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Progress in Rainfed Lowland Rice

INTERNATIONAL RICE RESEARCH INSTITUTE

Progress in Rainfed Lowland Rice

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CONTENTS

FOREWORD
WELCOME REMARKS 1
Rainfed lowland rice ecosystems: characterization and distribution 3
D.P. Garrity, L.R. Oldeman, R.A. Morris, and D. Lenka
Production constraints of rainfed lowland rice in eastern India 25
B. Misra, S.K. Mukhopadhyay, and J.C. Flinn
Rainfed rice in West Bengal 53
B. Mandal and P.V. Shenoi

INTERNATIONAL NETWORKS

Cropping systems for rainfed lowland rice environments 59
R.A. Morris, A. Patanothai, A. Syarifuddin, and V.R. Carangal
Rice varietal testing in the rainfed lowlands of South and Southeast Asia 77
D.V. Seshu
Results of INSFFER rainfed lowland rice trials 103
C.P. Mamaril, S.K. De Datta, and R.R. Villapando

VARIETAL IMPROVEMENT

Varietal improvement for rainfed lowland rice in South and Southeast Asia: results of a survey 115
D.J Mackill
Drought resistance in rainfed lowland rice 145
J.C. O'Toole and S.K. De Datta
Breeding rice varieties for rainfed lowland areas 159
D.M. Maurya and C.N. Mall
Breeding for drought- and submergence-prone rainfed lowland rice in Thailand 167
S. Pushpavesa, B. Somrith, and V. Petpisit
Screening for submergence tolerance 177
D. HilleRisLambers, A.R. Gomosta, and T. Kupkanchanakul
Breeding for submergence tolerance in rice in India 191
H.K. Mohanty and R.C. Chaudhary
Tolerance of rice varieties for stagnant flooding 201
S.K. Datta
Integrated breeding program for medium-deep, stagnant-water, rainfed rice in India 207
S. Biswas, S. Mallick, and N.K. Mitra
Integrated breeding program for medium-deep, stagnant-water, rainfed rice in Bangladesh 217
N.M. Miah, M.A.A. Miah, and S.B.A. Dewan

Breeding program for medium-deep waterlogged rainfed lowland rice in Burma 223
Ohn Kyaw and P.B. Escuro
Progress in breeding rice for medium deep water rainfed lowland areas in Vietnam 235
Pham Van Ro and Vu Tuyen Hoang
Varietal improvement and resistance to insect pests 241
M.B. Kalode, A.N.M. Rezaul Karim, S. Pongprasert, and E.A. Heinrichs
Disease resistance in rainfed lowland rice 253
A P.K. Reddy, S.A. Miah, and T.W. Mew
Breeding for soil stresses 263
M. Akbar, I.E. Gunawardena, and F.N. Ponnamperuma

SOIL, CROP, AND WATER MANAGEMENT

Soil fertility and fertilizer management for rainfed lowland rice 275
N.N. Goswami, S.K. De Datta, and M.V. Rao
Management techniques to overcome soil salinity problems in coastal rainfed lowland rice 285
A.K. Bandyopadhya and I.P. Abrol
Efficient use of water for rainfed lowland rice 295
A.M. Fagi, S.I. Bhuiyan, and J.L. McIntosh
Physical characteristics of lowlands and promising traditional and new cropping patterns 311
P.P. Ghildyal and K.G. Pillai
Associated crops in rice-based cropping systems 323
V.R. Carangal and R.A. Morris

PEST MANAGEMENT

Diseases and disease management of rainfed lowland rice 339
T.W. Mew, A.K.M. Shahjahan, and V. Mariappan
Management of insect pests in rainfed lowland rice 349
E.A. Heinrichs, W. Katanyukul, A.N.M. Resaul Karim, and B.C. Misra
Weed control in rainfed lowland rice 359
K. Moody, S.K. De Datta, V.M. Bhan, and G.B. Manna
Rat control in rice 371
K.S. Kushwaha

TECHNOLOGY TRANSFER

Operational research projects on rice in India 383
C. Prasad, J.P. Kulshrestha and V.R.P. Sinha
Transfer of technology for increasing yields of rainfed rice in eastern India 391
P.V. Shenoi and B. Manda.
Prospects for rainfed lowland rice production in India by the year 2000 395
H.K. Pande
RECOMMENDATIONS 417
PARTICIPANTS 426
INDEX OF VARIETIES 432

FOREWORD

Rainfed lowland rice comprises more than 40% of the rice area of South and Southeast Asia. Despite its importance, progress in increasing production of rainfed lowland rice has been slow, and many farmers are still using traditional varieties and cultural practices. Drought, excess water, and poor soils are common constraints to production in rainfed lowland areas. Therefore, scientists at the International Rice Research Institute (IRRI) and various national programs are placing special emphasis on improving the productivity of rainfed lowland rice areas.

IRRI has sponsored an International Rice Research Conference (IRRC) every year, to which rice scientists throughout the world are invited. In alternate years, the IRRC is held outside the Philippines and focuses on specific topics. The Government of India, through the Indian Council of Agricultural Research, graciously agreed to host and cosponsor this conference on rainfed lowland rice. We are grateful to the Indian Council of Agricultural Research; the Central Rice Research Institute, Cuttack; and the Orissa University of Agriculture and Technology for their painstaking efforts, which made the conference pleasant and purposeful.

The choice of eastern India as the venue was based on the considerations that India has the largest area of rainfed lowland rice, and that a considerable amount of research is being conducted by Indian scientists on the subject. The IRRC on rainfed lowland rice was designed as a forum for review of past progress and for formulating a collaborative approach for future work on rainfed lowland rice.

The papers in this volume were edited by Jay Maclean and Stephen J. Banta, with the assistance of Gloria S. Argosino.

M.S. Swaminathan
Director General

WELCOME REMARKS

It is appropriate that this first International Conference on Rainfed Lowland Rice is being held in Bhubaneswar, since Orissa is one of the early centers of rice domestication. The Jeypore tract of Orissa is characterized by a rich diversity of rice germplasm material.

Orissa, Assam, Bihar, West Bengal, and the northeastern states have over 45% of India's rice area, but they produce only a third of the country's rice output. Hence, in formulating the Seventh Five-Year Plan, considerable emphasis has been placed on improving the productivity of rice farming systems in eastern India. This conference is timely, since the scientists present here from all over the world will be in a position to indicate the steps that can be taken immediately to improve rice production under rainfed lowland conditions, besides identifying the major gaps in our current knowledge. Holding this conference in Bhubaneswar will also help the scientists who have come from outside to see the excellent research in progress at the Central Rice Research Institute (CRRI) at Cuttack and the Orissa University of Agriculture and Technology (OUAT).

The rice plant may face a combination of adverse factors — including drought and floods — at different stages in its growth. Hence, the development of production technologies that can help to elevate and stabilize the yields of rainfed rice is scientifically very challenging. This scientific challenge can be met only through interdisciplinary and interinstitutional collaboration. The International Rice Research Institute (IRRI), which represents a global family of rice research workers, has developed the following six-pronged mechanism for promoting purposeful collaboration among scientists working on the improvement of rainfed lowland rice.

- *International Rice Germplasm Center.* IRGC now has about 75,000 rices from all over the world — a mine of valuable genes for all rice research workers to use in their breeding programs. A Five-Year Plan (1983-87) for collecting the remaining rice germplasm is being implemented to preserve for posterity the fruits of thousands of years of natural and human selection.
- *International Rice Testing Program.* IRTP operates an International Rainfed Lowland Rice Observational Nursery and a corresponding yield nursery. Varieties with tolerance for drought, submergence, and major pests and diseases are identified in these nurseries.

- *International Network on Soil Fertility and Fertilizer Evaluation for Rice.* INSFFER, which aims to improve the health of rice soils and the efficiency of fertilizer use, conducts nitrogen fertilizer efficiency trials in rainfed lowland rice.
- *Asian Rice Farming Systems Network.* Under ARFSN, crop rotations that can give maximum yield, income, and employment are identified. A research program for increasing the income of rice farmers and for raising the production of oilseeds and pulses in rice-farming areas was drawn by the Indian Council of Agricultural Research (ICAR) jointly with IRRI, the International Maize and Wheat Research Center in Mexico, the International Crops Research Institute for the Semi-Arid Tropics in Hyderabad, and the International Potato Center in Peru. The best materials from all these centers are being tested for developing more productive cropping sequences.
- *Shuttle breeding.* IRRI is using the powerful tool of shuttle breeding in collaborative programs for selecting material with a broad spectrum of adaptation to different soil stresses, climatic conditions, pests, and diseases.
- *Prosperity Through Rice.* With financial support from the Asian Development Bank, IRRI and the University of the Philippines have started a demonstration project on the theme Prosperity Through Rice. The project has three major components:
  - — producing maximum yield at minimum cost,
  - — increasing yield and income through multiple cropping and mixed farming, and
  - — preparing value added products from straw, bran, and husk.

IRRI's approach, in summary, is to provide multiple choices in technology so that the ones most relevant to needs and socioeconomic circumstances can be utilized by cooperating national research systems.

Our gratitude goes to the Governments of India and Orissa for hosting this conference. We are grateful to Dr. O.P. Gautam, director general, ICAR; Dr. M.V. Rao, deputy director general, ICAR; Dr. H.K. Pande, director, CRRI; Dr. B. Mishra, vice-chancellor, OUAT; and all their colleagues and staff members for the trouble they have taken to make such excellent arrangements for the conference. Above all, we are grateful to the rice scientists who traveled long distances to share their knowledge with fellow scientists.

M.S. Swaminathan
Director General

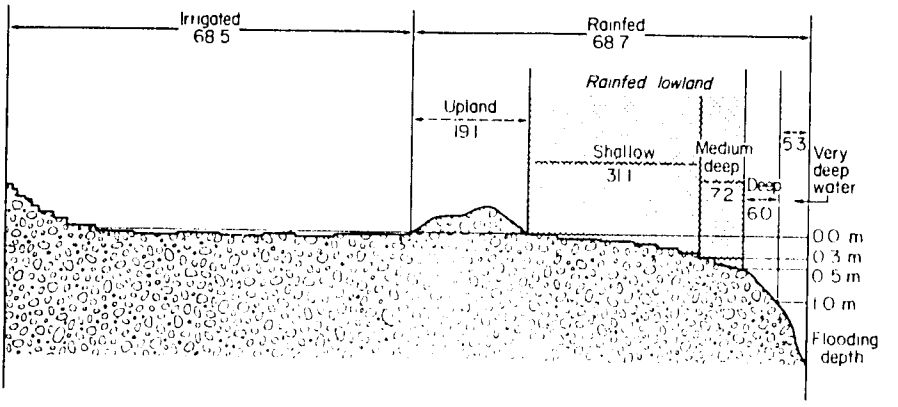
RAINFED LOWLAND RICE ECOSYSTEMS: CHARACTERIZATION AND DISTRIBUTION

D.P. Garrity, L.R. Oldeman, R.A. Morris, International Rice Research Institute, P.O. Box 933, Manila, Philippines; and D. Lenka, Orissa University of Agricultural Technology, India

This paper reviews recent efforts to define and classify the major ecosystems within the rainfed lowlands for practical use in rice research and development. The recent international terminology for rice environments includes five major categories of rainfed lowland. Subsequent work has delineated the areas in each category by developing a database of the general soil and climatic conditions for all shallow rainfed rice-producing locations in Asia. Fifty-four percent of rainfed lowland rice areas may be drought-prone or highly drought-prone. More than 50% of the shallow rainfed lowland rice in South Asia and 75% in Southeast Asia is grown on soils with potentially major fertility constraints, severe P fixation being the most widespread. The test of a model of temperature and radiation effects on rice yields in eastern India supported the contention that high minimum temperatures during the monsoon seriously limit the yield potential of wet season rice unless it is harvested late in the year. A classification that integrated the factors of growing season length, favorability of water balance, and soil fertility constraints revealed that the most common rainfed lowland rice environment has favorable water balance and fertile soils. Applications of improved environmental characterization in targeting breeding and testing programs, in extrapolating work on optimum crop establishment methods, and in developing double cropping in rainfed areas are discussed. Comparative environmental analysis among ecologically homologous areas may also assist in the efficient development of new ricelands in Africa and Latin America.

Rainfed lowland rice may be considered as that part of the global rice-growing continuum in which the crop is not irrigated but the soil is flooded for at least a portion of the crop cycle to a maximum sustained water depth less than 50 cm (8). This broad definition distinguishes a major class of riceland estimated to cover about 38 million ha, or 28% of the rice area of the world (Fig. 1). India leads all other countries by a wide margin in the area of rainfed lowland rice, with 15 million ha. The rice area of many South and Southeast Asian countries is dominated by rainfed lowlands (Table 1). Future increases in rice production must come largely from such areas in most of those countries.

The term rainfed lowland does not encompass a homogeneous class of riceland. It includes an immense array of unique physical environments.



1. World rice area by water regime. Width is proportional to the extent of each class (values are in million ha). Data from Huke (6) and Herdt and Palacpac (5).

Table 1. Rainfed lowland rice (RLR) area and its relative importance in the countries of South and Southeast Asia.[a]

Country	Area (thousand ha) Shallow rainfed lowland (0-30 cm)	Medium deep water (30-50 cm)	Total rainfed lowland	Total rice area (thousand ha)	Rainfed lowland (%)
		RLR dominant			
Bhutan	121	22	143	189	76
Thailand	5,128	551	5,679	8,677	65
Nepal	678	127	805	1,262	64
Bangladesh	4,293	1,423	5,716	10,012	57
Burma	2,291	641	2,932	5,317	55
		RLR important			
Eastern India[b]	10,597	2,182	12,779	26,763	48
Cambodia	713	94	807	2,031	40
Laos	277	—	277	695	40
Philippines	1,307	208	1,415	3,515	40
Vietnam	1,549	537	2,086	5,573	37
Sri Lanka	210	12	222	760	29
		RLR minor			
Malaysia	147	11	153	735	21
Indonesia	1,084	294	1,378	8,204	11

[a]Adapted from Huke (6). Rice area in Huke's category Intermediate was allocated as 55% medium deep water and 45% deep water (excluded from rainfed lowland).
[b]Includes the states of Assam, West Bengal, Bihar, Orissa, Madhya Pradesh, and Uttar Pradesh.

These diverse circumstances are so complex that we are only beginning to understand them and their significance to the development of new rice technology. To approach the limits of efficiency, greater precision is needed in refining and quantifying rainfed ecosystems. At least several major subdivisions are essential for practical purposes such as the targeting of breeding objectives. Much more detailed classification is required for other purposes, as

in prediction of the rice-based cropping pattern potential at a site. This paper reviews recent efforts to define and classify the major ecosystems within rainfed lowland rice areas in ways that may be of practical value to researchers and rice development workers concerned with the environmental fit of both new and old technologies. The role of classification in solving major problems in the areas of varietal improvement, optimum cultural practices, and the development of more intensive rice-based cropping patterns is discussed.

TERMINOLOGY

Many breeders and agronomists working on rainfed rice have subdivided rainfed environments according to their observations, local circumstances, and purposes. A major review of these systems throughout the world was recently undertaken by an international committee (8). Twenty-four systems of terminology were explored and correlated, and the committee proposed a general terminology for rice environments for international usage (8). Eighteen distinct categories of riceland were recognized.

Rainfed lowland rice was subdivided into five broad categories from the point of view of varietal improvement and crop management (Table 2). The target environments were divided according to the prevalence of the two major hydrological stresses: inadequate or excess moisture.

- Rainfed shallow, favorable environments are areas in which drought or submergence is not a serious constraint to the use of varieties and management practices that are essentially similar to those in fully irrigated systems.

Table 2. Terminology for rice growing environments (8).

1. *Irrigated.*
   a. Irrigated, with favorable temperature
   b. Irrigated, low temperature, tropical zone
   c. Irrigated, low temperature, temperate zone
2. *Rainfed lowland*
   a. Rainfed shallow, favorable
   b. Rainfed shallow, drought-prone
   c. Rainfed shallow, drought- and submergence-prone
   d. Rainfed shallow, submergence-prone
   e. Rainfed medium-deep, waterlogged
3. *Deep water*
   a. Deep water (50-100 cm water depth)
   b. Very deep water ([illegible]-100 cm water depth)
4. *Upland*
   a. Favorable upland with long growing season (LF)
   b. Unfavorable upland with long growing season (LU)
   c. Favorable upland with short growing season (SF)
   d. Unfavorable upland with short growing season (SU)
5. *Tidal wetlands*
   a. Tidal wetlands with perennially fresh water
   b. Tidal wetlands with seasonally or perennially saline water
   c. Tidal wetlands with acid sulfate soils
   d. Tidal wetlands with peat soils

- Rainfed shallow, drought-prone environments may experience frequent and severe water deficit at any growth stage. The rainy period may be short (90-110 d) or may continue for longer periods, but with highly uncertain distribution. The former situation is common in central and eastern India, the latter in Bangladesh and northeast Thailand.
- Rainfed shallow, submergence-prone areas frequently experience short-term flooding that may damage or destroy the crop when specifically adapted varieties and management practices are not used. Otherwise the water regime is generally favorable in these areas.
- Rainfed shallow, drought- and submergence-prone ricelands may experience both water deficit and short-term flooding on a frequent basis.
- Rainfed medium-deep, waterlogged ricelands accumulate water at depths of 25-50 cm for a substantial portion of the growing season. One of the major constraints of these conditions is the growth depression or toxicity caused by stagnant water remaining in the field for months during the crop season. Short-term crop submergence may also occur.

Khush (9) discussed the attributes of current varieties and the general directions in breeding improved materials for rainfed lowland conditions. Ricelands that experience sustained water depths greater than 50 cm are considered deep water lands and are therefore not included. This gives rainfed lowland a more restricted meaning than has frequently been imputed.

Since many local terminologies for the types of rainfed lowland are in use in different countries, a correlation of the prevalent terms is desirable. In eastern India, rainfed rice environments are designated highlands, medium lands, and lowlands, thus emphasizing the strong influence of landscape position. This terminology was related to the IRRI terminology and to varietal maturity and planting practices in Orissa, India (Table 3). There is a broad correspondence between the two terminologies.

CLASSIFICATION AND AREA ESTIMATION

The immediate problem upon establishment of a proposed terminology for rainfed lowland areas was the need for better data on the relative importance and spatial distribution of the lands in the several classes of rainfed lowland. Further work at IRRI to delineate and quantify these categories has revealed the relevant diversity within each category. A database was constructed on the Asian region to define the climatology and soils in the production areas of rainfed lowland rice. The regional maps of Huke (6) gave information on the geographical location of the ricelands. The analysis included the 30.3 million ha of shallow rainfed lowland rice. Medium-deep ricelands (about 12% of Asian rainfed lowland rice) were not included, since the maps did not separate these areas from deep water ricelands.

The determinants of the physical environment were

- five-month growing season rainfall,
- number of months with rainfall exceeding potential evaporation by 20%,
- soil textural class,

Table 3. Land categories and rice culture in Orissa, India.

Land category	Rice area (%)	Duration (d)	Sowing		Ripening	Correlation and remarks
			Date	Method		
High land (Beali)	15	<105	15-30 Jun	broadcast line sown drilled	15 Sep	rainfed shallow drought-prone; drought stress occurs for part or most of the season
Medium high (Laghu-Sarad)	20	105-120	10-25 Jun	broadcast line sown transplanted	10 Oct	rainfed shallow favorable, water control adequate; varieties developed for irrigated situations are suitable
Medium (Sarad)	27	120-135	8-20 Jun	broadcast transplanted	25 Oct	rainfed shallow drought- and submergence-prone
Low medium	23	135-150	4-14 Jun	broadcast	20 Nov	rainfed shallow submergence-prone; periods of heavy rainfall cause complete submergence of the crop, for 10-25 d
Low (Gahirapata)	12	150-165	Before 10 Jun	broadcast	30 Nov	rainfed medium-deep waterlogged lowlying, drainage problems, water stagnation for 2-3 mo
Very low (Fata)	3	>165	25 May-5 Jun	broadcast	20 Dec	deep water

- slope class, and
- soil mapping unit (from which physical and chemical constraints were interpreted).

Regional maps of these factors were correlated with regional rice distribution maps to obtain estimates of the shallow rainfed rice areas in different environments.

Drought

Drought stress is a difficult parameter to quantify. Estimation of the "drought-proneness" of a site was attempted by interpreting the relative favorability of the water balance. The water balance is influenced by the water retention potential and the rainfall regime at a site. This was modeled as the interaction of the edaphic features (slope and soil texture) with climatic features (rainfall and growing season length). Initially, the cumulative influence of the respective parameters on the overall water balance at a series of sites was examined. Quantifiable relationships among the determinants were estimated. Relative weights were assigned to the levels of the four determinants. Summing the weights gave a value for the relative favorability of the water balance (Table 4). As the inherent physical limitation increases, the value of the water balance decreases.

For example, a site classified as having a favorable water balance is one with level slope, medium to fine soil texture, long growing season, and greater than 1,200 mm of rainfall during a 5-mo crop growth period. Areas with steeper slopes, coarser textures, shorter growing seasons, and lower 5-mo rainfall

Table 4. Numerical values used for classifying water balance based on water retention potential and rainfall regime for shallow rainfed lowland rice, South and Southeast Asia.

Water retention potential				Rainfall regime			
Slope	Value[a]	Texture	Value[a]	5-mo rainfall	Value[a]	Length of growing season	Value[a]
0-8	1.0	fine	1.0	High to very high (>1500 mm)	1.0	long (5-12 mo)	1.0
		medium	0.6			medium (4 mo)	0.6
		coarse	0.3			short (0-3 mo)	0.3
8-30	0.6	fine	1.0	Medium (1200-1500 mm)	0.8	long	0.8
		medium	0.5			medium	0.5
		coarse	0.2			short	0.2
>30	0.3	fine	1.0	Low (1000-1200)	0.5	long	0.6
		medium	0.4			medium	0.4
		coarse	0.1			short	0.2
				Very low (<1000 mm)	0.2	medium	0.2
						short	0.1

[a]Water balance class	Code	Cumulative value (sum of four determinants)
Favorable	4	3.6-4.0
Intermediate	3	3.1-3.5
Drought-prone	2	2.4-3.0
Highly drought-prone	1	<2.3

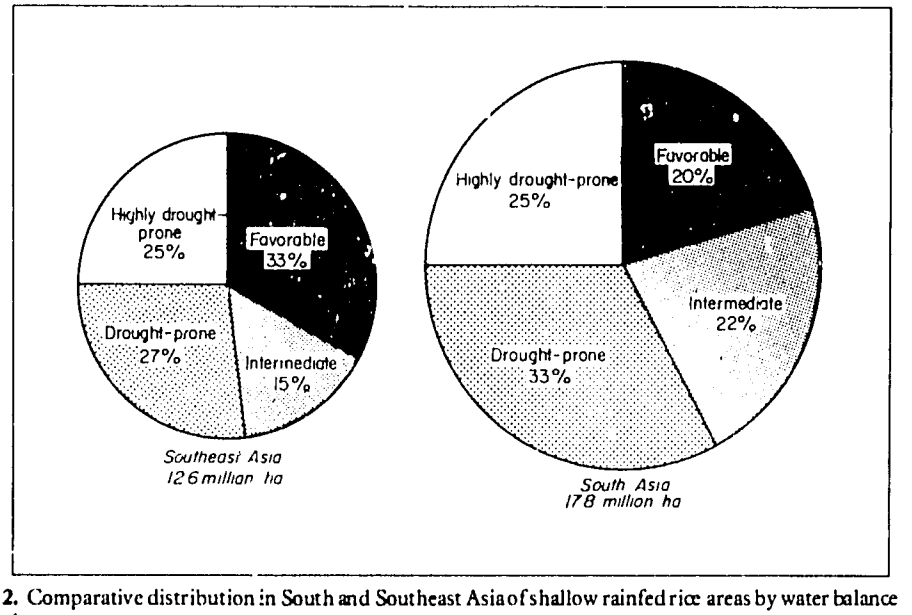
totals were classed as intermediate, drought-prone, or highly drought-prone as dictated by lower cumulative values as the constraints intensified (Table 4).

Twenty-five percent of the rainfed lowland rice areas in South and Southeast Asia were classified as favorable, 21% intermediate, 32% drought-prone, and 22% highly drought-prone. The distribution by region is given in Figure 2. The landscape positions of ricelands within a site create variability in the favorability of the water balance (16). This factor was addressed at a crude level of precision by the slope class.

Submergence

The propensity for submergence or flash flooding is a function of water accumulation in excess of the drainage capacity. Water may accumulate as a result of heavy rainfall in a local area — climatic submergence — or overflow of river water transported from a different area — fluvial submergence. Climatic submergence may be predicted on the basis of rainfall and topographic data. Fluvial submergence depends on river flood level and topography. Reliable estimation of the threat of submergence requires development and testing of procedures to predict how these factors interact and can be mapped at the drainage basin level. The timing, depth, and duration of submergence are important distinguishing factors.

Bruce and Morris (2) developed, for a major river valley in the Philippines, a land classification that permits a limited but objective evaluation of the correspondence between terrain units and flooding propensity and depth. No other work that addresses the specific problem of mapping the submergence threat in shallow rainfed ricelands is known to the authors.



2. Comparative distribution in South and Southeast Asia of shallow rainfed rice areas by water balance class.

In the recent survey of Asian rainfed lowland breeding programs (10), responding scientists estimated the percentage of submergence-prone ricelands to be about 12% of Asian rainfed lowland rice; 8% was considered drought- and submergence-prone.

Growing season length

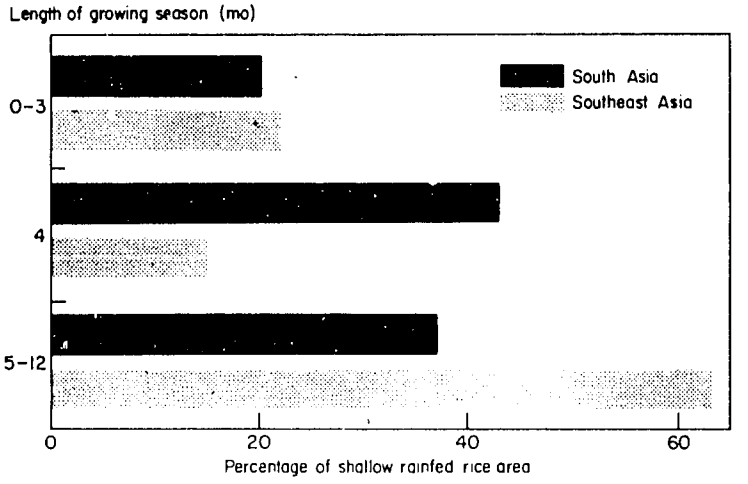
One of the most serious and universally recognized discriminators of environmental conditions among rainfed rice sites is the length of time available for crop growth. Rainfall classifications have been attempted using various methodologies to gain insight into the critical differences among sites. Results differ depending on the criteria used and the data available (15).

A technical classification by which mapping units were based on the number of wet months (>200 mm precipitation) and dry months (<100 mm precipitation) was developed for Indonesia (18) and was extended to other countries in Asia (7,11). Huke (6) used those criteria in developing regional maps for South and Southeast Asia. The criteria have proven useful for broadly differentiating areas as to the number of rice and upland crops that may be grown in sequence.

One specific need in the case of rainfed lowland rice is to delineate environments better in terms of the growing season constraint on varietal maturity. Such an analysis requires specification of the hydrologic growing year for the crop. This is determined not only by rainfall distribution but also by soil properties governing infiltration and by terrain or surface drainage features.

While recognizing the limitations of a strictly climatological approach to defining growing season length, a classification based on available climatic records was developed. The relationship between monthly rainfall (R) and potential evaporation (PE) was calculated and mapped for South and Southeast Asia. Rice growing season length was defined as the number of months in which R exceeded PE by 20%. This parameter was developed with specific reference to the rice crop and is often considerably less than the total length of the entire rainy period, since the less humid months are not included.

Growing season lengths varied widely among Asian rainfed ricelands (Fig. 3). The proportion of rainfed areas with a potential growing season constraint (4 or fewer months) was observed to be much higher in South Asia than in Southeast Asia. The three growing season length classes (0-3 mo, 4 mo, and 5 mo or longer) were selected to correspond to the broad varietal maturity requirements for these respective situations (very early, early, and medium/late maturity classes). Areas with a growing season of 0-3 mo may be expected to require varieties of less than 105 d duration. Areas with a growing season of 5 mo or more may have no significant environmental constraint on the maturity limits of the rice variety grown. These relationships are most relevant to drought-prone rainfed lowland rice areas; they may not be relevant in discriminating the situation where surface water accumulates due to a high water table, e.g., medium deep water areas.



3. Comparison of the proportion of shallow rainfed lowland rice grown under three growing season lengths, South and Southeast Asia.

Soil fertility constraints

A portion of Asian rainfed lowland rice does not encounter serious soil fertility constraints other than a moderate requirement for N and, less frequently, P and K fertilizers. However, other major areas experience a range of serious chemical imbalances that may seriously affect productivity and influence varietal adaptation. The main soil problems are salinity, alkalinity, Fe toxicity, P deficiency, Zn deficiency, and organic and acid sulfate conditions. The nature of these problem soils and their geographical locations are discussed by Ponnamperuma (19).

Correlation of the rainfed lowland rice dot map of Huke (6) with the FAO-UNESCO regional soils maps of South and Southeast Asia permitted the derivation of estimates of shallow rainfed lowland rice found on the respective soils. The Fertility Capability Classification (FCC) system was used to interpret the fertility constraints associated with the FAO soil mapping units (23). The respective constraints were designated with a series of modifiers indicating a common fertility problem. The rice areas on all soil mapping units that had properties conforming to each constraint were totaled by country. The analysis indicated that slightly less than one-half of the shallow rainfed lowland rice in South Asia is grown on soils expected to be without major soil constraints (Table 5).

For Southeast Asia, one-third of rainfed lowland rice is grown on soils that have no major constraints. Soils with low cation exchange capacity ("e" modifier) are very common in both regions, necessitating exacting N management. About 4.7 million ha of shallow rainfed lowland are found on such soils in Thailand. These soils exhibit Fe toxicity if the adjacent uplands have Fe-rich soils. In India, 4.7 million ha of shallow rainfed lowland are found on soils with a low cation exchange capacity.

Table 5. Comparative distribution of shallow rainfed rice areas by type of soil fertility constraints for countries of South and Southeast Asia (Garrity and Agustin, unpubl. data).

Country	Area classified (thousand ha)	Area (thousand ha) in each type of constraint[a]								
		f	e	ie	b	s	c	o	n	l
		Fertile, no major constraints	Low cation exchange capacity	High P fixation, low CEC[b]	Alkaline, potentially Zn deficient	Saline	Acid sulfate	Organic	Sodic	Shallow soils
				South Asia						
India	12,686	6,165	4,047	658	516	625	43	—	—	601
Bangladesh	4,293	2,873	179	5	758	235	65	178	—	—
Nepal	678	283	224	101	—	—	—	—	—	70
Sri Lanka	210	48	78	65	12	—	—	—	7	—
Bhutan	121	—	39	82	—	—	—	—	—	—
Total	17,988	9,369	4,567	911	1,286	891	108	178	7	671
%	100	52	25	5	7	5	1	1	0	4
				Southeast Asia						
Thailand	5,128	281	786	3,885	—	101	39	—	—	36
Burma	2,291	1,602	403	124	—	162	—	—	—	—
Philippines	1,207	848	296	63	—	—	—	—	—	—
Vietnam	1,549	220	174	479	—	181	400	44	—	51
Indonesia	1,084	522	214	225	19	—	—	57	—	47
Kampuchea	713	417	5	285	—	—	6	—	—	—
Laos	277	15	21	241	—	—	—	—	—	—
Malaysia	147	3	16	70	—	9	6	37	—	6
Total	12,396	3,908	1,915	5,372	19	453	451	138	—	140
%	100	32	16	43	0	4	3	1	—	1
All	30,384	13,277	6,482	6,283	1,305	1,298	605	316	7	811
%	100	44	21	21	4	4	2	1	0	3

[a]Classification was done by correlating the Fertility Capability Classification System (FCC) (22) with the soil mapping units of the FAO-UNESCO soil maps for South and Southeast Asia and summing the areas for all sites where shallow rainfed lowland rice is produced according to the maps of *Rice area by culture types* (6). [b]Potentially very acid and P deficient. CEC = cation exchange capacity.

About 1.3 million ha of Asian shallow rainfed lowland rice soils are alkaline, where Zn deficiency is common (Table 5). About 1.3 million ha (3%) are saline soils. The area of shallow rainfed lowland rice on acid sulfate soils is relatively small except in southern Vietnam. Most rice on acid sulfate soils in Thailand is in medium-deep or deep water hydrological regimes rather than shallow rainfed. Rainfed lowland soils with high organic matter or peat conditions occupy a small proportion (about 1%). Among the soil constraints, the importance of the P-fixing soils suggests that P-deficiency tolerance is a character that should be given greater attention in rainfed lowland rice breeding efforts.

Temperature and radiation effects

Temperature is one of the dominant climatic factors that affect the growth and yield of rice. The duration of the vegetative phase of rice is determined primarily by temperature and daylength. After flowering, temperature largely determines the length of the ripening period (27). Rice is most sensitive to high temperature at flowering. Daytime temperatures of more than 35 °C may drastically decrease spikelet fertility.

Yield is also correlated with solar radiation received by the crop canopy. High levels of radiation and relatively low night temperatures during the postflowering stage of the rice crop are associated with high yields.

Rainfed lowland rice yields in eastern India are low and have not increased significantly in recent years (1). Researchers attribute the low yields partially to low solar radiation (250-300 cal/cm^2 per day) during the growing season, coupled with high temperatures at tillering and floral initiation (22). These conditions result in impaired dry matter production, high tiller mortality, high spikelet sterility, and reduced harvest index. The extent to which radiation and temperature interact to dictate low yields was tested using a radiation/temperature yield model developed by Seshu and Cady (24). They constructed the model with data from the International Rice Testing Program (IRTP) network of irrigated rice trials. Minimum temperature (MINT) and solar radiation (RAD) for the period from flowering to maturity were related to yield (Y) in the following manner:

$$Y = 30.2 + 0.00408\,(RAD) - 2.10\,(MINT) + 0.0375\,(MINT)^2$$

The model was used to estimate yield potential for different assumed harvest dates in Uttar Pradesh, Madhya Pradesh, Bihar, Assam, West Bengal, Orissa, Andhra Pradesh, and Madras. Climatic data were assembled from Mani (12) and Mani and Rangarajam (13). The mean total radiation and minimum temperatures for a 30-d period prior to maturity were inserted in the prediction equation to estimate the combined effects of temperature and solar radiation on rice yield.

Assuming a postflowering period occurring in July or August, the mean yield for the 27 locations studied was estimated to be 3.1 t/ha, with most locations predicted to have yields of 3 t/ha or less. With the postflowering period in September, the mean yield prediction was 3.3 t/ha. The situation

when rice is harvested in late October is of particular interest. Mean yield was predicted at 4.5 t/ha. At 9 of the 27 locations, yields were predicted to exceed 5 t/ha.

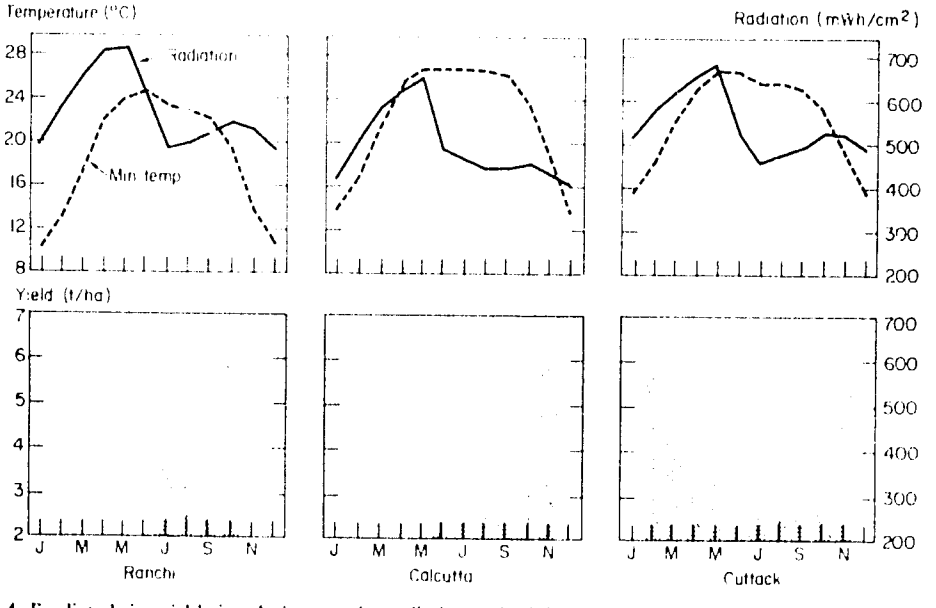
The effects of radiation and minimum temperature are clear (Fig. 4). While the months of July and August are characterized by high night temperatures and relatively low radiation (monsoon season), night temperatures drop in September and October with a slight increase in radiation.

The lowest predicted yields were found in Calcutta (West Bengal), Vishakhapatnam (Andhra Pradesh), Berhampore (West Bengal), Rajahmundi (Andhra Pradesh), and Cuttack (Orissa). These sites are all located where minimum temperatures do not drop during the July-October period and radiation is relatively low. Predicted yields respond dramatically as minimum temperatures decline at later harvest dates even though solar radiation remains low.

Further study and mapping of these relationships may aid in better defining the yield potential between locations and may enable the setting of realistic targets for rainfed lowland rice yield gains. Work on these aspects is continuing (19).

Climatic/edaphic environments

With the climatic and edaphic data assembled for each of the 6,300 rainfed lowland rice sites (dots), the database contained information to enable a tentative integrative environmental classification. The objective was to delineate broadly the major rainfed lowland rice ecosystems and determine their spatial distribution. Sites were sorted and described on the basis of the



4. Predicted rice yields in relation to solar radiation and minimum temperature at 3 sites in India.

growing season length, favorability of the water balance during the growing season (drought proneness), and the presence of soil fertility constraints.

The description of a number of the more important Asian rainfed lowland rice production areas and of certain key research sites is given in Table 6. The submergence threat could not be included in the system at present since a geographical database concerning its occurrence has not yet been developed. Submergence would be an additional modifier of the environmental description in many of the areas shown.

Areas typifying the long growing season-favorable water balance-fertile soils class of environment are observed frequently in the Philippines, Indonesia, southern Burma, Bangladesh, Assam, and Kerala. This particular class contains the largest area of shallow rainfed lowland rice in Asia (Fig. 5). It has the most favorable combination of climatic and soil conditions of all rainfed lowland ecosystems. These areas would apparently have promising production potential. The second largest ecosystem (long growing season-favorable water balance-adverse soils) is encountered in southern Thailand, the Mekong Delta of Vietnam, and southwestern Sri Lanka. It is climatologically favorable, but soil constraints may be a severe limitation. The third largest ecosystem (medium-drought-prone-adverse) is characterized by major climatic and soil constraints. Examples of this environment are Ranchi (Bihar) and Dhankanal (Orissa) in India.

This tentative breakdown of the shallow rainfed ecosystems may yield insight into the relative importance of the major environments and some broad understanding of the homologous groups of rice-producing regions. However, more work is needed to test the utility and accuracy of the groupings.

APPLICATIONS

Environment and varietal adaptation

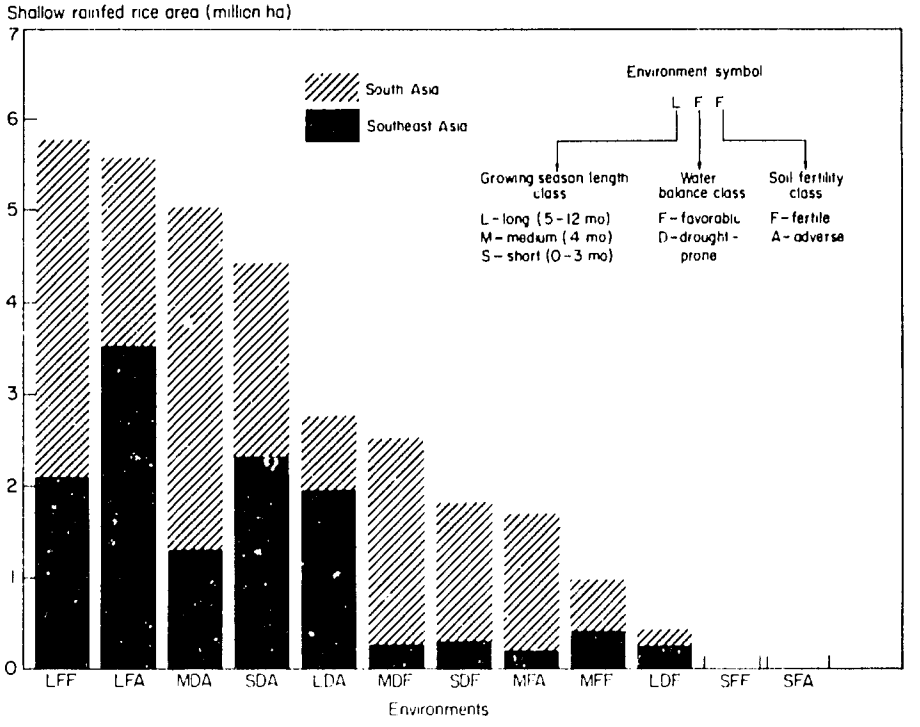
One of the major purposes of broad agroecological zoning of rainfed ricelands is to assist in the definition of breeding priorities and objectives. In line with this is the need to target the international flow of genetic materials through the IRTP as efficiently as possible. Knowledge of the type and extent of ecologically homologous conditions among countries improves the effectiveness of germplasm trading. Selection of optimum test sites and interpretation of multisite trials may also be enhanced by the appropriate characterization of the test sites and knowledge of the respective environments they represent.

One specific issue that may illustrate the utility of this information is the rationale for using photoperiod-sensitive varieties under shallow rainfed lowland conditions. There are several million ha of rainfed lowland rice where photoperiod-insensitive varieties have now been adopted but where photoperiod-sensitive varieties were formerly grown. There are also millions of ha of shallow rainfed lowland rice where photoperiod-insensitive varieties have been and are still widely grown. However, photoperiod sensitivity is still predominant in most shallow rainfed lowland rice areas. A thorough regional study of the environment associated with these three situations is needed to

Table 6. Classification of shallow rainfed lowland (RFL) rice physical environment at various locations in South and Southeast Asia (Garrity and Agustin, unpubl. data).

