institute for Fruit Growing, Viticulture and Horticulture.

Progress and prospects of IRRI collaborative research in Myanmar. Dr. R. K. Palis.

Agriculture research and development—experiences in Bhutan. W. Roder, Bhutan National Potato Programme, Bhutan.

Technology transfer: the role of patents, license agreements, and industrial partners. Dr. A. K. Watson, visiting scientist, Agronomy, Physiology, and Agroecology Division.

Population regulation of rice green leafhoppers in Japan. Dr. D. A. Andow, University of Minnesota, USA.

Farming systems economic research within national programs. Dr. D. Norman, Agricultural Technology Improvement Project, Sebele, Botswana.

Ideotyping rice and breeding of the first prototype for direct seeding. Dr. M. Janoria, research fellow, Agronomy, Physiology, and Agroecology Division.

Thursday seminars

Biological methods of soil management in African highlands. Dr. V. Balasubramanian, maize agronomist and coordinator, Soil Fertility, IITA-Cameroon, Ibadan, Nigeria.

The guns of Manila Bay. Mr. J. Black, retired business executive.

Advanced executive leadership skills. Mr. T. L. Bertotti.

Engineered control of golden snail. Dr. G. R. Quick and Agricultural Engineering Division staff.

1990—IRRI on the move: implementing an exciting program. Dr. K. Lampe.

Moving from institutional shock to problem solving—learning from 2 years of change at IRRI. Dr. G. Egan, professor, Organization Studies and Psychology, Loyola University, Chicago, USA.

IRRI Board Meeting February 1990: results and outlook. Dr. K. J. Lampe.

The law of legibility: how to get readable slides. Mr. W. H. Smith.

Vetiver grass and its use in soil and moisture conservation. Dr. R. Grimshaw, chief, Asia Technical Agriculture Division, The World Bank.

San Bartolome: 1970-1990. Dr. R. E. Huke, visiting scientist, Social Sciences Division.

Decision tools for R&D and advice in pest management. Dr. G. Norton, director, Silwood Center for Pest Management, Imperial College, London.

The choice of germplasm for evaluation. Dr. D. A. Vaughan

Rice-wheat system: soil fertility and fertilizer use issues in relation to wheat agronomy in India. Dr. R. P. Singh, principal investigator (Agronomy), Wheat Improvement Project Directorate, IARI, New Delhi, India.

Environmental and health costs of pesticide use in rice production. Dr. P. L. Pingali

Use of natural abundance of ^{15}N for the measurement of N_2 fixation in legumes. Dr. M. Peoples, senior research scientist, Division of Plant Industry, Commonwealth Scientific and Industrial Research Organization, Canberra, Australia.

Seed health for crop management and seed exchange. Dr. F. W. Mew.

State of the art for transformation of plants. Ms. Miriam Stricklen, assistant professor, Plant Tissue Culture and Genetic Engineering Laboratory, Crop and Soil Science Department, Michigan State University, USA.

Ecological assessment of Taal Lake: considerations in planning for lake development. Dr. M. T. Zafaralla, associate professor, Botany and Environmental Sciences, Institute of Biological Sciences, Institute of Environmental Sciences and Management, College of Arts and Sciences, University of the Philippines at Los Baños (UPLB).

Electronic communication: a hands-on introduction. Mr. M. van den Berg.

Simulating competition and sustainability in multiple cropping systems. Mr. J. Henson, agronomist, Mindanao Baptist Rural Life Center, Bansalan, Davao del Sur.

Mechanisms and causes of resistance of rice to leaffolder, *Cnaphalocrocis medinalis* Guenee (Lepidoptera: Pyralidae). Dr. R. Ramachandran, postdoctoral scientist, ICIPE-IRRI Collaborative Project, Entomology Division.

Restriction fragment length polymorphism analysis of Philippine strains of *Xanthomonas campestris* pv. *oryzae* and *oryzicola*. Dr. A. K. Raymundo, associate professor, Institute of Biological Sciences, College of Arts and Sciences, UPLB.

Association of phytopathogenic bacteria with rice seeds. Dr. M. F. van Outryve, collaborative research scientist, Plant Pathology Division.

Genetic studies on salinity tolerance in rice towards better productivity in salt affected soils. Dr. B. Mishra, visiting postdoctoral scientist; Dr. M. Akbar, plant breeder; and Dr. D. V. Seshu, plant breeder and global coordinator, International Network for Genetic Evaluation of Rice.

Fungi and seed health of rice. Dr. J. K. Misra, postdoctoral scientist II, Seed Health Unit.

Paradigms and perspectives in training. Dr. D. R. Minnick.

Mechanisms of immunity to pathogens and parasites. Dr. G. P. Kaaya, International Centre of Insect Physiology and Ecology, Kenya.

Soil effects on blast resistance in upland rice. Dr. E. Kurschner, collaborative research scientist, Plant Pathology Division.

Two decades of green revolution in Central Luzon: an economic evaluation. Dr. K. Otsuka, visiting scientist, Social Sciences Division.

Symbiotic N_2 fixation—mineral N assimilation relationships: implications for exploiting legume N_2 fixation in crop systems. Dr. T. George, collaborative research scientist, Soil Microbiology Division.

1000 to one: good odds—agricultural engineering moves upstream. Dr. G. R. Quick.

Rodents and rice: presentation of reports by members of the Expert Panel Meeting on Rice Rodent Control. Dr. G. R. Quick.

Looking ahead at the global issues of food, population, and the environment. Dr. R. F. Chandler, Jr., IRRI founding director general and 1988 World Food Prize laureate.

Prospects for improving drought tolerance in lowland rice. Dr. D. J. Mackill.

Utilization of wild species germplasm. Dr. D. S. Brar.

Biotechnology: A decade and beyond. Dr. I. F. Dalmacio, National Institutes of Biotechnology and Applied Microbiology, UPLB.

Can biotechnology help enhance pest resistance? Dr. J. M. Bonman and Dr. D. G. Bottrell.

Molecular tools for analyzing pest populations. Dr. R. Nelson.

Perspectives on nonconventional virus resistance: advances, potential, and biosafety considerations. Dr. R. Hull, visiting scientist, Plant Pathology Division.

Improving yields: designing and testing VHYVs. Dr. F. Penning de Vries.

Modeling in the analysis of pest management strategies. Dr. K. L. Heong.

Soil processes with N-dynamics as an example. Dr. G. J. D. Kirk, associate soil chemist; and Dr. R. Singh, research fellow II, Soil and Water Sciences Division.

Understanding and quantifying damage by leaf blast and air pollution. Dr. M. Kropff, agronomist/crop modeler; and Ir. L. Bastiaans, research fellow, Agronomy, Physiology, and Agroecology Division.

Simulation of rice pathosystems and disease losses. Dr. P. S. Teng, plant pathologist and epidemiologist; Mr. S. B. Calvero, research assistant; and Dr. H. Pinnschmidt, collaborative research fellow, Plant Pathology Division.

Optimizing economic returns from rainfed ricelands with limited water in on-farm reservoirs. Mr. A. L. Galang and Dr. S. I. Bhuiyan.

Simulating soil nitrogen transformations and crop response to nitrogen using the CERES-RICE model. Dr. R. J. Buresh, visiting scientist, Agronomy, Physiology, and Agroecology Division; Dr. U. Singh and Dr. D. C. Godwin, International Fertilizer Development Center; Dr. J. T. Ritchie, International Benchmark Sites Network for Agrotechnology Transfer-Michigan State University; and Dr. S. K. De Datta, principal agronomist, Agronomy, Physiology, and Agroecology Division, IRRI.

Saturday Seminars

Water deficit and weed population effects on rainfed lowland rice. Ms. F. D. Bueno, Dr. K. T. Ingram, Dr. K. Moody, Mr. P. Pablico, and Mr. J. D. Janiya.

Water relations of upland rice in response to phosphorus fertilizer. Mr. J. D. Siopongco, Dr. K. T. Ingram, and Ms. F. D. Bueno.

Interactions of physical and biological stresses on the growth and yield of lowland rice. Ms. E. M. Pasuquin and Dr. T. Woodhead.

Ischaemum rugosum—A potential weed problem in rainfed lowland rice. Mr. R. T. Lubigan and Dr. K. Moody.

Fallow systems and nutrient status of rice soils. Ms. A. M. Robles and Dr. H. U. Neue.

Tillage and soil-water management for high production of legumes following irrigated lowland rice. Ms. M. E. Tenedora, Ms. T. R. Savares-Salire, and Dr. T. Woodhead.

Quantitative theory and flooded soil chemistry. Dr. G. Kirk and Ms. J. Solivas.

A comparative study of *Azolla* growth under sub-desertic and tropical humid conditions for determining its environmental requirements. Mr. T. de Waha, collaborative research fellow, Soil Microbiology Division.

Electronic monitoring of feeding behavior of green leafhoppers on rice, wild rice, and graminaceous weeds in relation to tungro virus transmission. Dr. A. N. M. Rezaul Karim, visiting scientist; and Dr. R. C. Saxena, entomologist, Entomology Division.

Upland rice cultivation with leguminous tree hedgerow on strongly acid soils. Dr. I. H. Basri, postdoctoral scientist; Mr. A. R. Mercado, Jr., research aide; and Dr. D. P. Garrity, agronomist/crop ecologist and acting head, Agronomy, Physiology, and Agroecology Division.

The spatial distribution of rainfed lowland rice flowering dates in South and Southeast Asia. Dr. Mai Van Quyen, visiting scientist; Dr. D. P. Garrity, agronomist/crop ecologist; and Mr. P. C. Agustin, Jr., research assistant, Agronomy, Physiology, and Agroecology Division.

Staff changes

January

Dr. Keith Moody, agronomist, Agronomy, Physiology, and Agroecology (APA) Division, returned from a 1-yr study leave.

Dr. Ernesto L. Aragon, postdoctoral scientist, APA Division, was appointed associate agronomist and coordinator of INSURF.

Dr. James S. Fujisaka, associate visiting scientist, Agricultural Economics Department, was appointed as social scientist, Social Sciences Division.

Dr. Minoru Yamauchi, former senior researcher, Tropical Agriculture Research Center, Japan, was appointed as plant physiologist, APA Division.

February

Mr. Michael F. L. Goon, former assistant director general, ICRISAT, Andhra Pradesh India, was appointed as deputy director general for finance and administration.

Dr. Anthony J. Ringrose-Voase, Division of Soil, CSIRO, Australia, joined the Agricultural Engineering Division as consultant.

Dr. Keijiro Otsuka, associate professor, Faculty of Economics, Tokyo Metropolitan University, Japan, joined the Social Sciences Division as consultant.

Dr. Frank J. van Schoubroeck, from Churchill 1, 6707 JA Wageningen, joined INGER as consultant.

Dr. Romeo Bruce, professor, College of Engineering; and Training Center for Applied Geodesy and Photogrammetry, University of the Philippines, joined the APA Division as consultant.

March

Dr. Dale G. Bottrell, professor, Department of Entomology, University of Maryland, College Park, Maryland, USA, was appointed as entomologist and head, Entomology Division.

Dr. Yujiro Hayami, professor of Economics, School of Politics, Economics and Business, Aoyama Gakuin University, Japan, joined the Social Sciences Division as visiting scientist.

Dr. Robert E. Huke and Mrs. Eleanor H. Huke, visiting scientists, Social Sciences Division, left after completing their assignment.

April

Dr. Paul S. Teng, rejoined IRRI as pathologist and coordinator, Integrated Pest Management, Plant Pathology Division.

Dr. N. Panda, former professor and head, Department of Entomology, Orissa University of Agriculture and Technology (OUAT), Bhubaneswar, India, joined the Plant Breeding, Genetics, and Biochemistry Division as consultant.

Dr. Keijiro Otsuka, consultant, Social Sciences Division, left after completing his assignment.

Dr. Yujiro Hayami, visiting scientist, Social Sciences Division, left after completing his assignment.

May

Dr. Susan McCouch, former research assistant and graduate teaching, Department of Plant Breeding and Biometry, Cornell University, Ithaca, NY, was appointed as associate geneticist, Plant Breeding, Genetics, and Biochemistry Division.

Dr. N. K. Awadhwal, agricultural engineer, ICRISAT, Andhra Pradesh, India, joined the Agricultural Engineering Division as project engineer.

Ms. Gina Ordoñez, principal, NGO Project Finder, Manila, joined the Training Center as consultant.

June

Dr. Dennis P. Garrity, agronomist, APA Division, left for study leave at North Carolina State University, USA.

Mr. J. Bart Duff, agricultural economist, Social Sciences Division, resigned.

Dr. Lesley A. Sitch, visiting scientist, Plant Breeding, Genetics, and Biochemistry Division, resigned.

Dr. Baij Nath Singh, visiting scientist, Plant Breeding, Genetics, and Biochemistry Division, left after completing his assignment.

July

Dr. David J. Mackill, plant breeder, Plant Breeding, Genetics, and Biochemistry Division, returned from 1-yr study leave.

Dr. James S. Townsend, visiting scientist, Agricultural Engineering Division, left after completing his assignment.

Dr. Keijiro Otsuka, rejoined the Social Sciences Division as consultant.

Dr. Leonardo A. Gonzales, agricultural economist, Social Sciences Division, returned to IFPRI after completing his assignment at IRRI.

Dr. Ellis L. Matheny, Jr., professor, Entomology, University of Florida, USA, joined the Training Center as visiting scientist.

Dr. B. B. Shahi, plant breeder, IRRI-Madagascar Rice Research Project, left after completing his assignment.

August

Dr. John Schiller, former team leader and advisor, Manpower Planning Project, National Agricultural Research, Thailand, was appointed as agronomist, IRRI-Lao Project.

Dr. Frank J. van Schoubroeck, visiting scientist, INGER, left after completing his assignment.

Dr. V. A. Samanarayake, associate professor, Department of Mathematics and Statistics, University of Missouri-Rolla, Missouri, USA, joined the Project Management Services and Biometrics as visiting scientist.

Dr. Dan R. Minnick, training specialist and head, left for study leave at University of Florida, Institute of Food and Agricultural Sciences (IFAS), USA.

Dr. A. K. Watson, professor, Department of Plant Science, MacDonald College of McGill University, Canada, joined as visiting scientist, APA Division.

Mr. Klaus Wahl, general manager and chef, Mamburao Beach Resort, Mindoro, Philippines, joined the Administration, Food and Housing Services as consultant.

September

Dr. Gaston Amedee, professor, Soil Science Department, California Polytechnic State University, USA, joined the Soil and Water Sciences Division as visiting scientist.

Mr. John M. Dowling, consultant, Philippine Transactional Analysis Organization (PHIL-TAO), Manila, joined the Office of the Deputy Director General for Finance and Administration as consultant.

Dr. Gerard Second, senior scientist, ORSTOM, France, joined the Plant Breeding, Genetics, and Biochemistry Division as visiting scientist.

October

Mr. Suvit Pushpavesa, former plant breeder, Rice Division, Department of Agriculture, Thailand, was appointed as plant breeder, IRRI-Lao Project.

Mr. Jit Bhuktan, research scholar, joined IPMO as consultant.

Dr. A. K. Watson, visiting scientist, APA Division, left after completing his assignment.

November

Dr. Martin Kropff, former scientific researcher/lecturer, Department of Theoretical Production Ecology, AK Wageningen, Netherlands, was appointed as agronomist/crop modeler, APA Division.

Mr. John M. Dowling, consultant, Office of the Deputy Director General for Finance and Administration, left after completing his assignment.

Dr. Philip Williams, Canadian Grain Commission, Grains Research Laboratories, Winniper, Manitoba, Canada, joined the Office of Deputy Director General for Research as consultant. He left the same month after completing his assignment.

December

Dr. Robert E. Huke and Mrs. Eleanor H. Huke, rejoined the Social Sciences Division as visiting scientists.

Dr. F. W. T. Penning de Vries, agronomist/crop modeler, APA Division, left after completing his assignment.

Dr. George C. Krajesik, computer software coordinator, Computer Services, Information Center, left after completing his assignment.

Mr. Klaus Wahl, consultant, Food and Housing Services, left after completing his assignment.

Finances

Summary of financial support to IRRI core and special projects committed for 1990.