Country	Location	Region or site[a]	Shallow RFL area[b]	Growing season length	5-mo rainfall mm	Soils: Texture	Soils: Slope %	Soils: FAO soil map unit	Soils: FCC modifiers	Water balance class[c]	Shallow rainfed lowland rice environment[d]: Code	Shallow rainfed lowland rice environment[d]: Description
						Southeast Asia						
Burma	Irrawaddy Div	PR	710	long	>1,500	medium/fine	0-8	Ge	f	4-favorable	L4f	long-favorable-fertile
Indonesia	Ujung Pandang	PR	95	long	>1,500	medium/fine	0-8	Je	f	4-favorable	L4f	long-favorable-fertile
Kampuchea	Tonle Sap Flood Plain I	PR	250	short	< 1,000	fine	0-8	Ge	f	1-highly drought prone	S1f	short-highly drought prone-fertile
Philippines	Los Baños, Laguna	PR & RS	86	long	1,200-1,500	medium/fine	0-8	To	f	4-favorable	L4f	long-favorable-fertile
	Solana, Cagayan	RS	--	medium	1,000-1,200	medium/fine	0-8	Bg	f	2-drought-prone	L2f	medium-drought prone-fertile
	Iloilo	PR & RS	254	long	1,200-1,500	fine	0-8	Vp	f	4-favorable	L4f	long-favorable-fertile
Thailand	Khonkaen, NE	PR & RS	266	short	1,000-1,200	medium	0-8	Ag	e	1-highly drought prone	S1e	short-highly drought prone adverse
	Surat Thani, S	PR	305	long	>1,500	medium	0-8	Ag	e	4-favorable	L4e	long-favorable-adverse
	Chiangmai, N	PR	216	long	1,000-1,200	medium	0-8	Ag	e	2-drought prone	L2e	long-drought prone-adverse
Southern Vietnam	Mekong Delta west of Ho Chi Minh	PR	745	long	>1,500	fine	0-8	Jt	c	4-favorable	L4c	long-favorable-adverse
						South Asia						
Bangladesh	Rajshahi	PR	286	long	1,200-1,500	medium	0-8	Ge	f	3-intermediate	L3f	long-intermediate-fertile
	Barisal	PR	287	long	>1,500	fine	0-8	Gc	f	4-favorable	L4f	long-favorable-fertile
India	Bilaspur, M. P.	PR	135	medium	1,200-1,500	medium	0-8	Ge	f	2-drought prone	M2f	medium-drought prone-fertile
	Cuttack, Orissa	PR	243	medium	1,200-1,500	medium/fine	0-8	Je	f	3-intermediate	M3f	medium-intermediate-fertile
	Dhenkanal, Orissa	PR	200	medium	1,000-1,200	coarse	0-8	Lf	ie	1-highly drought prone	M1ie	medium-highly drought prone-adverse
	Midnapur, West Bengal	PR	451	medium	1,200-1,500	medium	0-8	Lf	e	3-intermediate	M3e	medium-intermediate-adverse
	Ranchi, Bihar	PR	228	medium	1,200-1,500	medium	8-30	Nd	e	2-drought-prone	M2e	medium-drought prone-adverse
	S. Paraganas, Bihar	PR	215	medium	1,200-1,500	medium	8-30	Ne	f	2-drought prone	M2f	medium-drought prone-fertile
	Faizabad, U. P.	PR	60	short	< 1,000	medium	0-8	Be	f	1-highly drought prone	S1f	short-highly drought prone-fertile
	Basti, U. P.	PR	142	medium	1,000-1,200	medium	0-8	Be	f	2-drought prone	M2f	medium-drought prone-fertile
	Kamrup, U. P.	PR	204	long	>1,500	medium	0-8	Be	f	4-favorable	L4f	long-favorable fertile
	Palghat, Kerala	PR	88	long	>1,500	medium	0-8	Ge	f	4-favorable	L4f	long-favorable fertile
Nepal	Central Tarai	PR	158	long	>1,500	medium	0-8	Je	f	4-favorable	L4f	long-favorable-fertile
Sri Lanka	Colombo	PR	30	long	1,200-1,500	medium	0-8	Ag	e	3-intermediate	L3e	long-intermediate-adverse
	Kurunegala	PR	39	long	1,000-1,200	medium	0-8	Lg/Lg	e	2-drought prone	L2e	long-drought prone-adverse

[a]PR = production region, RS = research site. [b]The environment classified represents the majority of the total shallow rainfed rice area of the province or district. [c]No. of months with rainfall exceeding potential evaporation by 20%. [d]The three descriptors are length of growing season, relative favorability of water balance during the growing season, and presence or absence of potential soil fertility constraints (fertile = no major constraints; adverse = one or more FCC modifiers for potential constraints).

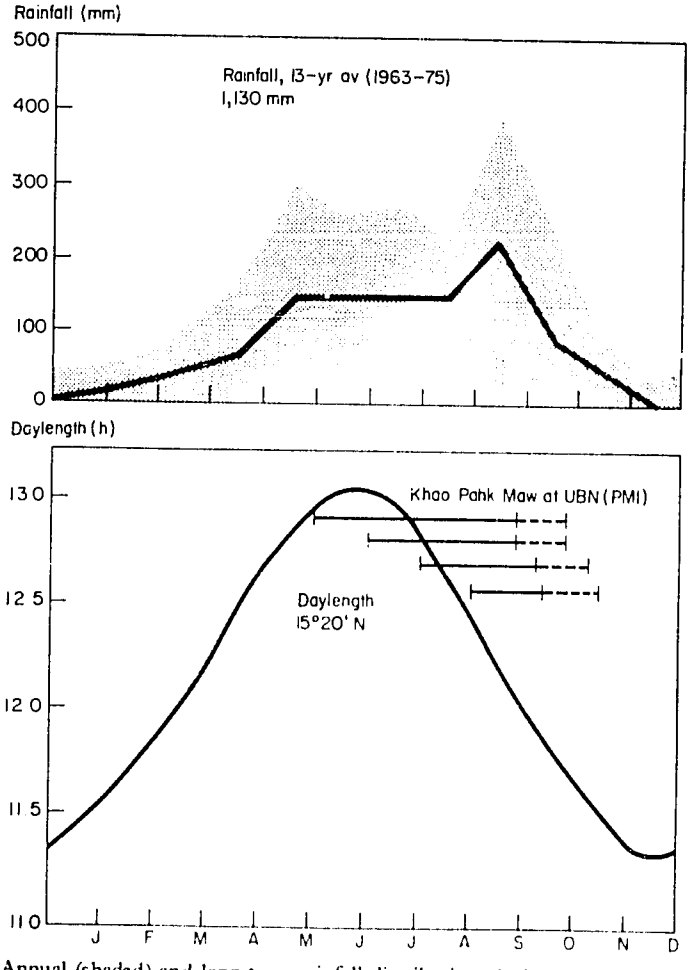


5. Distribution of major shallow rainfed rice environments in South and Southeast Asia. Favorable water balance includes intermediate; drought-prone includes highly drought-prone.

better define the respective areas of adaptation of sensitive and insensitive varieties.

Photoperiod sensitivity is universal in deep water ricelands and nearly so in medium-deep areas. There appear to be clear adaptive advantages explaining continued farmer preference for sensitive varieties in certain shallow areas.

Over 3 million ha of shallow rainfed lowland rice are planted to photoperiod-sensitive rices on the Khorat Plateau in northeastern Thailand. The bimodal rainy period is reasonably long, but mean rainfall is low and highly uncertain throughout the early monsoon in this drought-prone environment (Fig. 6). The predictability of planting dates is hazardous at any time, with peak rains occurring late in the season. A similar rainfall pattern is encountered in the northern Cagayan River Basin in the Philippines, where flash flooding may occur at any time during the season, but with greatest frequency during October-November. Using photoperiod-sensitive varieties, farmers can plant early or late depending on the onset of the monsoon. Seedlings do not suffer serious damage when left in the seedbed for prolonged periods, and yield is not sensitive to late transplanting (4, 21). However, yields of some insensitive late-maturing varieties are not deleteriously affected by late transplanting (26), and insensitive varieties have proven to be stable in some conditions where they were not expected to be (25). The relative adaptation of insensitive varieties may be dependent upon soils as well as rainfall pattern (17).



6. Annual (shaded) and long-term rainfall distribution, daylength variation, and flowering date of Khao Pahk Maw 148 at Pimai Rice Experiment Station in northeast Thailand. Broken lines indicate panicle initiation stage (20).

Environment and crop establishment practices

Crop establishment practices differ remarkably among rainfed lowland areas. Seeding methods are highly dependent on the rainfall pattern and the internal and surface drainage characteristics of the site. There are three major seeding methods with many variants within each: dry seeding, wet seeding, and transplanting. These systems, which have been refined through centuries of use, are briefly outlined with particular emphasis on India. Comparative environmental analyses are needed to draw a more quantitative insight into the relative merits of the alternative systems.

Dry seeding is common in all rice growing states of India and in Sri Lanka, Bangladesh, Burma, Malaysia, Thailand, Indonesia, the Philippines, and

Japan. Dry seeding methods are broadcasting on dry or wet soil, drilling, and dibbling. Large areas of India's rainfed rice crop are planted by dry broadcast of seed before the onset of the southwest monsoon (Table 7). Broadcasting has advantages in areas with a very short growing season, since time is gained in establishing the crop early. It is also advantageous in zones where deep water is expected early in the season. Early establishment improves the chances for the crop to withstand flooding successfully. Broadcasting proceeds from the fields at the lowest level of topography upward to the highlands (i.e., from very deep water to deep water to medium deep to shallow rainfed). The land is prepared after harvest of the previous rice crop or by plowing with the premonsoon rains. When land preparation is not possible before the monsoon rains arrive, broadcasting is done on moist soil.

In Orissa, Bihar, and Madhya Pradesh the broadcast rice crop, whether seeded in dry or moist fields, is tilled once again by plow in 10-20 cm standing water when plants are about 20-30 cm high. This practice (beusaning) performs the functions of weeding, thinning, and inducing tillering. In some areas it has been found as productive as transplanting.

Wet seeding of pregerminated seeds on well leveled puddled land is practiced on limited rainfed areas in India. Successful wet seeding is highly dependent on the specific characteristics of the dry to wet transition period at the onset of the monsoon, and on adequate surface drainage (16).

Transplanting is increasingly practiced in India in areas where control over water management is improving. Comparisons of broadcasting vs transplanting have given situation-specific results. In many cases there is little difference in yield between them. Broadcasting has given higher yields than transplanting when done early and with good management in Bihar, West Bengal, Orissa, and Uttar Pradesh. But since ideal conditions for broadcasting are not always possible, it is often safer to transplant as a matter of expediency.

Much work has been done in studying and comparing rice planting practices, but rarely has the work monitored the environment adequately to make a viable extrapolation of the results. Much insight can be gained by detailed comparison among sites.

Variability in the onset and termination of rainfall must be better understood. Methods to characterize these transition periods are being developed to explain differences in optimum crop establishment systems, even among sites with similar rainfall patterns (16).

Environment and rice cropping system

Most rainfed lowland areas in India, Bangladesh, Burma, Thailand, Malaysia, Indonesia, and the Philippines are potentially two-crop areas. However, it is often necessary to make adjustments in the rice variety (particularly growth duration) and in management for the potential to be realized.

The length of the hydrologic year ultimately determines the cropping period available (14). The dynamics of the rainfall regime, particularly during the transition periods of onset and recession of rains, determine the viable crop

Table 7. Rice crop seasons in India.[a]

State	Season 1			Season 2			Season 3		
	Period	Local name	Establishment method[b]	Period	Local name	Establishment method[b]	Period	Local name	Establishment method[b]
Assam	Apr-Aug	ahu/aus	T, B	Jun-Nov	sali/aman	B, T	Apr-Dec	bao/asa/aman	B, T
West Bengal	Apr-Sep	aus	B	Jun-Dec	aman	B, T	Dec-Apr	boro	T
Bihar	Jun-Sep	aus/autumn	B	Jun-Dec	aman/winter	B, T, L	—	—	—
Uttar Pradesh	Jun-Sep	early/mid-early	B, T	Jun-Nov	aman	B, T	—	—	—
Orissa	May-Sep	beali, laghu	B	Jun-Dec	sarada	B, T	Jan-May	dalwa	T
Andhra Pradesh	Jun-Oct	kar abi/tabi	B, L	Jun-Dec	sarva	B, L, D	Jan-Apr	dalwa	T
Madhya Pradesh	Jun-Oct	early	B	Jun-Dec	late	D, B, T	—	—	—
Maharastra	—	—	—	Jun-Oct	—	L, T, D	—	—	—
Tamil Nadu	May-Sep	swarnavari	B	Jul-Jan	samba/thaladi	B, T	Jan-May	—	T
Mysore	Jun-Dec	haine	B, T	Feb-May	summer	T, B	—	—	—
Kerala									
Travancore & Cochin	Apr-Jun	virupu	B, T	Sep-Feb	mundakan	T	Jan-Apr	punja	L, T
Malabar	Apr-Sep	—	B, T	Sep-Jan	—	T, B	Feb-May	—	T
South Kankan	Jun-Oct	samba	B, T	Oct-Jan	thaladi	T, B	Feb-May	navari	T

[a]In all the rice growing states, monsoon and premonsoon crops are mostly broadcast. The irrigation-dependent third crop (summer/dalwa) is transplanted. [b]B = broadcast, T = transplant, L = line sowing, D = drilling/dibbling. The order of letters indicates the priority of the cultural practice.

Table 8. Extent of lowland soils and harvested rice area in 3 developing regions.

Region	Area of lowland soils[a] (million ha)	Rice area harvested[b] (million ha)	Rainfed lowland rice area[c] (million ha)
South and Southeast Asia	121	90.3	36.7
Africa	203	4.9	1.1
Latin America	231	8.2	0.5

[a]Based on analysis of the *FAO soil maps of the world* by Sanchez and Buol (22). [b]FAO (3). [c]Huke (6) and Herdt and Palacpac (5).

choices in the pattern. A predictive synthesis is emerging from comparative studies of the physical environment and cropping pattern tests at a number of shallow rainfed lowland rice cropping systems research sites in Asia (14).

Expansion of rainfed lowland rice to new areas

Rainfed lowland rice is approaching the limits of expansion in tropical Asia, and in most countries the area is declining as irrigation facilities expand. However, Latin America and Africa present vast new frontiers for the expansion of wet rice cultivation. The areas of lowland soils on these continents are enormously greater than that of Asia (Table 7), while their current harvested rice areas are minute in comparison with that of Asia (Table 8).

In Africa, immense areas of river floodplains (fadamas), poorly drained shallow depressions on the central and southern African plateaus (dambos), and inland valley swamps (bolilands) are potentially suitable for rice cultivation. In Latin America, the Amazon River basin and the floodplains of other major rivers are being brought into rainfed cultivation.

Rainfed lowland rice is expected to expand greatly as African and Latin American countries strive to produce adequate rice to meet their exploding domestic demand. Lowland rice cultivation in Africa is generally not highly refined or productive. Some aspects of the Asian experience may be useful. The establishment of ecological homologues with Asian environments may aid in guiding the development of African lowlands in some aspects of technology choice. However, comparative environmental information of this kind has not yet been assembled.

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25

PRODUCTION CONSTRAINTS OF RAINFED LOWLAND RICE IN EASTERN INDIA

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The eastern region of India accounts for over 45% of the country's more than 36 million ha of rice but only a third of its total rice production. While rice yields have increased in the remainder of India, they have stagnated in the eastern region at about 1.5 t/ha. Socioeconomic factors that may constrain rice production in eastern India include rice prices and marketing; the farmer's resource base, including farm size, fragmentation, and irrigation potential; the profitability and riskiness of input use, specifically fertilizer; crop insurance; and the prevailing poverty in the region. For the foreseeable future, the eastern region will remain small-farm dominated, and so new technology should be biased toward low-resource farmers, making maximum use of labor and having a high cash payoff and low debt requirement.

The diversity of rice culture types classified as rainfed and the difficulty of developing precise yet easy to apply systems of classification were reviewed for this workshop by Garrity et al (15). For consistency, we adopt the terminology suggested by Khush (21): the rainfed lowland rice setting excludes irrigated, deep water, upland, and tidal wetland situations. On this basis about one quarter of the world's ricelands are rainfed, concentrated in South and Southeast Asia (Table 1). In seven Asian countries, the area of rainfed rice exceeds 1 million ha, and rainfed rice accounts for half or more of the rice area of Bangladesh, Burma, India, Vietnam, and Thailand (Table 2). Over one-third of the 32 million ha of rainfed rice in Asia is found in the four major river deltas — the Mekong in Vietnam, the Chao Phraya in Thailand, the Irrawaddy in Burma, and the Ganges-Brahmaputra in Bangladesh and eastern India.

The Ganges-Brahmaputra Delta has always been more heavily populated than the major river deltas of Southeast Asia (40). Most farms in Bangladesh and eastern India are less than 1 ha, but those of the Southeast Asian deltas typically exceed 3 ha. Indeed, these sparsely settled deltas set the stage for the first so-called "green revolution" in rice nearly a century ago (4). The opening of export markets (e.g., China, Indonesia) provided the price incentives for increased rice production through area expansion. Similarly, agriculture in the Ganges-Brahmaputra Delta provided much of the exportable agricultural surplus for India in the 19th and early 20th centuries.

Table 1. Summary of the world's rice-growing area by culture type (44).

Region	Area allocated (thousand ha)					
	Upland	Deep water	Irrigated		Rainfed	
			Wet	Dry	Shallow	Intermediate
Asia						
East[a]	0	0	34,800	[d]	1,800	0
Southeast[b]	3,700	3,750	9,000	4,900	10,800	1,300
South[c]	7,000	7,300	15,500	3,900	16,300	3,650
Africa	2,300	700	800	0	700	0
Latin America	6,100	900	1,200	0	0	0
Others	0	150	6,900	0	100	0
World	19,100	12,800	68,200	8,800	29,700	4,950

[a]China and South Korea. [b]Burma, Thailand, Vietnam, Kampuchea, Laos, Malaysia, Indonesia, Philippines. [c]India, Bangladesh, Pakistan, Sri Lanka, Nepal. [d]All rice is grown during the summer months and is shown under wet season.

Table 2. Distribution of ricelands by culture type in Southeast Asia.[a]

Country	Area allocated (thousand ha)					
	Upland	Deep water	Irrigated		Rainfed	
			Wet	Dry	Shallow	Intermediate
Bangladesh	858	1,117	170	987	4,293	2,587
Bhutan	28	—	—	—	121	40
Burma	793	173	780	115	2,291	1,165
India	5,973	2,434	11,134	2,344	12,677	4,470
Indonesia	1,134	258	3,274	1,920	1,084	534
Kampuchea	499	435	214	—	713	170
Laos	342	—	67	9	277	—
Malaysia	91	—	266	220	147	11
Nepal	40	53	261	—	678	230
Pakistan	—	—	1,710	—	—	—
Philippines	415	—	892	622	1,207	379
Sri Lanka	52	—	294	182	210	22
Thailand	961	400	866	320	5,128	1,002
Vietnam	407	420	1,326	894	1,549	997
Total	11,593	5,290	21,254	7,613	30,375	11,587

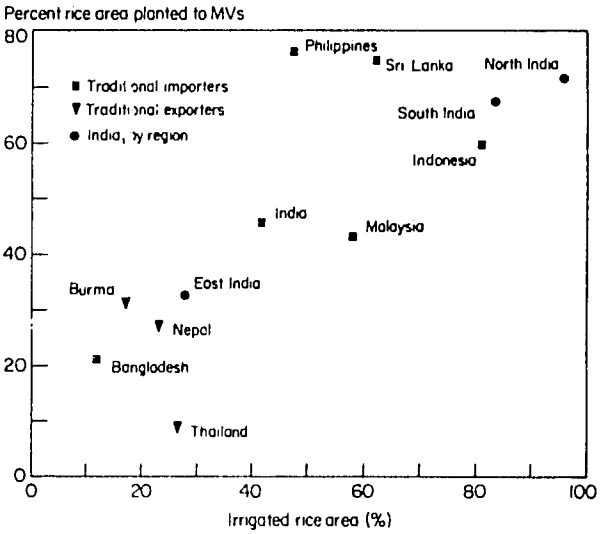
[a]Derived from Huke (19); includes areas double-cropped to rice. Figures may differ from those in Table 1 because of data source and definition.

These delta areas, which in the past were a major source of Asia's exportable surplus, are not well suited to modern rice technology. In adverse environments, where drought, flooding, and stagnant water are common and where major nutrient deficiencies and soil problems exist, new varieties have shown little if any yield gain over farmers' varieties. As a result, the adoption rates of modern varieties (MVs) have been relatively low in these environments, including eastern India (Fig. 1).

RICE PRODUCTIVITY IN EASTERN INDIA

Rice area and production by culture type

The largest continuous area of rainfed rice in the world is the Ganges-Brahmaputra river basin. This region has about 28 million ha of rice and



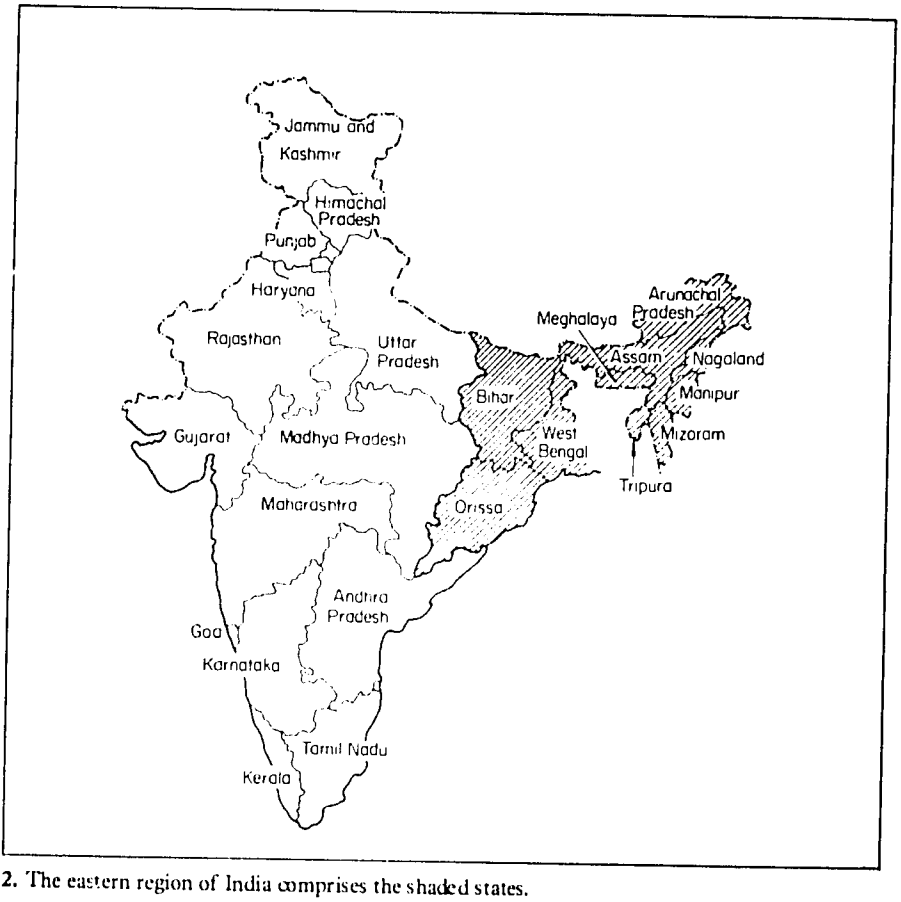
1. Percent of rice area irrigated and planted to modern varieties (MVs) in regions of India and in Southeast Asian countries, 1980.

supports a population of over 250 million. In this paper, we focus on the states of eastern India (Fig. 2) — Assam, Bihar, Orissa, West Bengal, and the northeastern states (Arunachal Pradesh, Manipur, Mighalaya, Mizoram, and Nagaland) — which account for over 45% of India's rice area but only a third of its total rice production.

Huke (19) estimated that some 18.2 million ha is sown to rice in eastern India, which includes areas double cropped to rice. The region contains a third or less of India's irrigated rice (Table 3) as well as examples of almost all rice culture types from shifting cultivation in the northeastern states to irrigated, double-cropped rice in the lowlands; from high altitudes in the northeastern states where low temperatures are a constraint, to low altitudes where high night temperatures limit yields; from the fertile tracts of Hooghly District to the lateritic soils of the Tarai region, to the saline coastal plains of Orissa and West Bengal; from the low-rainfall, drought-prone regions of western Orissa and Bihar to the irrigated lands of West Bengal, to the flood-prone river terraces and coastal plains of the Ganges, Brahmaputra, and Mahnnadi Rivers.

There are three major rice seasons in eastern India. For the purposes of this paper, the autumn (aus or premonsoon) and winter (aman or monsoon) crops are combined as the kharif crop, while the dry season crop is termed the rabi or boro crop. The bulk of India's rice production (over 90%) is produced in kharif (Table 4). The major areas of premonsoon rice are in the northwestern and southern regions.

Rice yields in general are higher in rabi than in kharif because the crop is irrigated (Table 4). Irrigation, coupled with high solar radiation, makes the adoption of modern varieties and fertilizer profitable. Average rabi rice yields in West Bengal are above the all-India average. In contrast, average kharif yields in the eastern states, where the bulk of the crop is grown, are about half that of the northern and southern rice-producing states. In short, while kharif



2. The eastern region of India comprises the shaded states.

Table 3. Summary of rice area locations, eastern India and India.[a]

Region state	Upland	Deep water	Irrigated		Rainfed	
			Wet	Dry	Shallow	Inter-mediate
			Area allocated (thousand ha)			
Eastern India	2,640	1,639	3,657	631	6,186	3,492
Assam	215	100	189	14	892	857
Bihar	531	672	1,440	72	1,696	847
Orissa	691	150	893	169	1,743	886
West Bengal	883	677	984	340	1,685	853
NE States	320	40	151	36	170	49
Northern India[b]	—	—	1,261	—	—	—
Southern India[c]	785	240	3,808	1,682	1,092	339
All India	5,973	2,434	11,134	2,344	12,677	4,470
			Distribution (%)			
Eastern India	44	67	33	27	49	78
Northern India	—	—	11	—	—	—
Southern India	13	10	34	72	9	8

[a]Derived from Huke (19); includes area double-cropped to rice. [b]Punjab, Haryana, Jammu and Kashmir. [c]Andhra Pradesh, Karnataka, Kerala, Tamil Nadu.

Table 4. Summary of rice production and yield in India for 1978-79 to 1981-82.

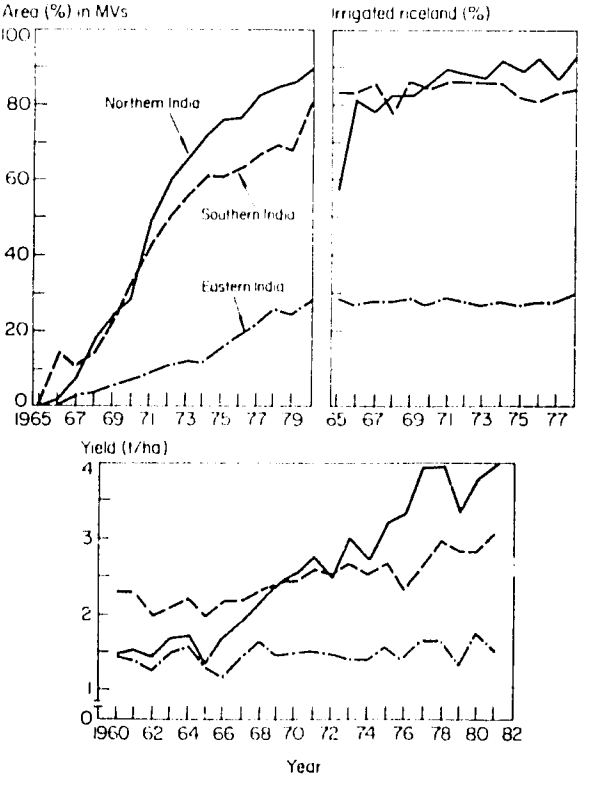
Region	Production (thousand t)			Yield (t/ha)		
	Kharif	Rabi	Total	Kharif	Rabi	Pooled
Eastern India	16,089	1,116	17,204	0.99	2.03	1.02
Assam	2,163	40	2,203	0.98	1.12	0.99
Bihar	4,697	58	4,756	0.87	1.06	0.88
Orissa[a]	3,529	196	3,721	0.86	1.32	0.88
West Bengal	5,574	796	6,370	1.19	2.64	1.28
Northern India	4,975	—	4,975	2.59	—	2.59
Southern India	13,583	2,468	16,051	1.94	2.16	1.96
All India	46,765	3,702	50,468	1.23	2.10	1.27

[a]1980-81 was excluded because of incomplete data for rabi.

rice yields have increased in the remainder of India they have stagnated in the eastern region (Fig. 3). The comparatively higher yields in the northern and southern states are associated with a higher level of adoption of modern semidwarf varieties and such complementary inputs as fertilizer and irrigation (Table 5).

Growth rates in production, area, and yield

Most estimates of the sources of change in rice production are aggregates across rice culture types and often across seasons, because disaggregated data



3. Trends in adoption of modern varieties (MVs), percent of irrigated area, and rice yields in 3 major rice-growing regions in India.

Table 5. Rice production technology of India by region.

Item	Eastern[a]	Northern[b]	Southern[c]	All India
Total production[d] (thousand)	25,698	8,333	25,325	80,362
(%)	32	10	32	100
Paddy yield (t/ha)	1	4	3	2
Rice irrigated (%)	29	95	84	42
Area in modern variety (%)	31	70	68	42
Fertilizer[d] (kg NPK/ha)	17	60	43	32

[a]Assam, Bihar, Orissa, West Bengal. [b]Punjab, Haryana, Jammu and Kashmir. [c]Andhra Pradesh, Karnataka, Kerala, Tamil Nadu. [d]Palaepac (33).

are not reported (e.g., 13, 28, 30). In general the aggregate growth rate in total rice production in eastern India has lagged behind the all-India pattern (Table 6). The northeastern states, with an annual growth rate in total production above the all-India average, registered a growth rate in excess of 3% from 1971-72 to 1981-82, due more to yield (2.1%) than to area (1.2%). However, this production growth took place in a small area (less than 0.75 million ha) with a low yield base. Thus, it had a minimal impact on total production increases over the region. In Assam the production growth rate exceeded 1% over the decade, due largely to area and partly to immigration (13); the negative growth in yield may be partly attributed to expansion into marginal rice-growing areas. The three states that dominate rice production in eastern India — Bihar, Orissa, and West Bengal — reported negligible growth rates in production, area, and yield over the decade.

The data in Table 6 are annual aggregates and provide no insight into whether there have been differential growth rates in rice production between kharif and rabi. Misra (28) concluded that there had been no significant increase in growth rate of production, area, or yield in autumn, winter, or dry season rice in Orissa.

Growth rates by district

State-level analysis masks any insight into the comparative performance of the rice sector at the district level. Desai (13) and Mukhopadhyay (30) reached similar conclusions when analyzing growth rates in rice production at the

Table 6. Growth rates of production, area, and yield of rice in eastern India, 1971-72 to 1981-82 (13).

Region, state	Growth rate[a] (%)		
	Production	Area	Yield
Eastern India	0.87^{ns}	0.12^{ns}	0.75^{ns}
Assam	1.20*	1.59*	-0.47*
Bihar	0.89^{ns}	0.64^{ns}	0.25^{ns}
Orissa	0.87^{ns}	-0.84^{ns}	1.71^{ns}
West Bengal	0.40^{ns}	0.40^{ns}	0.80^{ns}
Northeastern states	3.27*	1.15*	2.12*
All India	2.76*	0.89^{ns}	1.87*

[a]* = significant at the 5% level, ns = not significantly different from zero.

district level. Desai (13) focused on 50 districts in Assam, Bihar, Orissa, and West Bengal that produced over 50,000 t of rice each year. Of the 50, 11 districts — 4 in Assam, 1 in Bihar, and 6 in West Bengal — had more than 2% growth rates in total production from 1963-64 to 1977-78 (Table 7); 14 districts — 4 in Bihar and 10 in Orissa — had negative production growth rates.

The associated changes in yields are reported in Table 8. Thirteen districts showed a greater than 1% growth rate in yield. However, only Hooghly in West Bengal registered a growth rate of more than 2%, possibly due to its large area of irrigated boro rice. Of the 13 districts, 7 were in West Bengal, 5 in Bihar, and 1 in Assam. Twenty-four districts, nearly half of those analyzed, showed negative yield gains over the 14-yr period reviewed: 10 were in Orissa, 7 in Bihar, 5 in West Bengal, and 2 in Assam. The causes of yield stagnation in some districts merit investigation. One contributing factor may be the extent of irrigation. For example, based on Huke's data, districts exhibiting a growth rate of 1% or better had a mean of 40% of their riceland irrigated. Districts with a negative growth rate had a mean of 17% of their rice area irrigated, which was significantly less ($P<5\%$) than that in districts with a positive growth rate.

In summary, rice yields have not increased materially in half or more of the rice-growing districts of eastern India. The picture is particularly bleak in

Table 7. Districts in eastern India that experienced positive (>2%) and negative growth rates in total rice production over the period 1963-64 to 1977-78 (13).

State	Districts exhibiting	
	>2% growth rate	Negative growth rate
Assam	Goalpara Nowgong Lakhimpur + Dibrugarh Mikir Hills + N.C. Hills	—
Bihar	Sitamanhi + Muzzaffurpur + Vaishali	Purnea + Kathihar Ranchi E. Chanpuran + W. Champuran Dhanbad + Hazaribag
Orissa	—	Bolangir Dhankanal Gunjam Keonjhar Mayurbanj Phulbani Samlulpur Sundargarh Cuttack + Puri Kalahandi + Koraput
West Bengal	Nadia Murshidibad Burdwan Hooghly Malda Darjeeling	
Total	11	14

Table 8. Districts in eastern India that experienced positive (>1%) and negative growth rates in rice yield over the period 1963-64 to 1977-78 (13).

State	District exhibiting	
	>1% growth rate	Negative growth rate
Assam	Mikir Hill + N.C. Hills	Kamrup Darang
Bihar	Shahbad = Bhojpur + Rohtas Sitamarhi + Muzzaffurpur + Vaishali Gaya + Nawdah + Aurangabad Bhagalpur Palamau	Purnea + Kathihar Ranchi E. Champaran + W. Champaran Monghyr + Saharsa + Bagasarai Dhanbad + Hozaibagh Darbhanga + Madubani + Samastipur Saran + Gopalgunj + Siwan
Orissa		Gunjam Mayurbhanj Bolongir Kaluhandi + Koruput Sambalpur Cuttack + Puri Dhenkanal Keonjhar Phulbani Sundargarh
West Bengal	Nadia Murshidabad Burdwan Birbhum Malda East + West Midnapore Hooghly	Jalpaiguri Bankura W. Dinajpur Cooch-behar Darjeeling
Total	13	24

Orissa, where no district reported significant long-term gains in yield from 1963-64 to 1977-78. Many writers (9) caution that growth rate estimates are sensitive to the time period included in the analysis. In this case, the final year (1977-78) was a particularly bad year because of floods in eastern India.

There is speculation on and qualitative evidence of the causes of yield stagnation in eastern India (20, 28). However, the report of the Government of India Commission under the chairmanship of Dr. A.K. Sen (38) is possibly the first systematically integrated analysis of the problem.

ESTIMATES OF POTENTIAL PRODUCTIVITY

Yield gap

The comparative productivity of recommended varieties (and associated crop management) and farmers' husbandry practices may be assessed from the All India Coordinated Project on National Demonstrations rice trials and state average yields. A substantial gap exists between potential and actual farm yields when estimated in this manner (Table 9). Defined as a ratio, the gap between potential and actual yields ranged from 2.5 in West Bengal to 4.5 or higher in Assam, Bihar, and Orissa. The yield gap appears to be larger in the eastern region than in the southern and northern rice-growing regions.

Table 9. Average yield of rice in national demonstrations compared to state average, 1975-76 to 1979-80.

Region, state	Average yield (t/ha)		Ratio[c]
	National demonstration[a]	State[b]	
Eastern India			
Assam	4.43	0.98	4.52
Bihar	4.98	0.95	5.24
Orissa	4.97	0.92	5.40
West Bengal	3.22	1.28	2.52
Northern India			
Punjab	6.91	2.85	2.42
Southern India			
Andhra Pradesh	6.19	1.60	3.87
Kerala	4.80	1.18	4.07
Tamil Nadu	5.44	2.19	2.48

[a]All India Coordinated Rice Improvement Project on National Demonstrations, Annual Report, Indian Council of Agricultural Research, New Delhi (various issues). [b]Agricultural Situation in India, various issues. [c]Ratio of national demonstrations to state average.

Table 10. Potential (P) and district average (D) yields of rice and their ratio (R) in different districts of West Bengal in the three rice-growing seasons[a] (29).

District	Yield (t/ha)								
	Pre-kharif			Kharif			Boro		
	P	D	R	P	D	R	P	D	R
Burdwan	4.60	2.76	1.67	5.80	2.14	2.71	7.20	3.92	1.89
Hooghly	4.60	2.30	2.00	6.10	2.05	1.98	7.54	4.23	1.78
Midnapur (West)	—	—	—	3.52	1.37	2.57	5.42	2.70	2.01
Midnapur (East)	—	—	—	4.15	2.02	2.05	6.00	3.25	1.85
Birbhum	—	—	—	5.32	1.66	3.20	—	—	—
Purulia	—	—	—	2.01	1.17	1.72	—	—	—
Bankura	—	—	—	3.56	1.40	2.54	—	—	—
Howrah	—	—	—	3.10	1.75	1.77	5.25	2.60	2.02
24-Parganas (South)	—	—	—	3.10	1.80	1.72	—	—	—
24-Parganas (North)	—	—	—	3.00	1.75	1.71	5.55	3.10	1.79
Nadia	2.86	0.95	3.01	2.90	1.85	1.57	5.55	4.38	1.27
Murshidabad	1.64	0.86	1.91	3.60	2.28	1.59	6.50	4.17	1.32
Malda	2.20	0.63	3.49	3.20	1.82	1.76	5.25	2.70	1.95
West Dinajpur	2.81	0.68	4.13	5.40	1.45	3.72	5.60	3.21	1.74
Jalpaiguri	2.60	0.72	3.61	2.70	1.30	2.08	—	—	—
Coochbehar	2.20	0.62	3.55	2.85	1.90	1.50		—	—
Darjeeling	—	—	—	2.90	1.51	1.92	—	—	—

[a]— means not available.

Mukherji (29) calculated the district-level yield gap estimates for West Bengal by season (Table 10). The data imply that the yield gap may be higher in prekharif and kharif than in boro, and show that the yield potential varies enormously among districts.

Barker and Pal (5) estimated what they regarded as "farmer realistic" yield potentials and the yield gap by culture type for eastern India (Table 11). They believed that the yield gap lay in the range of a ratio of 1.5 to 2.0, i.e., that the

Table 11. Estimated actual and potential rice yields based on type of rice culture (5).

Type of culture	Present average yield (t/ha)	Potential yield (t/ha)
Irrigated		
Wet	1.8	3.6
Dry	2.6	4.2
Upland (unbunded)	1.0	1.5
Rainfed		
Shallow (0-20 cm)	1.5	2.3
Intermediate (21-50 cm)	1.2	2.0
Semideep (51-100 cm)	1.0	1.5
Deep water (100 + cm)	1.0	1.5
Average	1.5	2.5

difference between potential and actual yields was between 50 and 100%, and was higher in the wet season on irrigated lands than in other rice environments.

Constraints analysis

The cited figures are frequently misleading and provide unrealistic estimates of the yield gap. Demonstration plots are frequently located on irrigated sites, whereas eastern India is predominantly rainfed. Therefore, the two sets of yield figures may not be comparable. Furthermore, the levels of inputs used on demonstration plots (e.g., fertilizer rates) may be too costly, or not available to farmers. Therefore, it is necessary to distinguish between the "technical" yield gap and the "economically recoverable" yield gap, defined as the input level and yield that lead to maximum profit.

On-farm experiments specifically designed to investigate the yield gap issue under farmers' circumstances were conducted by the Central Rice Research Institute in Cuttack, Orissa, and by the University of Kalyani in West Bengal. Their research designs provided an opportunity to assess a) the magnitude of the yield gap under farmers' conditions, b) the contribution of individual management factors to the yield gap, and c) the profitability of changing farmers' practices to those recommended by the researchers (12). The yield gap ratio measured by the CRRI researchers fell in the range of 1.6 to 1.7 (Table 12). However, researchers' yields (6-7 t/ha) and simulated farmers' yields (about 4 t/ha) seem high compared with district-level data for kharif.

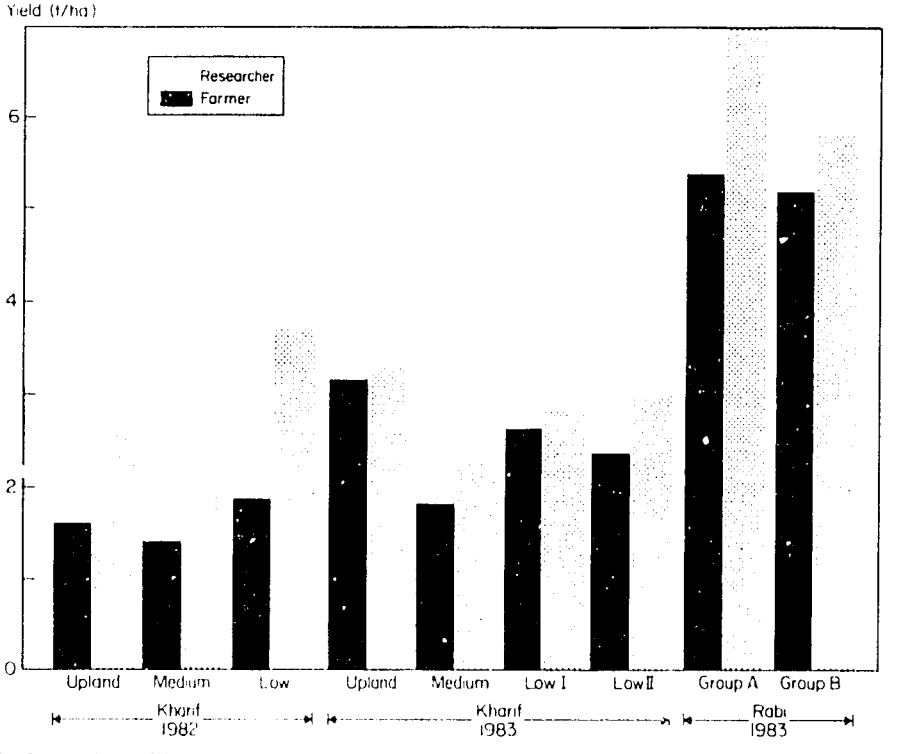
Table 12. Estimates of farmer's rice yields and those achieved using high input technology in kharif, Orissa, India, 1979-81.

Year	Farmer's yield (t/ha)	High level input yield (t/ha)	Yield gap	
			t/ha	Ratio
1979	3.89	6.68	2.79	1.72
1980	3.86	6.07	2.21	1.57
1981	4.02	6.92	2.90	1.72

The yield gap estimated in West Bengal was higher in 1982 kharif (1.4-1.9) than in 1983 kharif (1.1-1.3). Both seasons were unusually dry, reducing both farmers' and experimental yields below those normally anticipated at the research site. This may partly explain the higher yield on the lowland rainfed site in 1982 compared with higher landscape positions (Fig. 4).

The management factors included in the Kalyani experiments included variety, fertilizer, and insect control. Experimental sites were located in upland, medium, and lowland environments. In 1982 kharif, for the three hydrological environments, the farmers' varieties were ERI, Patnai, and Katranqi, while the researchers' varieties were IET1444, IR36, and IET5656. In 1983 kharif, MVs Biraj (CMN539) and Swarna (IET5656) were compared with the farmers' variety Pankaj at the lowland sites. In 1983 rabi, ERI and IR579 were the dominant farmers' varieties. Rassi (IET1444), designated as Group A, and IR36, designated as group B, were used as the researchers' varieties. Therefore, varietal comparison was between earlier and more recently released MVs as opposed to comparing local traditional varieties with improved ones.

Fertilizer contributed most to the yield gap in both kharif and rabi (Table 13). Shifting from no fertilizer to the researchers' recommendation (100-80-80 in kharif and 120-60-60 in rabi) increased yields by 0.5-1.0 t/ha.