Source	Amount (US$)				
	Core		Special projects		Total
	Unrestricted	Restricted	Essential	Complementary	
Japan		6,350,332	759,812	212,900	7,323,044
United States Agency for International Development	5,285,000		26,738	1,348,493	6,660,231
International Bank for Reconstruction and Development	3,400,000				3,400,000
European Economic Community	2,579,571				2,579,571
Canadian International Development Agency	1,523,594			291,070	1,814,664
Australia	758,901		39,650	935,685	1,734,236
United Nations Development Programme		1,695,300			1,695,300
Overseas Development Administration-United Kingdom	1,557,812				1,557,812
The Swiss Development Cooperation		378,121	5,450	1,000,954	1,384,525
Federal Republic of Germany	590,715		41,367	644,201	1,276,283
The Rockefeller Foundation		400,000	284,043	504,707	1,188,750
The Netherlands		161,840	151,484	685,722	999,046
France*		234,445		709,420	943,865
Swedish Agency for Research Cooperation	814,986				814,986
Asian Development Bank			403,466	338,733	742,199
Danish International Development Agency	587,929			5,398	593,327
Finland	501,746				501,746
Belgium		62,166	282,766	51,514	396,446
The Ford Foundation	150,000	60,500		108,042	318,542
International Development Research Centre-Canada				288,696	288,696
Italy	85,583	200,000			285,583
The Philippines	103,961			105,505	209,466
Sweden				193,757	193,757
Norway	121,899				121,899
India	100,000				100,000
International Food Policy Research Institute			66,490		66,490
People's Republic of China	50,000				50,000
Food and Agriculture Organization-UN				45,975	45,975
Spain	30,000				30,000
International Fertilizer Development Centre			26,206		26,206
International Centre of Insect Physiology and Ecology		22,169			22,169
Republic of Korea				10,138	10,138
Others				141,064	141,064
Total	18,241,697	9,564,873	2,087,472	7,621,974	37,516,016

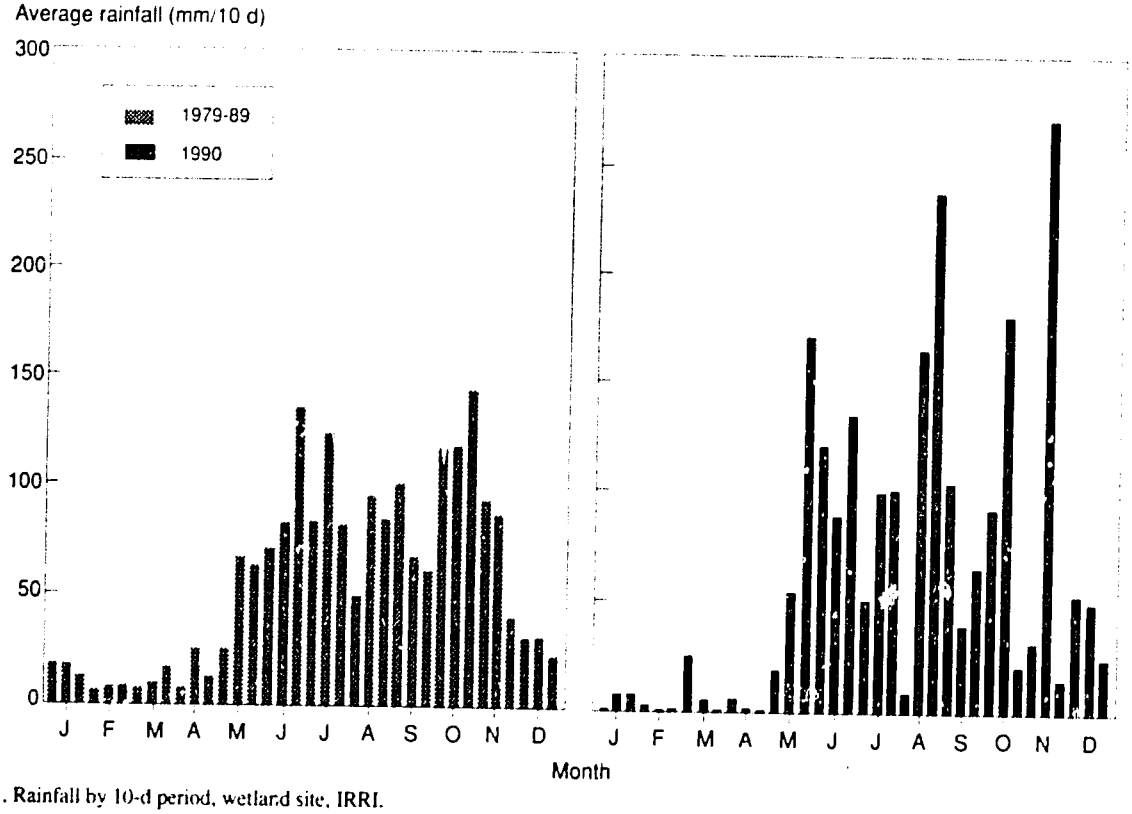
*The Government of France (through the research organizations ORSTOM and IRAT) also provided IRRI the services of four resident scientists; the value of their services cannot be quantified

Weather summary

The 1990 annual rainfall totals were 2,445 mm for the dryland (upland) site and 2,261 for the wetland (lowland) site (Table 1). These values were higher by 349 and 234 mm, respectively, than the normal values for both sites. Dry months were from January to April (Fig. 1). The longest dry spell of 25 d occurred in Los Baños from 27 January to 20 February. The longest wet spell was from 11 to 28 August. August was exceptionally wet, with rainfall of 527 mm at the dryland site and 410 mm at the wetland site. The heavy rains were caused in part by the 5-d-long typhoon Gading and tropical depression Hiling.

Solar radiation averaged 16.5 MJ/m^2 per d at the dryland site and 16.4 MJ/m^2 per d at the wetland. For Los Baños, solar radiation peaked in April at 21 MJ/m^2 per d and was lowest in December at 13 MJ/m^2 per d (Fig. 2).

Average daily maximum temperature was 31.7 °C at the dryland and 30.8 °C at the wetland site (Fig. 3). The daily minimum averaged 23.3 °C at the dryland site and 23.5 °C at the wetland.



1. Rainfall by 10-d period, wetland site, IRRI.

Table 1. Monthly weather data for IRRI Outreach and cooperating stations in the Philippines, 1990.[a]

Site		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total daily average
							Rainfall (mm/mo)							
Banaue, Ifugao	(16 56'N, 121 00'E)	127	M	148	145	485	404	590	445	447	388	408	285	3872
Betinan, Zamboanga del Sur	(07 54'N, 123 27'E)	28	0	27	77	234	379	285	464	299	266	326	15	2400
Cavinti, Laguna	(14 17'N, 121 30'E)	163	84	128	57	413	380	243	425	245	655	608	485	3886
Claveria, Misamis	(08 38'N, 124 55'E)	111	20	11	16	136	227	226	156	258	373	632	78	2244
Guimba, Nueva Ecija	(15 39'N, 120 47'E)	1	1	0	151	181	669	358	274	519	73	50	0	2277
IRRI, dryland site	(14 13'N, 121 15'E)	15	2	34	18	215	370	253	527	213	291	343	164	2445
IRRI, wetland site	(14 11'N, 121 15'E)	14	3	29	6	242	346	255	410	206	295	319	136	2261
PhilRice, Muñoz, Nueva Ecija	(15 45'N, 120 56'E)	3	0	2	38	177	439	393	386	454	59	55	0	2006
Solana, Cagayan	(17 39'N, 121 41'E)	14	14	2	29	43	378	176	327	87	189	103	124	1486
Visayas Experiment Station Iloilo	(10 32'N, 122 34'E)	20	2	11	7	240	478	475	571	274	144	156	25	2403
							Solar radiation (MJ/m² per d)							
Banaue, Ifugao		13.5	M	16.4	20.7	17.5	14.9	17.2	15.0	16.2	14.3	13.8	12.0	15.6
Cavinti, Laguna		15.9	18.8	19.3	20.1	18.7	15.0	16.0	14.4	16.6	14.2	13.6	13.3	16.3
Claveria, Mis. Oriental		15.8	20.8	20.4	21.3	20.5	17.7	21.0	19.8	18.6	20.2	17.2	20.2	19.5
Guimba, Nueva Ecija		19.0	21.3	21.4	22.6	19.0	16.8	19.6	17.6	21.0	18.8	17.8	17.1	19.3
IRRI, dryland site		15.3	19.4	19.7	21.5	18.0	15.5	16.1	14.3	16.3	14.7	13.8	13.2	16.5
IRRI, wetland site		14.3	18.8	19.3	21.3	19.1	15.5	16.7	14.1	16.4	14.6	13.9	12.9	16.4
PhilRice, Muñoz, Nueva Ecija		19.1	21.0	21.2	21.8	19.7	17.5	21.0	17.2	19.7	17.5	17.0	18.2	19.3
Solana, Cagayan		14.0	19.0	18.2	24.2	18.8	18.9	M	17.6	19.3	15.7	13.9	13.2	17.4
Visayas Experiment Station Iloilo		15.4	20.1	20.8	20.9	18.8	15.4	17.2	16.3	17.0	16.7	15.7	16.6	17.6
							Temperature (°C)							
Banaue, Ifugao	Max	21.6	M	24.4	28.2	27.8	26.6	27.2	26.5	26.1	24.8	24.3	22.1	25.4
	Min	14.8	M	16.3	17.7	18.2	18.8	18.7	19.0	18.4	17.8	17.5	16.2	17.6
Betinan, Zambales del Sur	Max	32.6	34.2	33.6	33.1	32.0	29.8	30.0	30.2	30.4	30.7	30.2	31.9	31.6
	Min	20.7	20.6	21.4	21.9	22.7	23.1	21.5	22.1	21.8	21.7	21.5	21.4	21.7
Cavinti, Laguna	Max	25.5	26.6	27.5	31.3	31.0	29.5	29.8	28.9	28.9	27.6	27.1	25.8	28.3
	Min	19.4	20.0	19.9	21.2	21.8	21.4	21.2	22.0	21.4	21.3	20.6	19.9	20.8
Claveria, Misamis Oriental	Max	26.9	28.9	29.5	30.4	30.0	28.7	28.9	30.1	29.3	28.5	27.5	28.9	29.0
	Min	20.5	20.1	20.6	21.6	22.5	22.5	21.9	22.3	21.6	21.6	21.2	20.0	21.4
Guimba, Nueva Ecija	Max	31.2	32.0	32.6	35.3	35.2	31.8	32.5	31.3	31.6	31.9	33.0	32.1	32.5
	Min	20.2	20.6	21.4	23.3	23.4	23.5	23.7	23.5	22.7	22.1	22.1	20.2	22.2
IRRI, dryland site	Max	30.3	31.7	31.6	34.6	33.8	32.1	31.8	31.2	31.4	31.0	30.8	29.5	31.7
	Min	21.2	22.3	22.0	23.8	24.9	24.2	23.5	24.3	23.8	24.0	23.3	22.6	23.3
IRRI, wetland site	Max	28.8	29.9	30.2	33.0	32.7	31.6	31.4	31.0	31.2	30.4	30.3	28.8	30.8
	Min	21.4	22.0	22.0	24.0	25.0	24.5	24.1	24.7	24.1	24.0	23.6	22.7	23.5

continued on next page

Table 1 continued.

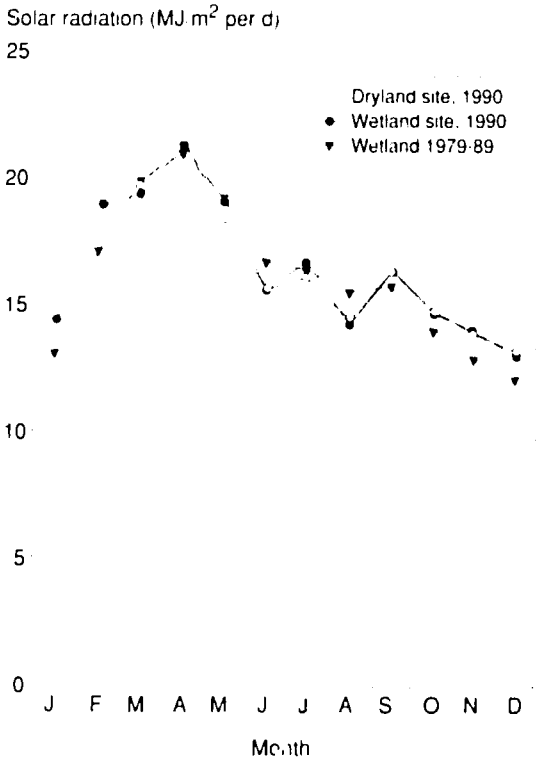
Site		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total daily average
							Temperature (°C)							
PhilRice, Muñoz, Nueva Ecija	Max	30.4	31.2	31.4	33.5	34.1	31.6	32.2	30.9	31.8	31.5	30.8	29.9	31.6
	Min	21.3	21.7	21.6	23.1	24.5	24.5	24.4	24.4	23.5	23.0	22.5	21.8	23.0
Solana, Cagayan	Max	29.0	31.3	32.3	36.2	36.2	33.3	33.3	32.5	32.4	30.6	29.6	27.8	32.0
	Min	20.0	20.2	21.6	23.4	24.5	24.7	24.6	24.7	24.1	23.2	22.8	21.3	22.9
Visayas Experiment Station Iloilo	Max	31.1	32.9	33.6	35.7	34.4	31.7	31.5	31.0	31.7	31.2	30.8	30.2	32.3
	Min	21.7	22.9	22.4	23.9	24.0	23.8	23.3	23.2	22.7	23.8	23.3	23.1	23.2
							Windspeed (m/s)							
Banaue, Ifugao		0.5	M	0.6	0.7	0.6	0.6	0.5	0.9	0.5	0.3	0.3	0.2	0.5
Betinan, Zamboanga del Sur		0.6	0.9	0.8	0.8	0.6	0.9	0.6	0.8	0.5	0.5	0.5	0.5	0.7
Cavinti, Laguna		2.5	2.5	2.1	2.0	1.8	1.4	1.2	2.2	1.5	1.5	2.2	2.7	2.0
Claveria, Misamis Oriental		0.6	1.2	1.2	1.2	1.2	1.0	0.7	0.9	1.0	1.0	0.9	0.6	1.0
Guimba, Nueva Ecija		2.4	2.2	2.2	2.0	1.3	1.0	1.0	0.8	0.8	1.1	1.6	3.0	1.6
IRRI, dryland site		1.8	2.1	1.7	1.8	1.4	1.4	1.3	2.6	1.5	1.1	1.5	1.8	1.7
IRRI, wetland site		1.8	1.9	1.6	1.7	1.3	1.3	1.2	2.3	1.3	1.1	1.6	1.8	1.6
PhilRice, Munoz, Nueva Ecija		3.0	2.8	2.2	1.8	1.3	1.2	1.3	1.5	1.4	1.1	1.5	3.6	1.9
Solana, Cagayan		0.8	0.7	0.9	1.1	1.0	1.1	0.7	0.8	0.8	0.5	0.6	0.6	0.8
Visayas Experiment Station Iloilo		2.0	2.3	2.2	1.8	1.6	1.2	1.1	2.0	1.0	0.9	1.2	2.2	1.7
							Evaporation (mm/mo)							
Banaue, Ifugao		79	M	100	138	134	120	137	119	116	106	92	80	1221
Betinan, Zamboanga del Sur		128	140	149	144	144	134	133	142	130	142	124	131	1641
Cavinti, Laguna		118	131	151	174	166	128	135	123	125	111	99	78	1539
Claveria, Misamis Oriental		108	134	179	181	173	144	166	168	146	153	122	125	1799
Guimba, Nueva Ecija		162	160	171	168	151	126	152	139	152	154	135	136	1806
IRRI, dryland site		152	186	198	236	196	134	137	140	141	136	127	124	1907
IRRI, wetland site		124	154	174	204	171	125	131	135	126	123	116	106	1689
PhilRice, Muñoz, Nueva Ecija		147	156	175	174	154	120	141	118	138	128	133	126	1710
Solana, Cagayan		110	131	179	218	211	164	167	155	149	127	101	91	1803
Visayas Experiment Station Iloilo		150	157	191	194	175	140	147	154	135	138	76	143	1800

M = missing data.

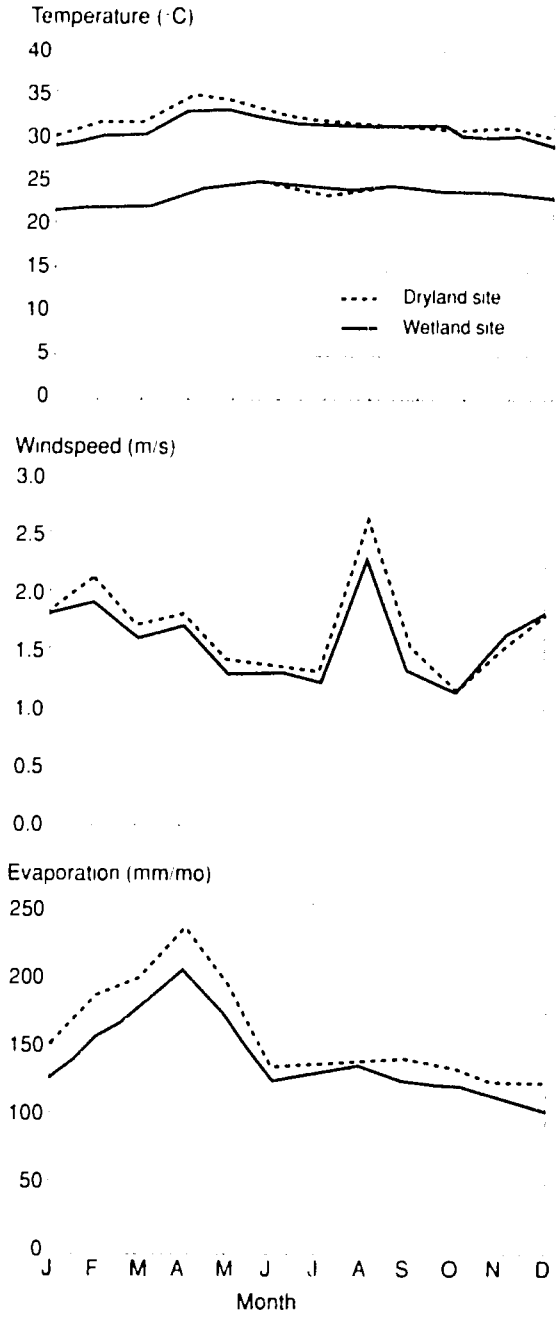
Windspeed measured at 2 m above the ground was highest in August, with 2.6 m/s at the dryland site and 2.3 m/s at the wetland. It was lowest in October.