4. Comparison of farmers' and researchers' yields in constraints experiments, Kalyani, West Bengal, India.

Table 13. Contribution of test factors to the yield gap in the constraints experiments, Kalyani, West Bengal, India (31).

Landscape	Variety		Contribution (kg/ha) of				
	Farmer	Researcher	Variety	Fertilizer	Insect control	Residual	Gap
Kharif, 1983							
Upland	ERI	IET1444	265	916	213	57	1415
Medium land	IR579	IR36	65	611	161	4	833
Lowland I	Pankaj	CMN539	0	488	48	119	655
Lowland II	Pankaj	IET5656	354	470	118	-3	939
Rabi, 1983							
Group A	ERI	IET1444	444	965	253	33	1695
Group B	IR579	IR36	287	789	257	-40	1293

Calculated from Table 6.4 and 6.6, assuming no significant higher-order interactions between factors.

The impacts of variety and insect control were modest. IR36 performed slightly better than IR579 on medium elevation land in kharif, while the direct effect of yield of Pankaj and IET5656 was similar on lowlands. The large residual (0.1 t/ha) suggests that variety and fertilizer interaction may have been important in that experiment.

The profitability of the researchers' practices was compared with the farmers' and an "intermediate" technology level (Table 14). These values were used to calculate three rates of return: a) net product value (NPV) per ha, b) NPV per unit cost, and c) the benefit-cost ratio. The NPVs were higher under the researchers' practices than the farmers' practices except for medium land sites in 1982 kharif (Table 15). On the other hand, NPV per unit cost was lower in the high-input experiments than with farmers' technology except for the upland and lowland farms in 1983 kharif and for group A farms in 1983 rabi.

The marginal benefit-cost ratios indicate the rate of returns earned by increasing investment from the low or intermediate to the recommended researchers' practice. As a rule of thumb, this value should exceed 2.0 before

Table 14. Estimates of costs and product values in the constraints experiments, Kalyani, West Bengal, India (31).[a]

Season	Land level farmer group	Farmer practice		Low-input experiment		High-input experiment	
		Cost/ha (Rs)	Product value/ha (Rs)	Cost/ha (Rs)	Product value/ha (Rs)	Cost/ha (Rs)	Product value/ha (Rs)
1982 kharif	upland	3,088	3,148	4,320	2,463	5,275	4,160
	medium land	2,748	3,773	3,638	2,665	4,635	3,610
	lowland	2,347	3,620	3,855	4,279	4,600	5,915
1983 kharif	upland	5,371	6,562	4,120	5,164	4,725	7,050
	medium land	--	--	3,370	4,282	3,975	5,428
	lowland I	3,760	5,782	3,495	5,378	4,170	6,496
	lowland II	3,110	5,375	3,495	5,056	4,170	6,496
1983 rabi	group A	5,856	11,168	5,775	11,070	6,915	14,752
	group B	5,312	11,685	5,697	11,037	6,840	13,401

[a]US$1 = Rs 11.41.

Table 15. Estimates of rates of net product values (NPV) per ha, NPV per unit cost, and benefit-cost ratios, Kalyani, West Bengal, India 1982-83 (31).[a]

Season	Farm level/ group	Farmer practice		High-input experiment		Benefit-cost ratio[b]
		NPV/ha (Rs)	NPV per unit cost (Rs)	NPV/ha (Rs)	NPV per unit cost (Rs)	
1982 kharif	upland	96	0.03	-1,115	-0.21	0.45
	medium	1,025	0.37	-1,025	-0.22	-0.09
	lowland	1,273	0.54	-1,315	-0.28	1.02
1983 kharif	upland	1,191	0.22	2,325	0.49	-0.49
	lowland I	2,022	0.54	2,748	0.66	3.38
	lowland II	2,265	0.73	2,326	0.56	1.07
1983 rabi	group A	5,312	0.91	7,837	1.13	3.82
	group B	6,373	1.20	6,840	0.96	1.13

[a]US$1 = Rs 11.44. [b]Computed by dividing high-input experiment figures by farmer practice values.

farmers will judge a change attractive. On this basis, other than for the Lowland I "package" in kharif and IET1444 in 1983 rabi, the researchers' technology was not clearly more attractive to farmers (Table 15).

The experiments demonstrate the potential response to fertilizer and, in some cases, improved varieties. However, the unusually dry kharif seasons probably prevented full expression of the researchers' and possibly the farmers' technology. The vagaries of weather may therefore make farmers hesitant to invest in costly inputs in circumstances when returns are uncertain.

SOCIOECONOMIC CONSTRAINTS TO HIGHER RICE PRODUCTIVITY

Khalon and Singh (20) discussed the broad array of economic and institutional factors which may constrain rice productivity growth in the eastern region of India. We focus on a subset: rice prices and marketing; the farmer's resource base, including farm size and irrigation potential; the profitability of input use, specifically fertilizer; crop insurance; and the prevailing problem of poverty in the region. This does not imply that other economic and institutional factors are not critical to productivity growth. Rather, they are beyond the scope of this presentation (e.g., credit), or other presentations at this workshop are addressing the issues (e.g., technology transfer).

Infrastructure development

A common hypothesis in development theory is that infrastructure facilities determine the initial conditions for sustained and successful growth. The hypothesis was statistically supported in the case of interstate variations in agricultural development in India during 1970-80, which was induced by economic, social, and demographic factors (32). The slow rate of growth of rice yield in eastern India is associated with a relatively deficient infrastructure compared to the rest of the country.

A set of demographic, economic, and agricultural indicators for the eastern states and for India is presented in Table 16. By and large the eastern region is

Table 16. Selected characteristics of eastern India[a] (20).

Item	Bihar		Orissa		West Bengal		All India
Demographic							
Population (million), 1981	69.82		26.27		54.49		683.81
Density of population in 1981 (no./km^2)	402	(3)	169	(13)	614	(2)	221
Rural population (%)	87.5		88.2		73.5		76.3
Population growth (%), 1971-81	23.9		19.7		2.30		24.8
Annual compound (%)	2.17		1.82		2.09		2.24
Rural population growth (%), 1971-81	20.5		15.3		20.1		19.0
Annual compound (%)	1.88		1.43		1.85		1.75
Agricultural labor as % of agricultural workers, 1971	47.3		36.5		45.3		37.8
Agricultural workers as % of total workers, 1971	82.3		77.5		58.4		69.7
Work force participation rates (%)							
1971	31.0		31.2		27.9		33.1
1981	29.7		32.8		28.5		33.4
Unemployment rates by current activity status, 1977-78	4.5		4.5		4.6		4.0
Per capita consumption (calories/d), 1973-74	2186	(9)	2125	(11)	2070	(13)	2328
Population below poverty line (%), 1977-78							
Rural	58.9	(3)	69.0	(1)	58.9	(4)	50.8
Urban	46.1		42.2		34.7		38.2
Combined	57.5	(3)	66.4	(1)	52.5	(4)	48.1
Area cultivated (million ha), 1977-78	10.16		6.63		6.18		155.63
% of geographical area	58.6		42.7		69.5		51.0
% of current fallow to cultivated land	15.6		10.5		n.a.		8.4
Forests, permanent pastures, and other grazing land (%)	16.8		46.4		13.4		26.1
Average farm size, 1976-77 (ha)	1.11		1.60		0.99		2.0
Proportion of holdings below .	84.6		75.7		87.1		72.6
Proportion of area in holdings below 2 ha	37.7		40.3		55.7		23.5
Proportion of holdings below 1 ha	72.6		46.6		66.5		55.9
Proportion of area in holdings below 1 ha	23.3		14.8		27.1		10.7
% increase in holdings below 1 ha between 1970-71 and 1976-77	48		13		38		26
Technological							
Ultimate irrigation potential (area % of gross area)	70		70		70		60
Irrigated area (%), 1977-78	32.7	(7)	18.3	(10)	19.6	(8)	26.6
Tractors per thousand ha, 1977	1.5	(9)	0.4	(17)	0.4	(16)	2.1

No. of oil engines or electrical pump sets per 100 ha, 1977	1.1	(12)	0.8	(13)	0.3	(15)	3.3
% of holdings having iron plows, 1972	19	(10)	4	(13)	1	(17)	16
Cropping intensity, 1977-78	135	(5)	132	(8)	127	(9)	121
Proportion of area under high-yielding variety, 1978-79	33.9	(9)	14.4	(16)	33.4	(10)	29.8
Fertilizer consumption (kg/ha), 1980-81	15.9	(12)	8.5	(15)	30.6	(9)	30.5
Infrastructure							
Proportion of villages electrified, Mar 1981	30.9	(16)	40.0	(12)	37.5	(14)	47.1
Power used in agriculture (kWh/capita), 1978-79	3.1	(13)	1.4	(14)	1.3	(15)	18.4
Surfaced roads (km/100 km^2), 1975-76	124	(11)	89	(13)	350	(5)	164
Regulated markets (thousand ha served per RM), 1977	23	(2)	99	(13)	56	(10)	37
Public outlay on agriculture (RS/ha), 1981-82	127	(8)	113	(10)	206	(4)	37
Public outlay in irrigation (RS/ha), 1981-82	190	(4)	106	(11)	138	(6)	—
Plan outlay on minimum needs program (Rs/capita), 1980-85	60	(10)	55	(14)	58	(12)	—
Development expenditure by state govt (Rs/capita), 1980-81	101	(17)	193	(9)	176	(13)	—
Institutional credit							
Outstanding (Rs/ha), June 1979	238	(12)	203	(14)	333	(9)	369
Proportion of overdues to demand							
PACS, Jun 1978	68.9	(16)	49.8	(12)	47.1	(10)	43.3
LDB, 1978 to 1980	65.7	(16)	46.1	(8)	33.5	(6)	46.6
CB, 1977 to 1979	64.0	(16)	57.2	(13)	59.7	(14)	48.6
No of holdings per:							
PACS	603		1137		666		702
Viable PACS	na		2014		939		1648
LDB (thousand)	77		65		203		47
Eligible LDB (thousand)	115		75		220		—
CB branch (100)	9.6		9.2		7.9		5.6
Proportion of rural CB branches, Dec 1979	58.2		64.9		33.2		45.8
Proportion of PACS borrowing members, Jun 1979	36.1		29.2		49.4		35.7
PACS, paid-up capital + deposits per member (Rs), Jun 1979	28	(16)	76	(12)	76	(13)	130
Performance							
Per capita (rural) income from agriculture (Rs) av of 1973-74 to 1975-76	360	(17)	519	(9)	519	(9)	545
Food grains yield (kg/ha), 1978-79	981	(11)	869	(14)	1317	(6)	1025
Growth rate of food grains production during 70s (%/annum)	0.84	(12)	0.42	(15)	1.29	(11)	2.32

[a]Figures in parentheses are rankings relative to 17 major states.

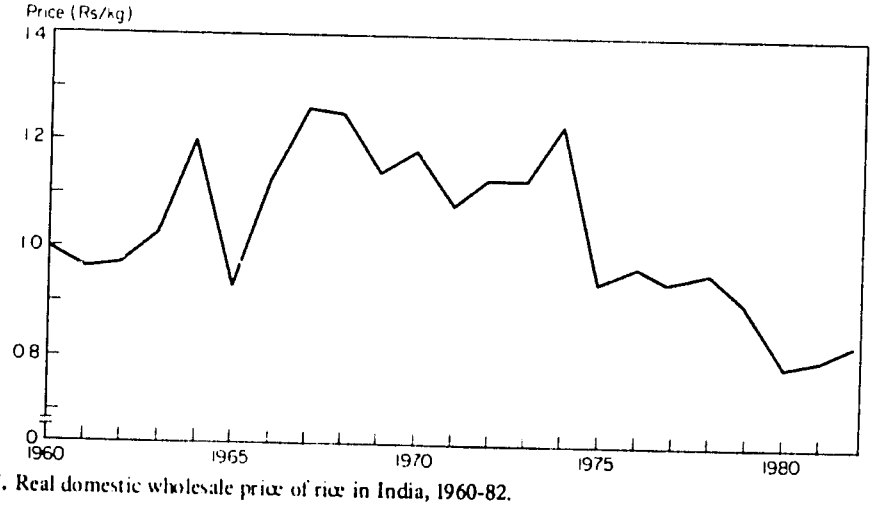
comparatively disadvantaged in regard to key demographic characteristics: population, population growth rates and density, dominance of rural to total population, and lower literacy rate. Net domestic product per capita (except for West Bengal), percentage of villages electrified, and road length per 100 km^2 in eastern India lag behind the rest of the country. As a result there is a large gap in rural income per capita and production growth between the eastern and other regions.

Prices and marketing

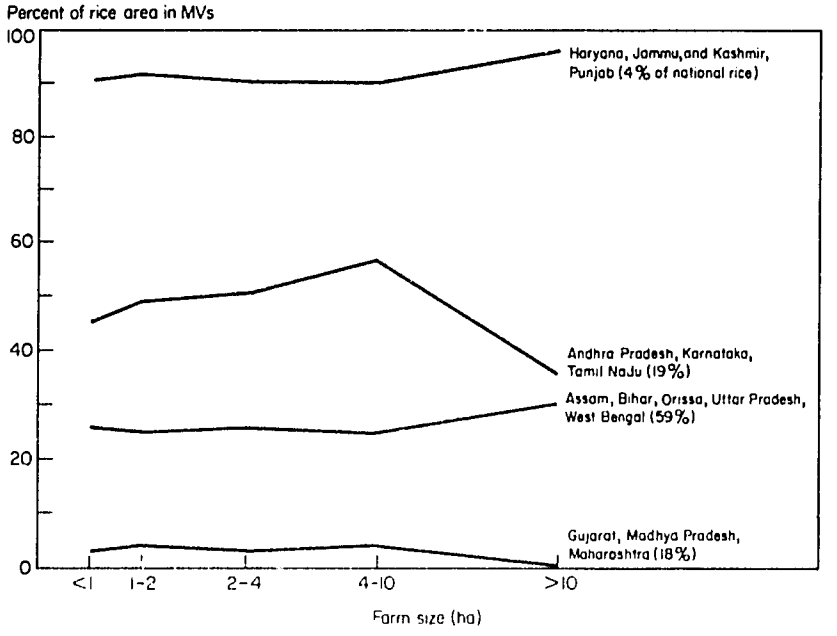
Indian rice farmers experienced a long-term decline in rice prices in the 1970s (Fig. 5). The Agricultural Prices Commission recognized that the terms of trade of rice farmers were deteriorating, and in 1980 it revised its methods for calculating procurement prices (25). While the procurement price is almost always below the market wholesale price, the volume of procurement is sensitive ($e = 0.5$) to this price. Similarly, total rice production is also sensitive to the ratio of market to procurement price, which has narrowed over the past few years (23). Ray (35) confirmed this responsiveness of rice output to price and showed that the responsiveness was higher in 1950-80 than before independence.

In the early 1980s, domestic rice prices in India were below world prices. This was a reflection, in part, of the national growth in productivity, government policy with respect to rice import and export, and a concern to keep consumer prices low (8). The declining real prices of rice benefited consumers. However, this situation is not conducive to investment in rice production unless cost-reducing or production-increasing technology is also made available to farmers. Sukhatme (42) estimated that the decline in producer benefits from this price policy outweighed the gains experienced by consumers.

The high levels of adoption of MVs (42) and complementary inputs such as



5. Real domestic wholesale price of rice in India, 1960-82.



6. Adoption of modern rice varieties (MVs) in India.

irrigation, fertilizer, and infrastructure development show that technical change and the benefits of MV technology have been more rapid in the northern and southern rice-producing regions than in the eastern region (Fig. 6, Table 16). Rice producers in the eastern region, without access to the new rice technology, lost absolutely and relatively to the gaining regions since they faced reduced rice prices without an associated reduction in production cost.

A second and related problem is the "thin" market for rice in eastern India. About one-third of the food grain produced in India enters the market. For the eastern region, the marketed surplus of rice is probably less, given the small holdings, high rural population densities, and low yields (Table 16). Under these circumstances a small increase in production leads to a more than proportionate increase in marketed surplus, both in absolute and percentage terms (Table 17). Also, the demand for rice tends to be inelastic (Fig. 7). Under such circumstances, a given increase in production results in a larger change in price (ΔP) than was the change in production (ΔQ).

Thus, the market for rice tends to be volatile and price responsive to small changes in production. Hazell observes that the standard deviation of harvest price for rice in West Bengal is significantly higher now (Rs 0.40/kg) than it was in the mid-1950s (Rs 0.15/kg). Zoning restrictions and the policy of restraining private trade in rice between states further contribute to price volatility. This policy also increases interstate price differences, which hurts the producers in surplus states and the consumers in deficit states (23). Logistical problems, particularly severe at the end of the wet season, increase

Table 17. Illustration of the impact of increasing production on the marketed surplus when a small proportion of total production is marketed.

Item	Technical change	
	Before	After
Production (kg)	1000	1500
Disposal		
Retained for consumption (kg)	800	850
Retained for seed (kg)	100	100
Marketed (kg)	100	550
Proportion sold (%)	10	37

transport costs and decrease market efficiency, exerting a downward pressure on farmer-effective rice prices (20).

A third market-related problem that increases the gap between retail rice price and farmers' price is the Government's levy on milled rice to provide rice to ration shops. In West Bengal the levy proportions have varied from 15 to 55% in recent years. Since late 1981, the levy percentage has been 60%, and the procurement price, at Rs 1.93/kg for rice, was Rs 1.0 below the local wholesale price of rice, at least in 1982 (16). It was further shown (16) that West Bengal millers were unable to cover milling costs at this levy and procurement price. Consequently, other prices on the nonlevy 40% of the miller's trade were increased, or prices paid to purchase agents and farmers for rice were reduced, or both. These institutional constraints provide strong incentives for millers to pursue other means of increasing their income from rice milling and trading.

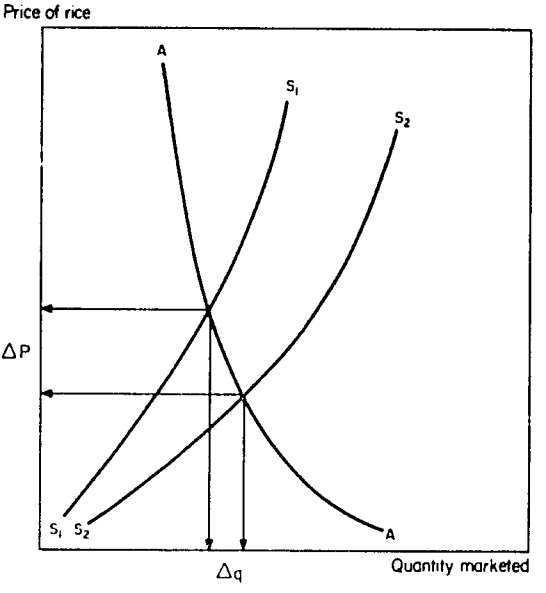
Farm size

There is a popular belief that farms with larger cultivated areas are more likely to adopt MVs and fertilizer than are small farms. If this were true, the small farm size in eastern India compared with the nation as a whole (Table 16) implies that farm size would be a deterrent to the adoption of MVs and associated technology. This conventional wisdom is rarely substantiated in fact (37). For example, a recent India-wide study demonstrated that farm size per se was not a dominant determinant of farmers' adoption of MVs. What was important was the farmers' access to irrigation, given the characteristics of MVs now available to them.

Irrigation

About 30% of the eastern region's rice is irrigated, while the potential irrigable area is probably about 70% (Table 16). The opportunities for expansion of large-scale, gravity-fed systems in the region may be limited, considering the World Bank's estimated irrigation development cost of $5,000-$6,000/ha. However, the eastern region has the aquifers and groundwater supplies that may be readily exploited using known tubewell technology (1, 36). Indeed, the eastern region probably represents the greatest untapped potential for future irrigation development in India (Table 18).

The rates of return on shallow tubewell investment, on the order of 50%, are attractive to the public (1). However, several constraints may limit rapid



7. When the demand for a commodity is price-inelastic, a small change in quantity supplied to the market brings about a large change in market price.

development of this technology from a private viewpoint. For example, farm size is often too small to justify individual ownership of tubewells; land fragmentation results in problems of water conveyance, reducing irrigation potential and water use efficiency (1, 20). Tenant farmers are hesitant to invest in irrigation; indeed, when land is brought under irrigation, landowners tend to farm the land themselves (14). Finally, a 50% rate of return on capital is probably less than the opportunity cost of money in informal money markets.

Institutional constraints that are widely regarded as an impediment to greater tubewell development in rural eastern India are power shortages, low availability of electricity, and weak credit and other support services (Tables 16, 18). These same factors also constrain the rehabilitation and exploitation of existing wells. Kahlon and Singh (20) reported that of the 197,500 shallow tubewells surveyed in West Bengal, only 24,900 were electrified. As a result, many remained idle. As long as the availability of power remains erratic,

Table 18. Groundwater development and rural electrification in northwestern and eastern India, 1979-80 (1).

Region	Level of groundwater development (% of potential)	Villages electrified (%)	Pump sets connected (thousand units)
Northwestern			
Punjab	82	100	262
Haryana	80	100	203
Eastern			
Bihar	35	31	152
Orissa	19	38	13
West Bengal	19	36	24

farmers will remain unwilling to convert their diesel pumps into electric ones even when the former cost three times more than the latter) operate.

Management and technical problems also reduce the efficiency of existing irrigation developments. Indeed, the full potential of the eastern region's 4 million ha of irrigated ricelands will be hard to realize unless appropriate institutional arrangements are derived for dealing with such problems as conflicts over water use, water scheduling and allocation, and maintenance of delivery and drainage systems, all of which are common problems in irrigation scheme management. In this sense, priority for policy should perhaps include building up cooperatives and farmer groups at the village level to manage water supply, in addition to land consolidation, land shaping, and land development for utilizing controlled water supplies.

The major problems of irrigation water management in Bardhan's (3) view are organizational and political rather than technical or economic. The benefits from solving these problems in eastern India are far-reaching. Irrigation with MVs still provides the best way to intensify agriculture. Both together raise output, reduce production risks, and increase employment. Later we argue that rice technology must be adapted to suit the environment through investment in water management to increase the profitability and success of MV technology.

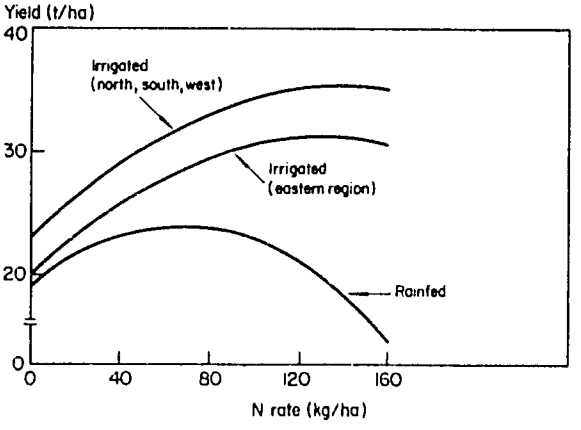
Investment in productive inputs

The lack of investment in capital inputs such as tubewells, iron plows, or power reflects both the cost of these inputs and the small size of farms, which make their purchase by individuals uneconomic. The low agricultural productivity of the region further reduces returns, and so capital investment is not attractive among poor farmers.

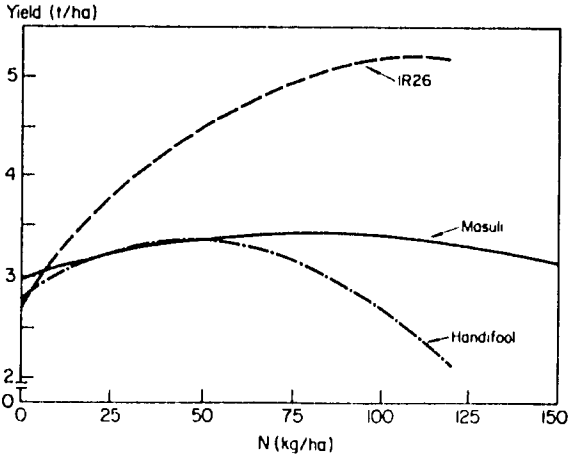
Farmers' use of recurrent inputs such as MVs and fertilizer is also low in the eastern region compared with India as a whole (Table 5). Contributing factors may be the scarce supply of the inputs and the high credit costs faced by poor farmers. However, particularly in kharif, when local varieties predominate in rainfed fields, the major constraint is lack of profitability, which is the result of both the lack of suitable fertilizer-responsive varieties and, historically, the high real costs of fertilizer.

The nature of fertilizer response in rice on different land types and regions of India is demonstrated in Figure 8. Local varieties, more widely grown, are less fertilizer responsive (Fig. 9). It is more profitable to use higher fertilizer rates for any given set of fertilizer and rice prices in other rice-growing regions than in eastern India, and on modern as opposed to local varieties.

Mukhopadhyay (31) quotes a rice price of about Rs 1.40/kg at harvest time, while urea, at official interest rates, costs about Rs 3.10/kg or Rs 6.71/kg of N. The ratio of kg of N to kg of rice was about 5, indicating that it required about 5 kg of rice to buy 1 kg of N. The constraint trials showed typical conversion ratios (with MVs) of 1 kg N increasing rice yield by 8-10 kg. With local varieties the figure is lower. Thus, a farmer pays 5 kg of rice for fertilizer that



8. Rice response to N by region and water regime (18).

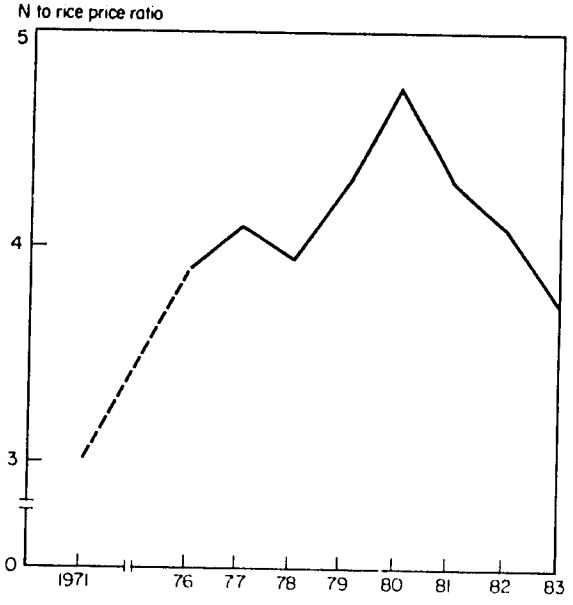


9. Yield response of 3 rice varieties to N, Parwanipur, India, 1976 (39).

returns 8-10 kg of rice or less. This considers neither the interest charged for credit in the local market, which often exceeds 100%, nor the risks involved. The use of fertilizer under these circumstances, particularly with local varieties, may not be a bargain.

The ratio of fertilizer to rice prices and crop responsiveness to fertilizer are the two principal determinants of the profitability of fertilizer use. In the decade up to 1980, the real price of fertilizer increased in India (Fig. 10). From 1980 to 1983 it declined due to an increase in the real price of rice and a reduction in fertilizer prices (26).

S.K. Ray (35) attributed most of the dramatic increase in fertilizer use and cereal production in 1982-84 in India to input-output prices becoming more favorable. Nonetheless, the domestic price of fertilizer remained high compared with that in countries where prices were allowed to reflect world prices (Table 19). That is, Indian farmers were penalized by the objective of promoting domestic fertilizer production.



10. Real price of fertilizer in India, 1971-83.

Table 19. Relationship between farm price of paddy and price of fertilizer in Asian countries, 1980 (10).

Country	Farm price of paddy ($/t) (1)	Price of urea ($/t N) (2)	Urea/ paddy price ratio[a]	Domestic/world price ratio of	
				Paddy	Urea
India	156	603	3.9	0.6	3.0
Pakistan	80	289	3.6	0.3	1.4
Bangladesh	230	385	1.7	0.8	1.9
Nepal	204	452	2.2	0.8	2.2
Sri Lanka	129	140	1.1	0.5	0.7
Burma	64	122	1.9	0.2	0.6
Malaysia	296	325	1.1	1.1	1.6
Indonesia	174	282	1.6	0.6	1.4
Thailand	112	340	3.0	0.4	1.7
Philippines	149	567	3.8	0.6	2.8
Japan	1469	658	0.5	5.4	3.2
South Korea	661	714	1.1	2.4	3.5
Average	310	406	1.3	1.1	2.0
World price	271	204	0.8		

[a]Column (2) divided by column (1).

Reducing profit variability

Droughts and floods in eastern India contribute to yield variability. Rice farmers face considerable price volatility. The resulting year-to-year variability in profits contributes to farmers' unwillingness to purchase cash inputs because of the risk of losing their investment.

Infrastructural development (e.g., irrigation and flood control, increased reliability of electricity supplies); focusing agricultural research on varieties

resistant to flooding, droughts, pests, and other disturbances that cause crop loss (11); and seeking opportunities to shift drought-prone and marginal rice areas into upland crops each offer promise to reduce rice production instability. Some of these options are expensive and may be constrained by socio-institutional realities, e.g., water control. Others, such as technology derived from the research process, are less certain and longer-term in nature. Farmers' willingness to shift from rice to upland crops may also be conditioned by market performance, both to provide a remunerative market for the new crop and an assured supply of rice for consumption at a reasonable cost. These factors imply that improvements in institutional performance may be a precondition for socially desirable technical change.

The General Insurance Corporation of India plans to promote its crop loan insurance scheme in eastern India as part of the Government's coordinated effort to increase rice supplies in the region during the Seventh Plan period (27). The scheme is based on V.M. Dandekar's "homogeneous area scheme" wherein both premiums and indemnities are determined at the same rate for all farmers within a "homogeneous area" (2). To focus the program on small farmers, the maximum coverage is 150% of the farmer's production loan up to a limit of Rs 10,000 in irrigated areas or Rs 5,000 in rainfed areas (26). But because it is a loan insurance scheme, resource-poor farmers, who rarely have access to institutional credit, are unlikely to readily avail of the option.

Others question how effectively such a scheme meets farmers' insurance objectives (41). When farmers' yields are not highly correlated with average yields, the scheme might increase, not reduce, income variability. Since indemnities are based on average yields over the "homogeneous" area, they become further sources of uncertainty with which the farmer has to cope in addition to existing production risks. In this situation, farmers may not perceive any personal benefits from participating in the scheme. There may also be collusion between farmers in homogeneous areas to exert group pressure on damage assessors, which may jeopardize the long-term viability of the scheme.

The economic viability of insurance schemes is also threatened if widespread crop failure occurs due to flooding or drought. If so, a high reserve ratio is required unless the scheme receives emergency support from the Government. This problem may become increasingly serious, since yield correlation among states in India appears to increase over time (17). Therefore, the insurance scheme may not reduce farmers' risk or increase their willingness to adopt recommended rice technology.

Poverty and productivity

The eastern states have among the highest incidence of rural poverty in India; Orissa ranks first, Bihar third, and West Bengal fourth relative to the 17 major states (Table 16). This is attributed partly to the lack of growth in agricultural productivity and partly to the inadequate resource base, as typified by the lack of infrastructure and small size of farms. Poverty, combined with low technology, results in a vicious circle that must be broken before substantial

productivity and welfare gains can be anticipated from rice culture in the eastern region (22).

Investment is insufficient in the eastern Indian small farm sector because it is considered unproductive. The sector remains unproductive although substantial productivity and profitability potentials exist and remain unexploited. The Government recognizes that a big thrust, with coordinated technology, extension, input delivery systems, and market backup, is necessary to break this vicious circle (26). Even so, it is unrealistic to expect that improved rice technology alone can solve the poverty-related ills of the region. Other options to increase land productivity — for example, diversification to other crops, livestock, and fisheries — must also be examined. Opportunities for generating gainful employment in agricultural support industries and the nonagricultural sectors must also be vigorously pursued.

A FOCUS FOR RAINFED LOWLAND RICE TECHNOLOGY

While the comparative importance of biotechnical, economic, and social constraints to increased rice productivity in eastern India may be debated, one point is clear: there is an urgent need to develop rice technology (varieties and cultural practices) adapted to the adverse environments found there. Quantum jumps in cereal production are possible in spite of poverty. This was clearly demonstrated by the doubling of wheat yields in the region in the early 1970s, and the above-India average for rice yields in West Bengal in rabi.

In the foreseeable future, the eastern region will remain small-farm dominated. For maximum impact, new technology must be biased toward low-resource farmers. This implies that technology should have two characteristics. First, it should make maximum use of the most plentiful resource — labor. Second, it should have a high cash payoff and low cash input intensity. Research should therefore focus on labor-using, and low and nonmonetary input technology. Improved varieties, where the technology is embedded in the seed, are probably the best examples. The use of naturally occurring products such as neem for insect control, or hand placement of N to increase fertilizer use efficiency (24) are others. These examples of biological innovations are divisible, and thus scale neutral. By comparison, many mechanical innovations are nondivisible and tend to substitute capital for labor. They bias technology away from low-resource toward high-resource farms.

An objective of employment-generating rice technology for the eastern region does not imply that scientists or policy makers should insist that all operations be labor intensive. The issue is to design technology that, in aggregate, increases employment. The selective use of capital to reduce labor constraints (e.g., herbicides with direct seeding in rainfed areas) may increase labor productivity per crop. Others, such as selective mechanization to facilitate early crop establishment or reduced turnaround period, may increase total labor use through their impact on crop intensification. Possibly the best example of a capital-using technology that increases total employment is irrigation.

In practice, the distribution of benefits from a technology will depend on the characteristics of the technology, the relative land and labor endowments, and the access to output, modern input, and credit markets. Often the low-resource farmers have less access to these markets than their wealthier neighbors. If access to input and credit markets is unequal before the introduction of a technology, a technology that leads to greater dependence on these markets will lead to a regressive distribution of gains of modern input-using technical change; changes in rural institutions may be a precondition for resource-poor farmers to avail of market-based improved rice technology.

The Indian Council of Agricultural Research and the state governments commit considerable resources to technology transfer through, for example, the Operation Research Program (ORP), National Demonstrations, Farmers' Training Centres, and the Lab-to-Land project. Stagnation in rice production in the eastern region suggests that these projects have not materially contributed to increased rice productivity. One reason may be that varieties suited to many environments in the region are not available, although promising ones have been identified (34). Another may be that the technology now recommended does not meet the needs of resource-poor farmers.

Chambers and Ghildyal (7) argue that the transfer-of-technology model as practiced in India has a built-in bias that favors resource-rich farmers whose conditions resemble those of research stations. They contrast the physical (Table 20) and socioeconomic (Table 21) conditions of research stations, resource-rich farmers, and resource-poor farmers. When these contrasts are taken together, it is easier to appreciate why technology developed and

Table 20. Contrasts in physical conditions of research stations, resource-rich farmers, and resource-poor farmers[a] (7).

Environmental characteristic	Research experiment station	Resource-rich farm	Resource-poor farm
Topography	flat or terraced	flat or terraced	often undulating and sloping
Soils	deep, fertile, no constraints	deep, fertile, few constraints	shallow, infertile, often severe constraints
Hazards	nil or few	few, usually controllable	more common — floods, droughts, animals grazing crops, etc.
Macro- and micro-nutrient deficiency	rare, remediable	occasional	quite common
Irrigation	very reliable	fairly reliable	unreliable or nonexistent, often rainfed
Size of management unit	large	large or medium	small
Diseases and pests	controlled	controlled	crops vulnerable to infestation

[a]Not all apply all the time, but most apply most of the time.

Table 21. Contrasts in socioeconomic conditions of research stations, resource-rich farmers, and resource-poor farmers (7).

Item	Research experiment station	Resource-rich farm family	Resource-poor farm family
Access to seeds, fertilizers, pesticides, and other purchased inputs	unlimited, reliable	high, reliable	low, unreliable
Seed used	high quality	purchased, high quality	own seed
Access to credit when needed	unlimited	good access	poor access and seasonal shortages of cash when most needed
Draft power	available, timely use	available, timely use	unreliable and often untimely
Labor	unlimited, no constraint	hired, few constraints	family, constraining at seasonal peaks
Priority for food production	neutral	low	high
Appropriateness of technology generated on research experiment station to the receiving environment	very high by definition	high	low

recommended by the research system is not adopted by the bulk of resource-poor farmers.

The message is clear, although implementing it may require a shift from existing methods of research management. Research problems and priorities must be identified through concern for the needs and opportunities of low-resource farm families rather than through scientists' perceptions of what is relevant to farmers. Research needs to be reoriented to respond to the needs and seek the participation of farm households in identifying biological, economic, and policy problems; designing technologies to ameliorate these problems; and evaluating the options. In brief, the criteria of excellence must shift from on-station and laboratory research, or yields on research stations and resource-rich farms, to the more rigorous test of whether new practices will spread among resource-poor farmers (7).

The eastern region has a large endowment of labor relative to land or capital. On efficiency grounds, the thrust in rice research should be toward land-saving and labor-using technical change (6). Technology of this nature will increase land productivity and at the same time achieve the equity objective of increasing employment and growth in agricultural wages. There need be no conflict between the objectives of social justice (targeting technology to resource-poor farm families), efficiency (increasing output per unit of resource use), and equity (e.g., employment generation for poor people).

Swaminathan (43) relates that "famines in India are often famines of work rather than food, since when work can be paid for, food is always forthcoming." The benefits and opportunities for developing rice technology that increases the food supply and reduces the "famine of jobs" are self-evident. These criteria for research design may serve as guidelines in considering how productivity gains may be realized for rainfed rice.

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53

RAINFED RICE IN WEST BENGAL

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Rainfed rice production in West Bengal is described. The use of indigenous rice varieties for developing improved varieties is emphasized. A number of remaining problems in rice research in the state are noted.

Rice is grown in West Bengal under diverse ecological situations in three seasons: aus (March to July in northern Bengal and May to October in southern Bengal), aman (June to December), and boro (December to May). The areas under rice in these seasons are 0.7-0.8 million ha during aus, 4.0-4.2 million ha during aman, and 0.4-0.5 million ha during boro. The crop is grown from coastal areas to the terraced lands of Darjeeling district (around 1,300 m altitude). It grows under annual precipitation ranging from about 1,100 mm in the drought-prone western belt to about 3,600 mm in the northern districts. Temperature also shows wide variation from below 10 °C to about 35 °C. The boro crop is entirely irrigated and is not discussed here.

The aus and aman crops are partially irrigated, and 35-40% are modern varieties. Only about 30% of the area is irrigated, and the remainder, about 3.5 million ha, is rainfed, ranging from upland drought-prone to deep water flood-prone situations. Soil texture varies from coarse sand and even gravel in the uplands to deep, heavy clays in the lowlands. Soil pH of ricelands varies from 4 to 6 in the north and west, and from 7 to 9 in the south and east.

AGROCLIMATIC REGIONS

West Bengal has six agroclimatic regions:

- hill region in the north;
- Terai and Teesta alluvial regions in the north;
- red, lateritic, and gravelly undulating region in the west;
- Gangetic alluvial region in the east;
- Vindhya alluvial region in the center; and
- coastal alluvial region in the south.

Though the regions differ greatly in soil and climatic conditions, rice is grown in each as a major crop. The distribution of aus and aman crops grown under favorable conditions during kharif is shown in Table 1.

Table 1. Areas of agroclimatic regions in West Bengal.

Agroclimatic region	Area (thousand ha)		Total area (thousand ha)
	Aus	Aman	
Hill region	—	10	10
Terai region	250	500	750
Red and lateritic	100	1150	1250
Ganga alluvium	350	600	950
Vindhya alluvium	100	1280	1380
Coastal alluvium	—	660	660
Total	800	4200	5000

About 70-80% of total rainfall occurs from June to September. In northern Bengal, however, mild to moderate rainfall is received during summer (i.e., March to May), when the aus crop is direct sown. This crop is also grown in Gangetic alluvium with premonsoon and monsoon rains. About 0.3 million ha of aus crop in southern Bengal use transplanted rice, mostly with modern varieties. The aman crop is direct sown in rainfed lowland areas in premonsoon showers. Toposequence, soil texture, and character of the monsoon and pre- and postmonsoon precipitation, particularly their distribution and intensity, play a vital role in kharif rice cultivation as they determine the moisture regimes of soil on which the crop is grown.

Rainfed lowland areas are subject to drought, flooding, and intermittent submergence at different stages of crop growth depending upon land situation, soil texture, and rainfall. Drought is common in the western red and lateritic tracts. Floods are frequent in the low-lying areas of the alluvial plains in the north, the central region, and the south. Varieties having drought tolerance at different growth stages are needed for the western tracts and for the rainfed shallow and intermediate lowlands of other regions. Similarly, varieties having submergence and flood tolerance and with medium and long duration are desirable for semideep and deep water conditions. Since low temperature at the reproductive stage may result in high sterility and subsequent low yield, varieties having cold tolerance at this stage, especially during mid-October to November, are desirable for lowland aman crops.

Skillful crop management, cultivation of suitable improved or high yielding varieties, maintenance of optimum plant population to obtain about 250 panicles/m^2, and efficient use of balanced plant nutrients and plant protection measures will go a long way to improve the yield of the main kharif crop.

RESEARCH ASPECTS

The initial rice research work in West Bengal was on indigenous varieties. A large collection of germplasm was maintained, and seed performance was assessed. Through pureline selections, more than 40 varieties have been developed to suit the different regions. Many of these are still popular among farmers and have not yet been replaced by more suitable modern varieties.

Dular, NC1626, and other photoperiod-insensitive varieties are still being grown in the uplands for their tolerance for drought. In the medium land situations, Bhasamanik, Nagra, Kalma, Raghusail, and other indigenous improved varieties are popular with farmers in kharif. In lower situations, Achra, Tilakkachari, NC1281, NC678, and OC1393 are popular. In coastal saline areas, Patnai-23, SR26B, and Kumargore are grown. For aromatic grains, the choices are Badshabhog, Gobindabhog, and Randhunipagal.

The rich collection of germplasm has provided many genotypes for utilization as donor parents in incorporating specific qualities in modern varieties. Latisail is in the pedigree of the first popular modern variety IR8. Similarly, FR13A and FR43B were utilized for flood tolerance, Dular for drought, Badshabhog for high photosynthetic efficiency under cloudy days, Latisail and Kataribhog for resistance to rice tungro virus, and NC1626 for resistance to bacterial leaf blight.

The indigenous improved variety NC1281 for lowland situations gives good yields, even with staggered planting, which becomes necessary in the event of flood or drought. Seedlings as old as 80 d can give good yields, unlike modern varieties. Another such variety for lowland situations is OC1393; it is tolerant of most of the major diseases and pests and has cold tolerance at the flowering stage.

It has been shown at the Chinsurah Rice Research Station that many of these long-duration varieties can compete in yield with modern varieties, particularly under low input management.

Admirable achievements have been made during the last decade by the Rice Research Stations at Chinsurah and Bankura in developing short-duration varieties such as CNM25 and CNM6, medium-duration varieties such as CNM20 and CNM31 through X-ray irradiation, CNDP217 through hybridization, CN540 (selected and developed at Chinsurah from IRRI-Thailand Cooperative Rice Project materials), and CNM539 through X-ray irradiation from OC1393 for lowland situations. Jaladhi I and Jaladhi II for deep water situations and Matla and Hamilton for saline conditions have come from indigenous varieties at Chinsurah.

RESEARCH REQUIREMENTS

Many objectives are yet to be attained by rice research workers:

- developing varieties with a wide spectrum of tolerance for major diseases and pests such as rice tungro virus, bacterial leaf blight, blast, stem borer, brown planthopper, and gall midge;
- developing varieties with tolerance for problem soils such as the high pH soils of the Nadia-Murshidabad area, the low pH soils in northern Bengal, and Fe and Al toxic soils;
- developing varieties tolerant of flooding, drought, poorly drained lowlands, and low temperature, particularly for the boro season at the early vegetative stage;

- identifying inexpensive fertilizers and convenient methods of application for maximum utilization by plants;
- improving fertilizer and pesticide use management; and
- strengthening research-extension-training linkages to improve the communication of research results to farmers.