Total class A pan evaporation was 1,907 mm at the dryland and 1,689 mm at the wetland site.

Of the 20 tropical cyclones that entered the Philippine area in 1990, 3 affected Los Baños. A very destructive typhoon Ruping caused serious damage to the Visayas area in November.



2. Solar radiation at dryland and wetland sites, IRRI.



3. Temperature range, windspeed, and evaporation at dryland and wetland sites, IRRI, 1990.

Keyword index

A

A. afraspera See Aeschynomene Afraspera
abiotic stresses, tolerance for **153**
Aceria saccharini **191, 193**
acetylene-reducing activity **77, 78, 79**
acid-base reactions **28**
acid sulfate condition **164**
acid sulfate soils **136, 141**
acid upland conditions **107, 108, 110, 121, 237, 241**
acidic rice soils **85, 123**
acidity **29, 139, 204, 241**
acidity-tolerant materials **141**
adapting field structures for nonrice crops **33**
aeroponic setup **287**
Aeschynomene afraspera **50, 51, 56, 68, 71, 82, 83**
Africa **218, 220, 272**
agroecology **66**
agroforestry **54, 55, 246**
alien gene introgression **156, 157, 158**
alkaline soils **13, 14, 28**
alkalinity **11, 12, 28, 139, 145, 159, 164, 232**
alkalinity, tolerance for **159**
allelochemicals **186**
aluminum **204, 290**
ammonia-excreting mutants of *Anabaena variabilis* **23, 24**
ammonia fluxes **38, 82, 83**
ammonia loss **27, 136**
ammonia volatilization **24, 27, 29, 39, 83, 84, 89**
ammoniacal N **27, 83**
amylose-extender mutant **211, 212**
analytical services **284**
anastomosis group **189**
annelid worm **193**
antagonistic bacteria **44, 46**
anther culture **145, 156, 157, 158, 159, 162, 273, 286**
Argentina **236**
arthropod guilds **201**
Asia **181, 182**
Aspergillus niger **190**
Australia **191**
axial-flow thresher **212**
azolla **30, 31, 237, 248, 259, 286**
azolla N, availability of **31**

B

bacterial blight, durable resistance to **16**
bacterial blight pathogen **54, 199, 200**
bacterial blight resistance **9, 11, 16, 17, 18, 22, 145, 153, 273**
bakanae disease **44**
Bangladesh **33, 117, 148, 159, 177, 178, 180, 181, 182, 218, 219, 242, 246, 248, 249, 264, 268, 269, 270**
Bani, Pangasinan **139, 140**
Bantog silt loam **81**
basal urea incorporation **27, 83, 84, 88**
BB *See* Bacterial blight
between-stubbles rototillage **55**
beusani **70, 71, 73**
BGA *See* Blue-green algae
Bhutan **242, 268, 270**
biological control **44, 45, 46, 227, 259, 274**
biological nitrogen fixation **153**
biomass **23, 24, 25, 41, 51, 61, 83, 106, 109, 135, 169, 184, 185, 198, 203, 205, 208, 209, 210, 212, 246, 271**
blast (Bl) **9, 10, 18, 19, 93, 98, 100, 102, 118, 119, 120, 121, 122, 123, 145, 146, 153, 154, 157, 158, 183, 238, 272**
blast-conducive soils **118**
blast disease model **202**

blast, durable resistance to **18**
blister mite pest **191, 193**
blue-green algae **23, 24, 25, 62**
boro rices **12, 13, 14**
boron **210**
BPH *See* Brown planthopper
Brazil **236**
broadcast seeding **42, 135**
brown planthopper **11, 21, 22, 54, 93, 145, 152, 153, 156, 157, 186, 202, 280**
bulk population **10, 14, 92, 127, 141**
bulu rices **12**
bypass flow **171**

C

Cambodia **66, 68, 89, 166, 168, 218, 221, 227, 242, 254, 268, 270, 271, 280**
carabao-plow **36**
carbon dioxide and temperature **59, 60**
carbon dioxide concentrations **57, 59, 210**
carbon dioxide measurements **28, 29, 83, 89, 196, 197, 204**
carbon:nitrogen ratio **208**
carbonic anhydrase **29**
cell suspension **161**
Centralized Research Farm **285**
cereal grains demand system **178**
CERES-rice **26, 27, 183, 185**
chemical fingerprinting **31, 186**
Chile **236**
Chilo suppressalis *See* Striped stem borer
China **20, 130, 148, 171, 177, 178, 180, 182, 191, 218, 221, 234, 237, 238, 242, 243, 245, 248, 268, 278, 281**
chlorine **209**
chlorine:sodium ratio **140**
chlorine concentrations **140**
chlorophyll content **7, 37, 58, 59, 133, 134**
cicadellid hoppers **201**
CIMMYT **56**
CIRAD/IRAT **154**
Claveria **103, 107, 108, 109, 110, 111, 239**
climate change, global **57**
clippings of legume intercrops **81, 106**
cluster analysis **189, 250**
CMS *See* Cytoplasmic male sterility
cms-WA cytoplasm **19**
Cnaphalocrocis medinalis *See* Leaffolder
coastal saline soil **139**
cold tolerance **12, 160**
collaborative research **33, 84, 85, 89, 227, 236, 268, 269, 272, 274, 280**
collaborative training **264**
Colombia **235, 236, 268, 276**
communication, research in **226, 235, 265, 284**
competition between bacterial blight pathogen races **199**
conferences **227, 268, 273, 280, 285**
consortium **57, 66, 185, 264**
constraints to sustained productivity growth **66**
contract labor **285**
control charts **284**
controlled flooding **127, 130, 131**
cooked-rice hardness **145, 210**
copublication **226**
cosegregation **154**
course transfer approach **264**
courseware development **257, 263**
credit, availability of **48**
critical moisture content **210**
crop and resource management **135, 236, 251**
crop-animal systems **244**
crop-area allocation **73, 74**
crop diversification *See* Diversified cropping
crop establishment **37, 40, 42, 55, 68, 69, 70, 71, 72, 73, 77, 95, 96, 109, 117, 279**
crop health inspection **223**
crop simulation(s) *See* Simulations, crop
cropping intensification **28, 61, 68, 73, 76, 103, 176**
cropping pattern(s) **69, 77, 106, 107, 108, 109, 110, 164, 242, 243, 244, 245, 279** *See also* improved cropping patterns
crude protein **135, 245**
cumulative transpiration **90**
Cyrtorhinus lividipennis **201**
cytoplasmic male-sterile lines **19**
cytoplasmic male sterility **19, 162**

D

data base(s) **30, 31, 44, 69, 145, 146, 147, 148, 163, 164, 166, 169, 212, 221, 226, 228, 235, 269, 277, 285**
data base management **220, 264**
dawn leaf water potential **114**
deadhearts **47, 138**
decision tree model **73**
deep water **102, 127, 163, 242**

deepwater rice **126, 131, 134, 135, 136, 137, 138, 154, 163, 166, 168, 218, 227,243, 248, 269, 273, 280**
deepwater rice intercropped with upland crops **137**
deepwater tanks **126, 269**
defoliator pests **46**
delphacids **201**
demand system, complete **177**
demand for rice, structural changes in **177, 178, 179, 180**
density dependence **43**
diagnostic survey(s) **53, 57, 71, 98, 99, 270, 275, 279**
diallel crossing **152**
Dichogaster nr. *curgensis* **193**
diffusion **28, 204, 207**
direct seeded rice **36, 37, 68, 202, 272**
disease resistance of hybrids **9, 22**
disease severity index (DSI) **18**
diversified cropping **33, 34, 48**
DNA fingerprinting **199**
DNA introgression **156, 157, 162, 284**
DNA transformation **152**
Dominican Republic **160, 236**
draft animal **36, 244, 245, 281**
draft requirement **36**
drainage-cum-interceptor channels **34, 35**
drought **13, 66, 67, 69, 73, 76, 77, 96, 100, 106, 116, 117, 118, 126, 153, 156, 166, 238, 247**
drought at seedling stage **131**
drought-prone land form **69, 94, 116, 163, 269**
drought resistance **90, 92, 93, 94, 96, 98, 113, 115, 122, 154, 172**
drought screening testing **113, 131**
drought stress index **90**
drought-tolerant legume **106**
drought-tolerant rice cultivars **67, 91, 92, 100, 117, 131**
dry matter production **21, 135, 137**
dry seeded rice **36, 37, 38, 39, 40, 70, 71, 72, 73**
dry spell **76, 100, 304**
dryers, fluidized bed **212**
dryers, mobile **212**
dryland **304**
DSR *See* Dry seeded rice
durable resistance to blast **18**
durable resistance to pests **14** *See* also specific pests
DWR *See* Deepwater rice

E

ear-cutting caterpillar **193**
Echinochloa colona **121, 195**
economic incentive **33**
economic threshold **46**
ecosystem characterization **162**
ecosystem nurseries **230**
Egypt **19, 20, 21, 159, 268, 272, 273, 278**
elasticity, expenditure **178, 180, 181, 182**
elasticity, structural change **181, 182**
electrical conductivity **40**
ELISA *See* Enzyme-linked immunosorbent assay
elite breeding lines **5, 9, 11, 13, 145, 157**
elongation ability **126, 127, 130, 154**
elongation testing **130, 133**
embryo rescue **157, 286**
emission of gases **60**
employment **166**
environment-sensitive male sterility **20**
environmental effects of pesticides **60**
enzyme-linked immunosorbent assay **10, 14, 149, 202**
epicuticular wax **59, 90, 118**
evaporation **304**
excess moisture **55**
extrapolation domains for new technology **68**
exudation **205**

F

fallows **28, 49, 50, 51, 52, 80, 81, 99, 100, 103, 107, 108, 109, 250, 278**
farm ditch density **34**
farm household income **48**
farm income **61, 244, 246**
farm productivity **61, 77, 264, 270**
farm reservoir optimization model **73**
farm-constraint surveys **57**
farm-level decisionmaking **68**
farmer management **68**
farmer perceptions **53, 109**
farmer practices **53, 288**
farmholding **166**
farmyard manure **53, 68, 84, 89, 237**
fertility restoration **153**
fertilizer response **135, 174, 275**
fertilizer use **173**
fertilizer-use function **174**
field evaluation **36**

field plot techniques **93, 94**
flash floods **139**
flavonoid content **58, 59**
floating rices **126, 129, 134**
floodwater depth **82, 84**
fluidized bed dryer **212**
fluorescent pseudomonads **146, 190**
fodder **52, 68, 81, 106, 110, 135, 245, 246, 247, 250**
forage legume(s) **51, 52, 81, 82, 106, 107, 244, 245, 278**
forage legume intercrops **52, 81**
fumigation-incubation **207**
Fusarium moniliforme **44**

G

gender **227, 246, 247, 270**
gene **10, 17, 18, 20, 22, 89, 91, 120, 122, 139, 145, 148, 152, 153, 154, 155, 156, 157, 158, 160, 162, 199, 211, 230**
gene pool **152, 156, 157, 162**
gene tagging **89, 152, 153**
genetic evaluation **12, 93, 116, 223, 230, 258, 259, 261, 276**
genetic transformation **156**
genetic variation **91, 152, 156, 186, 189**
genetics of resistance **89, 118, 119, 294**
genome manipulation **145, 152**
genome mapping **152**
Geographic Data Base **69, 164**
Geographic Information System **69, 145, 163, 164, 168, 169, 172, 257, 259, 262**
germplasm bank **130, 131, 147, 148, 152, 218**
germplasm collection **131, 146, 148, 218, 274**
germplasm evaluation **146, 235, 259**
germplasm, improved **5**
GIS *See* Geographic Information System
glaberrima *See Oryza glaberrima*
GLH See Green leafhopper
global climate change **57, 171**
glutelin a3 molecular weight **211**
grain production **135**
grain quality **153, 210**
grain quality, superior **5, 9**
grassy stunt virus *See* Rice grassy stunt virus
grazing **24, 25, 80, 102, 245, 247**
green hairy caterpillar **47**
green leafhopper **10, 11, 14, 21, 22, 44, 46, 93, 145, 146, 148, 149, 152, 153, 188, 202**
green leafhopper populations, genetic evaluation in **186**
green manure **28, 31, 50, 51, 52, 54, 55, 68, 71, 79, 80, 81, 82, 83, 88, 89, 106, 208, 209, 237, 243, 244, 271, 275, 278, 279, 280, 285**
gross margins **35**
group training courses **257**
gypsum **55, 56**

H

Haplaquept **140**
harvest index **21, 135**
harvester, mixed crop **212**
health effects of pesticides **60, 61**
herbage **52, 79, 80, 81, 135, 245**
herbage yield **244**
heterosis **21, 22, 23, 153**
high density grains **6, 40**
high temperature effects **18, 59**
histopathological methods **158**
horizontal windspeed **82**
host diversity **16**
host plant, resistance of **14**
Human geography of rice in Southeast Asia **166**
Humicola fuscoatra var. *fuscoatra* **190**
Huntra Rice Experiment Station **126, 129, 130, 131, 280**
hybrid rice **19, 20, 22, 162, 287**
hybrid rice seed production **22**
hybridization **7, 30, 130, 146, 147, 155, 156, 157, 234, 259**
hydraulic conductivity **169, 170**
hydrogen ion **141, 204**
hydrological parameters **76**
hydrotillers **35, 36, 82, 279**

I

ideotype, rice **169, 203**
immobilization of nitrogen **208, 237**
improved cropping patterns **48, 49, 50, 244**
improved germplasm **5, 8, 14, 18, 92, 98, 139**
indica/japonica cross **154**
in-country training **257, 264**
in situ hybridization **146, 155**
incident radiation **28**
India **12, 13, 14, 19, 20, 35, 53, 57, 66, 68, 70, 71, 73, 76, 77, 85, 89, 98, 100, 108, 122, 126, 133, 138, 148, 159, 171, 177, 178, 180, 181, 185, 191, 234, 237, 238, 239, 242, 268, 269, 273**

Indonesia 19, 33, 35, 73, 85, 89, 148, 166, 168, 177, 178, 179, 180, 181, 191, 218, 234, 237, 238, 239, 242, 245, 246, 249, 254,264, 268, 274
inefficient N use 54, 55
infection type 17, 18
INGER *See* International Network for Genetic Evaluation of Rice
inheritance of resistance to tungro 10
inoculation 14, 15, 16, 17, 18, 22, 23, 24, 25, 31, 78, 79, 118, 149, 150, 158, 188
inorganic fertilizer 50, 54, 61, 68, 81, 82, 237, 238, 239, 275
inorganic N 50, 51, 52, 106, 208, 209, 237
insect resistance, bases of 185
insect resistance of hybrids 22
integrate f nutrient management 82, 237, 270, 271
integrated pest management 14, 46, 62, 68, 135, 138, 185, 247, 264, 265, 280
intercrops 52, 81, 106, 108
intercropped sorghum 51
intercropping deepwater rice with upland crops 137
intercropping sesbania 79, 80
international exchange of improved breeding materials 230
International Network for Genetic Evaluation of Rice 230, 234, 235
International Pest Management Office (IPMO) 268
International Rice Genealogy Data Base 147
International Rice Germplasm Center 7, 116, 147, 218, 219
internode elongation 130
ion leakage 59
iron deficiency 209
iron, exchangeable and total 141
iron oxidation 139, 141, 203, 204
iron toxicity 141, 164
irrigated lowland 5, 27, 193, 241, 275, 279
irrigated rice program 5
irrigation systems 32, 33, 34, 37, 166, 260
irrigation water 12, 33, 34, 82, 172, 193, 209, 210, 258
IRRI-Japan Shuttle Program 154
isogenic lines 10