West Bengal has doubled its rice production within 30 yr, which is commendable. Productivity in the boro season is now comparable to that in Punjab and Haryana. In the main kharif season, so many constraints to rice production exist in West Bengal that growth in productivity during kharif has been very slow for the last 15 yr. An increase in yield of 0.5 t/ha in the 5 million ha of kharif rice would make a significant impact in food grain availability in this state.

. 51

INTERNATIONAL NETWORKS

CROPPING SYSTEMS FOR RAINFED LOWLAND RICE ENVIRONMENTS

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In tropical Asia, where land for expanding crop cultivation is limited, multiple cropping is being tested as a means to increase crop production. In this paper, results from cropping systems research in six environments are examined. Discussion is restricted to two-crop sequences (rice - rice, rice - upland crop, upland crop - rice). In all environments, several innovations and supporting component technologies were tested. While some sequences performed well and have been adopted by farmers, no new sequence worked perfectly. Experiences suggest that if the defects of innovations can be overcome, the adaptation ranges of several cropping sequences could be increased.

During the tropical Asian wet season, few crops other than rice can be successfully grown on extensive areas of heavy alluvial, coastal marine, and lacustrine soils. Rice is a highly esteemed staple food that stores easily in the humid tropics. Governments in the region recognize the economic and political nature of rice and therefore promote rice production with price support, institutional credit, and input subsidy programs. Rice cultivation remains central to most Asian cropping systems (CS) research programs. The need for rice-based CS research, however, arises from increased pressure on the land. In Asia, land for agricultural expansion is limited, but the population is expected to increase by 138% before it stabilizes in 2090. Furthermore, as incomes rise, land must produce more and a greater variety of food. The expanding need for food offers opportunities for farm families to increase income by increasing output. With arable land limited but population expanding, multiple cropping (i.e., growing two or more crops on the same field in one year) is regarded as an important strategy to increase production. Since the early 1970s, on-farm rice-based CS research has been conducted in selected environments in Southeast Asia. The main objective has been to increase farm productivity by increasing the frequency of cropping in rainfed rice-growing environments.

OBJECTIVES AND ROLE OF CROPPING SYSTEMS RESEARCH

When reporting on-site research, CS scientists have generally emphasized those technologies that were successful. But we are as interested in the weak

technologies as in the strong ones. Weaknesses represent research challenges to innovative crop and soil scientists.

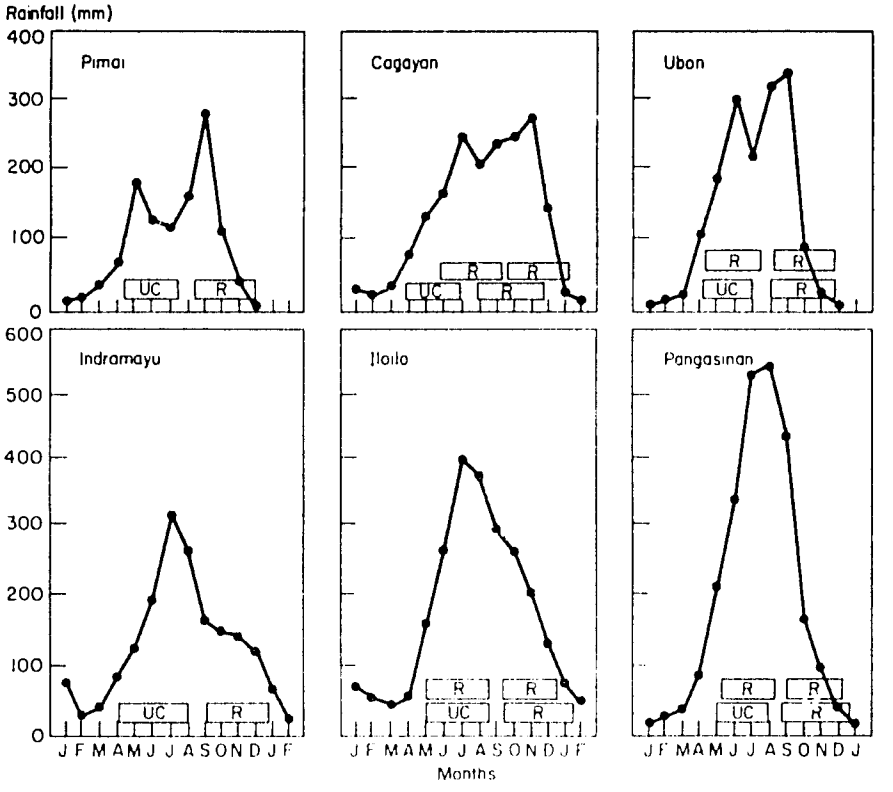
When implemented with linkages to conventional agricultural research programs, on-farm CS research complements experiment station research. Innovations that are selected for on-farm testing are identified from the stream that is generated by international, national, and regional research programs. Those technological innovations that appear to fit within the physical, biotic, and socioeconomic limits of the environment, and that are regarded as having potential to increase productivity by incorporating a better mix of cropping activities into a farming system, are identified from the stream. Testing must be conducted under the same management that the innovations are likely to receive but in a way that permits sound conclusions to be drawn from the results.

Although a new technical innovation may be the ultimate source of improved systems performance, use of that innovation invariably has ramifications for other cropping activities. For example, substitution of an early maturing, high yielding, photoperiod-insensitive rice variety for a late maturing, low yielding, traditional variety will create slack field time. However, to exploit that field time by growing a second crop it will be necessary to harvest, thresh, and store the first crop before the field can be prepared for the second crop. Without the pressure to plant a second crop, harvesting and threshing of the traditional crop is often slow. To save valuable growing time, realistic techniques to secure the first crop and to plant the second crop must be identified. If the second crop is an upland crop, the question of flood hazard has to be examined. Furthermore, a newly introduced crop must be protected, so protection specialists must initiate appropriate research. The crop must be sold or consumed, and these matters are of concern to marketing specialists and regional development project officials. Recognizing that no single discipline has the expertise required to address all problems that will be encountered, CS research projects are commonly multidisciplinary.

Farmer involvement in the testing process is important. Many farmers are skillful in crop husbandry, financially astute, and keen observers of physical, biotic, and socioeconomic variables. Given their many confrontations with weather, pests, and prices, farm households quickly recognize and exploit suitable technology and expose unsuitable technology.

In this paper we examine the results of research at six sites: one in Indonesia (Indramayu), two in Thailand (Pimai and Ubon), and three in the Philippines (Cagayan, Iloilo, and Pangasinan). The sites represent a range of rainfed conditions in Southeast Asia. At all research sites, many technical innovations were examined in combinations with traditional technology that, hypothetically, should enable a farmer to increase production.

Rainfall patterns at the six sites are summarized in Figure 1. Table contains information on soils and terrain and compares farm and family size. At all sites, many cropping patterns were tested, but in this paper we restrict discussion to double crop patterns, i.e., rice - rice (R - R), upland crop - rice (UC - R) or



1. Rainfall patterns at 6 CS sites: Pimai and Ubon (Thailand), Indramayu (Indonesia), and Cagayan, Iloilo, and Pangasinan (Philippines). UC = upland crop, R = rice.

rice - upland crop (R - UC). Because socioeconomic settings and physical environments differed among sites, we do not discuss differences among upland crop species. We assume that the upland crops had local marketability and that superior modern photoperiod-insensitive rice varieties were selected from among those available.

The hydrologic growing year, which is an abstract concept defined as the period of the year during which water is sufficient to produce a crop with a value exceeding production costs, determines the potential sequences of crops that can be grown. The hydrologic growing year is influenced by rainfall (seasonal distributions and year-to-year differences in distribution), soil properties (internal drainage), and terrain (surface drainage) features.

When synthesizing new cropping patterns for rainfed rice environments (physical and socioeconomic), the common strategy has been to increase harvest frequency by substituting high yielding crops with short maturities (which create slack field time) for late maturing, inefficient, traditional ones. Because scientists seek increased harvest frequencies, crops are forced earlier and later in the hydrologic year, increasing the hazard of drought. Crop species and varieties that can avoid or tolerate drought have found favor in rainfed systems.

Table 1. Predominant soils, terrain features, and average farm and family sizes at 6 cropping systems sites.

Site	Soils	Terrain	Farm size (ha)	Family size (no.)
Iloilo	Pelluderts, Eutropepts, Tropfluvents, silty clay surface soils	Gently sloping (1-2%) broad marine terrace, with inter-hill mini-plains at the boundary with range of hills	1.5	5.7
Indramayu	Tropaquepts, silty clay loam to loamy clay surface soils	Broad, gently sloping marine terrace, slight relief		
Pangasinan	Eutropepts, clay loam to loamy clay surface soils	Broad, flat plains with slight depressions and eroded levees in an alluvial system	1.1	5.8
Pimai	Tropaquepts, Entisols, light to heavy clay surface soil	Erosion plain, local alluvium, gentle relief features	5.8	7.0
Cagayan	Tropaquepts, silty clay to clay surface soil	Alluvial plain, no local relief, about <0.5% slope	3.0	6.4
Ubon	Paleaquults, Paleustults, sandy loam to loam sand surface soil	Erosion plain, local alluvium, gentle relief features	5.0	7.0

In this discussion, we ignore insects and diseases and assume that they can be satisfactorily controlled. This is obviously not always the case. Also, we do not discuss three-crop sequences. It is our experience that in most lowland rice environments dominated by the Asian monsoon system, yields of third crops, if they can be successfully established, are low except in an occasional year or on soils of high water-holding capacity located in favorable terrains. Moreover, third crops generally are too low yielding and unreliable to be counted on for family security.

RICE - RICE PATTERNS

In the mid-1970s, several rice varieties and lines that matured in less than 120 d became available. At four sites, rainfall patterns or a combination of rainfall and terrain features suggested that it was possible to grow two rice crops (R-R) per year. Whereas varieties of short duration triggered research on double rice cropping in rainfed environments, constraints of the hydrologic growing year and farm resources forced scientists to focus on methods to establish the first rice crop early and to reduce the interval between first crop harvest and second crop planting. That early establishment of the first crop would be necesssary was well recognized, and alternative planting techniques were compared. That farmers would face a major labor bottleneck between crops that would delay

the second crop was not fully appreciated, but finding ways to break the bottleneck quickly became an important research objective.

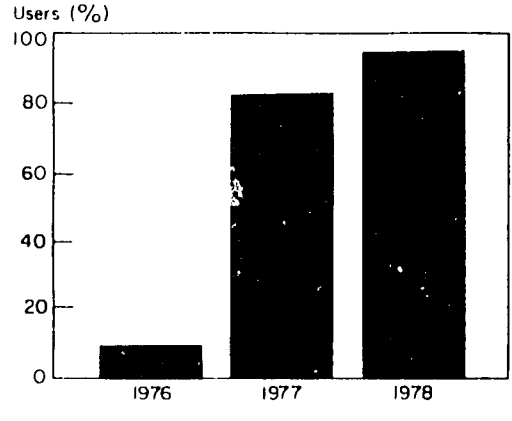
Iloilo, Philippines

The objective at Iloilo was to replace a late maturing, tall, low yielding, traditional crop with two short maturing crops. Wet seeding, a strategy to avoid the risk of insufficient rainfall for transplanting seedlings in the optimum age range, was used to establish the first crop early. Farmers managed this technique easily. For most farmers in most years, an accumulation of about 200 mm of rainfall was sufficient for wet seeding. Early drought at the vegetative stage had little effect on first crop yields. Heavy rainfall within 3 d after broadcasting often caused seed to float and collect at the leeward end of the field; but after the radicle had penetrated the soil, the very slight slope and a natural drainage network in this terrain was used to advantage to drain excess water. Weeds were controlled by puddling, high seeding rates, spot hand weeding, and herbicides. Direct dry seeding (unpuddled soil, but in bunded fields) found favor in some of the lighter texture fields and in some years. When rice was dry seeded, however, weeds were more difficult to control.

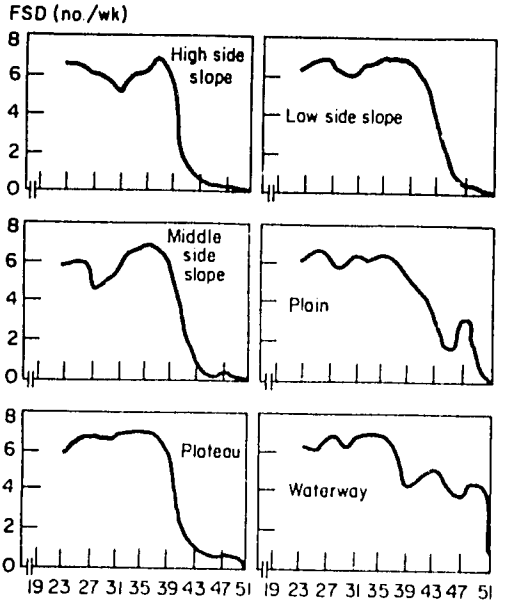
Although scientists advocated that the second crop should be transplanted to shorten its field duration and thereby avoid drought, most farmers wet seeded the second crop about 10 d before those farmers who transplanted.

When a late maturing crop was harvested in the early dry season, the traditional threshing method (by foot) was appropriate to process field-stacked sheaves over 1-2 mo. This threshing technique, however, was inadequate for an early crop, which would be exposed to rains, and when the field had to be prepared for a second crop. Power threshing quickly replaced the traditional method. The rate of power thresher adoption is shown in Figure 2.

Because it was pushed into the wet/dry season transition period, the second crop was exposed to drought and was often lower yielding than the first.



2. Thresher adoption by rainfed rice farmers in Iloilo, Philippines, 1976-78.



3. Flooded status days (FSD) for 6 heavy-textured rainfed Iloilo, Philippines, land units, weeks 19 to 51, 1976.

Double rice cropping is now commonly practiced only on low-lying terrain or where internal drainage is slow (heavy soil texture or high water table). Field water observations from 1976 illustrate differences in terrain positions (Fig.3). The significance of these water regimes on yields of the second rice crop is obvious from Table 2. On the lower fields, the second crop was successful, although neither as high yielding nor as stable as the first crop.

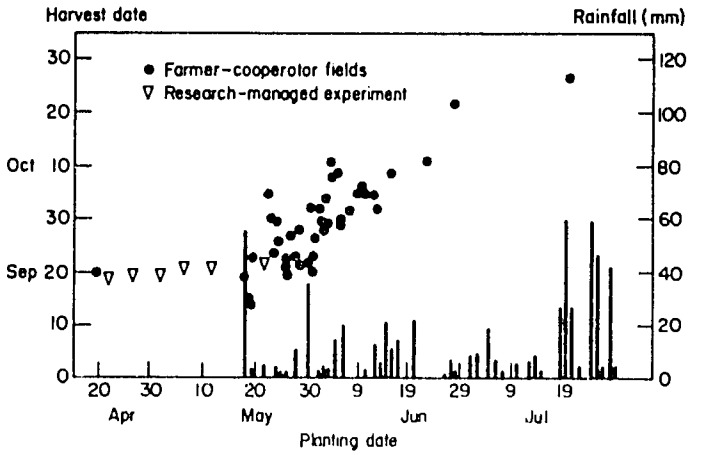
Pangasinan, Philippines

Except in a few favorably located fields where several farmers acquired the skills necessary to make the sequence work, double rice cropping was not successful. The system failed for several reasons. For the sequence to work, early direct dry seeding was necessary. However, tillage capacity was limited, and fields were prepared late, losing the advantage of early rainfall. Figure 4 shows that, although the research staff planted on experimental plots in advance of early rains, the farmers waited for rains to start before planting. The later the planting, the later the crop was harvested.

Table 2. Average yields of single- and double-cropped rice for Iloilo, Philippines, crop years 1976-77 and 1977-78, by landscape position.[a]

Crop year	Yield (t/ha)					
	Side slope		Plateau		Plain and drainageways	
	Single	Double	Single	Double	Single	Double
1976-77	5.1 (33)	5.0±1.7 (67)	5.2 (6)	5.3±2.3 (94)	4.4 (30)	5.5±3.4 (80)
1977-78	4.6 (93)	6.9±1.0 (7)	5.2 (100)	5.8±0 (0)	4.5 (31)	5.8±1.8 (69)

[a]Figures in parentheses are percentages of observations. Total observations were 45 on the side slope, 60 on the plateau, and 37 on the plain and drainageway positions.



4. Dry seeded rice planting and harvest dates in farmer-cooperator fields and in an experiment, and daily rainfall during the planting period, Pangasinan, Philippines, 1977.

Weed competition was another constraint to direct dry seeding. Chemical weed control methods advocated for direct seeding were very sensitive to soil moisture and therefore not reliable.

Even when the distribution of early rains was favorable and direct dry seeding was successful, the yield of the second crop was generally low. The more delayed the first or second planting, the lower were the yields (Table 3).

As an early rice establishment technique, wet seeding was no better than direct dry seeding. Soils, local relief, and the natural drainage system did not permit reliable control of water.

It is instructive to compare selected rainfall pattern parameters for Iloilo and Pangasinan. The parameters in Table 4 were determined from long-term daily rainfall records. In 50% of the years, Pangasinan should expect wet seasons of less than 184 d, and in 20% of the years less than 146 d, suggesting little margin for lost time, and drought for the second crop in many years. For Iloilo, 50% of wet seasons should be 205 d, and 20% should be 171 d. Obviously Iloilo was more favorable for a double rice crop sequence.

Ubon, Thailand

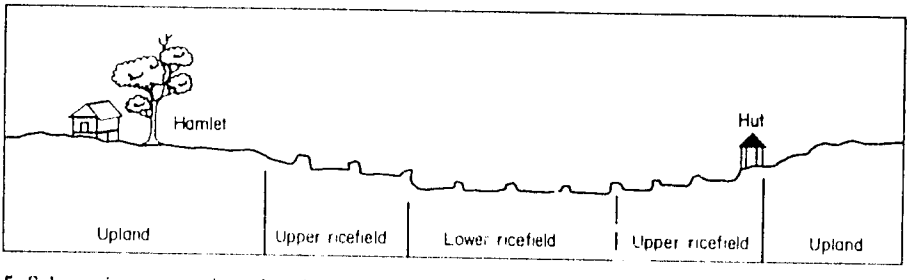
Figure 5 is a schematic cross section of the typical undulating rice-growing terrain in northeastern Thailand. For double rice cropping, low-lying fields

Table 3. Mean yields of direct dry seeded rice (first crop) followed by transplanted rice (second crop), by date of first crop seeding, Pangasinan, Philippines, 1977.

First crop	Rough rice yield (t/ha)	
	First crop	Second crop
21 May and earlier	5.3	4.0
22 May-31May	4.8	2.4
1 Jun and later	4.1	1.5

Table 4. Total days available for first and second rainfed rice crops at the Pangasinan and Iloilo cropping systems sites.

Location	Probability	Expected date of 75 mm accumulation	Expected date of 100 mm accumulation	Days (no.) available for 2 crops
Pangasinan	0.8	11 May	4 Oct	146
Pangasinan	0.5	27 Apr	28 Oct	184
Iloilo	0.8	25 May	12 Nov	171
Iloilo	0.5	9 May	10 Dec	205



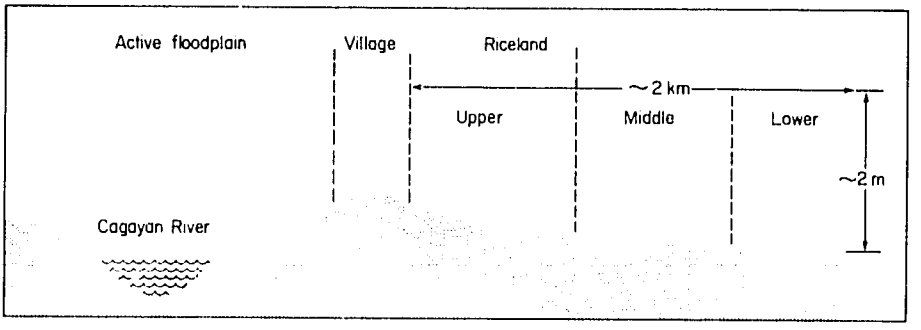
5. Schematic cross section of a mini-watershed in northeastern Thailand.

were favored. For the first crop, early maturing, photoperiod-insensitive modern varieties were direct seeded on unpuddled soil. While yields were not high (e.g., 1.4 t/ha mean from 1977 to 1979), they were sufficient to make the crop attractive to farmers. Major drawbacks to cultivation were drought, root-knot nematodes, and weeds. Root-knot nematode was a problem because fields were not submerged until late in crop development.

Yields from the second crop were generally higher (e.g., 2.3 t/ha mean from 1977 to 1979) than yields from the first crop. In many years, however, old seedlings had to be transplanted, because when the seedlings were in the optimal age range, rainfall was inadequate for puddling. Late drought was a common occurrence, and yields were not stable. In northeastern Thailand, glutinous rices are preferred. Glutinous varieties are late maturing, which increases exposure to terminal drought, and therefore lower the acceptance of double rice patterns.

Cagayan, Philippines

Figure 6 shows a cross section of the rice-growing terrain in Cagayan. To double crop rice successfully, close adherence to a planting schedule was necessary to avoid having young (recently transplanted) or old (postheading) crops in the field during the period of highest flood probability (late October, early November). With present technology, double rice cropping in this environment is not reliable. When the first rice crop was direct seeded on puddled soil in the middle stratum, short maturing rices generally could not



6. Schematic representation of landscape, cropping systems site, Cagayan Valley, Philippines.

compete with weeds. When exposed to lengthy drought, rice did not die but was sufficiently prolonged in development to delay the second crop. In the lower stratum, first crops were transplanted. Even the lower fields were often dry when seedlings were in the optimum age range. As in the middle stratum, drought frequently prolonged development, thereby forcing the reproductive stage into a period of greatest flood probability or delaying the second rice crop.

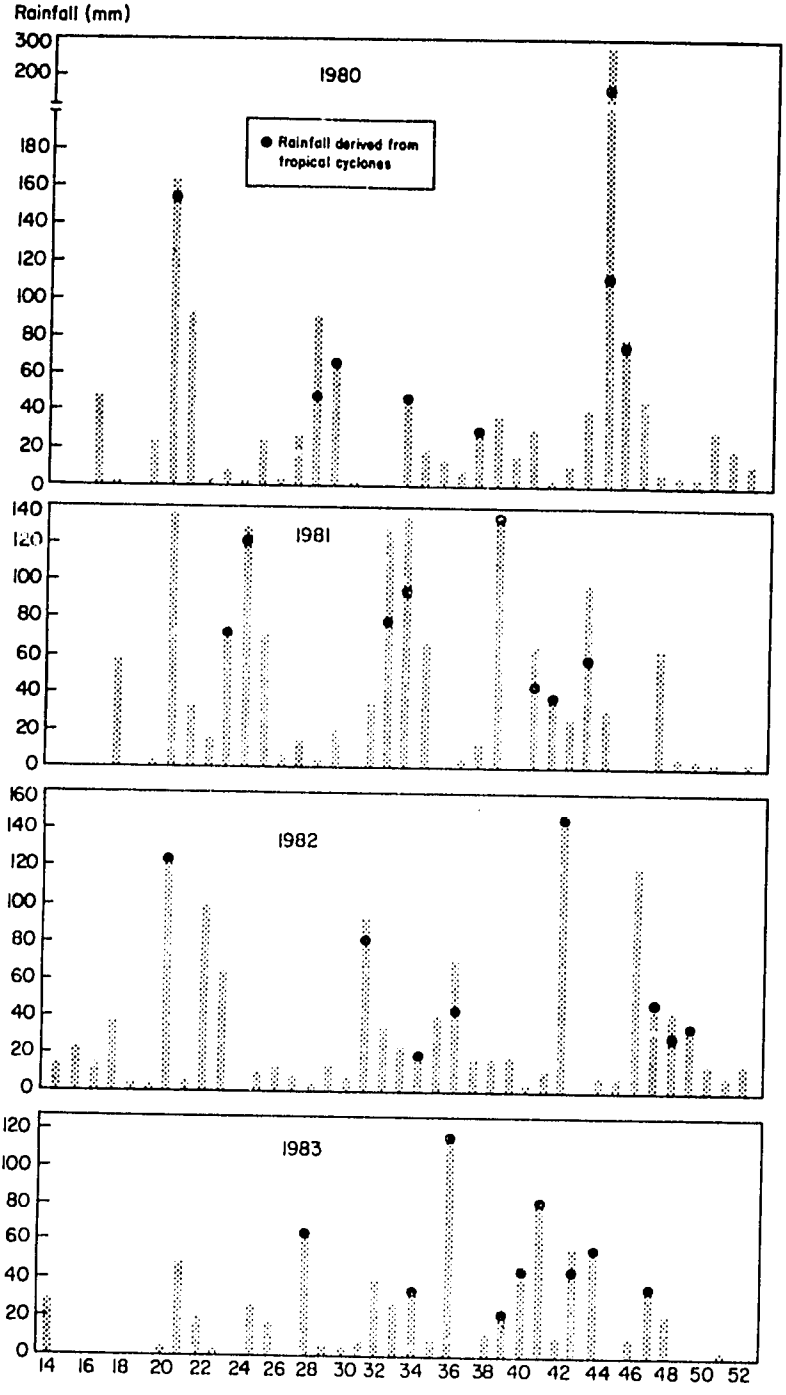
Without a means for surface drainage, and where rainfall was erratic (Fig. 7), wet seeding was not a successful technique for the first crop because water depth could not be controlled. If a dry period occurred after seeding, drought and weeds limited crop development; if rains were heavy, floods reduced plant density and tillering.

Yields of the second crop were low because dry field conditions frequently delayed transplanting, forcing farmers to plant old seedlings. However, farmers commonly transplant seedlings of traditional rices that are more than 60 d old. Figure 8 illustrates the relative insensitivity of traditional varieties to seedling age.

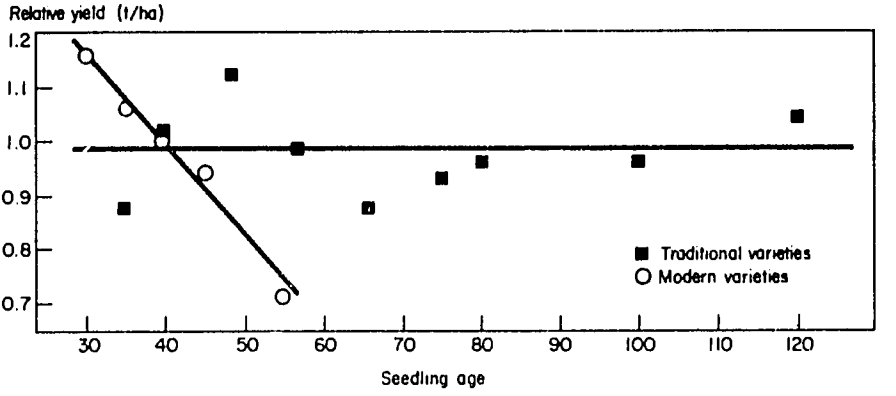
Modern varieties were often higher yielding than traditional ones. For example, yields from farmers' fields were 0.6 t/ha (n=59) in 1980 and 1.6 t/ha in 1981 (n=73). Yields from fields grown by farmer cooperators were 1.1 t/ha in 1980 (n=52) and 2.7 t/ha in 1981 (n=55). Because of their vulnerability, however, modern varieties have enjoyed only limited acceptance by farmers in this environment.

RICE - UPLAND CROP PATTERNS

Should rainfall-soil terrain complexes not combine to produce hydrologic years of sufficient duration and intensity to grow double rice sequences, sequences of rice and upland crops (R - UC) or upland crops and rice (UC - R) can be grown. Where wet season onset is abrupt and fields become saturated quickly, rice is the logical crop with which to start a sequence. Wet season onsets at three sites were rather abrupt. For this situation the objectives were



7. Uneven rainfall has contributed to the erratic performance of crops in environments similar to Solana in Cagayan, Philippines. About half the growing season rainfall is derived from tropical cyclones.



8. Grain yield of modern and traditional rice varieties expressed as ratios relative to yields from 40-d-old seedlings, Cagayan, Philippines.

to find combinations of rice varieties and establishment techniques that produce high and stable yields, but that leave adequate time for an upland crop. Furthermore, a balance must be struck between early and late upland crop establishment. If upland crops are established too early, flooding is a hazard; if too late, moisture is often inadequate for emergence or the crop encounters severe terminal drought. An important additional criterion is that the species must have good market value.

Iloilo

As in the R - R sequence, the early planted rice crop grew well. Although an early maturing variety (110 d) was commonly wet seeded, the second crop was not strongly sensitive to the way the first crop was established or to its duration, provided that the fields were ready for planting in October if rains ceased early.

The upland crop was sensitive to terrain and soil factors. Figure 3 shows how much longer water remained in lower fields (plateaus and waterways) than in upper fields (plateaus and upper and middle side slopes). Light-textured fields were less risky with respect to flooding than low-lying and heavy-textured fields.

No tillage technique (zero, minimum, and conventional) reliably promoted seed emergence. Furthermore, conventional tillage demanded power and time, and often resulted in a very cloddy seedbed so that seeds were not in good contact with the soil. On heavy-textured soils, upland crops performed poorly, but on intermediate-textured soils, growth and yields were satisfactory.

Of the upland crops tested — maize, sorghum, sweet potato, cowpea, and mungbean — the grain legumes were generally more attractive to farmers than the others. Cowpea and mungbean can escape drought because they mature earlier. They do not require N fertilizer, do not suffer from drought-induced N deficiency, and command strong market prices. Despite the less than ideal

conditions for establishment and growth of upland crops, farmers now plant greater hectarages of mungbean and other crops than in the past.

Pangasinan

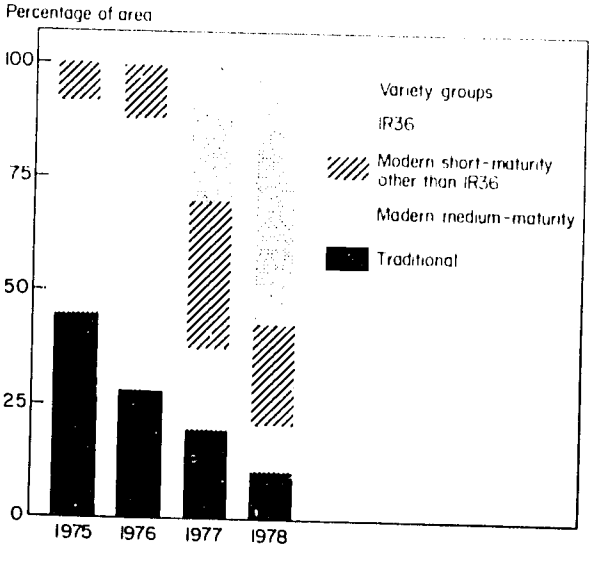
In this environment, transplanted early-maturing, modern varieties quickly replaced transplanted traditional and intermediate modern varieties (Fig. 9). Although direct seeding on unpuddled soils would have left the soil in an improved state for the following upland crop, direct seeding was rejected for the reasons presented in the section on R - R systems.

As crops to follow rice, grain legumes were preferred over coarse grains in Pangasinan for the same reasons as in Iloilo. Before the project started, farmers in the area commonly planted upland crops after rice, but after the adoption of early-maturing varieties, the second crop could be established earlier. The importance of early establishment is illustrated by Figure 10, which indicates the influence of planting delay on mungbean yield and the relationship between mungbean yield and plant density. Earlier establishment and improved insect control measures contributed to yield increases in farmers' fields.

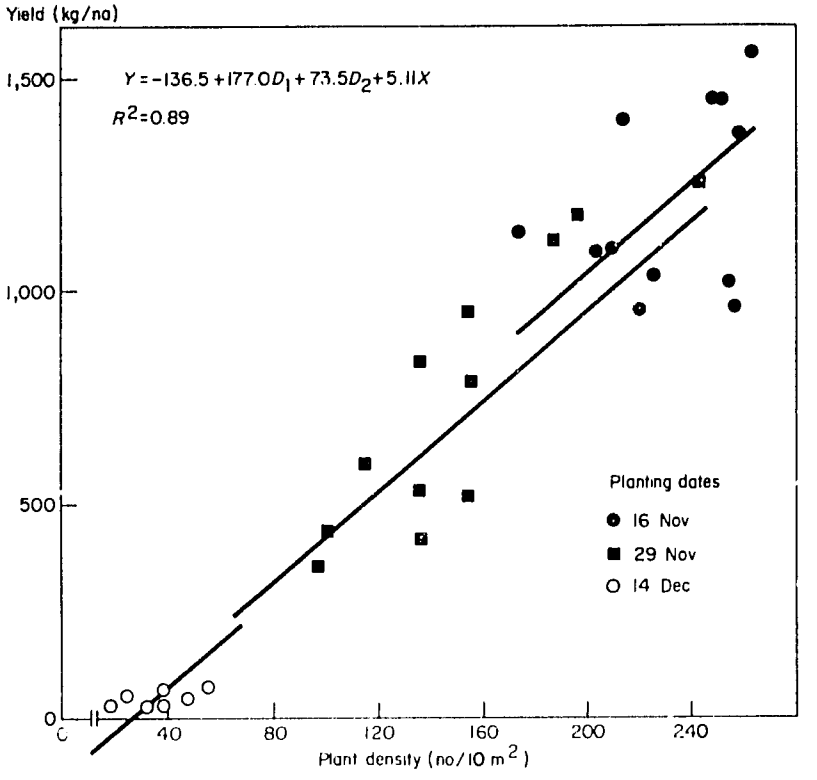
As in Iloilo, no tillage technique tested (zero, minimum, or conventional) could be relied on to give high plant populations. In instances where rains were heavy after planting, the crop benefited from conventional tillage. Conventional tillage, however, was seldom economically superior to zero or minimum tillage.

Indramayu, Indonesia

In this environment, the duration of the heaviest and most reliable rains is short, but soils are fine-textured and water flows onto ricefields from higher terrain. Critical to the R - UC pattern was the early establishment of a modern,



9. Changing percentages of Manaoag (Pangasinan, Philippines) site rice area planted to traditional, modern short-maturity, and modern medium-maturity varieties.



10. Effect of planting date on plant density and grain yield of mungbean; X is plant density and D_1 and D_2 are dummy variables for 16 Nov and 29 Nov. Pangasinan, Philippines.

early maturing rice variety. To achieve early establishment, a sowing technique (gogorancah) peculiar to north coastal Java was used to advantage. Seeds and fertilizer were dibbled into dry soil so that within 3-4 wk of emergence the crop was difficult to distinguish from a transplanted crop. Regular hill spacings enabled farmers to control weeds by traditional methods. The gogorancah technique has four advantages: it helps the rice crop to escape late drought; it reduces the hazard of early and prolonged flooding of rice seedlings; it leaves more growing time for upland crops; and, compared to puddling, it leaves the soil in better physical condition.

In this environment, rice may also be transplanted, but it should be transplanted 2 wk earlier than the usual date if upland crops are to escape severe late drought.

Constraints to upland crop production are excess moisture during the early vegetative stage and drought during the reproductive stage; when the rice crop is late or rains stop unusually early, dry surface soil reduces emergence.

UPLAND CROP - RICE PATTERNS

For environments in which the wet season onset is gradual or soils are permeable, harvest frequency can be increased by planting upland crops

before rice (UC - R). For reasonably reliable yields, the expected period between the date of earliest effective rains and the date of damaging saturation should be 75-90 d. A prerice crop should be able to cope with occasional short periods of excess moisture.

In this type of environment, by the date the first crop is ready for harvest, fields will be very wet; crop residues and late weed growth will be heavy. Rice will commonly be transplanted on puddled soils. Depending on seasonal rainfall distribution and terrain features, rice may encounter drought or flooding. Varieties and management practices must be selected with the most common local hydrologic patterns in mind.

Cagayan

Mungbean was tested as a crop to fit into a 70-d period (last half of April to end of June) in the upper stratum. Mungbean was not a new crop in the area, but farmers averaged yields less than 100 kg/ha, and failure was common. Table 5 shows the difference between traditional and cooperators' yields and high annual variation. In the CS project, an improved variety was tested at a seed rate double that of the farmers. Yields exceeded 1.5 t/ha in some fields in some years, but complete crop losses occurred in other fields when early rains were heavy. Figure 11 shows weekly rainfall plotted against the cumulative number of fields planted in 1980. Although 1980 was an extreme case, mungbean yields were often depressed by temporary flooding after short periods of high rainfall in other years, even though the fields had been planted early.

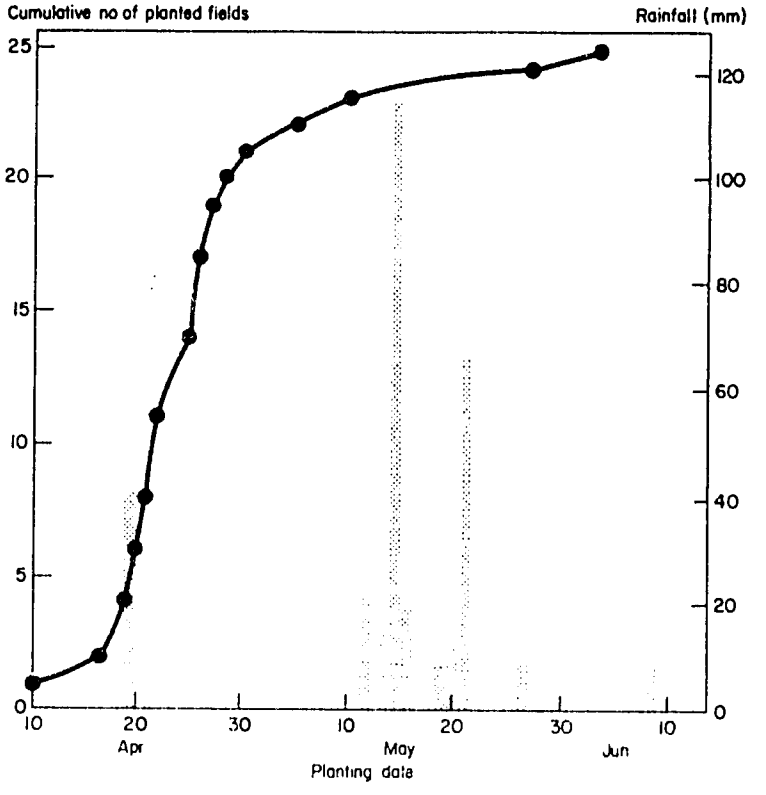
Most of the yield difference between farmers' traditional mungbean practices and those advocated by the project is attributed to the higher seed rate and therefore to greater plant density. Farmers were reluctant to plant at higher seeding rates because seeds are expensive and flood risks are high.

The rice crop was scheduled for transplanting in August or early September, but the schedule could seldom be kept because soils were too dry for field operations. Direct seeding proved unreliable because water could not be controlled. When properly established, IR46 was the best adapted modern variety. However, it did not exhibit the seedling age insensitivity of the photoperiod-sensitive traditional crops. Limitations to field operations and yields of the second crop in the UC - R pattern were similar to those of the second crop in the R - R pattern. The sensitivities of traditional and modern varieties to seedling age are compared in Figure 8. In Cagayan, traditional varieties are commonly between 50 and 80 d old when transplanted.

Table 5. Mungbean yields from local (traditional) and cropping systems project (cooperator) technologies.

Technology	Yield[a] (kg/ha)		
	1980	1981	1982
Traditional	0 (42)	67 (39)	43 (20)
Cooperators	88 (13)	472 (16)	309 (10)

[a]Figures in parentheses are number of observations.



11. Effect of rainfall on mungbean planting dates, Solana, Cagayan, Philippines, 1980.

Pimai, Thailand

Although early monsoon rainfall in this environment is relatively low, excess moisture is often detrimental to prerice crops. Legumes are preferred because they are early maturing and require only low applications of N. For reasons not identified, however, mungbean performs poorly in this environment, an observation common in northeastern Thailand. Cowpea and yardlong bean are well adapted. In favorable years, the prices of crops grown for the fresh vegetable market (green maize, yardlong bean) are subject to depressions.

Drought is a common limitation to the rice crop. Mean rice yield from 1977 to 1981 was 1.8 t/ha. When high yielding, photoperiod-insensitive varieties were grown, dry field conditions often forced delays in transplanting; yields were reduced because seedlings were kept in the seedbed beyond their optimum age. Furthermore, when the first crop was delayed or was of long duration, the vegetative development period of photoperiod-sensitive traditional varieties was often too short, reducing yields.

Ubon

UC-R patterns were grown on upper and middle fields where some degree of surface drainage was feasible (compared with Cagayan, where it was not

feasible). To reduce the excess moisture hazard further, shallow bedding was advocated. Even with these provisions, excess moisture often depressed yields and reduced the range of crop adaptation. Grain legumes were most favored as prerice crops, but vegetables were also grown for the fresh market.

Limitations encountered by farmers who planted were similar to those at Pimai, except that the frequency and intensity of drought was less severe. The mean yield of the second rice crop following an upland crop was 2.1 t/ha (1977 to 1979).

CONCLUSIONS

Cropping patterns performed well at some sites and poorly at others. In no case did the new cropping patterns work perfectly. For example, the first crop in Iloilo was high yielding and reliable, but the second crop was often exposed to drought. Under some conditions, technical innovations — such as modern photoperiod-insensitive varieties as a second rice crop in Cagayan — that were envisaged as a source of increased productivity did not perform as desired. In some cases, cultural practices necessary to exploit the innovation could not be found. For example, direct dry seeding techniques were not reliable in Pangasinan. Without a reliable method to plant an early maturing variety at the beginning of the wet season, the feasibility of a second rice crop became even more remote.

If improved, some innovations could increase the range of adaptation of the cropping patterns tested. In many of these locations, crops are introduced when field conditions are marginal for rice or for upland crops, although the field may be very favorable for a crop during another period. Innovations are needed that will help farmers get by these periods of temporary marginality. Some are suggested in the following paragraphs.

Rice - rice patterns

R - R patterns were tested in two environments. In one, wet season onset is abrupt and the first crop is most reliable (Iloilo and Pangasinan). In the other, onset is gradual and the second crop is most reliable (Cagayan and Ubon). R-R patterns can be successful in environments like Iloilo, but where combinations of rainfall and terrain factors prevent water from standing on fields for about 7 mo, yields from second crops will be low. Even in Iloilo, yields from the second crop were frequently depressed. To improve the performance of the pattern and to increase the range of its adaptation, the elapsed time between the planting of the first crop and harvest of the second must be shortened, rice varieties with earlier maturities must be available, and farmers must be able to perform operations between crops faster.

The major field operations between crops are reaping, threshing, cleaning, drying, plowing, harrowing, and sowing. Small-scale equipment has been developed to mechanize operations, but its adoption depends on many factors, including the value of time saved vs marginal costs of completing the operation. Where two crops are now a marginal proposition, selective testing

of this equipment to reduce the turnaround time could pay dividends.

These CS studies suggest two other possibilities for improving adaptation. First, varieties with better terminal drought resistance would reduce the hazard of early wet season termination. Second, research is needed to formulate suitable sequences of primary and secondary tillage operations, weed control techniques, and seed placement methods for environments where early planting on unpuddled fields is necessary to fit a second crop into the hydrologic year. Whereas labor was cheap and abundant and could cope with the gogorancah technique in Indramayu, one or more of the establishment operations may require mechanization in other locations. Furthermore, a variety that has strong seedling vigor and high yield potential is needed.

Where flooded field conditions are clearly too short for two rice crops but longer than the 100-120 d required by a single rice crop, ratooning is an option for exploiting land that cannot be immediately planted with a postrice upland crop. In the humid tropics, ratoon yields with present technology are low and erratic. Research to identify plant factors that influence ratoonability, followed by a breeding program to exploit this knowledge, could have a payoff for rice farmers in borderline R - R environments.

Where wet season onset is gradual, drought-resistant varieties are needed for the first crop to exploit the underutilized period before the main rice crop. Strong and early seedling vigor, even with reduced yield potential, is needed to cope with weeds and drought. Vigorously developing rices must be supported by reliable crop establishment and weed control techniques. Because rice grown in this situation will seldom encounter a full season of ideal weather conditions, varieties bred for this environment should be able to produce 3-4 t/ha in 105 d with a high level of reliability.

For the second rice crop in Ubon and Cagayan, cultural techniques that farmers now use should be suitable for high yielding but photoperiod-sensitive varieties with flowering dates similar to those of currently grown varieties. Retention of the photoperiod trait would confer seedling age insensitivity and reduce vulnerability to flooding during postbooting growth.

Rice - upland crop patterns

For most environments, rice cultivation does not encounter major limitations. However, research that improves the tillage-weed-control-seed-placement complex should have a payoff for environments with physical characteristics similar to those in Indramayu, but where labor is not abundant. The objective of the research would be to devise techniques that enable farmers to complete planting before fields are saturated.

To improve upland crop performance, research is needed to develop manageable methods to cope with the hazards of too much water and too little water. Higher levels of excess moisture tolerance in otherwise well adapted varieties would permit farmers to advance planting, thereby reducing the risk of inadequate surface moisture for emergence. Lower soil moisture thresholds for germination would enable farmers to delay planting, thereby reducing the risk of flooding by heavy but late rains. Tillage and/or seed placement

techniques that reduce flood damage and promote emergence from marginally moist soils would reduce production risks, increase yields, and expand the area of upland crops planted after rice.

Upland crop - rice patterns

Temporary excess moisture was the major limitation encountered by prerice upland crops. Related to this was weed competition. Weeds gained in two ways. First, saturated fields were too wet to weed. Second, many weeds were better adapted than crops to excess soil moisture. While artificial surface drainage may pay for high value crops, it is not economic for most field crops. Breeding for excess moisture tolerance offers some scope for improvement.

For rice planted after upland crops, the limitations and the possible remedies are similar to those of the second rice crop in Ubon and Cagayan.

77

RICE VARIETAL TESTING IN THE RAINFED LOWLANDS OF SOUTH AND SOUTHEAST ASIA

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The International Rice Testing Program coordinated by the International Rice Research Institute organizes, among other nurseries, one yield and one observational nursery designed to identify improved rice varieties for rainfed lowland conditions where the maximum sustained water depth does not exceed 50 cm. Results from those nurseries evaluated in South and Southeast Asian countries during 1978-83 are summarized. Varieties with tolerance for drought and submergence, and resistance to some major diseases and insects are identified. Some outstanding entries with consistent performance are IR13146-45-2, IR4819-77-3-2, IR4829-89-2, IR10781-75-3-2, IR46, BR4, BR51-282-8, IR14632-2-3, IR14753-49-2, IR8192-166-2-2-3, and IR19431-72-2. All are of medium growth duration. IR13146-45-2 combines high yield potential with some stability in yield performance. Correlation analysis of genotype rankings among locations indicated that the relative performances of the test entries at Joydebpur and Comilla in Bangladesh, Cuttack in India, and Khonkaen in Thailand are correlated.

A network for rice improvement scientists around the world was systematized in 1975 by the creation of the International Rice Testing Program (IRTP). IRTP is funded by the United Nations Development Programme and coordinated by the International Rice Research Institute (IRRI). Its main objectives are to exchange elite genetic materials from different countries and from IRRI among rice scientists around the world and to provide a testing mechanism for the breeding material generated by individual rice improvement programs. This multicountry cooperative program also provides an opportunity for identifying genetic donors for resistance to various biological, physical, and chemical stresses and to monitor genetic variation in the major pathogens and insects that threaten rice production.

The international nurseries are broadly grouped into two categories: target environment nurseries and stress screening nurseries. The target environments for which the nurseries are composed and tested include irrigated and rainfed. The rainfed category includes upland, lowland (shallow water), deep water, floating rice, and tidal wetlands.

The rainfed lowland nurseries are designed to provide a mechanism for the exchange, evaluation, and identification of superior breeding lines and

varieties for a wide range of shallow water conditions with the maximum sustained depth not exceeding 50 cm. Barker and Herdt (1) estimated that a third of the world rice area and about half of the rice area in South and Southeast Asia represent those conditions. The subcategories recognizable within rainfed lowland rice areas for varietal improvement research purposes include favorable, drought-prone, drought- and submergence-prone, submergence-prone, and medium-deep waterlogged (2). Thus, the major varietal requirements in consideration of all these different categories of rainfed shallow water conditions include a combination of some of the following traits:

- early to medium or late duration (photoperiod sensitivity in some situations);
- semidwarf to intermediate plant height;
- tolerance for drought;
- tolerance for submergence;
- tolerance for water stagnation and associated problems; and
- resistance to major biological stresses.

TEST SITES AND MATERIALS

The International Rainfed Lowland Rice Observational Nursery (IRLRON) was initiated in 1978, and the yield nursery (IRLRYN) in 1981. The nurseries were redesignated in 1983 as the International Rainfed Rice Shallow Water Observational Nursery (IRRSWON) and the International Rainfed Rice Shallow Water Yield Nursery (IRRSWYN) to indicate clearly that the testing

Table 1. Test sites in South and Southeast Asia that evaluated the International Rainfed Lowland Rice Yield and Observational Nurseries, 1978-83.

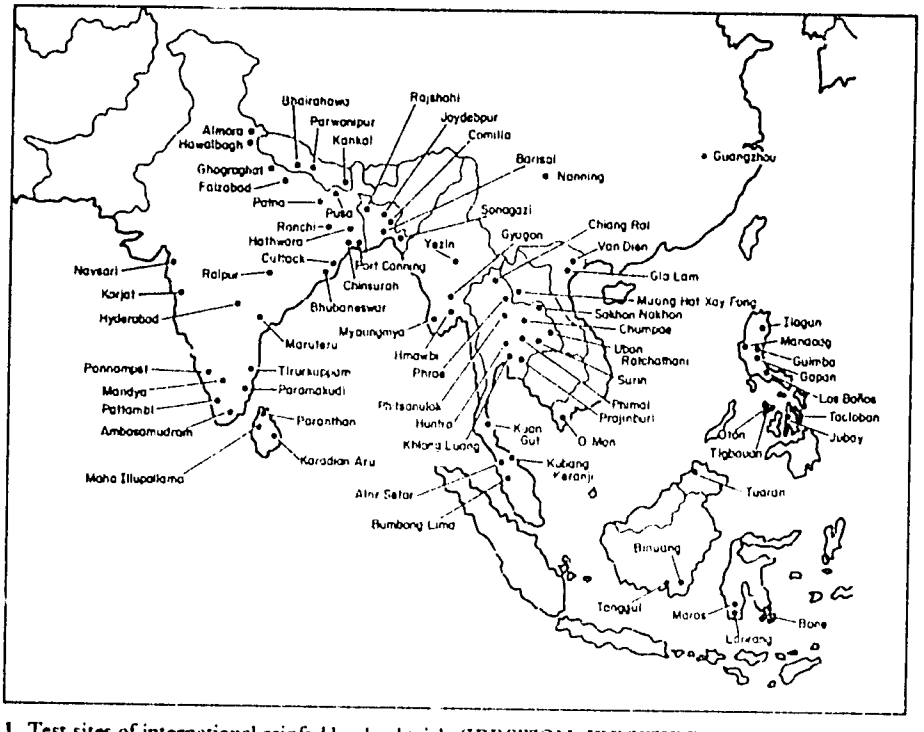
Country	Test sites
	Southeast Asia
Burma	Gyojon, Hmawbi, Myaungmya, Yezin
Indonesia	Bimrang, Bone-Bone, Lamrang, Maros, Tanggul
Laos	Muong Hat Xay Fong
Malaysia	Alor Setar, Bumbong Lima, Kulving, Keranji, Tuaran
Philippines	Gapan, Guimbu, Ilagan, Juluy, Los Banos, Manaoag, Oton, Tacloban, Tigbauan
Thailand	Chiang Mai, Chumpae, Huntra, Khlong Luang, Kuan Gut, Phitsanulok, Phrae, Pimai, Prajinburi, Sakhon Nakhon, Surin, Ubon Ratchathani
Vietnam	Gia Lam, O Mon, Van Dien
	South Asia
Bangladesh	Barisal, Comilla, Jovdebpur, Rajshahi, Sonagazi
India	Almora, Ambusamudram, Bhubaneswar, Chinsurah, Cuttack, Faizabad, Ghograghat, Hathwara, Hawalbagh, Hyderabad, Karjat, Mandya, Maruteru, Navsari, Paramakudi, Patna, Pattambi, Ponnampet, Port Canning, Pusa, Raipur, Ranchi, Tirurkuppam
Nepal	Bhairahawa, Kanker, Parwanipur
Sri Lanka	Karadian Aru, Maha Illupallama, Paranthan

situations for these nurseries would be such that the maximum sustained water depth does not exceed 50 cm. The test sites and cooperating scientists for the trials conducted from 1978 to 1983 in South and Southeast Asia are indicated in Tables 1 and 2. The sites are also shown in Figure 1.

The test materials consisted of semidwarf and intermediate-statured lines with a wide range of maturity and were predominantly photoperiod-insensitive. Most were from IRRI; the remainder were mainly from the

Table 2. Cooperators of the International Rainfed Lowland Rice Yield and Observational Nurseries evaluated in South and Southeast Asia, 1978-83.

Country	Cooperators
	Southeast Asia
Burma	Soe Hlaing, Saw Stanley, Kin Wa Win
Indonesia	S. Bachrein, K. Brown, L. Sjuaib, Sriwidodo, S. Sulaiman
Malaysia	Latifah Ahman, Lim Koon Hup, Alias Bin Ismail, Guok Hup Ping, C. T. Tseu, J. Varughese
Philippines	F. L. Andres, J. Into, R. J. Lara, M. Maguling, N. Ochea, N. Seno
Thailand	P. Bhekasut, C. Boonwite, B. Chaiwatana, L. Chankasem, B. Jongdee, P. Kaenza, W. Khumlekhasing, P. Kongohakote, K. Kupkanchanakul, T. Kupkanchanakul, S. Noonim, A. Panditwongse, P. Panditwongse, V. Petpisit, P. Pornraisanit, M. Potisurintara, S. Rachataserikul, B. Ruangsook, S. Seewisut, V. Sompaew, R. Sukhtep, V. Suwannavong, S. Tangchoopong, P. Vajanapoom
Vietnam	L. T. Duong, N. T. Gai, N. D. Giao, N. D. Khoi, N. V. Luat, T. N. Nguyen, D. N. Thanh, D. T. Tuan
	South Asia
Bangladesh	M. S. Alam, L. Ali, M. K. Bashar, A. Bhowmik, T. Das, S. B. A. Dewan, M. U. Ghani, M. A. Hamid, M. M. Haque, M. U. Haque, M. A. Islam, M. R. Islam, M. A. Kabir, N. M. Miah, M. A. A. Miah, P. K. Saha Roy, M. A. Yussouf
India	L. Acharya, L. Anavaradham, S. T. Bhakta, S. Biswas, R. C. Chaudhary, V. S. Chauhan, S. A. Chavan, S. R. Das, S. C. Dash, R. N. De, A. A. Devarathinam, S. R. Dhua, Y. S. Jadhav, K. I. James, B. C. Jena, T. A. Khan, S. B. Kharat, S. Kumaraswamy, M. Mahadevappa, C. N. Mall, E. H. Mallick, S. Mallik, T. Mallikarjunaiah, A. M. Mandokhot, L. S. Mani, W. W. Mamiel, D. M. Maurya, R. K. Mishra, C. Misra, N. K. Mitra, H. K. Mohanty, D. Muhkopadhyay, B. S. Naidu, G. C. Nayak, G. Nijaguna, K. D. Patel, V. H. Patil, S. C. Prasad, Y. Prasad, C. Bhaskara Rao, G. Babu Rao, A. Roy, J. K. Roy, Md. Safique, V. N. Sahai, S. P. Sahu, S. Saran, D. K. Sharma, A. K. Singh, B. N. Singh, K. J. P. Singh, M. P. Singh, R. S. Singh, B. N. Sinha, S. K. Sinha, T. S. Sinha, J. P. Tandon, R. Thakur, J. B. Tomar, P. A. Varkey
Nepal	G. Acharya, B. Adhikary, R. K. Agrawal, M. R. Bhatta, G. Chaudhary, S. Devkota, K. P. Dhungana, S. B. Mathema, R. Sahu, D. Sakya, B. B. Shahi, S. K. Shakya, S. P. Singh, B. S. Thapa, S. J. Yadav
Sri Lanka	S. Arumugam, P. Markandan, S. Rasanayagam, S. Raveendranath, R. Srilingan, P. Yogaratnam



1. Test sites of international rainfed lowland trials (IRRSWON, IRRSWYN), 1978-83.

breeding programs of Bangladesh, India, Indonesia, and Thailand. The check varieties included were Mahsuri, Pelita I-1, IR34, and IR46. The numbers of entries and locations that returned data are listed by year and nursery in Table 3.

The entries in the observational nurseries were grown in one or two rows of unreplicated plots, and the yield nurseries were laid out in a randomized complete block design with three replications. Plot size, hill spacing, fertilizer rates, insecticide applications, and other cultural practices appropriate to

Table 3. Test entries, participating countries, and data returns for IRRSWYN and IRRSWON, 1978-83.

Nursery	Year	Entries (no.)	Participating countries (no.)	Sites (no.) that returned data
1st IRRSWON	1978	261	13	26
2d IRRSWON	1979	250	14	32
3d IRRSWON	1980	229	13	32
4th IRRSWON	1981	135	10	21
1st IRRSWYN	1981	19	4	11
5th IRRSWON	1982	120	13	28
2d IRRSWYN	1982	30	10	19
6th IRRSWON	1983	144	8	22
3d IRRSYN	1983	29	5	21

individual test sites were followed. The nurseries were planted to coincide with the rice cropping season in each area where they were evaluated. Most trials were transplanted.

The observational nurseries evaluated such traits as plant height, days to flowering, phenotypic acceptability, tolerance for drought and submergence, and resistance to major insects and diseases. In the absence of yield evaluation, the phenotypic acceptability ratings provided the first approximation of varietal suitability for different situations. Data for the yield nurseries were the same except that, instead of phenotypic ratings, actual yield measurements were taken in a replicated trial. For both yield and observational nurseries, several cooperators gave information on rainfall during the crop season and on status of water regime in the experimental plots at different growth stages.

OBSERVATIONAL NURSERIES

The entries that received high phenotypic acceptability ratings each year are summarized in Table 4. Seven were rated good in more than one year's tests: IR4819-77-3-2, IR4829-89-2, IR13146-45-2, IR15853-89-7E-P3, IR19083-22-2-2, IR21141-24-2, and IR46. All entries were of medium growth duration. IR4829-89-2 showed tolerance for drought as well as submergence The major parents involved in the promising lines include IR24, IR20 BG90-2, and *Oryza nivara*. IR24 is one of the parents of IR46, which was among the consistently good performers; several of the IR46 derivatives gave above average to good performance in trials over different years.

Table 4. Entries in the 1978-84 IRRSWON that received good phenotypic ratings by year.[a]

Year	Growth duration	Entries with broad phenotypic acceptability
1978	medium	IR5677-17-3-1
1979	medium	IR14632-181-1, IR14753-49-2, IR14753-66-3, IR14753-133-2, IR4215-301-2-2-6, IR4819-77-3-2, Nam Sagui
1980	medium	BR10, BR51-282-8, IR10781-75-3-2, IR13146-41-3, IR13146-45-2-3, IR13564-95-1, IR4819-77-3-2, IR4829-89-2, Mahsuri, Pelita I-1
1981	early	IR3880-10, IR8608-82-1-3-1-3, IR9698-16-3-3-2
	medium	IR13146-13-3-3, IR13257-46, IE-P1, IR14497-15-2, IR14753-86-2, IR14875-98-5, IR2987-13,1, IR46, IR4819-77-3-2, IR4829-89-2, IR9852-22-3
1982	medium	IR13146-45-2-3, IR15853-89-7E-P3, IR19083-22-2-2, IR19256-88-1, IR21141-24-2, IR46
1983	medium	IR15853-89-7E-P3, IR21037-2-1-2E-P1, IR21567-16-3, IR21567-18-3-1, IR4828-89-2, IR54, RP975-109-2
1984	early	IR5853-198-1-2, IR21567-18-3-1
	medium	IR21836-90-3, IR13146-45-2-3, IR21141-24-2, IR21567-16-3, IR28941-164-1-5, IR31429-14-2-3, IR46

[a]Underscored entries are among the best in more than one year's entries.

Entries that were given phenotypic scores of 1 to 3 in 45% or more of the 22 trials in the 1983 IRRSWON were IR21037-2-1-2E-P1, B981D-SI-35-1, IR21567-18-3-1, RP975-109-2, BR51-282-8, IR4329-89-2, IR54, Mahsuri, IR21836-90-3, and IR34.

The trials were exposed to different stresses at different locations and years. Entries that were rated good under some such situations follow:

- The 1980 nursery at Barisal, Bangladesh, was under tidal submergence during the growing period, with water level ranging from 15 cm to 1 m. Most entries scored 7 to 9. The best score of 3 was given to IR4819-77-3-2 and IR4829-89-2.
- At Port Canning, India, where the 1980 nursery experienced submergence and soil stresses, the only entries rated good were CR1009, CR1023, IR4829-89-2, IR8192-166-2-2-3, IR13646-55-1, and Mahsuri.
- Three days after transplanting, the water level suddenly rose to 25 cm in the 1980 trial at Pusa, India, and within a month the level reached 75 cm. The entries rated good under those conditions were BR51-282-8, IR8073-65-6-1, IR4568-86-1-3-2, IR9288-B-B-244-2, RP6-516-33-1-1, IR10198-66-2, IR10781-75-3-2, IR13365-253-3-2, IR13419-13-1, and IR13564-95-1.
- Entries that showed more than 50% survival in the 1980 trial at Vytilla, India, where throughout the early growth stage the crop was under 30 cm, were IR4829-89-2, IR9830-26-3-2, RD15, DW170, IR2039c-Kn-7-2-5-3-1, C1117-2, KAU2019, CR14[illegible]244-198, and IR9288-B-B-B5-2.
- At the Rajshahi, Bangladesh, 1981 trial, the newly planted crop was briefly submerged, and drought occurred during the whole period of the booting and flowering stages. Entries rated good were Addey, BR111-140-1-1, IR10781-143-2-3, IR13564-95-1, IR14753-86-2, IR15853-89-7E-P3, IR19083-22-2-2, IR19256-88-1, IR19431-72-2, IR4819-77-3-2, and IR4829-89-2.
- In the 1981 trial at Ranchi, India, drought occurred during the period of panicle initiation to flowering. The entries that were rated good for phenotypic acceptability were IR10781-143-2-3, IR13369-86-2-2, and IR4829-89-2.

The appropriateness of plant height, growth duration, and other relevant traits of the test entries to individual situations determined the frequency of entries rated good at any given location. More than 60% of the entries were given scores of 1-3 at Phitsanulok in Thailand and Kubang Keranji in Malaysia, whereas almost none to very few entries were given those scores at Joydebpur and Comilla, Bangladesh; Cantho, Vietnam; Ujung Pandang, Indonesia; and Karjat, Faizabad, and Bankura, India (Table 5).

YIELD NURSERIES

The yield nursery entries numbered 19 in 1981, 30 in 1982, and 29 in 1983. They included one local check and the common check Mahsuri, a popular japonica/indica derivative of moderately tall stature. Data were received from 11 locations in 4 countries in 1981, 19 locations in 10 countries in 1982, and 21

Table 5. Frequency distribution of phenotypic acceptability scores of entries in selected Rainfed Lowland Observational Nurseries (IRRSWON).

Location	Year	Frequency of phenotypic scores of					
		1-3		4-6		7-9	
		Entries (no.)	% of total	Entries (no.)	% of total	Entries (no.)	% of total
		Southeast Asia					
Yezin, Burma	1980	133	59.4	88	39.3	3	1.3
Ujung Pandang, Indonesia	1980	17	7.6	207	92.4	0	0.0
Kubang Keranji, Malaysia	1982	75	62.5	26	21.7	19	15.8
Kedah, Malaysia	1982	15	12.6	53	44.5	51	42.9
Guimba, Philippines	1982	55	57.9	23	24.2	27	17.9
Chumpae, Thailand	1982	22	19.3	51	44.7	41	36.0
Phitsanulok, Thailand	1982	82	69.5	24	20.3	12	10.2
	1983	103	70.5	13	8.9	30	20.6
Phrae, Thailand	1983	11	7.5	119	81.5	16	11.0
Khonkaen, Thailand	1983	18	12.3	58	39.7	70	48.0
Khlong Luang, Thailand	1983	21	16.9	74	59.7	29	23.4
Kuan Gut, Thailand	1983	29	19.8	95	65.1	22	15.1
Cantho, Vietnam	1982	16	14.0	96	84.2	2	1.8
	1983	6	6.1	92	93.9	—	0.0
		South Asia					
Barisal, Bangladesh	1982	—	0.0	26	21.8	93	78.2
Joydebpur, Bangladesh	1982	—	0.0	50	43.1	66	56.9
	1983	—	0.0	51	35.7	92	64.3
Comilla, Bangladesh	1983	2	1.4	138	94.5	6	4.1
Rajshahi, Bangladesh	1982	5	4.3	72	61.5	40	34.2
	1983	64	47.5	71	50.7	5	3.6
Ranchi, India	1982	29	24.2	38	31.7	53	44.2
	1983	43	32.1	45	33.6	46	34.3
Karjat, India	1982	4	4.0	52	52.5	43	43.4
Faizabad, India	1982	6	5.7	33	31.1	67	63.2
Pusa, India	1982	21	18.6	40	35.4	52	46.0
	1983	20	13.7	40	27.4	86	58.9
Patna, India	1983	45	34.4	24	18.3	62	47.3
Bankura, India	1983	4	3.1	63	48.1	64	48.8
Parwanipur, Nepal	1983	51	34.9	95	65.1	—	0.0

locations in 5 countries in 1983. The data on grain yield and ancillary characteristics from those trials based on means over selected locations — trials with more than 30% CV for grain yield were excluded — are given by year in Tables 6, 7, and 8.

The selected test sites for the 1981 IRRSWYN included four from the Philippines, three from Thailand, and one each from Bangladesh, Burma, and Nepal (Table 6). The experimental mean yields ranged from 1.9 t/ha at Jubay, Philippines, to 5.4 t/ha at Phrae, Thailand. The varietal mean yields ranged from 2.5 t/ha for IR9129-192-2 to 3.8 t/ha for IR14632-2-3. Plant height ranged from 86 cm for IR9129-192-2 to 132 cm for Mahsuri. Days to flowering ranged from 78 d for IR9129-192-2 to 108 d for IR13358-85-1-3. The poor performance of IR9129-192-2 is obvious both from its shortest growth duration and shortest plants. Most entries flowered between 95 and 105 d, and plant height was between 100 and 116 cm. The entries that produced the highest overall yields were IR14632-2-3, IR14753-49-2, BR4,

IR13146-45-2-3, BR51-282-8, IR10781-75-3-2, IR46, and IR4819-77-3-2. All these are of medium growth duration; BR4, with intermediate plant stature, is taller than the others.

The selected sites for the 1982 IRRSWYN included two each from Bangladesh, Malaysia, and Philippines, and one each from Burma, India, Nepal, and Thailand. The site means for grain yield ranged from 2.2 t/ha at Bhairahawa, Nepal, to 5.1 t/ha at Tuaran, Malaysia. The varietal mean yields ranged from 2.4 t/ha for IR9129-192-2 to 4.1 t/ha for IR8192-166-2-2-3. Plant height varied from 80 cm for BPT3291 to 125 cm for CN540. Days to flowering varied from 85 d for IR9129-192-2 to 116 d for IR13358-85-1-3. The entries that produced the overall highest yields were IR8192-166-2-2-3, BR4, IR46, IR13146-45-2-3, IR14632-2-3, and IR14753-49-2.

The 1983 IRRSWYN had six test locations in Thailand, three in Nepal, and two each in Bangladesh, India, and the Philippines. The trial mean yields ranged from 1.5 t/ha at Chumpae, Thailand, to 4.7 t/ha at Khonkaen, Thailand. The varietal mean yields varied from 2.4 t/ha for IR18599-68-1 to 3.3 t/ha for IR19431-72-2. Days to flowering varied from 92 d for IR18599-68-1, which produced the lowest yields, to 188 d for RP975-109-2, which ranked second in overall mean yield. The entries that produced the highest mean yields were IR19431-72-2, BR4, RP975-109-2, Cisadane, IR10781-75-3-2-2, IR13146-45-2-3, IR14632-2-3, and IR4819-77-3-2.

Yield performance over three years

The entries that were among the top 5 ranks in all 3 yr were IR14632-2-3, IR13146-45-2-3, and BR4. The entries that were among the top five for at least 2 of the 3 yr were IR46, IR14753-49-2, IR10781-75-3-2-2, and IR4819-77-3-2. IR19431-72-2, which ranked first in 1983, was tested only in that year.

Entries among the top three for yield at selected locations in 1981-83 trials are listed in Table 9.

Yield performance in specific tests

At Sakhon Nakhon, Thailand (1981 IRRSWYN), where soil pH was 4.5, total rainfall was 933 mm, and fertilizer applied was 37N-25P-15K, the trial mean yield was 2.0 t/ha and Mahsuri produced the highest yield. None of the entries were statistically on par with Mahsuri.

At Phitsanulok, Thailand (1981 IRRSWYN), where soil pH was 5.5, total rainfall was 833 mm, and fertilizer applied was 76N-38P-38K, the mean yield was 4.5 t/ha, and IR13146-45-2-3 produced the highest yield. Second ranking UPL Ri-3 was not statistically different from IR13146-45-2-3.

The trial site at Kankai, Nepal, was a sandy loam with pH around 6.0. The 1981 IRRSWYN was seeded late as well as transplanted with 40-d-old seedlings due to late rains. The mean yield of the trial was 2.1 t/ha. IR9129-192-2, which was distinctly earlier than the remaining entries (growth duration shorter than the site mean by 25 d), produced the highest yield along with IR8192-166-2-3, a medium-duration line.

The 1982 IRRSWYN at Ranchi, India, experienced a long drought a month after transplanting, and several long-duration varieties were severely affected.

Table 6. Summary of grain yield, days to flowering, and plant height of entries in 1981 IRRSWYN.[a]

Entry	Yield (t/ha)										Mean	Rank	Av no. of days to flowering	Av plant height (cm)
	Burma	Philippines				Thailand			Bangladesh	Nepal				
	1	2	3	4	5	6	7	8	9	10				
BIET452 (RAU19-313-3-2)	4.4	3.4	1.6	2.3	2.4	5.3	2.0	3.3	1.9	1.8	2.8	18	98	127
BR4	4.2	4.7	2.1	3.0	3.5	5.8	2.3	5.1	3.1	2.1	3.6	3	102	116
BR51-282-8	4.3	4.3	2.2	3.7	3.1	5.7	2.3	4.2	3.3	2.0	3.5	5	95	106
C168	2.2	4.1	1.2	3.6	2.7	5.4	1.8	5.0	2.5	2.0	3.0	16	98	108
IR10781-75-3-2	4.1	4.0	1.3	3.5	3.6	5.9	2.1	4.3	3.6	2.5	3.5	5	101	100
IR13146-45-2-3	3.9	4.3	2.2	3.5	3.0	5.7	2.0	6.0	3.3	2.2	3.6	3	100	108
IR13358-85-[illegible]3	4.4	4.4	2.2	2.3	3.7	5.1	1.8	5.2	3.2	1.7	3.4	9	106	98
IR13365-253-3-2	4.0	4.8	2.1	2.5	2.6	5.2	2.0	4.6	2.8	1.8	3.2	13	105	102
IR14632-2-3	4.2	4.5	2.3	4.1	4.5	6.2	2.0	4.3	3.3	2.3	3.8	1	99	103
IR14753-49-2	3.9	4.4	3.1	4.4	4.1	5.8	2.0	4.3	2.8	2.1	3.7	2	97	109
IR46	3.5	4.6	2.2	3.8	3.9	6.2	2.1	4.7	2.6	1.7	3.5	5	94	100
IR4819-77-3-2	4.6	4.4	2.0	4.1	2.7	4.9	2.1	4.1	3.7	2.2	3.5	5	97	105
IR52	3.7	4.4	2.4	4.3	3.7	4.9	1.9	4.5	2.6	1.9	3.4	9	90	93
IR8192-166-2-2-3	3.5	4.1	0.8	3.4	2.8	6.0	2.0	4.6	3.8	2.7	3.4	9	107	109
IR9129-192-2	1.9	3.0	2.4	3.6	3.1	3.9	1.2	1.9	1.4	2.7	2.5	19	78	86
UPL Ri-3	2.9	4.1	1.5	4.1	3.0	4.9	1.6	5.3	1.9	2.0	3.1	15	94	116
UPL Ri-5	2.5	3.0	1.0	4.0	3.4	4.3	1.7	4.8	2.1	2.2	2.9	17	92	115
Mahsuri	3.8	4.0	1.9	2.7	2.4	5.8	2.5	4.3	2.9	1.9	3.2	13	103	132
Local check	3.9	3.2	1.9	4.5	2.9	4.8	1.9	4.6	3.1	2.1	3.3	12	97	110
Av. yield	3.7	4.1	1.9	3.5	3.2	5.4	2.0	4.5	2.8	2.1				
Rank	4	3	10	5	6	1	9	2	7	8				
CV (%)	13.5	13.9	21.0	13.0	18.9	12.5	6.4	11.4	10.7	13.6				
LSD (5%)	0.8	0.9	0.7	0.8	1.0	1.1	0.2	0.8	0.5	0.5				
Av days to flowering	98	95	86	93	74	102	108	95	111	112				
Rainfall (cm)	170	71	25	59	64	35	93	83	91	181				

[a]Test sites are indicated by numbers below each country. 1 = Hmawbi, 2 = Guimba, 3 = Jubay, 4 = Oton, 5 = Gapan, 6 = Phrae, 7 = Sakhon Nakhon, 8 = Phitsanulok, 9 = Joydebpur, 10 = Kankai.

Table 7. Summary of grain yield, days to flowering, and plant height of entries in 1982 IRRSWYN.[a]

Entry	Yield (t/ha)												Av no. of days to flowering	Av plant height (cm)
	Burma	Malaysia		Philippines		Thailand	Bangladesh		India	Nepal	Mean	Rank		
	1	2	3	4	5	6	7	8	9	10				
BPT3291	—	4.7	5.4	—	4.9	3.1	3.9	4.0	2.7	1.7	3.8	7	100	84
BR4	3.6	4.4	5.1	2.5	5.2	3.3	5.2	3.5	2.6	3.1	4.0	2	104	112
BR51-282-8	2.7	4.0	5.4	2.1	5.7	3.7	4.7	3.1	2.4	2.6	3.7	10	95	108
CNM539	2.1	—	4.8	1.0	3.0	3.3	3.7	2.7	2.5	2.0	2.7	29	110	122
CN540	3.2	2.4	4.8	0.6	3.9	3.0	5.1	3.3	2.1	2.2	3.1	24	111	136
CR1006	3.7	3.8	5.3	—	6.4	3.9	4.5	—	2.1	0.3	3.8	7	108	100
C168	1.4	2.8	5.1	2.7	6.0	2.8	4.3	2.7	2.5	2.6	3.2	20	98	106
IR10781-75-3-2	—	3.8	4.8	2.7	5.3	3.5	4.6	3.0	2.7	3.2	3.7	10	102	100
IR13146-45-2-3	3.5	3.4	5.3	5.0	5.2	2.9	4.5	3.4	2.1	2.2	3.9	4	111	88
IR13358-85-1-3	3.5	2.7	3.7	3.8	4.9	3.0	4.9	4.0	2.7	2.3	3.6	16	111	96
IR13365-253-3-2	—	4.5	5.2	3.8	4.8	3.1	4.3	3.6	2.2	2.2	3.5	18	110	100
IR13427-45-3-1-2-2-2	—	2.8	4.6	4.8	4.2	3.3	3.8	2.0	1.9	1.4	3.1	24	88	81
IR13429-130-2	1.9	3.2	4.6	3.4	4.7	3.3	3.3	2.6	2.1	2.1	3.1	24	83	84
IR14632-2-3	—	5.1	4.3	3.7	5.5	3.4	4.4	3.1	2.8	2.3	3.9	4	100	102
IR14753-49-2	3.1	4.5	5.5	2.9	5.2	3.1	4.5	3.4	3.2	2.7	3.9	4	101	97
IR19672-54-1-3-[illegible]-1	3.1	3.5	4.4	2.7	5.2	2.7	4.3	2.7	1.9	2.1	3.1	24	101	97
IR21836-90-3	3.5	3.2	5.1	3.2	4.8	3.1	4.6	3.1	2.6	2.7	3.6	16	106	102

IR24594-272-2-2	—	4.2	5.4	3.6	5.3	3.3	4.4	3.3	2.5	2.1	3.7	10	109	103
IR46	2.5	4.9	4.5	5.0	6.7	3.7	4.2	3.0	1.9	2.5	4.0	2	96	102
IR4819-77-3-2	—	4.3	5.4	1.5	5.4	3.6	4.7	4.0	2.5	2.7	3.8	7	98	107
IR52	2.6	4.6	6.3	3.1	5.2	3.3	3.8	2.7	1.9	2.5	3.7	10	90	84
IR8192-166-2-2-3	3.5	4.5	4.1	3.8	5.8	3.5	4.3	4.6	3.2	2.0	4.1	1	107	108
IR9129-192-2	1.1	2.4	—	1.8	3.3	3.4	2.6	1.9	2.5	1.6	2.4	30	80	85
RP975-109-2	3.2	3.4	6.8	2.3	5.2	3.6	3.0	2.3	2.0	2.8	3.2	20	107	96
R114-2-1-1-1	3.5	3.4	5.1	2.1	5.1	—	4.7	3.4	2.9	2.3	3.7	10	112	94
R9-1-6-1-3-7-7	—	2.9	4.2	1.7	4.2	—	2.9	2.5	2.5	2.4	3.0	28	111	89
UPL Ri-3	—	2.8	5.2	1.9	4.9	3.0	3.9	2.7	2.7	2.1	3.2	20	95	114
UPL Ri-5	1.5	2.8	6.3	1.9	5.6	3.1	4.0	2.1	2.7	2.4	3.3	19	92	113
Mahsuri	3.1	1.9	4.2	1.2	3.7	3.5	4.6	3.4	2.7	2.1	3.2	20	104	130
Local check	2.7	2.1	6.0	4.9	5.0	3.2	5.1	3.6	2.5	2.2	3.7	10	101	111
Av yield	2.8	3.6	5.1	2.8	5.0	3.3	4.2	3.1	2.5	2.2				
Rank	8	4	1	8	2	6	3	7	10	11				
CV (%)	16.8	12.1	11.5	17.5	16.2	10.9	11.9	12.2	8.7	17.3				
LSD (5%)	0.9	0.7	1.2	0.8	1.3	0.6	0.8	0.6	0.3	0.6				
Av days to flowering	103	100	91	97	100	86	111	116	100	119				
Rainfall (cm)	67	95	78	194	15	73	47	65	84	161				

[a]Test sites are indicated by numbers below each country. 1 = Hmawbi, 2 = Kubang Keranji, 3 = Tuaran, 4 = Los Baños, 5 = Guimba, 6 = Chumpae, 7 = Comilla, 8 = Joydebpur, 9 = Karjat, 10 = Bairahawa.

Table 8. Summary of grain yield, days to flowering, and plant height of entries in 1983 IRRSWYN.[a]

Entry	Yield (t/ha)																	Av no. of days to flowering	Av plant height (cm)
	Philippines		Thailand						Bangladesh		India		Nepal			Mean	Rank		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15				
BR10 (BR51-46-5)	2.1	3.4	2.1	4.6	2.8	4.0	2.4	2.0	4.3	2.0	3.4	3.0	2.5	2.7	2.4	2.9	14	98	96
BR4	1.0	3.9	1.3	5.9	2.7	3.9	3.2	2.6	5.4	2.6	3.3	4.3	3.0	2.3	2.4	3.2	2	111	113
Cisadane	1.9	3.8	—	5.2	2.2	4.1	2.2	2.8	5.2	2.9	3.5	3.9	2.5	1.5	2.2	3.1	4	113	102
C1158-8	1.9	5.2	1.7	3.7	3.0	3.6	1.7	—	3.7	1.3	1.8	2.6	2.4	2.8	2.8	2.7	22	89	76
IR10781-75-3-2-2	2.1	3.4	1.9	5.0	2.6	3.8	1.8	2.6	4.4	2.7	2.8	4.3	2.8	3.0	2.6	3.1	4	104	99
IR13146-45-2-3	3.0	3.3	1.1	5.3	2.7	4.2	1.9	2.5	4.6	3.3	3.1	4.5	2.5	2.8	2.4	3.1	4	107	108
IR13419-113-1	2.5	4.5	1.7	4.4	2.9	3.8	2.1	2.5	4.6	2.3	2.8	3.5	2.7	2.8	2.1	3.0	9	100	86
IR14632-2-3	1.7	3.9	1.8	4.9	3.1	3.9	1.8	3.4	4.4	2.5	3.1	4.9	2.8	1.9	2.2	3.1	4	105	102
IR14753-49-2	1.2	3.7	1.3	5.6	2.7	4.1	2.6	2.4	4.1	2.5	3.6	3.8	2.9	2.2	1.9	3.0	9	103	108
IR14875-98-5	1.3	4.0	1.6	4.6	3.3	3.6	1.8	2.4	4.1	2.6	2.9	3.6	2.5	2.3	1.8	2.8	17	101	99
IR15853-89-7E-P3	1.0	5.3	2.0	4.3	2.8	3.5	2.3	2.0	4.2	1.6	3.0	3.8	2.4	2.8	2.2	2.9	14	98	95
IR18599-68-1	1.7	5.2	1.7	3.4	2.6	2.8	1.0	1.3	3.3	1.8	2.4	2.6	2.4	2.0	2.1	2.4	24	90	89
IR19431-72-2	2.1	5.0	1.5	5.8	2.8	4.2	2.0	3.0	4.7	2.6	4.1	4.1	2.5	2.5	2.2	3.3	1	105	104
IR2307-247-2-2-3	2.2	4.2	1.6	3.9	3.2	3.3	1.7	1.0	4.0	1.9	2.9	3.5	2.7	3.0	2.6	2.8	17	94	80
IR24	1.5	5.1	1.9	3.2	2.4	3.7	2.0	—	3.8	1.3	2.8	2.6	2.3	3.2	2.6	2.8	17	94	87
IR3880-10	2.1	4.8	2.1	4.2	2.8	3.4	1.4	1.0	4.1	1.3	2.3	2.8	2.5	2.6	2.2	2.6	23	94	101
IR46	1.7	5.1	1.3	4.9	3.2	3.6	2.1	1.7	3.9	1.9	2.8	4.1	3.1	2.8	2.2	3.0	9	98	100
IR4819-77-3-2	0.9	3.9	0.8	5.6	3.0	3.7	1.7	2.2	5.3	2.6	4.2	4.5	2.8	2.3	2.5	3.1	4	104	99
IR4829-89-2	1.3	3.2	1.0	4.4	3.0	3.9	1.8	2.2	5.4	2.7	2.9	4.5	3.1	3.1	2.1	3.0	9	101	103
IR52	0.8	4.0	—	4.2	2.6	4.0	1.8	1.9	3.9	2.2	3.0	3.5	2.4	2.4	2.4	2.8	17	93	94
Mahsuri	1.2	2.5	1.0	4.5	2.8	3.9	3.3	1.5	4.5	2.9	2.6	4.4	2.6	2.7	1.9	2.8	17	109	130
RP975-109-2	1.1	3.6	1.1	5.2	2.9	4.3	2.6	3.1	5.9	2.7	3.1	4.5	2.9	2.7	2.4	3.2	2	115	107
UPL Ri-2	2.1	5.7	1.8	4.3	2.6	3.5	1.6	1.7	4.3	1.8	2.7	3.3	2.5	2.8	2.4	2.9	14	95	110
Local check	0.9	3.8	1.5	4.1	2.6	2.8	2.6	1.8	4.8	3.1	3.9	4.5	3.0	2.4	2.7	3.0	9	106	107
Av yield	1.6	4.2	1.5	4.7	2.8	3.7	2.1	2.2	4.5	2.3	3.0	3.8	2.7	2.6	2.3				
Rank	14	3	15	1	7	5	13	12	2	10	6	4	8	9	10				
CV (%)	25.3	21.4	18.0	11.2	18.2	8.1	20.5	15.8	12.8	12.6	16.9	11.0	8.4	9.5	8.0				
LSD (5%)	0.7	1.5	0.4	0.9	—	0.5	0.7	0.6	0.9	0.5	0.8	0.7	0.4	0.4	0.3				
Av days to flowering	98	87	98	94	101	96	106	106	103	109	104	112	100	106	97				
Rainfall (cm)	72	67	127	51	67	104	142	155	178	189	131	129	146	89	69				

[a]Test sites are indicated by numbers below each country. 1 = Los Baños, 2 = Jubay, 3 = Chumpae, 4 = Khonkaen, 5 = Sakhon Nakhon, 6 = Surin, 7 = Ubon Rachathani, 8 = Khong Luang, 9 = Comilla, 10 = Joydebpur, 11 = Maruteru, 12 = Cuttack, 13 = Bairahawa, 14 = Parwanipur, 15 = Kankai.

Transplanting itself was delayed due to late arrival of the monsoon. Under those conditions, the mean yield for the trial was 1.6 t/ha and the highest yields were from BR51-282-8, IR10781-75-3-2, IR21836-90-3, and IR52. In several screening trials IR10781-75-3-2 and IR52 showed good tolerance for drought.

The direct-seeded 1983 IRRSWYN trial at Chinsurah, India, remained waterlogged at a depth up to 35 cm from 1 mo after sowing until harvest. Many entries exhibited low tillering or mortality. The local check NC492 (3.9 t/ha) and Mahsuri (3.0 t/ha) produced the highest yields. All other entries yielded in the range of 0.6-1.8 t/ha.

Hydrographs for three specific sites of the 1983 IRRSWYN are shown in Figure 2. At Comilla, Bangladesh, the maximum water depth during the early growth stage reached 30 cm and remained at 5-10 cm at the flowering and ripening stages. At Cuttack, India, the water depth ranged from about 20 to 35 cm for more than 3 mo from 2 wk after planting. At Kankai, Nepal, where the soil is a sandy loam and rains stopped early, water depth remained below 10 cm throughout the test. Entries that are relatively taller and have medium growth duration produced the highest yields at the first two sites; those that produced the top yields at the third site were relatively early-maturing.

Performance of test entries relative to Mahsuri

At the Philippine and Malaysian sites, several entries in different years produced significantly higher yields than Mahsuri.

At five locations in Thailand — Phrae, Sakhon Nakhon, Surin, Ubon Rachathani, and Phattalung — in different years, none of the entries were superior to Mahsuri. At other locations in Thailand, IR13146-45-2-3, UPL Ri-3, IR13358-85-1-3, and BR4 were superior in the 1981 trials at Phitsanulok; BR4, IR4819-77-3-2, IR14753-49-2, and IR19431-72-2 were superior in the 1983 trial at Khonkaen.