J

Japan 19, 20, 177, 180
Jordan phosphate rock 85, 86

K

Kenya 254
Korea 12, 19, 21, 160, 177, 178, 180, 182, 218, 227 234, 242, 244, 249

L

lablab 106
land characterization 66, 76, 163
land use efficiency 135
Lao PDR 99, 166, 168, 242, 268, 274, 275, 280
LAR *See* Leaf area ratio
late-flowering rices 89
Latin America 30, 31, 234, 268, 275, 276
leaf area 6, 21, 40, 59, 133, 183
leaf area ratio 133
leaf blast 183
leaf epicuticular wax 90, 91
Leaffolder 43, 47, 103, 112, 146, 151, 152, 183, 185, 186, 200
legume 77, 79, 80, 81, 82, 100, 106, 107, 108, 110, 122, 245
LEW *See* Leaf epicuticular wax
linear programming 74
linkage 89, 122, 145, 153, 154, 155, 156, 162, 174
livestock 54, 80, 82, 181, 247
low light, tolerance for 7, 133, 134
low temperature 12, 13, 14, 83, 163
lysine digestibility 211

M

machine-sowing 135
MACROS 169
Madagascar 242, 268, 277
main crops 72, 81, 135
maintainers 19
Malaysia 19, 21, 89, 148, 168, 172, 218, 239, 242, 244, 264, 274
male sterility, environment-sensitive 20
manganese deficiency 209
mapping blast resistance loci 120
marginal benefit-cost ratio 50, 117
marginal value products 48
mass balance micrometeorological technique 38, 82
maturity date of deepwater rices 127
medical assessment of pesticide use 60
methane 210

micro hydrotillers **35**
microbial biomass **61, 205, 207, 208**
micromills **213**
mineralization of nitrogen **28, 31, 32, 207, 208**
minerals in brown and milled rices **212**
minirhizotron **72, 91**
mixed-crop harvester **212**
mobile dryer **212**
modern rice varieties in Nepal **172, 176**
modern variety adoption **173, 174, 175**
modified bulk pedigree selection **7**
moldboards **36, 103**
molecular biology **153**
molecular markers **91, 118, 120, 153**
molecular probes **182, 199**
monitoring visits **234**
Morocco phosphate rock **85**
multilocation testing **11, 18, 244, 251, 272, 273, 278**
mungbean **50, 75, 79, 80, 82, 108, 112, 137, 138, 189, 244, 246, 249, 250, 279**
Myanmar **166, 168, 218, 239, 242, 243, 262, 268, 279, 280**
mycoparasitic microorganisms **190**
Mythimna separata **193**

N

NARS See National agricultural research systems
national agricultural research systems **12, 14, 23, 139, 141, 169, 171, 220, 221, 226, 228, 230, 251, 254, 257, 264, 265, 268**
near-infrared reflectance spectroscopy **211**
near-isogenic lines **17, 119**
Nepal **57, 66, 163, 173, 242, 244, 245, 246, 249, 250**
Nephotettix virescens **186, 202** See also Green leafhopper
NH_3 volatilization See Ammonia volatilization
Nigeria **268**
nitrate N **27, 28, 107, 136, 137**
nitrogen **31, 40, 77, 136, 195, 197, 203, 211, 239**
nitrogen and nitrous oxide flux measurements **89**
nitrogen availability **136, 197**
nitrogen balance **138, 211**
nitrogen fixation **77, 153**
nitrogen-fixing BGA **25, 61, 62**
nitrogen management **39**
nitrogen nutrient efficiency **23**
nitrogen recovery **32, 80, 82**
nitrogen response **26, 80, 237, 241**
nitrogen uptake **80**
nitrogen use efficiency **22, 23, 40, 80, 153, 197, 280**
nitrogen-15 balance techniques **27, 84**
nitrogen-15 dilution **77, 296**
non-capsid protein **146, 188**
novel aneuploid stocks **156**
novel genetic variation **152, 156**
nucleic acids **59**
nutrient **23, 54, 55, 61, 62, 68, 82, 100, 103, 107, 109, 138, 139, 203, 207, 210, 212, 236, 237, 239, 241, 244, 250, 270**
nutrient depletion **53**
nutrient uptake **42, 141, 203, 205, 210, 255**
nutrients during milling **212**
nutritional value of rice **210**

O

optimal economic returns **76**
organic fertilizer **31, 50, 55, 80, 239, 290**
organic matter **29, 208**
organic N **79, 80, 237, 238**
Oryza alta **145, 152, 157**
Oryza australiensis **145, 152, 157**
Oryza barthii **138, 149**
Oryza brachyantha **157, 186**
Oryza eichingeri **145, 157**
Oryza glaberrima **7, 138, 146, 148, 149, 218, 219, 221**
Oryza latifolia **11, 157**
Oryza longistaminata **10, 153**
Oryza minuta **145, 149, 152, 154, 158**
Oryza nivara **138, 149**
Oryza officinalis **149**
Oryza perennis **186**
Oryza punctata **149, 219, 220**
Oryza rhizomatis **145, 157, 219**
Oryza rufipogon **138, 218**
Oryza schweinfurthiana **220**

P

Pakistan **19, 57, 148, 177, 178, 180, 181, 182, 242, 249**
palay picker **213**
Paleudult **141**
Papua New Guinea **218**
parasitization **43**
parasitoids **43, 46, 202, 203**
partial pressure of ammonia **83**

partial resistance to blast **10, 18**
partially acidulated phosphate rock **85**
pathogen races **14, 17, 199**
pathogen strains **199, 202**
peatiness **139**
percolation and seepage **34**
percolation rate **169, 170**
Peru **236**
pest control techniques, physical **47**
pest dynamics **42**
pest effects coupled to a rice model **182**
pest population dynamics **182, 198**
pest population models **185**
pest-yield interactions **182**
pesticide application technology **48**
pesticide residue laboratory **286**
pesticides **5, 53, 60, 61, 62, 208, 247, 255, 273, 286**
pests **14, 42, 46, 47, 48, 54, 55, 60, 68, 92, 98, 99, 103, 104, 109, 111, 126, 146, 169, 177, 182, 183, 185, 187, 197, 198, 202, 212, 221, 239, 269, 273, 275**
pH **13, 25, 27, 28, 29, 44, 54, 81, 83, 86, 106, 136, 141, 164, 188, 203, 204, 209, 237, 238, 239**
pH buffer power **204**
Phalaris minor **55**
pheromone **198, 199**
Philippine Rice Research Institute (PhilRice) **160**
Philippines **11, 19, 20, 21, 33, 66, 68, 85, 89, 149, 160, 166, 168, 177, 231, 237, 238, 242, 244, 247, 248, 250, 264**
phloem feeding **188**
phosphate **14, 86, 239**
phosphate rock **85, 137, 241, 271**
phosphate sources **85, 86, 87**
phosphorus **98, 164, 203, 205, 206**
phosphorus deficiency **13, 31, 108, 139, 164, 203, 241, 242**
phosphorus efficiency **277**
phosphorus sorption **203, 206**
phosphorus, kinetics of dissolution of **85**
phosphorus, slow reaction to **207**
photoperiod-sensitive cultivars **89**
photoperiod-sensitive genic male sterile lines **20**
photoperiod sensitivity **89, 153**
photosynthates, partitioning of **134**
photosynthesis **135, 183, 195, 210, 287**
photosynthetic rates of weeds **146, 195, 196**
phytotron **17, 20, 36, 58, 60, 77, 78, 133,140, 220, 286, 287**
pink stem borer **138**
pJEL101 **16, 17, 199, 200**
plant height **7, 34, 35, 59, 93, 133, 241, 242, 269**
plant regeneration **161, 219**
plant type, new
planting date **51, 54, 55, 59, 60, 89**
plating efficiency of microscopic culture **24, 161**
polymer matrix **198**
pond refuge **248**
population diversity **199**
postrice tillage **55**
postrice wheat **55**
potassium **29, 51, 55, 81, 82, 106, 107, 115, 116, 208, 209, 237, 239, 241**
potassium contents **140,164**
potassium:sodium ratio **140**
Prachinburi **126, 127, 135, 136**
prebreeding **12, 126, 135, 139**
prilled urea **237**
protein digestibility **211**
protein quality **211, 212**
protein, soluble **59**
protoplast **161, 162**
Pseudomonas marginalis **191**
Pseudomonas syringae pv. *syringae* **191**
*Pst*I analysis **200**
pTnX1 **16, 17, 199**
Pyricularia grisea populations **120, 121, 158** *See also* Blast

Q

qualitative resistance to blast **18**
quality assurance **284**
quantitative trait loci (QTL) **120, 153**
quantum efficiency **196**
quarantine objects **222**