In two years of trials at Hmabwi, Burma, none of the entries were superior to Mahsuri in one trial, and only IR4819-77-3-2 in the other trial was superior in yield and matured earlier by about 10 d.

In Bangladesh, none of the entries were superior to Mahsuri in one of the three years of trials at Joydebpur and in one of the two years at Comilla. IR4819-77-3-2 and IR8192-166-2-2-3 were superior to Mahsuri at Joydebpur in both the 1981 and 1982 trials. RP975-109-2, BR4, and IR4829-89-2 were superior at Comilla in the 1983 trial.

The tests were limited at the Indian locations. The trials at Cuttack, Pusa, and Chinsurah indicated that none of the entries were superior to Mahsuri in grain yield. In a single trial at Karjat, only IR14753-49-2 and IR8192-166-2-2-3 produced significantly higher yields.

In Nepal, IR4829-89-2 was superior to Mahsuri in the trials at both Parwanipur and Bhairahawa. Several entries showed promise at Kankai.

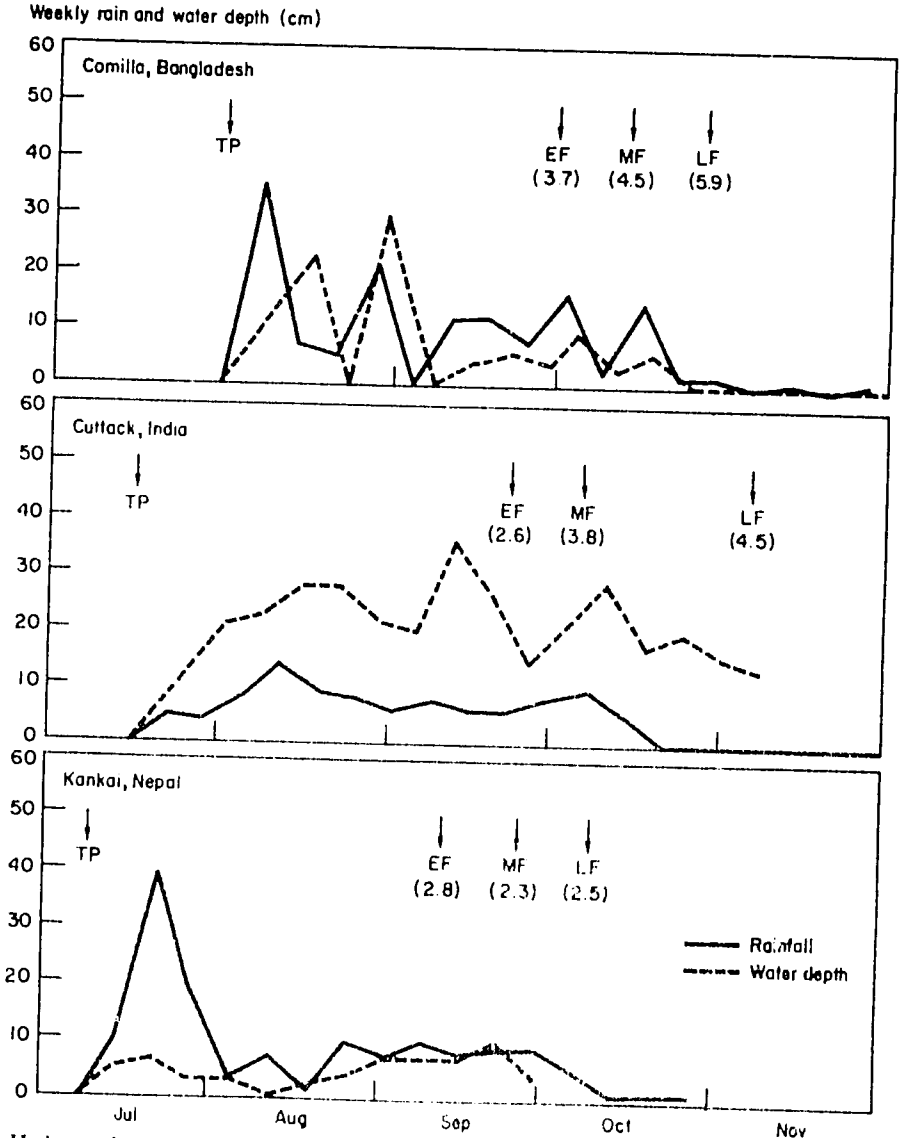
In several instances where none of the test entries was superior in yield to Mahsuri, some were statistically similar to Mahsuri for yield but were better in such traits as earliness or lateness, level of resistance to insects and diseases, and grain dormancy.

Table 9. Highest yielding entries at selected locations in the rainfed lowland yield trials in South and Southeast Asia, 1981-83 IRRSWYN.

Region and country	Location	Year	Entries
		Southeast Asia	
Burma	Hwan[illegible]	1981	IR4819-77-3-2, BIET452 (RAU19-313-3-2), IR13358-85-1-3[a]
		1982	CR1006, BR4, IR13146-45-2-3, IR13358-85-1-3[a], IR21836-90-3
Malaysia	Kubang Keranji	1982	IR14632-2-3, IR46, BPT3291
	Tuaran	1982	RP975-109-2, IR52, UPL Ri-5
Philippines	Los Baños	1981	IR13365-253-3-2, IR13146-45-2-3[a], IR14632-2-3[a]
		1982	IR13146-45-2-3[a], IR46, C1158-8 (local check)
		1983	IR19431-72-2, IR14632-2-3[a], IR13146-45-2-3[a]
	Jubay	1981	IR14753-49-2, IR52, IR9129-192-2
		1982	IR13429-130-2, R9-1-6-1-3-7-7, UPL Ri-5
		1983	UPL Ri-2, IR15853-89-7E-P3, C1158-8, IR18599-68-1
Thailand	Phrae	1981	IR14632-2-3, IR46, IR8192-166-2-2-3
	Sakhon Nakhon	1981	Mahsuri, BR4, BR51-181-8
		1983	IR14875-98-5, IR2307-247-2-2-3, IR46
	Phitsanulok	1981	IR13146-45-2-3, UPL Ri-3, IR13358-85-1-3
	Chumpae	1982	CR1006, BR51-282-8, IR46
		1983	BR10 (BR51-46-5), IR3880-10, IR15853-89-7E-P3
	Phimai	1982	IR52, BR4, NSG19 (local check)
	Khonkaen	1983	BR4, IR19431-72-2, IR14753-49-2
	Surin	1983	RP975-109-2, IR13146-45-2-3, IR19431-72-2
	Ubon Rachathani	1983	Mahsuri, BR4, IR14753-49-2, RP975-109-2, KDML105 (local check)
	Khlong Luang	1982	IR14632-2-3-, RP975-109-2, IR19431-72-2

		South Asia	
Bangladesh	Joydebpur	1981	IR8192-166-2-2-3[a], IR4819-77-3-2[a], IR10781-75-3-2
		1982	IR8192-166-2-2-3[a], BPT3291, IR4819-77-3-2[a], IR13358-85-1-3
		1983	IR13146-45-2-3, BR11 (local check), Cisadane, Mahsuri
	Comilla	1982	BR4[a], CN540, BR11 (local check)
		1983	RP975-109-2, BR4[a], IR4829-89-2
	Rajshahi	1983	IR19431-72-2, BR4, IR14753-49-2
India	Patna	1982	1R9129-192-2, R114-2-1-1-1, RP975-109-2
		1983	IR4829-89-2, IR4819-77-3-2, Cisadane
	Ranchi	1982	BR51-181-8, IR10781-75-3-2, IR21836-90-3
	Karjat	1982	IR14753-49-2, IR8192-166-2-2-3, R114-2-1-1-1
	Pusa	1982	IR4819-77-3-2, C168, IR13146-45-2-3[a], 1R14753-49-2
		1983	IR13146-45-2-3[a], IR19431-72-2, IET7970 (local ck)
	Cuttack	1983	IR14632-2-3, IR13146-45-2-3, IR4819-77-3-2, IR4829-89-2
Nepal	Kankai	1981	IR8192-166-2-2-3, IR9129-192-2, IR10781-75-3-2
		1983	C1158-8, Janaki (local check), IR10781-75-3-2-2, IR2307-247-2-2-3, IR24
	Bhairahawa	1982	IR10781-75-3-2, BR4[a], RP975-109-2
		1983	IR46, IR4829-89-2, BR4[a], Janaki (local check)
	Parwanipur	1983	IR24, IR4829-89, IR10781-75-3-2-2, IR2307-247-2-2-3

[a]Among top yielders at a particular location in more than 1 yr trials.



2. Hydrographs of 3 test sites, 1983 IRRSWYN. TP = date of transplanting, EF = flowering date of earliest entry, MF = mean days to flowering over different entries, LF = flowering date of latest entry. Figures in parentheses indicate grain yield in t/ha.

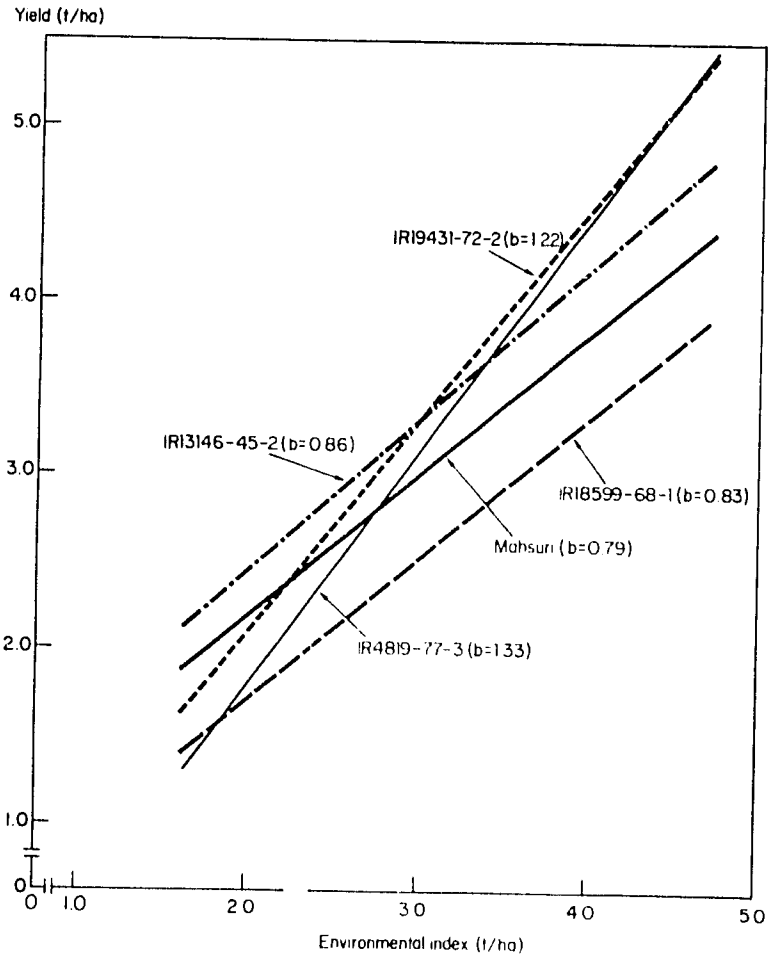
Stability of yield performance

Stability indices of entries in the 1983 IRRSWYN were calculated from data from 13 locations (4 from Thailand, 3 from Nepal, and 2 each from Bangladesh, India, and the Philippines) where the CV for yield was lower than 30% and where none of the 24 entries was missing in the trial (Table 10). Variance among locations was lowest for IR2307-247-2-2-3 and BR10. Regression lines for selected entries are shown in Figure 3. Based on stability indices, IR2307-247-2-2-3 (b = 0.72), BR10 (b = 0.79), Mahsuri (b = 0.79),

Table 10. Mean yield and stability indices of 24 rice entries tested at 13 locations[a] in the 1983 IRRSWYN.

Entry	Yield (t/ha)			Among locations		Stability		Correlation coefficient	Frequency[b]	
	High	Low	Mean	Variance	CV (%)	Index	SE	r	Superior to check	Top yield[c]
BR10 (BR51-46-5)	4.6	2.0	3.0	0.7148	27.8	0.79	0.108	0.91	3	4
BR4	5.9	1.0	3.4	1.7412	39.1	1.25	0.152	0.93	3	7
Cisadane	5.2	1.5	3.2	1.4975	38.6	1.14	0.159	0.91	3	6
C1158-8	5.2	1.3	2.8	1.1456	38.1	0.83	0.215	0.76	3	5
IR10781-75-3-2-2	5.0	1.8	3.2	0.9247	30.3	0.91	0.115	0.92	4	8
IR13146-45-2-3	5.3	1.9	3.4	1.0150	30.0	0.86	0.172	0.83	5	7
IR13419-113-1	4.6	2.1	3.1	0.8304	29.1	0.90	0.077	0.96	4	7
IR14632-2-3	4.9	1.7	3.2	1.3037	36.0	1.10	0.118	0.94	3	6
IR14753-49-2	5.6	1.2	3.1	1.3628	37.1	1.10	0.142	0.92	2	6
IR14875-98-5	4.6	1.3	3.0	1.0359	34.3	1.00	0.086	0.96	1	1
IR15853-89-7E-P3	5.3	1.0	3.0	1.3685	38.8	1.11	0.134	0.93	3	4
IR18599-68-1	5.2	1.0	2.6	1.0260	39.4	0.83	0.188	0.80	1	3
IR19431-72-2	5.8	2.0	3.4	1.5500	36.3	1.22	0.113	0.96	4	6
IR2307-247-2-2-3	4.2	1.7	3.0	0.6110	26.0	0.72	0.102	0.91	2	5
IR24	5.1	1.3	2.9	1.1790	37.7	0.94	0.178	0.85	2	4
IR3880-10	4.8	1.3	2.8	1.1033	37.5	0.94	0.156	0.88	3	3
IR46	5.1	1.7	3.2	1.2212	34.7	1.05	0.123	0.93	3	4
IR4819-77-3-2	5.6	0.9	3.3	1.8912	41.4	1.33	0.140	0.94	2	7
IR4829-89-2	5.4	1.3	3.2	1.3310	36.1	1.05	0.162	0.89	2	6
IR52	4.2	0.8	2.9	1.0188	35.4	0.99	0.085	0.96	1	2
Mahsuri	4.5	1.2	3.1	1.0413	33.2	0.79	0.204	0.76	1	5
RP975-109-2	5.9	1.1	3.4	1.6813	38.2	1.24	0.145	0.93	4	8
UPL Ri-2	5.7	1.6	3.0	1.3422	37.9	1.05	0.167	0.88	4	4
Local check	4.8	0.9	3.2	1.0795	32.8	0.87	0.184	0.82	0	7

[a]Locations were those with lower than 30% CV for yield and where none of the entries were missing (Philippines = 2, Thailand = 4, Bangladesh = 2, India = 2, Nepal = 3). [b]Over 15 locations. [c]Highest yield or statistically on par with highest yield.



3. Regression of yield of 5 selected varieties on site means (24 varieties, 13 sites), IRRSWYN, 1983.

C1158-8 (b = 0.83), and IR18599-68-1 (b = 0.83) showed greater stability in terms of relative flatness of slope. The regression line of IR13146-45-2-3 (b = 0.86), which also showed good stability for yield across locations, was higher in position throughout than those of the five varieties noted above. IR19431-72-2 (b = 1.22), which produced the overall highest yield in the trial, although less stable than BR10 or Mahsuri, had a regression line higher in position than that of Mahsuri throughout. Thus, from the point of view of relatively good performance at most locations, IR13146-45-2-3 and IR19431-72-2 appear promising. The former combines high yield potential with greater stability of performance.

Another way to judge the performance of entries in different environments is to evaluate their relative yields over different ranges of site means. Accordingly, the 13 locations noted above can be divided into three groups: those with site means lower than 2.5 t/ha, those with site means of 2.5 t/ha to

3.5 t/ha, and those with site means higher than 3.5 t/ha. The first and second groups were each represented by four locations and the third by five. The mean yields and yield ranks over these three groups of sites are given in Table 11. BR4, IR19431-72-2, RP975-109-2, and IR13146-45-2-3 occupied relatively high ranks in all three groups. C1158-8, IR18599-68-1, IR3880-10, and IR52 had poor rankings in all three groups. Mahsuri had high ranking in the means of poor sites and relatively low ranking in the means of good sites. The means for local checks had good ranking at poor and intermediate sites but not at good sites.

PROMISING ENTRIES FROM YIELD AND OBSERVATIONAL NURSERIES

Data from 6 yr of observational nurseries (1978-83) and 3 yr of yield nurseries (1981-83) showed the following entries to be promising for further trials in various national programs:

IR4819-77-3-2	IR21141-24-2	IR8192-166-2-2-3
IR4829-89-2	IR46	IR19431-72-2
IR10781-75-3-2	BR4	IR13358-85-1-3
IR13146-45-2	BR51-282-8	RP975-109-2
IR15853-89-7E-P3	IR14632-2-3	Mahsuri
IR19083-22-2-2	IR14753-49-2	Cisadane

Table 11. Yield of 24 rice entries in the 1983 IRRSWYN by 3 groups of site means.

Entry	Yield (t/ha)					
	Site mean < 2.5 t/ha		Site mean = 2.5-3.5 t/ha		Site mean > 3.5 t/ha	
	Mean over 4 sites	Rank	Mean over 4 sites	Rank	Mean over 5 sites	Rank
BR10 (BR51-46-5)	2.2	7	2.8	8	3.8	19
BR4	2.3	2	2.8	8	4.6	3
Cisadane	2.3	2	2.4	23	4.4	5
C1158-8	1.9	17	2.5	21	3.7	22
IR10781-75-3-2-2	2.3	2	2.8	8	4.1	13
IR13146-45-2-3	2.7	1	2.7	13	4.3	7
IR13419-113-1	2.2	7	2.8	8	4.1	13
IR14632-2-3	2.1	11	2.7	13	4.4	5
IR14753-49-2	2.1	11	2.8	8	4.2	9
IR14875-98-5	1.9	17	2.7	13	3.9	16
IR15853-89-7E-P3	1.8	21	2.7	13	4.2	9
IR18599-68-1	1.7	24	2.3	24	3.4	24
IR19431-72-2	2.2	7	2.9	3	4.7	1
IR2307-247-2-2-3	2.1	11	2.9	3	3.7	22
IR24	1.9	17	2.6	17	3.8	19
IR3880-10	1.8	21	2.5	21	3.8	19
IR46	2.0	14	2.9	3	4.3	7
IR4819-77-3-2	1.9	17	3.0	1	4.6	3
IR4829-89-2	2.0	14	3.0	1	4.2	9
IR52	1.8	21	2.6	17	3.9	16
Mahsuri	2.3	2	2.6	17	3.9	16
RP975-109-2	2.2	7	2.9	3	4.7	1
UPL Ri-2	2.0	14	2.6	17	4.2	9
Local check	2.3	2	2.9	3	4.0	15

Table 12. Agronomic traits, reactions to diseases and insects and grain quality of promising entries from IRRSWYN and IRRSWON, 1978-83.

Entry	Cross	Plant ht (cm)	Days to flowering	Tolerance for		Resistance[a] to	Grain quality			
				Drought	Submergence		Shape	Chalkiness	% amylose	Gel consistency
BR4	IR20/IR5-114	108	110			BB	5	5	27	34
BR51-282-8	IR20/IR5-114	106	98		x	BB	1	5	28	64
Cisadane	Pelita I-1//IR789-98/IR2157-3	101	111			ShB	5	9	18	72
IR4819-77-3-2	IR1737-19//IR3018/IR2948	104	106		x	BB, BPH, GLH	5	9	27	32
IR4829-89-2	IR1917-3//IR2948/IR2956	104	100	x	x	GLH, ShB	5	9	27	32
IR8192-166-2-2-3	IR32/IR2055-219//IR34	100	113	x	x	ShR	1	1	28	32
IR10781-75-3-2	BG90-2/IR44	98	107	x	x	GLH, BPH, WBPH	5	1	28	35
IR13146-45-2	BG90-2/IR34//IR46	108	107			GLH, ShB	1	1	27	100
IR13358-85-1-3	IR42*2/BG90-2	98	106				3	5	27	40
IR14632-2-3	IR44/IR46	101	106				1	1	28	90
IR14753-49-2	IR4683-54-2/IR46	108	104			ShR	1	1	27	82
IR15853-89-7E-P3	IR2307-217/IR46//IR2793-10	94	99	x	x	SHB	1	5	28	35
IR19083-22-2-2	Bhadoia 685/IR4227-2[illegible]/IR44	100	107		x	BB, BPH, GLH, ShB				
IR19431-72-2	IR4704-123/IR42//IR46	99	107		x	BB	5	1	28	73
IR21141-24-2	H5/IR42//IR4744-295	101	103			Bl, ShR				
IR46	IR1814//IR1366-120/IR1539-37	101	100			BPH, ShR	1	1	28	100
RP975-109-2	Sona/RPW6-13	111	115			ShR	5	1	26	34
Mahsuri	Taichung 65/2*Mayang Ebos	124	112		x		5	5	26	34

[a]BB = bacterial blight, Bl = blast, BPH = brown planthopper, GLH = green leafhopper, ShB = sheath blight, ShR = sheath rot, WBPH = whitebacked planthopper.

Some agronomic characteristics, resistance to disease and insects, and grain quality of the above entries are summarized in Table 12. IR13146-45-2 and IR8192-166-2-2-3 showed moderately high photoperiod sensitivity (Table 13).

The local checks at different locations that were among the best yielding varieties at those locations were NSG19 (Phimai, Thailand), KDML 105 (Ubon Rachathani, Thailand), BR11 (Comilla and Joydebpur, Bangladesh), IET7970 (Pusa, India), Badava Mahsuri (Maruteru, India), and Janaki (Kankai and Bhairahawa, Nepal). They should be included in future international rainfed nurseries to evaluate their performance at different locations.

Several entries over different years, although not rated good for phenotypic acceptability or yield, have shown a good level of resistance to one or more of the major diseases and insects as well as tolerance for drought and submergence. They may be useful as donors in breeding programs to improve specific stress-related traits of rainfed lowland rice.

Association of plant height and growth duration with grain yield

Correlation coefficients for association between a) plant height and grain yield, and b) flowering duration and grain yield based on the 1981-83 yield trials are given in Table 14.

A positive and highly significant relationship between yield and plant height within the ranges occurring in the nursery was evident in different years in the trials at several sites in Thailand, Bangladesh, and India. No significant association between the two traits was evident in the trials at various sites in the Philippines and Malaysia, although a negative tendency was indicated. The correlation was also not significant in the trials in Nepal. In Burma, where there was only one test site, the relationship was not significant in one year and significant only at the 5% level in another year. The correlation was not significant at Ranchi and Karjat in India.

Correlation of grain yield with flowering duration within the range occurring in the nursery was not significant at most sites in the Philippines and Malaysia, with a tendency for the negative relationship being indicated. A

Table 13. Flowering of IR13146-45-2-3 and IR8192-166-2-2-3 compared to Mahsuri at different latitudes, 1982 IRRSWYN.

Latitude (°N)	Location	Date of sowing	Days to flowering		
			Mahsuri	IR13146-45-2	IR8192-166-2-2-3
6	Tuaran, Malaysia	16 Sep	96	97	90
10	Jubay, Philippines	17 Aug	103	103	96
14	Los Baños, Philippines	21 Jun	108	107	104
15	Phimai, Thailand	15 Aug	107	105	103
18	Karjat, India	23 Jun	101	111	104
23	Comilla, Bangladesh	29 Jun	112	121	121
24	Joydebpur, Bangladesh	3 Jun	119	130	131
25	Patna, India	12 Jun	111	121	126
27	Bhairahawa, Nepal	17 Jun	118	128	128

Table 14. Correlation of yield with plant height and days to flowering in the International Rainfed Lowland (Shallow Water) Yield Trials (1981-83) in South and Southeast Asia.

Region and country	Location	Year	Correlation[a] of yield with			
			Plant height		Days to flowering	
			r-value	Range (cm)	r-value	Range (d)
		Southeast Asia				
Burma	Hwambi	1981	0.33	77-142	0.59**	82-112
		1982	0.44*	83-152	0.75**	79-119
Malaysia	Kubang Keranji	1982	-0.15	72-125	-0.27	85-109
	Tuaran	1982	0.11	55-119	-0.17	78-101
Philippines	Los Baños	1981	0.15	82-149	0.15	75-119
		1982	-0.50	89-130	-0.27	70-123
		1983	0.21	60-109	-0.19	86-113
	Guimba	1981	-0.41	109-142	0.56	70-106
		1982	-0.03	88-152	0.09	74-122
	Gapan	1981	-0.50	101-151	0.21	73-76
	Jubay	1981	-0.08	110	-0.49	71-97
		1982	0.07	58-99	-0.65	75-108
		1983	-0.47	85-155	-0.65	79-97
	Oton	1981	-0.09	91-133	-0.55	78-105
Thailand	Phrae	1981	0.08	84-119	0.64**	85-112
	Sakhon Nakhon	1981	0.50**	69-113	0.66**	83-118
		1983	-0.14	77-118	0.24	88-109
	Phitsanulok	1981	0.37	100-168	0.54**	73-107
	Chumpae	1982	0.13	80-135	-0.13	71-95
		1983	-0.34	69-103	-0.55	86-118
	Phimai	1982	0.55**	67-106	-0.15	82-116
	Khonkaen	1983	0.52**	82-147	0.70**	82-105
	Surin	1983	0.10	83-129	0.47**	85-111
	Ubon Ratchathani	1983	0.67**	67-127	0.55**	92-121
	Khlong Luang	1983	0.50**	83-137	0.68**	79-123
		South Asia				
Bangladesh	Joydebpur	1981	-0.01	80-124	0.69**	82-126
		1982	0.21	86-160	0.56**	84-139
		1983	0.53**	87-142	0.80**	102-124
	Comilla	1982	0.42**	85-139	0.42**	86-123
		1983	0.57**	77-144	0.85**	90-117
	Rajshahi	1983	0.74**	53-96	0.28	105-135
India	Patna	1982	0.24	86-157	0.24	83-132
		1983	0.12	75-138	0.35	101-131
	Ranchi	1982	0.28	49-79	-0.38	98-124
	Karjat	1982	0.18	84-145	0.12	78-120
	Pusa	1982	0.42**	56-136	0.47**	103-149
		1983	0.69**	81-145	0.59**	97-133
	Cuttack	1983	0.69**	92-172	0.72**	100-143
Nepal	Kankai	1981	-0.11	82-136	-0.30	88-122
		1983	-0.31	82-120	-0.26	84-111
	Bhairahawa	1982	0.15	70-136	-0.06	85-133
		1983	0.23	72-115	0.33	91-115
	Parwanipur	1983	0.01	70-130	-0.46	88-135

[a]Significant at 5% (*) and 1% (**) levels.

negative tendency without significant association was also evident in the trials at different sites in Nepal and at Ranchi in India. A positive and highly significant correlation between flowering duration and grain yield was

revealed by the trials at several sites in northeastern Thailand, Bangladesh, and eastern India.

Correlation of yield performance at different sites

Genotypic rankings for grain yield of the 1983 IRRSWYN at 19 test sites were correlated employing the Spearman rank correlation method (Table 15). Genotypic rankings at Khonkaen, Comilla, Joydebpur, and Cuttack are each significantly and positively correlated with those at other sites with a greater frequency than the number of sites correlated with the remaining sites. Those four locations could thus serve as key sites, selections from which would have greater relevance to most rainfed lowland sites. Ranking at each of the four sites is significantly correlated with that at the remaining three sites.

In similar correlation analysis of the 1981 and 1982 nurseries, Mallabanan et al (3) observed that genotypic rankings from the trials at IRRI were not significantly correlated with any non-IRRI trial. In 1982, two trials were planted at IRRI, one seeded on 14 Jun and transplanted on 28 Jul (44-d-old seedlings) and the other seeded on 18 Jul and transplanted on 9 Aug (25-d-old seedlings). Interestingly, the rankings from the first trial were significantly correlated with those obtained at two sites in Thailand (Chumpae and Khonkaen), one in Bangladesh (Rajshahi), three in India (Maruteru, Cuttack, and Pusa), and one in Nepal (Bhairahawa). The rankings in the second trial were not correlated with those at any other test site (including the other trial at IRRI), conforming with earlier findings (3). The two trials at IRRI in 1983 were seeded on different dates at two different sites. The trial in which significant correlations were obtained with other specific sites was transplanted with 44-d-old seedlings, suggesting that varieties identified as promising at IRRI may have greater relevance to sites in Bangladesh, India, and Thailand if evaluation at IRRI is done with aged seedlings. This needs to be verified in future trials. Rankings at Jubay, Philippines, and Chumpae, Thailand, are significantly and negatively correlated with those at several sites in Thailand, eastern India, and Bangladesh. Rankings at Parwanipur and Kankai in Nepal were not correlated with those at any other sites. Correlation of varietal performance among different sites depends upon the location of the sites in the given season and agronomic practices adopted in the individual tests. Thus, to determine if material identified as promising at a given site is relevant to other sites, factors mentioned earlier must be carefully analyzed.

The utilization of entries in various IRTP nurseries by the rice scientists in different countries in their respective research programs is monitored regularly. The entries are utilized either in hybridization programs or in yield evaluation trials at the local or national level. The entries in the rainfed lowland yield and observational nurseries that were reported to have been utilized most frequently in different national programs were IR10781-75-3-2-2, IR13146-45-2, IR15853-89-7E-P3, IR46, IR9763-11-2-3-3, and ITA230. The first four were among those that received broad phenotypic acceptability and also have good yield potential. IR9763-11-2-3-3 showed tolerance for submergence.

Table 15. Correlation coefficients for yield ranks among IRRSWYN sites [a] in 1983

	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19
L1	0.10	-0.30	-0.44*	0.65**	0.37	0.35	0.14	0.32	0.31	0.31	0.48*	0.48*	-0.03	0.55**	0.49**	0.50*	-0.07	-0.09
L2		0.11	0.24	-0.06	0.06	0.00	-0.35	0.02	-0.15	-0.16	-0.32	-0.32	-0.19	-0.31	0.11	-0.19	0.36	0.03
L3			0.38	-0.45*	0.02	-0.58**	-0.46*	-0.11	-0.58**	-0.80**	-0.41*	-0.39*	-0.44*	-0.63**	-0.41*	-0.50**	0.08	0.09
L4				-0.39	-0.41*	-0.18	-0.24	0.01	-0.44*	-0.49**	-9.42*	-9.21*	-0.41*	-0.60**	-0.33	-0.61**	-0.04	0.14
L5					0.05	0.72**	0.44*	0.43*	0.62**	0.56**	0.54**	0.63**	0.14	0.59**	0.50**	0.45*	-0.31	-0.19
L6						-0.10	-0.14	-0.05	0.00	-0.09	0.04	-0.07	0.03	0.20	-0.11	0.33	0.12	-0.21
L7							0.48*	0.54*	0.48*	0.52**	0.42*	0.50**	0.10	0.40*	0.35	0.14	-0.17	-0.17
L8								0.22	0.44*	0.46*	0.36	0.45*	-0.00	0.38	0.23	0.36	-0.10	-0.15
L9									0.27	0.16	0.16	0.27	0.06	0.20	-0.03	-0.04	-0.02	0.20
L10										0.76**	0.44*	0.58**	0.55**	0.75**	0.46*	0.57**	-0.14	-0.02
L11											0.59**	0.52**	0.62**	0.80**	0.56**	0.51**	-0.23	-0.10
L12												0.46*	0.24	0.57**	0.66**	0.58**	-0.39	-0.32
L13													0.24	0.54**	0.38	0.33	-0.45*	0.09
L14														0.43*	0.02	0.33	-0.15	-0.01
L15															0.60**	0.70**	-0.16	-0.04
L16																0.52**	-0.09	-0.13
L17																	0.04	-0.08
L18																		0.34

[a] Test locations: L1 = Los Baños (1), L2 = Los Baños (2), L3 = Jubay, L4 = Chumpae, L5 = Khonkaen, L6 = Sakhon Nakhon, L7 = Surin; L8 = Ubon Rachathani, L9 = Khlong Luang, L10 = Comilla, L11 = Joydebpur, L12 = Rajshahi, L13 = Maruteru, L14 = Patna, L15 = Cuttack, L16 = Pusa, L17 = Bhairahawa, L18 = Parwanipur, L19 = Kankai.

CONCLUSIONS

A review of the results from the international rainfed lowland trials over the past 6 yr indicates significant progress in varietal improvement for certain rainfed lowland shallow water conditions. These include the more favorable conditions as well as situations where moderate degrees of drought and submergence due to periodic flash floods interfere with crop productivity. However, under conditions of waterlogging in poorly drained soils, there is room for surpassing the known performance of varieties such as Mahsuri. The 1983 IRRSWYN trial at Chinsurah is a case in point.

Entries that consistently performed well at different locations should be further evaluated in local adaptive trials.

Several entries in the nurseries were found to possess one or more useful traits — tolerance for drought, submergence, and various biological stresses — and should be utilized in breeding programs targeting rainfed lowland rice.

The usefulness of moderately photoperiod-sensitive lines with high yield potential, such as IR8192-166-2-2-3 and IR13146-45-2-3, under delayed planting conditions needs to be determined.

At appropriate locations, the future rainfed lowland yield and observational nurseries may have to be evaluated under conditions of both late planting and normal planting time. The trial may also have to be direct seeded. A separate nursery may be designed for waterlogged conditions.

In the present trials, most entries originated from IRRI. Future trials should have an increasingly greater number of entries from national programs involved v ith rainfed lowland rice, especially those from Bangladesh, eastern India, northeast Thailand, and Vietnam. Selections made in situ from cooperatively exchanged, segregating generations will have to be entered in IRTP rainfed lowland nurseries to increase the usefulness of those nurseries in meeting the targets. International cooperation will be an essential element to meet the challenge of improvement of rice production in less favored environments.

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RESULTS OF INSFFER RAINFED LOWLAND RICE TRIALS

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Different forms of urea fertilizer were compared in 51 trials under rainfed lowland conditions and in six trials under medium-deep water. Although response to N forms and methods of application varied among sites and even among N levels within each site, in the first and second international trials deep-placed urea supergranules (USG), and both ordinary and forestry-grade sulfur-coated urea (SCU), broadcast and incorporated (B&I), gave higher average yields than B&I prilled urea (PU). Plowsole-applied PU and SCU produced the lowest yields. The effects of the different forms of urea were similar in deepwater rice. Applying urea as a foliar spray near panicle initiation gave no advantage over basal or deep-placed urea fertilizers. Because of high variability in the effects of SCU and USG, results from the third international trial in rainfed rice were analyzed and their response categorized into different forms using the multifertilizer regression model and the fertilizer test model. In 15 of the 33 trials where N response was observed, USG was better than PU, best split; in 15 trials, SCU was better than PU, best split. SCU and USG were just as effective as PU in more than 50% of the trials. This high variability in response requires the identification of site parameters that may have influenced the relative effects of the three fertilizer forms so that the proper form and method of N application can be recommended to farmers.

The International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) was established out of concern over the fertilizer shortage and high prices caused by the oil crisis in 1974. Its major objectives are to improve fertilizer use efficiency in rice and to improve soil fertility for sustaining reasonable rice yield levels through proper use of inorganic and organic (azolla, compost, straw, green manure, farmyard manure, etc.) fertilizers. The network, in which 18 national programs participate, is currently conducting 12 trials covering the four major types of rice culture, namely irrigated lowland, rainfed lowland, deepwater, and upland.

Recognizing the significant hectarage of rainfed lowland rice in rice-growing countries and the potential of increasing its productivity through the effective and judicious use of fertilizers, the INSFFER participants at the 1978 International Rice Research Conference agreed to conduct N fertilizer efficiency trials in rainfed lowland rice. Since then, four sets of trials have been carried out.

BRIEF DESCRIPTION OF INSFFER TRIALS

First international trial

Four forms of urea, three methods of application, and three N rates were compared in the first trial. Prilled urea (PU) was applied with the plowsole applicator. Ordinary sulfur-coated urea (SCU) containing 37.5% N was either broadcast and incorporated (B&I) or applied with the plowsole applicator. Forestry-grade SCU containing 38.5% N was B&I, and urea supergranules (USG) were deep-placed (DP) 10-12 cm below the surface and at the middle of every 4 hills. N was 0, 27, and 54 kg/ha.

Six trials were carried out in four countries: three in India (Coimbatore, Chinsurah, and Kharagpur) and one each in Indonesia (Banjarmasin), Nigeria (Badeggi), and Thailand (Chumpae). Some soil properties of four sites (Coimbatore, Kharagpur, Badeggi, and Chumpae) were reported. Badeggi had sandy loam and the rest clay loam; pH values ranged from 5.1 to 8.1, organic matter (OM) from 0.3 to 1.1%, total N from 0.05 to 0.10%, and CEC from 4 to 30 meq/100 g. Rainfall during the experimental period in 5 locations ranged from 244 mm (Chumpae) to 613 mm (Badeggi).

Second international trial

The second trial consisted of 10 treatments and was formulated in 1979 when the results of the first trial did not show any significant differences among treatments. Three forms of urea — PU B&I basally, SCU B&I basally, and USG DP — were compared at 0, 29, 58, and 87 kg N/ha.

The trial was carried out at 10 sites in 6 countries: 3 in India, 2 each in the Philippines and Bangladesh, and 1 each in Burma, Indonesia, and Thailand. Only seven sites reported some soil characteristics. The pH ranged from 4.4 (Joydebpur, Bangladesh) to 8.3 (Pusa, India), OM from 0.8% (Mithapur, India) to 3.5% (Joydebpur), total N content from 0.10% (5 sites) to 0.30% (Joydebpur), and CEC from 7 meq/100 g (Comilla, Bangladesh) to 39 meq/100 g (Los Baños, Philippines). Soil texture was clay to sandy loam. There was thus wide variation in soil characteristics among the sites. Rainfall received during the experimental period ranged from 718 mm (Los Baños) to 1,516 mm (Joydebpur); the Burma site also received more than 1,000 mm during the period.

Third international trial

The number and composition of the treatments of the third trial were essentially the same as in the second. The only difference was that PU in the third trial was applied best split (BS), while that in the second trial was B&I at planting. PU, SCU, and USG were also compared at 0, 29, 58, and 87 kg N/ha. The trial began in 1981 and is still ongoing at several sites. As of July 1984, 35 experiments had been reported at 21 sites in 7 countries: 17 in India, 7 in the Philippines, 3 in Burma, and 2 each in Bangladesh, Indonesia, Sri Lanka, and Thailand.

Soil characteristics of 26 of the 35 trials were determined. The pH ranged from 5.0 (Chumpae, Thailand) to 7.9 (Pusa, India), OM from 0.9% (Titabar, India) to 4.8% (Sorsogon, Philippines), total N content from 0.08% (Titabar, Cuttack, and Karjat, all in India) to 0.38% (Sorsogon), CEC from 5 meq/100 g (Pusa) to 57 meq/100 g (Buenavista, Philippines), available P (Olsen's method) from 3 ppm (Cuttack) to 39 ppm (Dhobighat, India), exchangeable K from 0.04 meq/100 g (Chandana, Bangladesh) to 2.67 meq/100 g (Buenavista), and soil texture from clay (Los Baños, Philippines) to sandy loam (Dhobighat). Rainfall received during the experimental period in 18 trials ranged from 356 mm (Buenavista) to 1,924 mm (Insein, Burma). Sunshine hours recorded for 13 trials ranged from 217 (Los Baños) to 425 (Chinsurah, India).

Medium-deep water rice trial

The medium-deep water trial, which was initiated as a consequence of the deepwater rice conference in Calcutta, India, in 1978, was conducted at two sites: Chinsurah, India, and Los Baños, Philippines. Two trials have been conducted since 1979. The first consisted of the following treatments: 1) PU B&I basally; 2) SCU B&I; 3) 1/2 N from PU and 1/2 N from SCU B&I; 4) 2/3 N from PU B&I, and the remaining 1/3 N as PU solution, foliar applied at 5-7 d before panicle initiation (DBPI); 5) 2/3 N from SCU, B&I, and 1/3 N as PU solution, foliar applied at 5-7 DBPI; and 6) USG DP.

The second trial consisted of 13 treatments comparing PU, SCU, and USG at 4 rates of N. PU was either B&I as basal only or 2/3 N was B&I, followed by 1/3 N foliar applied at 5-7 DBPI; SCU was B&I basally; and USG was DP.

Floodwater at both locations was never deeper than 50 cm. Soil at the Chinsurah site had silty clay at pH 7.2, 2.3% OM, 0.16% total N, 32 meq/100 g CEC, 15 ppm Olsen P, and 0.55 ppm available Zn (K and P). The Los Baños site had clay loam at pH 6.4, 1.9% OM, 0.11% total N, 33 meq/100 g CEC, 100 ppm $Bray_2$ P, and 0.44 ppm available Zn (K and P). Average 3-season rainfall was 782 mm in Chinsurah and 1,189 mm in Los Baños.

RESULTS

First international trial on rainfed lowland rice

Among the six sites reporting on the first trial, Badeggi showed no N response even with a check yield of 2.3 t/ha. Table 1 presents the average yield response to the treatments at the five N-responsive sites. Although differences among forms and methods of application within one rate of N appear insignificant, plowsole application of either PU or ordinary SCU gave the lowest yields. B&I ordinary and forestry-grade SCU produced yields slightly higher than USG DP.

Response to the different forms and methods of application varied among sites and among N rates (2). At the Indonesian site (Banjarmasin) there was no significant increase in N response beyond 27 kg N/ha except for PU plowsole

Table 1. Rice yields with different forms of N and methods of application in rainfed lowland rice at 5 sites in India, Indonesia, and Thailand, first international trial on N fertilizer efficiency in rainfed lowland rice, INSFFER, 1978-80.

Form and method of application	Grain yield (t/ha)[a]		
	No N	27 N	54 N
Control	2.9	—	—
PU, plowsole applied		3.4	4.0
SCU (ordinary)[b], B&I		3.8	4.3
SCU (ordinary), plowsole applied		3.5	3.9
SCU (forestry-grade)[c], B&I		3.6	4.3
USG, DP		3.7	4.1

[a]Mean of 5 sites that responded to N application: 3 in India and 1 each in Indonesia and Thailand. [b]Containing 37.5% N with release rate of 21% in 7 d. [c]Containing 38.5%, with release rate of 20.7% in 7 d.

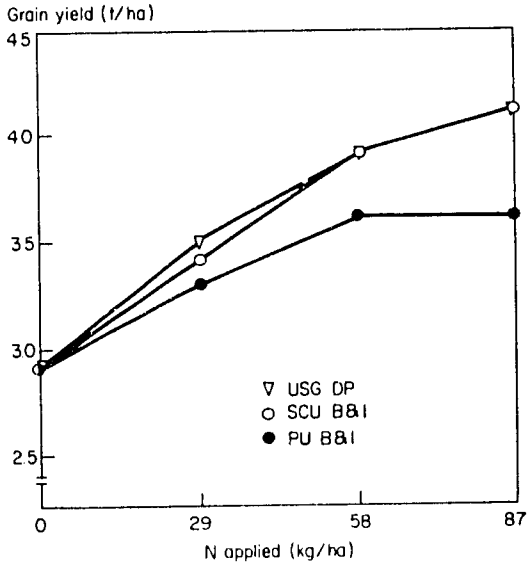
applied. An increase from 3.4 t/ha at 27 kg N/ha to 4.9 t/ha at 54 kg N/ha was obtained by such treatment. At Coimbatore, USG DP produced an increase of 0.5 t/ha over PU plowsole applied at 27 kg N/ha and an increase of 0.8 t/ha over PU plowsole applied at 54 kg N/ha. Except for SCU plowsole applied, all other forms and methods of application produced higher yields than PU plowsole applied at 54 kg N/ha. At Chinsurah, USG DP and SCU (ordinary or forestry-grade) B&I gave significantly higher yields than PU B&I only at 54 kg N/ha. In Kharagpur, SCU (ordinary or forestry-grade) differed significantly from PU plowsole applied at 54 kg N/ha, but not at 27 kg N/ha. There were no significant differences among N treatments at Chumpae at either N rate despite the low check yield of 1.6 t/ha. That Chumpae received the lowest rainfall (244 mm) during the experiment might explain its low yields and the absence of significant differences among the N forms and methods of application.

Second international trial

In the second trial, significant N response was observed at all sites except Tentuiara, Bangladesh. The average of the 10 trials with N response showed that SCU B&I and USG DP produced higher yield than PU B&I (Fig. 1). The effect was pronounced at 87 kg N/ha. The trends in yield response, however, varied among sites and even among N levels within each site (2).

In Joydebpur, Bangladesh, USG and SCU did not significantly differ from PU B&I except at 27 kg N/ha. In Insein, Burma, with check yield of 2.6 t/ha and the highest yield response to N of 1.0 t/ha, significant differences among the three forms of urea were observed at all N rates. USG DP was superior to PU B&I at all rates of N. At 27 kg N/ha, USG was better than SCU B&I. The trial in Pulau Pinang, Indonesia, showed that all forms of urea were equally effective. At increasing rates of N, however, SCU was better than PU B&I at 54 kg N/ha, and SCU was the best at 87 kg N/ha.

In one trial at IRRI, a sharp yield increase over the check plot was observed at 27 kg N/ha. Beyond that rate, however, no further yield increase was



1. N response of rice to forms of urea and rates of application in 10 trials, second international trial on nitrogen fertilizer efficiency in rainfed lowland rice, INSFFER, 1979-80.

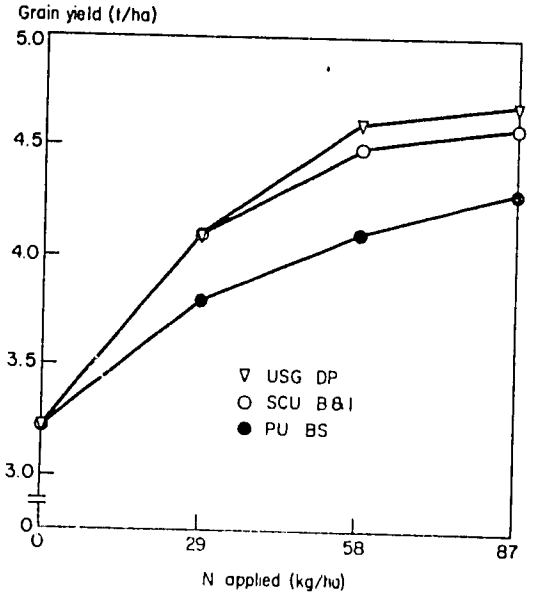
observed for all forms of urea. The yield of the Tanay (Philippines) trial declined with increasing rate of N for all forms.

Check yields at the three sites in India ranged from 2.9 to 3.8 t/ha, with the highest yield responses to N of 1.8 t/ha at Chinsurah, 3.3 t/ha at Mithapur, and 1.6 t/ha at Pusa. All forms of urea at 27 kg N/ha were comparable at each of the three sites. In Pusa, however, SCU and USG at 54 kg N/ha gave increases of 0.6 and 0.5 t/ha over PU B&I. The yield difference of 1.0 t/ha between USG and PU B&I was significant at 87 kg N/ha. In Mithapur, USG produced yield differences of 0.5 t/ha at 27 kg N/ha, 1.1 t/ha at 54 kg N/ha, and 2.3 t/ha at 87 kg N/ha; only at 54 and 87 kg N/ha were the differences significant. There were no differences among the forms of urea in Chinsurah at all N rates. Yields tended to decline with N rate, which is similar to observations in Tanay, Philippines.

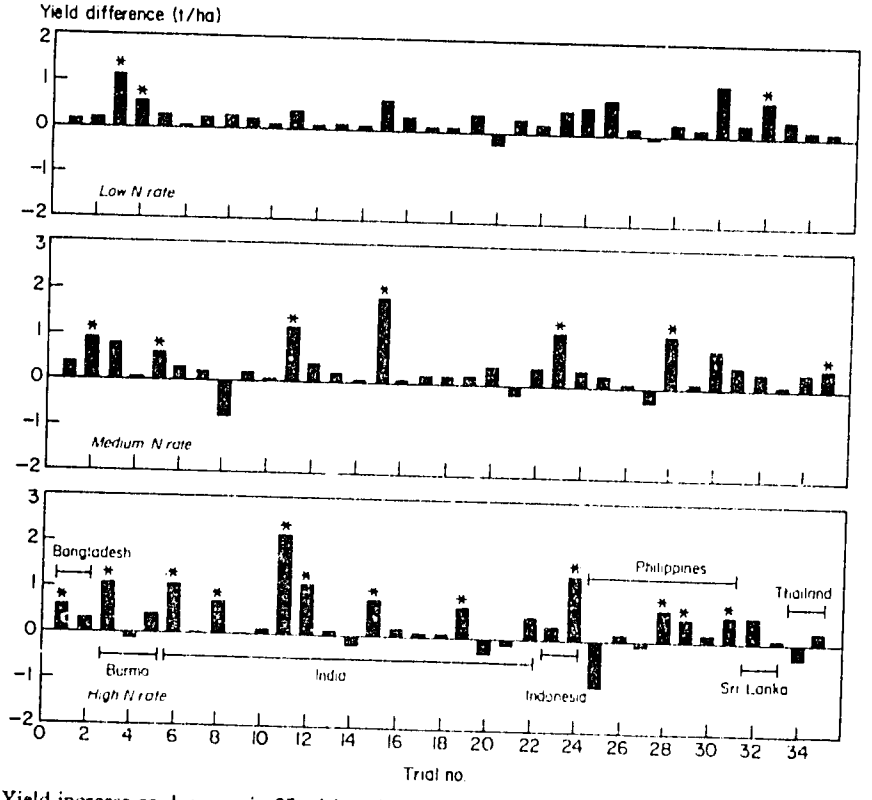
While N response was observed in Chumpae, Thailand, the yields were very low and the different forms of urea were comparable. Yields ranged from 1.3 to 1.6 t/ha.

Third international trial

According to an analysis of variance test of the 35 trials, 2 from India (Mithapur in 1983 and Titabar in 1981) did not give significant response to N. Based on the multifertilizer response model (MRM) and fertilizer test model (FTM), four sites did not respond to N. These sites include the two mentioned earlier and the trials in Mithapur in 1981 and in Sorsogon, Philippines. The last 2 sites had check yields above 4 t/ha. On the average, USG DP and SCU B&I produced yields higher than PU BS and ranged from 0.3 to 0.4 t/ha at all 3 rates of N. USG and SCU were comparable. Figure 2 shows the



2. N response of rice to forms of urea and rates of application in 35 trials, third international trial on nitrogen fertilizer efficiency in rainfed lowland rice, INSFFER, 1981-83.



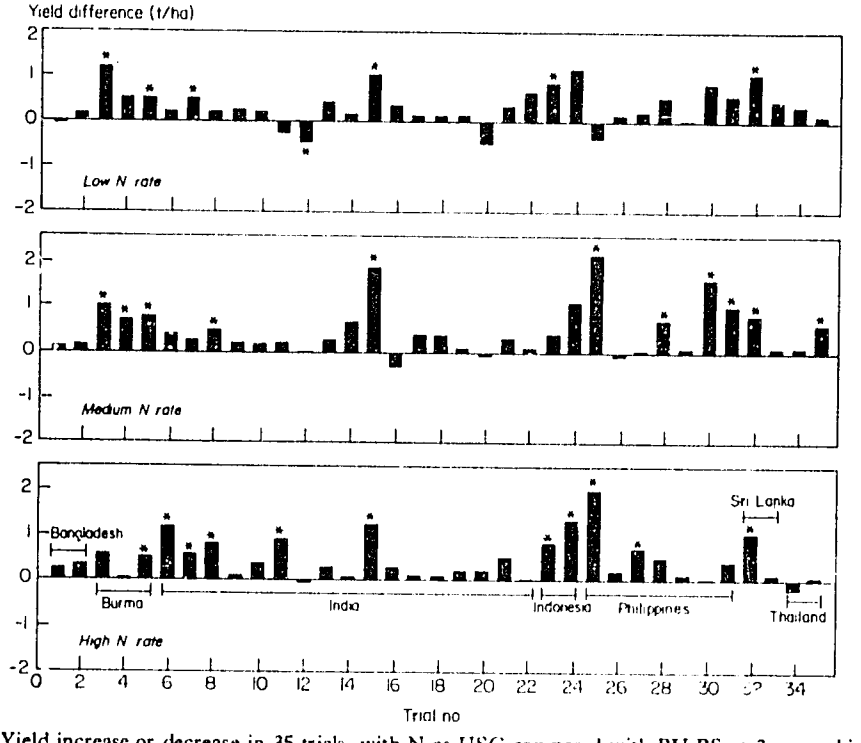
3. Yield increase or decrease in 35 trials, with N as SCU compared with PU BS at 3 rates, third international trial on nitrogen fertilizer efficiency in rainfed lowland rice, INSFFER, 1981-83. The asterisk indicates significance at the 5% level.

comparative trends of the three forms of urea tested; however, Figures 3 and 4 show that yield differences between USG or SCU and PU were not consistent at all sites. Only in one trial (Mithapur, India, 1982) was the difference between SCU and PU significant at all three rates of N (3). On the other hand, three sites (Insein, Burma, 1983; Mithapur, India, 1982; and Bombuwela, Sri Lanka, 1982) exhibited significant differences between USG and PU at all N rates.

The average significant positive yield differences between SCU and PU were 0.6 t/ha at 29 kg N/ha, 1.1 t/ha at 58 kg N/ha, and 1.0 t/ha at 87 kg N/ha.

Because yield differences were not significant at all N rates in one trial and because the treatments were levels of continuous variables, the MRM (4) was used to analyze the results and to categorize the response to the different forms. The MRM model, however, does not provide a direct test of whether the response functions for the three N forms differed significantly one from another (1). Thus, the FTM was used to test the differences in slope parameters and then levels of significance based on t-tests among the three forms.

Using the MRM and FTM models, the response categories of the different trials conducted in the seven countries were established and are reported in Tables 2 and 3. Of the 33 trials where N response was observed, USG was



4. Yield increase or decrease in 35 trials, with N as USG compared with PU BS at 3 rates, third international trial on nitrogen fertilizer efficiency in rainfed lowland rice, INSFFER, 1981-83. The asterisk indicates significance at the 5% level.

Table 2. Comparisons of PU and USG in 7 countries during the third international trials on N fertilizer efficiency in rainfed lowland rice, INSFFER, 1981-83.

Country	Trials (no.) for each response category[a]			
	Total	USG>PU	USG=PU	No response
Bangladesh	2	0	2	0
Burma	3	2	1	0
India	17	5	10	2
Indonesia	2	2	0	0
Philippines	7	4	3	0
Sri Lanka	2	1	1	0
Thailand	2	1	1	0
Total	35	15 (45)[b]	18 (55)[b]	2

[a]The fertilizer test model for linear functions was used to classify individual experiments into response categories. The category USG<PU had no trials. [b]Values in parentheses are percentages of the 31 trials with positive N response.

Table 3. Comparisons of PU and SCU in 7 countries during the third international trials on N fertilizer efficiency in rainfed lowland rice, INSFFER, 1981-83.

Country	Trials (no.) for each response category[a]			
	Total	SCU>PU	SCU=PU	No response
Bangladesh	2	2	0	0
Burma	3	2	1	0
India	17	5	10	2
Indonesia	2	2	0	0
Philippines	7	2	5	0
Sri Lanka	2	1	1	0
Thailand	2	1	1	0
Total	35	15 (45)[b]	18 (54)[b]	2

[a]The fertilizer test model for linear functions was used to classify individual experiments into response categories. The category USG<PU had no trials. [b]Values in parentheses are percentages of the 31 trials with positive N response.

better than PU BS in 15 trials. In another 15 trials, SCU was better than PU BS.

This suggests that in certain situations, USG DP and SCU B&I are no better methods than PU BS. There is therefore a need to identify site parameters that influence the relative effects of the three forms so that the proper form and method of N fertilizer application can be recommended to farmers.

Medium-deep water rice trials

The first set of the medium-deep water test consisted of two trials each at Chinsurah, India, and at IRRI. N response was observed at both sites, but yields at Chinsurah were higher than at IRRI (Table 4). Treatments with SCU and USG DP produced higher yields than PU at the Chinsurah trials. These treatments produced an average yield increase of 0.5 t/ha over PU B&I. Foliar application of PU solution at 5-7 DBPI was not of great benefit. The same

Table 4. Yield of 8 treatments tested in the first international trial on nitrogen fertilizer efficiency in medium deep water rice, INSFFER, 1980-81.

Treatment	Yield (t/ha)					
	Chinsurah, India			Los Baños, Philippines		
	1980	1981	Mean	1980	1981	Mean
Control	3.2	2.8	3.0	1.6	1.6	1.6
PU B&I	4.3	3.1	3.7	2.9	1.8	2.4
SCU B&I	4.0	4.2	4.1	3.4	2.0	2.7
0.5 PU + 0.5 SCU B&I	4.1	4.2	4.2	2.9	1.9	2.4
PU, 0.67 B&I and 0.33 foliar	4.2	3.0	3.6	2.1	1.4	1.8
0.67 SCU B&I + 0.33 PU foliar	4.1	4.3	4.2	2.7	2.0	2.4
USG DP	4.2	4.3	4.2	2.7	2.3	2.5
PU with soil B&I	3.7	2.9	3.3	2.4	2.1	2.2
Mean	4.0	3.6		2.6	1.9	
SE mean	0.2	0.2		0.2	0.2	
LSD (5%)	0.5	0.5		0.6	n.s.	
CV (%)	7.8	9.9		16.3	18.6	

Table 5. Yield of 13 treatments tested in the second international trial on N fertilizer efficiency in medium deep water rice, INSFFER, 1982.

Form of urea	Rate (kg N/ha)	Yield (t/ha)	
		Chinsurah, India	Los Baños, Philippines
Control		2.7	2.4
PU B&I	29	3.5	2.7
	58	3.4	2.8
	116	3.6	3.3
PU, 0.67 B&I, 0.33 foliar	29	3.4	2.7
	58	3.1	3.0
	116	3.3	3.2
SCU, B&I	29	3.4	2.5
	58	3.4	3.1
	116	4.3	2.7
USG, DP	29	3.8	2.7
	58	4.1	3.1
	116	3.8	2.8
Mean		3.5	2.8
SE mean		0.2	0.2
LSD (5%)		0.7	0.6
CV (%)		12	12

trend was observed in the IRRI trials, but the differences were not so pronounced.

The second trial, consisting of 13 treatments, showed no marked yield differences among the forms of urea at the 2 sites (Table 5). Yields at Chinsurah, however, were higher than at IRRI. There were yield differences between USG and PU B&I at all N rates at Chinsurah, but they were not significant except at 58 kg N/ha. SCU was better than PU B&I only at 116 kg N/ha. The three urea forms were the same at IRRI at all N rates. Yields were generally lower when a portion of the N was foliar applied.

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113

VARIETAL IMPROVEMENT

115

VARIETAL IMPROVEMENT FOR RAINFED LOWLAND RICE IN SOUTH AND SOUTHEAST ASIA: RESULTS OF A SURVEY

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A survey of rice breeders in nine countries in South and Southeast Asia was conducted to document current work on rainfed lowland rice improvement. Disease and insect susceptibility is regarded as the major weakness of current varieties; this is followed by poor drought and flood tolerance and low yield potential. The major diseases are bacterial blight, blast, brown spot, sheath rot, and tungro virus. The major insect pests are stem borer, brown planthopper, and gall midge. Drought and flash floods are the important environmental stresses, followed by stagnant flooding, salinity, P deficiency, and Zn deficiency. Long or medium slender grains with intermediate amylose are favored. The cultural types "shallow, favorable" and "shallow, drought-prone" represent about 30% each of the rainfed lowland area. "Drought- and submergence-prone" and "medium-deep, stagnant water" are present in almost equal amounts. "Submergence-prone" rainfed lowland rice is less common. Breeding objectives for disease and insect resistance and adverse soils tolerance are apparently not strongly related to cultural type. Information from the survey should facilitate exchange of germplasm among programs with similar objectives.

The complexity of the environmental conditions in which rainfed rice is found has given rise to a wealth of terms used to describe each type of rice culture. Breeders divide their target areas according to the predominant varietal constraints of their particular environment. These categories are commonly based on what the farmers already know about the various varietal requirements for each field they plant. Lack of a consistent terminology among breeders, however, makes it difficult to classify the types of rainfed lowland rice they are working with. This makes a collaborative and concentrated approach to the problem of varietal improvement difficult.

The present study aimed to document the work being done on rainfed lowland rice improvement in South and Southeast Asia. A questionnaire was sent to rice breeders working in countries (or states in the case of India) with a significant area of rainfed lowland rice. The questionnaire focused on the major constraints to rice production, grain quality preferences, released varieties and promising lines, and areas of each of the five rainfed lowland cultural types described by Khush (5). In addition, breeders described

programs for each type of rainfed lowland culture and related the terminology they use for classification to the cultural types.

Nine Asian countries, including 11 states of India, returned 23 questionnaires representing about 34 million ha of rainfed lowland rice. By present estimates (3) this is almost 90% of the rainfed lowland rice area in South and Southeast Asia. The results are reported both by giving equal weight to all questionnaires and by weighting according to the relative area represented by each questionnaire.

VARIETAL CONSTRAINTS

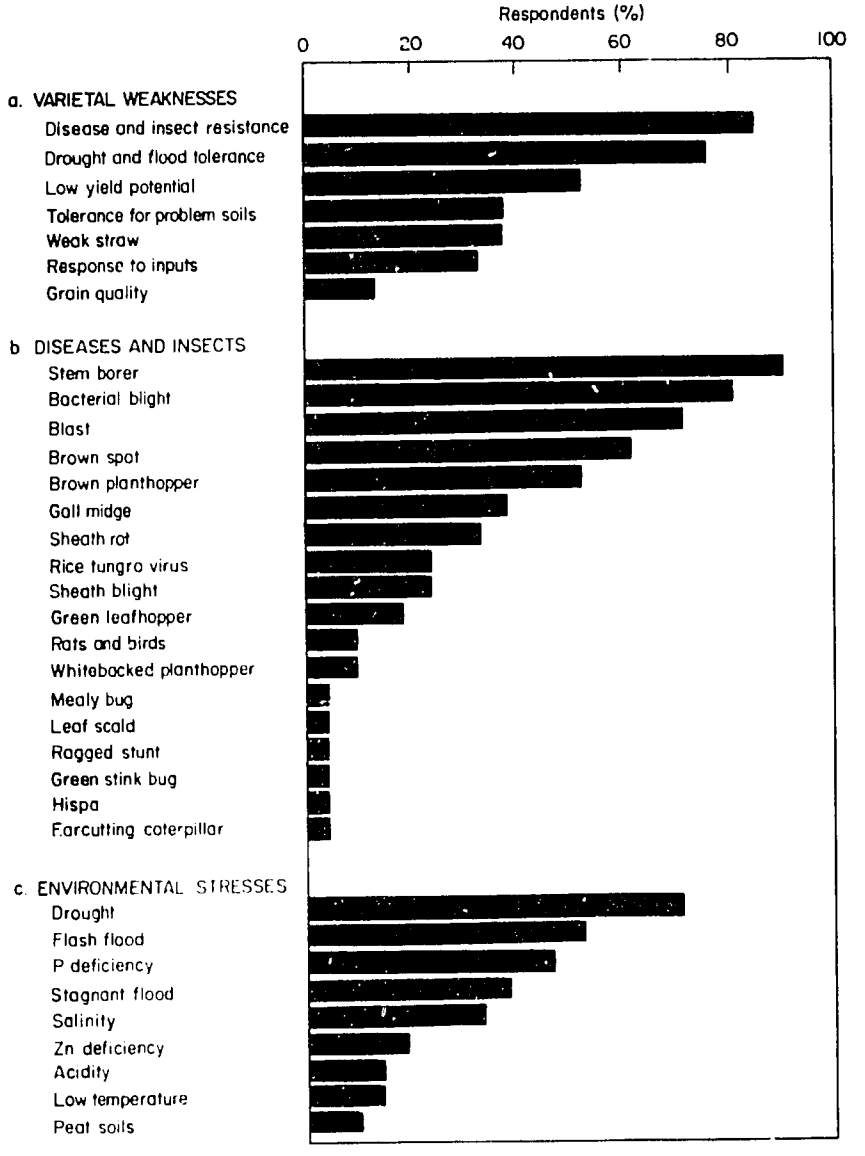
Breeders ranked, in order of importance, the limiting factors to currently grown rainfed varieties. The number of times each limiting factor was listed among the three most important ones is shown in Figure 1. Resistance to diseases and insects was listed as the most important constraint of current rainfed varieties, followed by flood and drought tolerance. In contrast, grain quality was rarely listed as a limiting factor. Popular varieties generally have the desired grain quality.

Respondents also ranked the biological and environmental stresses in order of perceived importance. The five most important diseases and insect pests in order of severity and weighted by area were stem borer, bacterial blight, blast, brown spot, and BPH. The percentage of respondents listing each disease or insect pest as one of the five most important is shown in Figure 1. Gall midge was rated an important pest in northern and northeastern Thailand, Sri Lanka, and several states of India. Rice tungro virus (RTV) was rated important in Indonesia, the Philippines, Bangladesh, Bihar, and West Bengal.

Drought was rated the most important environmental stress, followed by flash floods and then P deficiency (Fig. 1). When weighted by area, the most important were drought, flash floods, stagnant floods, and salinity, in that order. Salinity was listed as an important constraint in southern Thailand, Andhra Pradesh, Karnataka, Gujarat, and Vietnam. Acidity was rated important in Malaysia, central Thailand, and Vietnam. Zn deficiency was rated important in Bihar, Gujarat, and Madhya Pradesh, and low temperature stress in northern Thailand, Karnataka, and Ranchi, Bihar. Peat soils were important in Kerala and Maharashtra.

GRAIN QUALITY PREFERENCES

Breeders were asked to specify their preferences for amylose content, brown rice length, and brown rice shape. Intermediate (20-25%) amylose content was most preferred (61% of respondents), with high amylose second (26% of respondents). In general, intermediate amylose was preferred in Southeast Asia but was equally preferred with high amylose in South Asia. Low amylose was preferred in Vietnam and glutinous rice in northern and northeastern Thailand.



1. Percentage of respondents listing a) a varietal weakness as one of the three most important constraints of currently grown varieties, b) a disease or insect pest as one of the five most important constraints, and c) an environmental stress as one of the three most important constraints.

Medium (5.5-6.5 mm) and long (6.6-7.5 mm) brown rice grain length were equally preferred (39% of respondents each), followed by extra long (above 7.5 mm). Only Sri Lanka preferred short grains. The majority of the breeders (74%) expressed preference for slender grain; only Sri Lanka preferred bold grains.

RAINFED LOWLAND CULTURAL TYPES

Breeders were asked to estimate the area in their locality under the five major rainfed lowland cultural types. Only 17 breeders responded, representing about 29 million ha of rice, or 86% of that covered by the survey. About 32% of the area was classified as "favorable," 30% as "drought-prone," 8% as "drought- and submergence-prone," 12% as "submergence-prone," and 18% as "medium-deep, stagnant water." The estimates should be regarded as highly speculative. This system has not been widely used, and most breeders have used other systems to classify their own target areas. The relation between the proposed system and that used in national programs is considered in the next section.

RAINFED LOWLAND BREEDING PROGRAMS

Breeders were asked to classify the types of rainfed lowland rice they consider important in their target areas. A total of 38 breeding "programs" or target areas were specified by breeders in 9 Asian countries, including 9 states of India. The characteristics of the rainfed lowland types in each country are summarized in Appendix 1.

Cultural types

Many breeders found it difficult to classify their target environments into the rice cultural type terminology. Several target environments matched more than one rice cultural type (Appendix 1). This could reflect the existence of environments straddling two or more cultural types, or the presence of more than one cultural type in the area classified.

The respondents were asked to estimate the frequency of occurrence of 5 stresses: short-term submergence (less than 10 d), longer-term stagnant flooding, drought during the vegetative stage, drought during the reproductive stage, and delayed transplanting (beyond 35 d after seeding). A score of 1 to 5 was used: 1 = occurs regularly in most fields, 2 = occurs occasionally in most fields, 3 = occurs regularly in some fields, 4 = occurs occasionally in some fields, 5 = rarely occurs. A score of 1 or 2 indicates that the stress should be considered in the classification of the environment. If the stress is 2, then appropriate varieties should have tolerance for this stress. A score of 3 or 4 indicates that the environment should probably be further divided into fields that experience the stress and those that do not. Table 1 shows the frequency of the area under each stress score. Delayed transplanting occurs regularly on about 34% of the area covered in the survey. Although 32% of the area covered was considered "favorable," only the transplanted aman crop of Bangladesh, representing 11% of the total area, did not have a score below 4 for any stress. For favorable rainfed areas, varieties developed for irrigated conditions should be suitable (5). Tolerance for stress, however, should be considered in breeding for "favorable" rainfed lowland areas where the stress has a significant chance of occurring.

Table 1. Frequency of occurrence of 5 stresses in rainfed lowland areas of South and Southeast Asia.[a]

Stress	Percent of area under each stress score[b]				
	1	2	3	4	5
Submergence	11	4	23	24	38
Drought (vegetative stage)	15	20	20	20	25
Drought (reproductive stage)	2	24	15	32	27
Stagnant flood	13	7	17	13	50
Delayed transplanting	34	8	18	24	16

[a]Total area considered is 33,139,000 ha. [b]Stress score 1 = occurs regularly in most fields, 2 = occurs occasionally in most fields, 3 = occurs regularly in some fields, 4 = occurs occasionally in some fields, 5 = rarely occurs.

About 72% of the entire area considered in the survey is transplanted as opposed to direct seeded. Direct seeding is the predominant method in 12 cases; in 3, both direct seeding and transplanting are common. The method of crop establishment is not entirely dependent on the cultural type. Direct seeding is common in drought-prone areas and where drought is expected during the vegetative stage. In areas designated as medium-deep, transplanting is usual. Direct seeding predominates in Sri Lanka, Orissa, and Madhya Pradesh and is also common in West Bengal.

Varieties

Breeders were asked to list up to 10 varieties released in their locality and up to 10 of the best breeding lines along with particulars. These are given in Appendixes 2 and 3. The five most popular varieties in each type of rainfed rice are given in Appendix 1. A complete alphabetical list of the popular rainfed varieties along with their characteristics is given in Appendix 4. Most varieties listed appeared to be popular in only one country (or state in India), but a few, such as IR36, IR42, Mahsuri, Pankaj, and T141, were listed more than once.

Grain yields

Breeders were asked to indicate the current yield level on farmers' fields as well as the potential yield they regarded as a realistic breeding target. Current levels ranged from 0.4 t/ha for the "Bhata" crop of Madhya Pradesh to 5 t/ha for the "favorable" rainfed lowland of Sri Lanka. The targeted yields were typically 1-2 t/ha above the current yields and ranged from 2-3 t/ha in Gujarat to 6 t/ha in Sri Lanka. Present and target yields appeared to be lowest where drought was a significant factor. Two "favorable" areas — Karnataka and Maharashtra — had relatively low present and targeted yields. Karnataka had a present average yield of 1.6 t/ha and a targeted yield of 2.5 t/ha, and Maharashtra had a present yield of 2 t/ha and a targeted yield of 3 t/ha. Submergence was rated 3 in both cases.

Appropriate height and duration

The ideal height and duration specified for each type of rainfed lowland is given in Appendix 1. The desired height differed within the different cultural

types; however, areas prone to submergence or stagnant flooding generally required taller plants (120-150 cm). Only Vietnam ("shallow" and "semi-deep"), Bihar ("intermediate"), southern Thailand, Madhya Pradesh ("Bahara Kanhar"), and West Bengal ("medium") specified a *minimum* plant height of 140 cm. Intermediate plant height (100-130 cm) appears appropriate for most situations.

The ideal duration varied widely. Photoperiod sensitivity was specified in 16 out of 38 cases and was usually associated with submergence, stagnant flooding, or delayed transplanting. Short duration was usually preferred in the drought-prone areas and was also specified as desirable in the drought- and submergence-prone area of Sri Lanka.

Breeding objectives

The five most important breeding objectives for each type of rice are listed in Appendix 1. The frequency of occurrence and the area weighted scores for the most important objectives are presented in Figure 2. The breeding objectives closely followed the occurrence of the stresses shown in Figure 1. The most important morphological traits were lodging resistance and seedling vigor. Drought tolerance and submergence tolerance were important physiological traits. Good grain quality as well as resistance to bacterial blight, blast, stem borer, and brown planthopper were regarded as very important objectives.

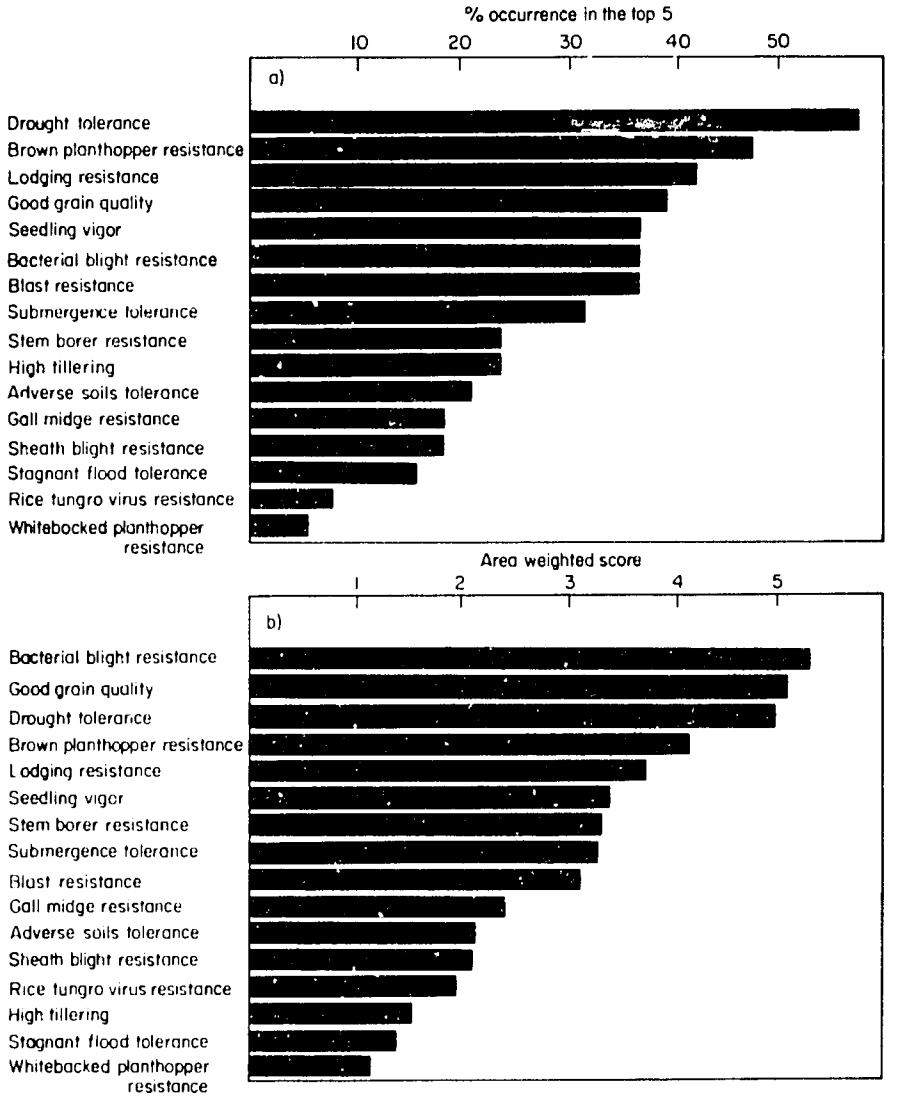
Breeding for tolerance for stagnant flood conditions was considered important only in areas classified as medium-deep and, with the exception of Vietnam, was associated with breeding for submergence tolerance. Submergence tolerance is probably an important breeding objective for medium-deep conditions either because submergence may occur together with stagnant flooding in these environments or because the mechanisms of tolerance for submergence and stagnant flooding are related.

DISCUSSION

Area of rainfed lowland cultural types

The area of rainfed lowland rice covered by this survey, which included areas with a maximum sustained water depth up to 50 cm, was 33,546,000 ha. Areas for which no information was received and that have a significant amount of rainfed lowland rice, include Uttar Pradesh and Tamil Nadu in India; and Nepal, Bhutan, Laos, and Cambodia.

It is somewhat difficult to compare the estimates given in this survey with those of other reports because the cut-off point between rainfed lowland and deep water has not been clearly recognized. Thus, Barker and Herdt (1) estimated areas of 28.7 million ha for shallow (5-15 cm) rainfed lowland and 12.8 million ha for medium deep (16-100 cm) rainfed lowland in South and Southeast Asia. Similarly, Huke (3) gave estimates of 30,375,000 ha for shallow (0-30 cm) rainfed lowland and 11,587,000 ha for intermediate (30-100 cm) rainfed lowland. If the areas of rainfed lowland given by Huke for the countries or states not included in this survey are considered, then all estimates



2. Breeding objectives for rainfed lowland rice improvement ranked by a) percentage of occurrence in the five most important objectives and b) the area weighted score based on the relative area represented by each survey.

indicate an area of between 35 and 40 million ha for South and Southeast Asia. This represents about 40-45% of the rice area of these regions.

The classification of rainfed lowland rice into five cultural types is based on the varietal traits required for particular water regimes (5). Several breeders found it difficult to classify their target areas into the cultural type terminology. This is understandable, since the occurrence of the stresses used for the cultural type classification is difficult to quantify. If flash floods occur almost every year, certainly the term "submergence-prone" is appropriate. If

the floods come less than once in 5 yr, however, a breeder may not regard this as an important constraint. If data from all relevant parts of the questionnaire are considered, the following tentative estimates can be made:

- About 30% of the rainfed lowland area covered in the survey (10 million ha) is favorable, even though it may also have various degrees of drought, submergence and stagnant flooding.
- Drought-prone rainfed lowlands represent an additional 30% of the area. Drought- and submergence-prone, and medium-deep rainfed lowlands are approximately equally represented in the survey (5-6 million ha each). Submergence-prone rainfed lowlands appear to be less common (1-2 million ha).

Breeding objectives

Susceptibility to diseases and insects is the most frequently cited limitation of current varieties. Breeding rainfed lowland rice with resistance to diseases (particularly brown planthopper, stem borer, and gall midge) should receive considerable attention. Susceptibility to drought and submergence is also a major limitation, and tolerance for these stresses needs to be incorporated into improved varieties. Salinity, acidity, P deficiency, and Zn deficiency are major soil problems for rainfed lowland rice. Breeders also consider lodging resistance and good seedling vigor important.

Following the 1978 International Rice Research Conference, which focused on rainfed lowland rice, the committee to develop future research strategies emphasized these major breeding objectives: drought and submergence tolerance, intermediate stature with suitable seedling height, tolerance for adverse soils, and appropriate maturity. The committee felt that disease and insect pests should not be a serious problem in the relatively less intense cropping patterns of rainfed lowland systems (4). In contrast, the breeders surveyed considered disease and insect susceptibility as the major weakness of current varieties (Fig. 1). Breeding for resistance to various diseases and insects was regarded as an important objective (Fig. 2). These results follow very closely those obtained by Hargrove and Cabanilla (2) in their survey of Asian rice breeders. In fact, the order of importance of the major insect and disease constraints found in their study, which included both irrigated and rainfed programs, is almost identical to that in the present study.

Breeding objectives other than tolerance for drought, submergence, and stagnant flooding are not clearly related to cultural type. This survey suggests that insect and disease problems as well as adverse soils are more related to geographic location than to cultural type. While many breeding objectives will be location-specific, most areas would benefit from rices resistant to bacterial blight, blast, stem borer, and brown planthopper.

Exchange of germplasm

Development of germplasm with valuable traits and its distribution to breeders in national programs have been among IRRI's major objectives. Therefore, it is important to understand the essential requirements for rainfed

lowland varieties. An important goal is to maintain or improve the level of tolerance for drought and submergence of the traditional varieties while incorporating disease and insect resistance and improved plant type. Most breeding materials may lack the necessary local adaptation but should function as donor parents in applied breeding programs.

The exchange of varieties and breeding lines among national programs has tremendous potential for the overall improvement of rainfed lowland rice. This is where the cultural type classification has particular relevance. Currently, improved germplasm from national programs is distributed on an international level mostly through the shallow rainfed lowland nurseries (IRRSWYN and IRRSWON) of the International Rice Testing Program. The nurseries have been valuable sources of germplasm for many breeders, but since they cover a wide range of target environments, most entries are generally not wholly adapted to any one particular location. If environments are classified by the predominant stresses (i.e., the cultural types) and the maturity requirements, it is easier to determine to which location appropriate materials should be dispatched.

Breeders working in specific environments have developed improved germplasm with adaptation to the predominant environmental constraints. Elite materials from these programs should be available to breeders in other states or countries where similar conditions prevail. Classification of all environments based on cultural type (i.e., emphasis on predominant stresses) would be ideal for this purpose. In its absence, the present list of environments (Appendix 1) and promising lines (Appendix 3) should assist breeders seeking potential sources of improved germplasm.

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Appendix 1. Breeding programs for different types of rainfed lowland rice in South and Southeast Asia.