R

races of the bacterial blight pathogen **199, 200**
ragged stunt virus *See* Rice ragged stunt virus
rainfall **27, 55, 56, 73, 74, 76, 279**
rainfed land types **69**
rainfed lowland conditions **20, 92, 94**
rainfed lowland environment **77, 80**
rainfed lowland rice **66, 69, 70, 72, 73, 82, 89, 93, 96**
rainfed lowland rice flowering dates **163**
rainfed lowland rice, spatial distribution **163**
rainfed lowlands **66, 68, 126**
rainfed riceland data base **163**

rainwater **73, 77, 82, 171, 210**
ratoon crop **135**
rDNA probes **156**
recurrent selection **93**
reduced soils **27, 141**
relative agronomic effectiveness **87**
relative humidity **140, 279**
released varieties **273**
research needs **53, 270**
reservoirs, on-farm **73, 300**
resistance genes **10, 16, 17, 120, 122**
resistance of wild rices to insects **152**
resistant check **131, 133**
resistant starch **211, 212**
restorers **19, 20, 154, 162**
restriction enzymes **154**
restriction fragment length polymorphism **200, 284**
See also specific RFLP entries
rethresher **212, 213**
RFLP map **153**
RFLP mapping population **153**
RFLP markers **10, 89, 120, 145, 152, 153, 154, 155, 156, 157, 162**
RFLP types **16**
RGSV *See* Rice grassy stunt virus
RH *See* Relative humidity
Rhizoctonia solani **149, 188, 190**
rhizosphere **44, 141, 203, 205, 207, 210**
riboflavin **212**
rice after intercropping **52, 108**
rice cultural type **166**
rice - fish farming **248, 249**
rice geographic data base **69**
rice germplasm in vitro culture **219**
rice grassy stunt virus **9, 148, 188, 201, 202, 255**
rice hybrids **19, 20, 22, 23**
Rice literature update **226**
rice ragged stunt virus **129, 146, 148, 201, 202**
rice seeds **23, 41, 103**
rice seeds, incoming **222, 223, 224**
rice seeds, outgoing **221, 223, 224**
rice-soil structural management **55**
rice tungro bacilliform virus **10, 14, 15, 16, 18, 148, 149, 188**
rice tungro spherical virus **10, 14, 188**
Rice Viruses Data Base **148**
rice - wheat systems **52, 53, 55**
rice yield reductions **48**
rock phosphate **137**
rodent barriers **47, 48**
root growth **59, 70, 71, 72, 91, 115**
root oxidizing ability **58, 59, 205**
roots **7, 14, 15, 23, 44, 55, 56, 59, 77, 78, 79, 203, 210**
rotation **55, 99, 107, 108, 205, 244**
rototillage between stubbles **55**
Rottboellia cochinchinensis **117, 195, 197**
row ratios **79, 108**
row-seeded rice **39, 70**
PRSV *See* Rice ragged stunt virus
RTBV *See* Rice tungro bacilliform virus
RTSV *See* Rice tungro spherical virus
ruminant feed **135**

S

SACCAR *See* Southern African Centre for Cooperation in Agricultural Research
saline soils **141, 272**
salinity **11, 12, 140, 156, 159, 210, 232, 286**
salinity tolerance **139, 140, 154, 159, 160**
salt tolerance **154, 160**
salt-tolerant varieties **14, 139**
Santo Tomas, Pampanga **139**
saturated genetic map **152, 162**
SB *See* Stem borers
secondary trisomics **170**
seed quality **40, 191, 210, 212**
seed vigor **210**
seedborne inoculum **191**
seeding rate **117**
semivariogram **170**
serological techniques **201**
sesame **137, 138, 243, 244, 280**
Sesbania cannabina **77**
Sesbania rostrata **208, 237, 271, 279**
shading, tolerance for **132, 246**
sheath blight **19, 44, 54, 145, 149, 183, 188, 189, 190**
shoot weight **132**
shuttle breeding for deepwater rice **126**
silica **59, 138, 139, 190**
silica absorption ability **139**
silica and rice resistance to pests **138, 139, 186**
silicon **212, 269, 278**
simulation models **169, 182, 183, 185**
simulations, crop **59, 73, 163, 168, 169, 170, 171, 172, 182, 184, 185**
sink activity **6**
siratro **106, 244**
slit seeder **55, 279**

sodium **140, 209, 211**
sodium concentration **140**
soil ammonia **136**
soil bulk density **27, 204, 208**
soil characteristics **169, 237**
soil characterization **169**
soil cracking **126, 171**
soil erosion **111**
soil fertility **164, 203, 207, 208, 239, 280**
soil hydraulic resistance **169**
soil nitrate **136**
soil physical building blocks **56**
soil resistance to cone penetration **56**
soil stresses **139, 203**
Solana, Cagayan **126, 127**
solar radiation **27, 42, 51, 84, 304** *See also* Ultraviolet-B radiation
somaclonal variants **14**
somatic embryogenesis **161**
sorghum, intercropped **51**
Southern African Centre for Cooperation in Agricultural Research **272**
spatial variability **163, 170**
spore adhesion **158**
Sri Lanka **19, 89, 141, 148, 242, 249, 250, 268, 279, 280**
standard blotter test **191**
starch, resistant **211**
stem borer losses **184**
stem borer resistance **138**
stem borers **46, 55, 138, 183, 274**
stomatal aperture **58**
stratum **246**
straw **208, 209, 212, 213, 237, 270**
straw flow characteristics **212**
stress-oriented nurseries **232**
stress tolerance **230, 234**
striped stem borer **21, 138, 152, 198**
stripper harvesting systems **212, 213**
stylosanthes **107**
submerged soil **205, 207**
submergence testing **127**
submergence tolerance **126, 127, 130, 131, 133, 139, 153, 154, 269**
sulfur **87, 241, 278**
sunflower **137, 243**
superphosphate **137, 239, 241, 271**
sustainable production of rice **103**
sustainable rice-based farming **236**

T

technology adopters **250**
technology-environment interactions **60**
temperature **160, 163, 190, 201, 209, 213, 248, 278, 279, 281, 286, 287, 304**
temperature, low **12**
Thai-IRRI **93**
Thailand **66, 68, 89, 141, 166, 168, 177, 178, 179, 180, 181, 182, 242, 244, 247, 248, 249, 250, 254, 268, 275, 280**
thematic maps **163**
thermosensitive genic male sterile lines **20**
thiamine **189, 212**
tidal wetlands **139, 154, 203**
tillage after rice **55**
tolerance of plants for saline-alkaline ricelands **14**
toxic elements **140**
trainees **254,255, 257, 260**
training **171, 172, 227, 247, 254, 255, 257, 258, 259, 260, 263, 264, 268, 269, 272, 274, 277**
transpiration **140**
transplanted rice **243**
transplanting, late **54, 55**
transposable genetic elements **199**
trench refuge **248**
Trichoderma koningii **190**
trichomes **158**
triple superphosphate **85**
tropical cyclone **304**
tungro disease **14, 145, 146, 148, 153**
tungro, dynamics of **44**
tungro, inheritance of resistance to **10**
tungro resistance **9, 10**
tungro vectors, migrating **202**
twin-furrow plow **36**

U

ultraviolet-B radiation **51, 58, 59, 60, 198, 287**
upland crop **249, 260**
upland weed **82, 195, 197**
urbanization **177, 178, 180, 182**
urea **245, 291**
urea supergranule **237**
urea-ammonium sulfate **87**
urea-elemental sulfur mixture **87, 284**
UPLB (University of the Philippines at Los Baños) **154**

UV-B radiation *See* Ultraviolet-B radiation
UV-B setup **287**

V

Vietnam **19, 20, 21, 85, 89, 160, 168, 218, 221, 242, 249, 268, 280**
viral diseases, resistance to **145, 148**
virus concentration in plants **14**
virus disease monitoring **201**
volatiles in rice **186**

W

water control structures **34**
water depths **126**
water management **139, 141, 258, 264, 272**
water retention characteristics **170**
water stress **34, 195, 196, 197, 286**
water supply reliability **73**
water table **34, 171**
water use efficiency **196**
waxy gene allele **211**
weed control **103, 117, 197, 271**
weeds **146, 187, 195, 196, 197, 226, 273**
wet spell **304**
wetland rice variety **277, 278**
wetland site **250, 304**
wheat in cropping patterns *See* Rice - wheat systems
wheat, tropical **56**
whitebacked planthopper **153**
wide compatibility **153**
wide hybridization **19,156, 162, 255**
wild rices species **138, 146, 152, 156, 157, 158, 218, 219, 221, 274, 279**
wind speed **250, 304**

X

Xa-4 gene **17, 199**
Xanthomonas pv. *oryzae* (Xoo) *See* Bacterial blight

Y

yellow stem borer **21, 138, 139, 152, 186, 269, 273**
yield, high **5**
yield potential **159, 163, 173, 175, 177, 272**
yield reductions **48**
yield stability **172**
YSB *See* Yellow stem borer

Z

zinc **204, 209, 241**
zinc deficiency **139, 164**
zymograms **30, 31**