Environment	Cultural types[a]	Area (thousand ha)	% trans-planted	Stresses[b]	Popular varieties	Promising lines	Breeding objectives[c]	Height and duration	Testing sites
BURMA									
Rainfed lowland, favorable	1	2,000	90	SUB-4 D(V)-4 D(R)-4 SF-3 DT-3	Ngwetoe Yebawsein Ngakywe Pawsanhmwe Shwetasoke	IR9129-7-1 IR21836-90-3	1. Good grain quality 2. Lodging resistance 3. BB resistance 4. SB resistance 5. ShB resistance	110-130 cm 130-150 d (sensitive)	Hmawbi Myaungmya
Rainfed lowland, drought-prone	2	260	70	SUB-5 D(V)-2 D(R)-1 SF-5 DT-5			1. Stable moderate yield 2. Drought tolerance 3. Seedling vigor 4. Good grain quality 5. SB resistance	90-110 cm 90-110 d	Yezin
INDONESIA									
Rainfed lowland, "Tadahhujan"	1	500	100	SUB-2 D(V)-5 D(R)-3 SF-5 DT-3	Cisadane Krueng Aceh IR42 Sadang		1 Drought tolerance 2. Submergence tolerance 3. BPH resistance 4. BB resistance 5. Seedling vigor	100 cm 130 d	
Dry-wetland "gogo rancah"	2	500	10	SUB-5 D(V)-2 D(R)-3 SF-5 DT-5	IR36 Cipunegar Krueng Aceh		1. Drought tolerance 2. BPH resistance 3. Bl resistance 4. BB resistance 5. Seedling vigor	100 cm 110 d	Jakenan
Waterlogged	5	700	100	SUB-5 D(V)-2 D(R)-5 SF-2 DT-3	IR42 Cisadane Barito Mahakam		1. Submergence tolerance 2. Adverse soils tolerance 3. BPH resistance 4. RTV resistance 5. Bl resistance	120 cm 130 d	
MALAYSIA									
Rainfed lowland	1, 2, 3	158	90	SUB-3 D(V)-4 D(R)-4 SF-5 DT-1	Kadaria Sekembang Setanjung Subang Intan	Kadaria Sekembang MR42 MR67 Muda	1. Drought tolerance 2. Submergence tolerance 3. RTV resistance 4. High tillering 5. Bl resistance	110-110 cm 130-140 d	Trenganu Kelantan Kedah
PHILIPPINES									
Rainfed lowland	1, 3	1400	80	SUB-5 D(V)-3 D(R)-3 SF-5 DT-1	IR36 BPI-3-2 BPI-76(NS) IR52 IR43		1. BPH resistance 2. Seedling vigor 3. Drought tolerance 4. Good grain quality 5. Lodging resistance	100 cm 100 d	

THAILAND									
Rainfed lowland (North)	1, 3	500	91	SUB-1 D(V)-1 D(R)-3 SF-4 DT-3	Niaw San Pah Tawng RD6 Leuang Yai 148 Khao Dawk Mali 105 Muey Nawng 62M	KKN6721-5-34-1 SPT7201-PRE-26-2 KKNLR75053-PMI-40-3 SPT6118-34 Niaw Ubon 1	1. Good grain quality 2. GM resistance 3. SB resistance 4. Bl resistance 5. BB resistance	20-140 cm 120-130d (sensitive)	Phan San Pa Tawng Phrae
Rainfed lowland (Northeast)	2, 3	3300	90	SUB-3 D(V)-1 D(R)-2 SF-4 DT-1	Niaw San Pah Tawng Khao Dawk Mali 105 Nam Sagui 19 RD6 RD15	Niaw Ubon 1 SPT7149-429-3 SPT6118-34 UBN6721-13-5-6 UBN6721-11-8-3	1. Good grain quality 2. Drought tolerance 3. Submergence tolerance 4. Adverse soils tolerance 5. Bl resistance	130-150 cm sensitive	Ubon Phimai Chum Phae Sakhon Nakhon Khon Kaen Surin
Rainfed lowland (Central Plains)	3	540	90	SUB-3 D(V)-3 D(R)-3 SF-3 DT-2	Nahng Mon S-4 Gow Ruang 88 Khao Pahk Maw 148 Leuang Pratew 123 RD27	SPT'58-37-400 BKN73004-419-2-1-1 SPRLR76130-75-1-1 SPRLR75067-62-1-1 SPR'76 Com. 3-38-3	1. Good grain quality 2. Bl resistance 3. BPH resistance 4. RSV resistance 5. BB resistance	130-150 cm sensitive	Pitsanulok Chainat Khok Samrong Klong Luang Rangsit Rathburi Prajinburi
Rainfed lowland (South)	4	500	90	SUB-1 D(V)-5 D(R)-5 SF-3 DT-1	Nahng Prayah 132 Puang Rai 2 Peuak Nam 43 RD13		1. Good grain quality 2. Submergence tolerance 3. Bl resistance 4. Adverse soils tolerance 5. BB resistance	140-150 cm sensitive	Nakhon Sithammorat Phathalung Pattani
VIETNAM									
Shallow rainfed (dry direct seeded)	3	500	85	SUB-4 D(V)-1 D(R)-4 SF-4 DT-1	IR36 IR8423-132-6-2-2 IR9129-169-2-3-5	IR9129-169-2-3-5 IR8423-132-6-2-2 IR18077-3-1 IR19728-9-3-2-3-3 IR21717-42-1	1. Drought tolerance 2. Submergence tolerance 3. Good grain quality 4. Seedling vigor 5. Acid soils tolerance	100 cm 90 d	
Shallow rainfed	1	1500	100	SUB-5 D(V)-5 D(R)-5 SF-2 DT-1	Ba thiet Than nong do Trang chum IR42	IR42 IR4432-52-6-4 Nang Nhuan	1. Tolerance for stagnant flood 2. Lodging resistance 3. BPH resistance 4. WBPH resistance 5. SB resistance	140 cm 140 d	
Semi-deep rainfed	5	1560	100	SUB-5 D(V)-4 D(R)-5 SF-1 DT-1	Tau huong Tam ruot lua Trang lun	Radin STR Mahsuri	1. Tolerance for stagnant flood 2. Good grain quality 3. Stem rot resistance 4. BPH resistance 5. WBPH resistance	140 cm 150 d	

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Appendix 1 continued

Environment	Cultural types[d]	Area (thousand ha)	% trans-planted	Stresses[b]	Popular varieties	Promising lines	Breeding objectives[c]	Height and duration	Testing sites
BANGLADESH									
Aus	2,3	2300	20	SUB-5 D(V)-3 D(R)-5 SF-5 DT-4	BR1 BR3 BR9 Hashi Kalmi Dharial	IR9729-67-3 IR9708-51-1-2 IR19743-25-2-2 BR201-193-1 BR203-26-2	1. BB resistance 2. RTV resistance 3. ShR resistance 4. Drought tolerance 5. ShB resistance	100-120 cm 100-110 d	Joydebpur Comilla Rajshahi Sonagazi
Transplant aman	3, 4	3800	100	SUB-4 D(V)-5 D(R)-4 SF-5 DT-4	BR4 BR10 BR11 Nizersail Latisail	BR593-698-5-1-8 BR593-676-4-1-2 BR316-15-4-4-1 BRC16-127-4-3 BR51-74-6-J1	1. Photoperiod sensitivity 2. BB resistance 3. Seedling vigor 4. BPH resistance 5. Leaf scald resistance	100-130 cm 130-150 d (sensitive)	Joydebpur Comilla Barisal Rajshahi
Boro	5	160	100	SUB-5 D(V)-5 D(R)-5 SF-5 DT-3	Hbj. Boro II Hbj. Boro IV Hbj. Boro VI BR3 BR9	BR153-2b-10-1-3 BR203-70-B-2 BR9-HR5 BR7-J9 IR9729-67-3	1. BPH resistance 2. Seedling vigor 3. High tillering 4. BB resistance 5. Lodging resistance	150 cm 130-150 d	Joydebpur Comilla Habiganj
SRI LANKA									
Favorable	1	125	75	SUB-5 D(V)-3 D(R)-3 SF-5 DT-4	Bg 94-1 Bg 34-8 Bg 276-5 Bg 400-1	Bg 573-7 Bg 380 Bw 288-2 Bw 298-2 At 74-1	1. Lodging resistance 2. High tillering 3. ShB resistance 4. Bl resistance 5. BPH resistance	90-100 cm 100-110 d	Batalagoda Peradeniya
"Manawari"	2	125	5	SUB-5 D(V)-2 D(R)-1 SF-4 DT-5	62-355 H-4 Bg 34-6 Bg 94-1	Bg 621-1 Bg 671-9 Pr 11 Pr 14 At 79-2	1. Drought tolerance 2. Bl resistance 3. Seedling vigor 4. Red pericarp 5. Lodging resistance	110-120 cm 80-90 d	Paranthan Karadianaru
Drought- and submergence-prone	3	40	20	SUB-1 D(V)-1 D(R)-2 SF-1 DT-2	Bw 100 Bg 3-5 Bg 407 Bg 745 Bw 272-6B	Bg 745-4 Bg 38-8 Bw 293-2 Bw 297-2 Bw 267-3	1. Lodging resistance 2. Bl resistance 3. ShB resistance 4. Submergence tolerance 5. Drought tolerance	100-110 cm 90-120 d (sensitive)	Bombuwela Batalagoda
Medium-deep stagnant	5	10	0	SUB-1 D(V)-1 D(R)-1 SF-1	Deveredderi Pokkali		1. Tolerance for stagnant flood 2. Submergence tolerance 3. Drought tolerance 4. Salinity tolerance 5. Seedling vigor	120-130 cm 140-150 d	Bentota

INDIA									
Bihar									
Shallow rainfed	1, 2, 3	720	90	SUB-4 D(V)-2 D(R)-3 SF-5 DT-1	Mahsuri Br 34 Bakol Br 8 T141	RAU83-18-8 RAU73-16-1-40-1 RAU83-8-4 RAU PTI-30 RAU77-2 IET 7970	1. Drought tolerance 2. BB resistance 3. Lodging resistance 4. Seedling vigor 5. Good grain quality	120-130 cm 140-150 d	Patna Pusa Sabour
Intermediate	1, 2, 3, 4	360	80	SUB-3 D(V)-2 D(R)-4 SF-5 DT-1	Pankaj Br 8 T141 Bakol Kalamdan	BIET 799 BIET 820 BIET 724 RAU79-113-54-2 RAU79-111-49-6 TCA48 TCA808	1. Lodging resistance 2. Seedling vigor 3. Drought tolerance 4. Submergence tolerance 5. BB resistance	140-150 cm 150 d (sensitive)	Patna Pusa Sabour
Ranchi, Bihar									
Kharif trans-planted and Bidhani	1, 2, 5	305	35	SUB-4 D(V)-2 D(R)-1 SF-5 DT-3	Kalamdan 498-2A(R-R-8) BR34 T141 Ratna Sita	IR36 IR50 RAU4009-15 RAU4004-105 RAU4004-109	1. Drought tolerance 2. Lodging resistance 3. GM resistance 4. Bl resistance 5. BB resistance	110-130 cm 130-150 d	Ranchi
West Bengal									
Rainfed shallow	1, 2, 3, 4	1400	80	SUB-1 D(V)-3 D(R)-4 SF-1 DT-5	Pankaj IET5656 Mahsuri Nagra Bhasamanik	CN505-5-32-9 CN506-147-14-2 CN499-160-2-1 IET6314 IET5882	1. Lodging resistance 2. Submergence tolerance 3. Seedling vigor 4. High tillering 5. Good grain quality	110-120 cm 150 d (sensitive)	Chinsurah Kakdwip Gosaba Pingla Uluberia Malda
Rainfed medium	5	1000	50	SUB-1 D(V)-4 D(R)-5 SF-1 DT-1	Suresh (CN540) Biraj (CNM539) Tilakkachari NC487/77 NC488/78	NC492 CN499-160-13-6 CN506-147-2-1 NC493 NC497	1. Submergence tolerance 2. Tolerance for stagnant flood 3. Drought tolerance 4. Lodging resistance 5. High tillering	140-150 cm (sensitive)	Chinsurah Kakdwip Gosaba
Assam (and northeast)									
Ahu	2, 3	540	30	SUB-3 D(V)-1 D(R)-5 SF-5 DT-4	Ch 63 Koimurali Bangalami Jaya Rasi	IR50 IET6148 IET6155 IET6223 IET3629	1. SB resistance 2. Drought tolerance 3. Lodging resistance 4. ShB resistance 5. Bl resistance	110-120 cm 90-100 d	Titabar Karinganj

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Appendix 1 continued

Environment	Cultural types[a]	Area (thousand ha)	% trans-planted	Stresses[b]	Popular varieties	Promising lines	Breeding objectives[c]	Height and duration	Testing sites
Sali	1, 3, 4, 5	1300	100	SUB-3 D(V)-5 D(R)-2 SF-3 DT-1	Mahsuri Manoharsali Pankaj Jaya IR8	Savitri	1. ShB resistance 2. BB resistance 3. SB resistance 4. Submergence tolerance 5. Stagnant flood tolerance	120-130 cm (sensitive)	Titabar Karinganj
Orissa									
Bahal (plateau region)	2, 3	600	50	SUB-4 D(V)-3 D(R)-2 SF-5 DT-3	Jagannath T141 CR1009 Padmakesasi Jhili	OR117-4 OR452-36 OR455-30-2 OR142-99 OR142-193	1. High tillering 2. GM resistance 3. Good grain quality 4. Lodging resistance 5. Drought tolerance	110 cm 150 d (sensitive)	Chiplima Similiguda
Sarad (coastal)	3, 4	800	30	SUB-2 D(V)-4 D(R)-3 SF-5 DT-2	T141 T90 Jagannath FR13A SR26B	OR117-4 OR142-105 OR142-99 OR142-193 OR143-7	1. Lodging resistance 2. High tillering 3. Acid sulfate soils tolerance 4. Submergence tolerance 5. SB resistance	110 cm 150-160 d (sensitive)	CRRI (Cuttack) OUAT (Kendrapan)
Pat or Gahir (coastal region)	5	300	0	SUB-1 D(V)-5 D(R)-5 SF-1	CR1014 T1242 BAM 6 FR43B FH60-124	OR143-7	1. Seedling vigor 2. Tolerance for stagnant flood 3. Submergence tolerance 4. Salinity tolerance 5. Drought tolerance	130 cm 160-165 d (sensitive)	
Maharashtra									
Rainfed shallow, favorable	1	1200	90	SUB-3 D(V)-4 D(R)-4 SF-5 DT-4	Jaya Ratna White Lychai 112 RP4-14 Mahsuri	KJT24-10-25-35 KJT-23 KJT-2-32-43-20-11 Ramagiri 500 SKL6-1-2-3	1. SB resistance 2. Good grain quality 3. BB resistance 4. Bl resistance 5. GM resistance	120-130 cm 120-130 d	Karjat Ratnagiri Panvel Sindewali Sakoli
Gujarat									
Rainfed lowland (transplanted)	1, 2	150	100	SUB-5 D(V)-3 D(R)-2 SF-5 DT-5	Kada 176-12 Kavchi Ankli Kolam (Halki) Khadasiya	GR3 Ratna IR28 GR4	1. High grain yield 2. Early maturity 3. Drought tolerance 4. SB resistance 5. Lodging resistance	90-130 cm 100-110 d	Waghai Vyara

Andhra Pradesh										
Rainfed lowland	1	1107	75	SUB-5	Tellahamsa	Tellahamsa	1. Drought tolerance	90-100 cm	Ragolu
				D(V)-2	Surekha	Surekha	2. GM resistance		Nellore
				D(R)-4	MTU7029	MTU7029	3. BPH resistance	110-140 d	Hyderabad
				SF-5	NLR9672	NLR9672	4. Seedling vigor		Warangal
				DT-2	AKP70-73	AKP70-73	5. High tillering		Rudrur
Karnataka										
Rainfed lowland	1	200	60	SUB-3	Intan	Mingolo	1. Bl resistance	100-110 cm	Mudigere
				D(V)-5	Phalguna	Intan Mahsuri	2. GM resistance		Ponnampet
				D(R)-5	A-200	KMP-39	3. SB resistance	140-150 d	Mugad
				SF-5	Vikram		4. Adverse soils tolerance		Sirsi
				DT-2	M-141		5. BPH resistance		
Madhya Pradesh										
Bhata (early) "bunded uplands"	2	1565	0	SUB-5	Lalu	Anupama	1. Early maturity	100-120 cm	Raipur
				D(V)-2	Niwari	Purwa	2. Drought tolerance		Rewa
				D(R)-2	Sathi	Samridhee	3. BS resistance	90-100 d	Jubalpur
				SF-5	Nungi		4. Bl resistance		
					Parewa		5. Rice bug resistance		
Matasi (medium) "lowland short-time submergence"	2	892	0	SUB-5	Safri 17	Usha	1. GM resistance	120-150 cm	Raipur
				D(V)-2	Gurmatia	Asha	2. BB resistance		Waraseoni
				D(R)-2	Parmal	Triptee	3. Drought resistance	120-150 d	Jubalpur
				SF-5	Bhondparewa	Deeptee	4. Lodging resistance	(sensitive)	Rewa
					Chatri	Madhuri	5. Good grain quality		Bagwai
Bahara (Kanhar) (late) "lowland continuous submergence"	5	202	0	SUB-5	Luchai	Jagritee	1. GM resistance	150 cm	Raipur
				D(V)-2	Jhilli	Mahsuri	2. BB resistance		Wareseoni
				D(R)-2	Chinor		3. Stagnant flood tolerance	150 d	Jubalpur
				SF-5	Dubraj		4. Lodging resistance	(sensitive)	Rewa
					Safri Desi		5. GLH resistance		Bagwai

[a]Rice cultural types: 1 = favorable, 2 = drought-prone, 3 = drought- and submergence-prone, 4 = submergence-prone, 5 = medium deep, stagnant. [b]Stresses: SUB = submergence, D(V) = vegetative drought, D(R) = reproductive drought, SF = stagnant flood, DT = delayed transplanting. Scores: 1 = occurs regularly in most fields, 2 = occurs occasionally in most fields, 3 = occurs regularly in some fields, 4 = occurs occasionally in some fields, 5 = rarely occurs. [c]BB = bacterial blight, Bl = blast, BPH = brown planthopper, BS = brown spot, GLH = green leafhopper, GM = gall midge, RSV = ragged stunt, RTV = tungro, SB = stem borer, ShB = sheath blight, ShR = sheath rot, WBPH = whitebacked planthopper.

Appendix 2. Varieties released by national programs for rainfed lowland conditions.

Variety	Parentage	Year of release	Origin	Duration[a] (d to harvest)	Comments[b]
BURMA					
Seintalay	C4-113/Yebawsein	1975	Yezin	140	grain quality, moderate yield
Eyamin	(Machando)	1978	Kyaukse	145	grain quality
Shwewartun	IR5 mutant	1978	Yezin	140	grain yield, long clear grain
Pelita I-1		1979	Indonesia	135	high yield
Kyawzeya (X70-18-38)	Aungzeya/IR5	1980	Yezin	140	high yield, long clear grain
Hmawbi 1	(IR42)	1980	IRRI	140	high yield
Hmawbi 2	(IR21836-90-3)	1982	IRRI	130	high yield, long clear grain
Hmawbi 3	(IR21841-91-2-3-3)	1983	IRRI	120	high yield, long grain
Syin Ekari (X72-8-22)	IR24/Kauk Hmwe	1984	Yezin	145	high yield, long clear grain
INDONESIA					
IR36	IR1561-288-1-2/IR1737//CR94-13	1978	IRRI	120	early, BPH resistant
Cisadane	Pelita I-1/B2388	1980	Bogor	135	submergence tolerant, good eating quality
Barito	Pelita I-1/B2393	1981	Bogor	135	submergence tolerant
Cipunegar	Pelita I-1/B2393	1981	Bogor	125	drought tolerant
IR42	IR1561-288-1-2/IR1737//CR94-13	1981	IRRI	135	tolerant of problem soils
Krueng Aceh	Pelita I-1/B2709	1981	Bogor	125	drought tolerant
Mahakam	Pelita I-1/IR442-36	1983	Bogor	135	submergence tolerant
Sadang	B459/IR2071	1983	Maros	130	resistant to RTV
MALAYSIA					
Sekembang	IR8//Engkatek/Segupak//RIA 163	1979	Kelantan	140-146	wide adaptability
Kadaria	IR8//Engkatek/Segupak//TKM6	1981	Kada	126-132	good adaptability
PHILIPPINES					
BPI-3-2	Fortuna/M4-3-2b	1961	BPI-MRRTC	125-130	medium slender grain, good eating quality
IR46	IR1461-131-5/IR1364-37-3-1 //IR1366-120-3-1/IR1539-37-3-1	1978	IRRI	130	high, stable yield
IR52	Nam Sagui 19/IR2071-88 //IR2061-214-3-6-20	1980	IRRI	115	drought resistant, susceptible to BI
THAILAND					
Nahng Mon S-4		1950	Thailand	26 Nov	nonglutinous, Central Thailand
Muey Nawng 62M		1959	Chiang Mai	20 Nov	North Thailand, glutinous, early, GM resistant
Niaw San Pah Tawng		1962	Chiang Mai	26 Nov	North and Northeast Thailand, glutinous, grain quality, wide adaptation, resistant to BS

Gow Ruang 88		1962	Thailand	21 Nov	Central Thailand
Nahng Prayah 132		1962	Thailand	16 Feb	South Thailand
Khao Pahk Maw 148		1965	Thailand	3 Dec	Central and Northeast Thailand
Leuang Pratew 123		1965	Thailand	19 Dec	Central Thailand
Leuang Yai 148		1965	Chiang Mai	25 Nov	North Thailand, nonglutinous, grain quality
Nam Sagui 19		1968	Thailand	4 Nov	early, nonglutinous, drought and submergence tolerant
Peuak Nam 43		1968	Thailand	22 Feb	South Thailand
Puang Rai 2		1968	Thailand	6 Feb	South Thailand
RD6	Khao Dawk Mali 105 mutant	1977	Thailand	21 Nov	glutinous
RD13	Nahng Prayah 132/Pak Sian 199-19-39	1978	Thailand	23 Feb	South Thailand
RD15	Khao Dawk Mali 105 mutant	1978	Thailand	11 Nov	Early mutant of Khao Dawk Mali, sensitive, aromatic, drought tolerant
RD27			Thailand		Central Thailand
Niaw Ubon 1	NSPT*2/IR262	1983	Thailand		glutinous, good plant type
VIETNAM					
IR36		1977			BPH resistance
IR2307-247-2-2-3		1979			
IR42		1979			
IR9129-169-2-3-5		1979			
BANGLADESH					
Nizersail	(sel. from GEB 24)		Bangladesh	1st wk Dec	strongly sensitive, good grains
IR8	Peta/Dee-geo-woo-gen	1967	IRRI	130-140	high yield
IR5	Peta/Tankai Rotan	1969	IRRI	130-140	high yield, weakly sensitive
BR1	Peta/TN1//TKM6	1970	IRRI	115-130	short duration
BR3	IR506-133-1/Latisail	1973	Bangladesh	125-140	high yield
BR4	IR20/IR5-114-3-1	1975	Bangladesh	140-150	intermediate height, high yield, weakly sensitive
BR8	IR272-4-1-2-J1/IR305-3-17-1-3	1978			
BR9	IR272-4-1-2-J1	1978			
BR10	IR20/IR5-114-3-1	1980	Bangladesh	125-135	intermediate height, high yield
BR11	IR20/IR5	1980	Bangladesh	115-130	intermediate height, high yield

Continued on next page

Appendix 2 continued

Variety	Parentage	Year of release	Origin	Duration[a] (d to harvest)	Comments[b]
			Bangladesh	140-145	intermediate height, weakly sensitive, high yield
			Bangladesh	140-145	intermediate height, high yield, weakly sensitive
SRI LANKA					
H-4	Murungakayan/Mas	1958	Batalagoda	120-135	Bl resistant
62-355	PP/H-4	1969	Batalagoda	90	drought tolerant, red rice
Bg34-6	IR8-246///PP/Mas//H-501	1971	Batalagoda	105	red pericarp, good yield
Bg 3-5	Pandunewee/Mas//Engatek	1973	Batalagoda	Sensitive	high yield
Bg 94-1	IR262/Ld66	1975	Batalagoda	105	high yield
Bw 272-6B	Bw 259-3/BW 242	1978	Bombuwela	90	tolerant of iron toxicity
Bw 100	H501//Podiwee A8/H-5	1979	Bombuwela	120-135	tolerant of iron toxicity
Bg 407	IR5/Pandunewee	1981	Batalagoda	Sensitive	good grain quality
Bg 750	Ainantsao//75-1870/PP	1981	Batalagoda	75	
Bw 266-7	Bw 242//Ob677//BG 90-2	1981	Bombuwela	105	tolerant of iron toxicity
Bw 267-3	Ld 125/Bw 248-1	1981	Bombuwela	105	tolerant of iron toxicity
Bg 745	71-554/Podiwee A8	1982	Batalagoda	Sensitive	good grain quality
INDIA					
Bihar					
BR 8	Sel. "Kessore rice"	1958	Bihar	4th wk Nov	0-50 cm depth, tall, sensitive
BR9	Sel "Tulsimanjari"	1958	Bihar	4th wk Nov	0-25 cm water depth, tall sensitive, scented
Br 34	Sel. "Dolangi rice"	1958	Bihar	2d wk Nov	0-25 cm depth, tall, sensitive
Mahsuri	Taichung 65/2*Mayang Ebos 80	1971	Malaysia	145-150	0-25 cm water depth, medium slender grain
Pankaj	Peta/Tangkai Rotan	1971		150-155	25-50 cm water depth, insensitive
Jaishree	Jaya/Mahsuri	1981	Bihar	145 150	0-25 cm water depth, medium slender grain
Sugandha	Sel. Cuttack Basmati	1983	Bihar	3d wk Nov	0-25 cm water depth, scented, sensitive
Ranchi (Bihar)					
Kanchan (CR141-4001-2-192)	IR8/N22	1976	CRRI	105	short bold grain, for uplands and transplanted medium lands
Kiran (RP79-18)	N22/TN1//T90/IR8	1976	AICRIP	105	short bold grain, for uplands and transplanted medium lands

Panidhan-2 (IR442-5)	IR95-31-4/LMN111	1972	IRRI	145	medium slender grain, suited to medium lands
Rajendra Dhan 202 (IET2895)	IR8/W1251	1978	AICRIP	130	long bold grain, GM resistant
West Bengal					
Biraj (CNM539)	OC1393 mutant	1982	Chinsurah	Late Nov	sensitive, 130-140 cm, drought tolerant, resistant to SB, RTV, BB, and BS
Suresh (CN540)	IR262/Khao Nahng Nuey 11	1982	Chinsurah	155-160	submergence tolerant, semitall (140-150 cm), purple culm
Assam					
Ch 63		1967	Titabar	110-115	rapid early growth, tall, ahu season
Manoharsali	Latisali/Guachhari	1968	Karimganj	25 Nov	tall, wide adaptability, transplanting can be delayed up to September
TTB 4/7	IR8/Ch 63	1977	Titabar	120-125	semidwarf, ahu season
KMJ 1-17-2	Manoharsali/IR8	1978	Karimganj	25 Nov	semidwarf, can stand delayed transplanting (up to September)
KMJ 1-19-1	Manoharsali/IR8	1978	Karimganj	25 Nov	semidwarf, can stand delayed transplanting (up to September)
Mahsuri		1978	Malaysia	140-150	good grain type, tall
Pankaj	Peta/Tongkai Rotan	1979	India	145-150	adaptable to low lying situations
Orissa					
BAM6	Sel. Ratnachudi	1940s	Orissa	165	tall, good adaptability, short slender grain
BAM9	Sel. Mypali	1940s	Orissa	165	tall, high yield potential, long bold grains
FRI3A	Sel. Dhullaputia	1940s	Orissa	145	tall, submergence tolerant, medium bold grain with red pericarp
FR43B	Sel. Bhetnasia	1940s	Orissa	160	tall, submergence tolerant, short bold grain, red pericarp
SR26B	Sel. Kalambank	1940s	Orissa	150	tall, adaptable to saline conditions, long bold grain
T90	Sel. Machhakanta	1940s	Orissa	160	tall, weakly sensitive, short slender grain
T141	Sel. Saruchinamali	1940s	Orissa	150	tall, medium slender, wide adaptation

Continued on next page

Appendix 2 continued

Variety	Parentage	Year of release	Origin	Duration[a] (d to harvest)	Comments[b]
T1242	Sel. Magura	1940s	Orissa	165	pigmented leaf sheath (favored for weeding), long bold grains
FH60-124	Indica/Japonica cross	1960	Orissa	160	tall, popular in South Orissa, medium slender grains, low yield
CR1014	T90/Baok	1962	CRRI	165	
Jagannath	Mutant of T141	1969	Orissa	155	short, sensitive
CR210-1009 (Savitri)	Pankaj/Jagannath	1983	CRRI		short, sensitive
Maharashtra					
Karjat-184	TN1/Kolamba	1971	Maharashtra	110	grain quality, dwarf
Ratnagiri-24	Zinia-63/TN1	1971	Maharashtra	120	grain quality
Karjat 14-7	IR8/Zinia-149	1975	Maharashtra	140	dwarf, grain quality
Ratnagiri 68	IR8/Sigadis	1975	Maharashtra	140	dwarf, BB resistant, coarse grain
Sakoli-17	Z-13400/WL-112	1982	Maharashtra	117	grain quality
Sindewali-75	TN1/2L-112	1982	Maharashtra	145	grain quality
Gujarat					
Ratna	TKM6/IR8	1970	CRRI	110-115	dwarf, early, moderately resistant to Bl
IR28	IR833-6-2-1-1//IR1561-149-1/IR1737	1975	IRRI	105	dwarf, responsive to fertilizer, resistant to pests and diseases
GR-2	IR8/Kada 176-12	1976	Gujarat	110	dwarf, early, high tillering
GR-3	Nawagam 19/IR9-60	1977	Gujarat	105-110	dwarf, early, moderately resistant to pests/diseases
GR-4	Z31/IR8-246	1981	Gujarat	100-115	fine grain, intermediate height
SLR 51214	Vijaya/Ftb 21	1983	AICRIP	120-125	dwarf, salt tolerant
Andhra Pradesh					
Tella Hamsa	HR12/TN1	1974	Andhra Pradesh Agric. Univ.	110-115	cold tolerant, long slender grain
MTU3626	IR8/MTU 3	1975	Andhra Pradesh Agric. Univ.	135-140	long bold, high yield
NLR9672	Millikuning/Bulk H9	1975	Andhra Pradesh Agric. Univ.	14 Jan	sensitive, drought tolerant, good grain quality
NLR9674	Millikuning/Bulk H9	1975	Andhra Pradesh Agric. Univ.	14 Jan	sensitive, drought tolerant, good grain quality
Surekha	IR8/Siam 29	1975	Andhra Pradesh Agric. Univ.	135-140	GM resistant, medium slender
AKP70-73	IR20/BAM 3	1982	Andhra Pradesh Agric. Univ.	15 Nov	sensitive, medium slender, drought tolerant

BPT1235	Sabarmati/WGL 12708	1982	Andhra Pradesh Agric. Univ.	120-125	GM resistant, long slender, high yield
MTU4407	Mahsuri/Vijaya	1982	Andhra Pradesh Agric. Univ	140-145	medium slender, suitable for late planting
MTU7029	Vasista/Mahsuri	1982	Andhra Pradesh Agric. Univ.	150-155	medium slender, high adaptability, stable yield with low N level
RPW 6-17	IR8/Siam 29		AICRIP	140-145	GM resistant, medium slender, high yield
Karnataka					
Vikram	IR8/Siam 29	1974	Mandya	135-145	
Intan	Cina/Latisail	1975	Indonesia	160-165	
Phalguna	IR8/Siam 29	1979	Mandya	140-145	
Madhya Pradesh					
Safri-17	Sel.	1964	Madhya Pradesh	140	tall, sensitive, drought tolerant, high tillering, long slender grain
Laloo-14	Sel.	1964	Madhya Pradesh	105	very early, tall, red husk, drought escaping, medium slender grain
Anupama (JR8-26-23)	SL 016/IR8	1975	Madhya Pradesh	115	semidwarf, long flag leaf, early, long slender grain
Kranti (R2022)		1976	Madhya Pradesh	120-125	intermediate height, drought tolerant, early, short bold grain
Pragati (R2076)		1976	Madhya Pradesh	130	long bold grain, BB resistant
Jagriti (R68-1)	Rikku/R-4	1976	Madhya Pradesh	20 Nov	low lying areas (tall), GM resistant, sensitive
Garima (JR3-756)	Cross 4/TN1		Madhya Pradesh	130	BB resistant
Tripti (R155-355)	CR44-35/NSJ-205		Madhya Pradesh	100	short, bold grain
Deepti (R34-2478)	IR22/NP130		Madhya Pradesh	125	long, slender grain, resistant to SB, moderately resistant to BB
Madhuri (R36-2468)	Jaya/Dubraj (R11)		Madhya Pradesh	120-125	scented, medium slender grain
Samridhi (R2384)	R68-1/Jaya		Madhya Pradesh	125	GM resistant, moderate resistant to SB, leaffolder, BPH, and BB
Asha (R35-2750)	IR22/W1263		Madhya Pradesh	132	resistant to GM, SB; moderately resistant to GLH, BPH, BB
Usha (35-2752)	IR22/W1263		Madhya Pradesh	128	resistant to GM, BB, RTV, BS, Helminthosporium
Poorva (JR16-105-3-1-1)			Madhya Pradesh	95	very early, long, slender grain

[a]Or approximate harvest date for photoperiod-sensitive varieties. [b]BB = bacterial blight, Bl = blast, BPH = brown planthopper, BS = brown spot, GLH = green leafhopper, GM = gall midge, RTV = tungro, SB = stem borer.

Appendix 3. Promising lines for rainfed lowland conditions from Asian national programs.

Designation	Parentage	Origin	Duration[a] (d)	Comments[b]
BURMA				
BKN6322-85	Nahng Mon S-4/Remadja	Thailand		
CN540		West Bengal		
IR9129-7-1	IR28/IR2053-54-1-1//IR2071-625-1	IRRI	143	high yield
IR11288-B-288-1	IR36/LMN 111	IRRI		
IR13437-20-4E-P1	KLG6987-191-P/IR2153-26-3-5-6//IR36	IRRI		
Mat Candu		Malaysia		
MALAYSIA				
BR4	IR20/IR5-114-3-1	Bangladesh	129	moderate drought and submergence tolerance
IR13365-253-3-2	IR42*2/Mahsuri	IRRI	131	moderate drought and submergence tolerance
MR67	Sel. Seribu Gantang	Bumbong Lima	132-136	wide adaptability, Bl resistance
MR70	Mahsuri*2/Pongsu Seribu 2	Bumbong Lima	135-140	wide adaptability, Bl resistance, good eating quality
Padi Hitam		Trengganu	140	drought tolerance
Tangkai Emas		Trengganu	130	drought tolerance
PHILIPPINES				
MRC356-172				
MRC801-411				
MRC2711-2503				
MRC4917-3146				
MRC5731-3438				
MRC5892-3460				
MRC8601-4927-1				
MRC-10922-147				
MRC-10923-148				
MRC-10929-184				
THAILAND				
SPRLR75067-62-1-1	KPG/IR32	Thailand	Early Dec	Central Thailand, sensitive
SPRLR76130-75-1-1	KPG/IR32//La/Sig	Thailand	Mid Dec	Central Thailand, sensitive
SPT'58-37-400	DML70*2/Chinese 345	Thailand	Late Nov	Central Thailand, sensitive

SPR6118-34	GP41/LT78	Thailand	Late Nov	North and Northeast Thailand, sensitive
SPT7201-PRE-26-2	NSPT/BKN6806-46-62	Thailand		North Thailand
UBN6721-11-8-3	NSPT*2/IR262	Thailand	Late Nov	Northeast Thailand, sensitive
UBN6721-13-5-6	NSPT*2/IR262	Thailand	Mid Nov	Northeast Thailand, sensitive
VIETNAM				
IR13240-10-1	IR30S/Babawee//IR36	IRRI		BPH resistance
IR19728-9-3-2-3-3	IR8608-298-3-1/IR10179-23	IRRI		BPH and Bl resistance, drought tolerance
IR18189-2-3-2	IR4219-35-3-3/IR46	IRRI		BPH and Bl resistance, drought tolerance
IR19743-25	IR9129-192-2-3/IR10176-79	IRRI		BPH resistance
IR19748-9-3-2	IR9129-192-2-3/IR10187-80	IRRI		BPH resistance
IR21717-42-2	Triveni/RP825-71-4-11//IR9129-303-2	IRRI		BPH resistance, tolerance of acid sulfate soils
BANGLADESH				
BR51-49-6-HR50	IR20/IR5-114-3-1	Bangladesh	145	
BR51-74-6-J1	IR20/IR5-114-3-1	Bangladesh	145	transplanted aman
BR51-282-8	IR20/IR5-114-3-1	Bangladesh	140	
BR51-282-8-HR9	IR20/IR5-114-3-1	Bangladesh	145	
BR315-12-1-4-1	IR5(J)/BR3	Bangladesh	145	
BR316-15-4-4-1	IR5(P)/BR3	Bangladesh	135	
BR593-676-4-1-2	Swarnalata/IR2061-464-2	Bangladesh	Late Nov	sensitive, transplanted aman
BR593-698-5-1-8	Swarnalata/IR2061-464-2	Bangladesh	Late Nov	sensitive, transplanted aman
BRC16-127-4-3	Kataribhog/BRJ27-10-1	Bangladesh	145	transplanted aman
SRI LANKA				
At 74-1		Ambalantota	90-110	seedling vigor, Bl resistance
At 78-2		Ambalantota	90-100	drought tolerance/escape, Bl resistance, seedling vigor
At 79-2		Ambalantota	90-100	submergence tolerance drought tolerance/escape, Bl
Bg 38-8	Engatek/H-4//Podiwa A8	Batalagoda	Sensitive	submergence tolerance
Bg 621-1	Obl280/H4	Batalagoda	90-100	drought tolerance/escape, Bl resistance, seedling vigor

Continued on next page

Appendix 3 continued

Designation	Parentage	Origin	Duration[a] (d)	Comments[b]
Bg 621-9	Ob1280/H4	Batalagoda	90-100	drought tolerance/escape, Bl resistance, seedling vigor
Bg 745-4	71-554/Podiwa A8	Batalagoda	Sensitive	submergence tolerance
Pr 14-1		Paranthan	90-100	drought tolerance/escape, Bl resistance, seedling vigor
Pr 17-1		Paranthan	90-100	drought tolerance/escape, Bl resistance, seedling vigor
INDIA				
Bihar				
BIET720	IR8/Br 8	Bihar	3d wk Nov	25-50 cm water depth
IET7970	Pureline selection	Pusa	150	130 cm, tolerance for RTV, medium slender grain, resistance to ShR and BB
RAU25-3-5 (BIET 821)	IR8/Br 14	Bihar	2d wk Nov	25-50 cm water depth
RAU79-113-54-2	Pankaj/Janki	Bihar	3d wk Nov	25-50 cm water depth
RAU83-18-8	BR51-46-51-Mahsuri	Bihar	145-150	0-25 cm water depth
TCA48	Pureline selection	Pusa	Sensitive	higher yielding than Br 8, Br 34
TCA808	Pureline selection	Pusa	Sensitive	higher yielding than Br 8, Br 34
Ranchi, Bihar				
RAU4004-109	TN1/Brown gora	Ranchi	105	bold grains, for direct seeded uplands and transplanted medium lands
RAU4004-105	TN1/Brown gora	Ranchi	105	bold grains, for direct seeded uplands and transplanted medium lands
RAU4009-3	Jaya/BR34	Ranchi	117	medium slender grain, drought escaping, for medium lands
RAU4009-15	Jaya/BR34	Ranchi	125	medium slender, drought escaping
BAU151-51	Mutant 14/IET5874	Ranchi	100	medium fine grain, for uplands and medium lands
BAU151-56	Mutant 14/IET5874	Ranchi	105	medium fine grain, for uplands and medium lands
RAU4024-10	Aus 8/IET5704	Ranchi	112	medium fine grain, for medium lands
RAU4074-77-10	IR2061-464-246/IR8635	Ranchi	112	medium fine grain, for medium lands
RAU4090-1	IR2070-423-2-5-6/IR8717	Ranchi	117	medium fine grain, for medium lands
RAU4070-68-19	IR1833-208-1-3/Mahsuri	Ranchi	120	medium slender grains, for lowlands

WEST BENGAL				
CN499-160-2-1	IR34/KLG6987-143-2-P// IR2070-2-5-6/Hbj DW8	Chinsurah	170-180	sensitive, high tillering, resistance to RTV, BB, submergence tolerance
CN499-160-13-1	IR34/KLG6987-143-2-P// IR2070-20-2-5-6/Hbj DW8	Chinsurah	170-180	sensitive, high tillering, resistance to RTV, BB, submergence tolerance
CN505-5-32-9	IR26/SML 40-10-4	Chinsurah	180-190	sensitive, 140-150 cm, submergence tolerance, resistance to RTV
CN506-147-2-1	IR30/LMN//IR1514A-E666	Chinsurah	180-190	sensitive, drought tolerance, purple base
CN506-147-14-2	IR30/LMN//IR1514S-E666	Chinsurah	170-180	sensitive, drought tolerance
NC487/77 (IET7976)	Pureline selection	Chinsurah	170-180	sensitive, resistance to stagnant flooding, stiff straw
NC490 (IET8987)	Pureline selection	Chinsurah	175-185	sensitive, tall, resistance to stagnant flooding
NC492	Pureline selection	Chinsurah	170-180	sensitive, seedling vigor, lodging resistance, high tillering, long slender grain
NC493 (IET8989)	Pureline selection	Chinsurah	170-180	sensitive, resistance to stagnant flooding, stiff straw
Assam				
TTB14-1	CRM13-3241/Kalinga II	Titabar	115	semidwarf, good yield
TTB15-1	IR24/CR44-118-1	Titabar	128	semidwarf, moderate resistance to BB, good yield
Orissa				
OR117-4	T141/Jagannath	Orissa	150	good yield stability, intermediate height
OR142-99	Pankaj/Sigadis	Orissa	150	good plant type, stiff straw
OR142-105	Pankaj/Sigadis	Orissa	150	intermediate height, pigmented leaf sheath
OR142-193	Pankaj/Sigadis	Orissa	150	intermediate height, good plant type
OR143-7	Pankaj/W1263	Orissa	150	moderate elongation ability for semideep water condition
OR452-36	Jajati//Pankaj/Sigadis///Jajati	Orissa	145	high yield potential, short slender grain
OR455-30-2	IR36//Pankaj/Sigadis	Orissa	145	intermediate height, high yield potential, short slender grain

Continued on next page

Appendix 3 continued

Designation	Parentage	Origin	Duration[a] (d)	Comments[b]
Maharashtra				
Karjat 2-32-43-20-11	K35-3/RPW 6-516	Maharashtra	130	long, slender grain
Karjat 23	IR20/Pusa 33	Maharashtra	110	scented, short, bold grain
Karjat 24-10-25-35	Karjat-35-3/Pusa 33	Maharashtra	125	
Ratnagiri 500	IR8/RTN-24	Maharashtra	115	long, bold grain
Andhra Pradesh				
IR36	IR1561-288-1-2/IR1737//CR94-13	IRRI	120-125	long slender, multiple insect/disease resistance
IR50	IR2153-14-1-6-2/IR28//IR36	IRRI	110-115	long slender, multiple resistance, high yield
MTU2400	MTU4407/WGL26888//MTU6024/IET4620	Andhra Pradesh Agric. Univ.	130-135	GM resistance, medium slender
MTU6861	MTU6024/IET4620	Andhra Pradesh Agric. Univ.	135-140	GM resistance, medium slender
NLRI 3936	Sona/Kakatiya	Andhra Pradesh Agric. Univ.	105-110	medium slender, drought tolerance
RGL 172	RGL 1/IR8	Andhra Pradesh Agric. Univ.	150-155	medium slender, drought tolerance
RGL 1746	BAM3/TN1	Andhra Pradesh Agric. Univ.	150-155	medium slender, drought tolerance
RGL 2624	Tellahamsa/TN1	Andhra Pradesh Agric. Univ.	105-110	medium slender, early vigor
RNR 1446	Tellahamsa/IET 1444	AICRIP	110-115	medium slender, cold tolerance
WGL 22245	IR579/WGL 12708	Andhra Pradesh Agric. Univ.	120-125	GM resistance, medium slender
Karnataka				
Intan Mahsuri				late, tolerance for diseases/insects, intermediate height

[a]Or approximate harvest date for photoperiod-sensitive varieties. [b]BB = bacterial blight, Bl = blast, BPH = brown planthopper, GM = gall midge, RTV = tungro, ShR = sheath rot.

Appendix 4. Popular varieties grown under rainfed lowland conditions in Asia.

Variety	Country or states	Comments[a]
AKP 70-73	Andhra Pradesh	Fine grain, drought tolerant, susceptible to GM
Ankli	Gujarat	
Asamchudi	Madhya Pradesh	medium duration
Asha	Madhya Pradesh	improved, medium, GM resistant
A-200	Karnataka	
Bakol	Bihar	BB and lodging susceptible, RTV susceptible, tall, 0-50 cm water depth
Bangalami	Assam	good yield, less disease incidence, Ahu season
BAM6	Orissa	medium-deep condition, good adaptability, short slender grain
Barito	Indonesia	"water logged" areas
Ba thiet	Vietnam	favorable and stagnant flooded areas
Bg 3-5	Sri Lanka	sensitive, high yield, for submergence-prone areas
Bg 34-6	Sri Lanka	red pericarp, 105 d, for drought-prone areas
Bg 34-8	Sri Lanka	favorable areas
Bg 94-1	Sri Lanka	105 d, high yielding, favorable areas
Bg 276-5		favorable areas
Bg 400-1	Sri Lanka	favorable areas
Bg 407	Sri Lanka	sensitive, good grain quality, submergence-prone areas
Bg 745	Sri Lanka	sensitive, good grain quality, submergence-prone areas
Bhasamanik	West Bengal	weakness — poor submergence tolerance, weak stems
Bhonduparewa	Madhya Pradesh	medium duration
Biraj (CNM 539)	West Bengal	weak stems
BPI-3-2	Philippines	good grain quality, medium maturity
BPI-76 (NS)	Philippines	good grain quality, medium maturity
BR1	Bangladesh	early, high yield, aus crop
BR3	Bangladesh	early, high yield, aus crop, boro crop
BR4	Bangladesh	intermediate height, high yield, weakly sensitive, transplanted aman crop
BR9	Bangladesh	intermediate height, early, high yield, aus, boro crop
BR10	Bangladesh	intermediate height, high yield, weakly sensitive, transplanted aman crop
BR11	Bangladesh	intermediate height, high yield, weakly sensitive, transplanted aman crop
Br 8	Bihar	BB, lodging susceptible, RTV susceptible, 0-50 cm water depth
Br 34	Bihar	lodging, BB susceptible, 0-25 cm water depth
Bw 100	Sri Lanka	tolerant of iron toxicity, 120-135 d
Bw 272-6B	Sri Lanka	tolerant of iron toxicity, grown in submergence-prone areas
Chatri	Madhya Pradesh	medium duration
Chinor	Madhya Pradesh	late, scented
Ch 63	Assam	white kernel, good yield, rapid early growth, ahu season
Cipunegar	Indonesia	drought-prone areas

Continued on next page

Appendix 4 continued

Variety	Country or states	Comments[a]
Cisadane	Indonesia	favorable and "waterlogged" areas, good eating quality
CR1009	Orissa	improved variety
CR1014	Orissa	improved variety, medium-deep condition
Dabola	Gujarat	
Deveredderi	Sri Lanka	grown in stagnant water areas
Dharial	Bangladesh	early tall, low yield, susceptible to BB/RTV, aus crop
Dubraj	Madhya Pradesh	late, scented
FH60-124	Orissa	lodging susceptible, BB susceptible
FR13A	Orissa	submergence tolerant
FR43B	Orissa	stagnant flood conditions, submergence tolerant
Garima	Madhya Pradesh	medium duration, improved, Bl resistant
Gow Ruang	Thailand	nonglutinous, central Thailand harvest 21 Nov
Gurmatia	Madhya Pradesh	medium duration
Habiganj Boro II	Bangladesh	tall, low yield
Habiganj Boro IV	Bangladesh	tall, early, low yield
Habiganj Boro VI	Bangladesh	tall, low yield
Haskikalmi	Bangladesh	early, tall, low yield, susceptible to BB, aus crop
H-4	Sri Lanka	blast resistant, for drought-prone areas, 120-135 d
IET5656	West Bengal	
Intan	Karnataka	
IR8	Assam	sali season, suitable for flood-free areas
IR36	Indonesia Philippines Vietnam Madhya Pradesh	drought-prone areas, BPH resistant
IR42	Indonesia Vietnam	favorable and "waterlogged" areas, tolerant of problem soils, moderate drought tolerance
IR43	Philippines	drought tolerant, short stature; poor competition with weeds
IR9129-169-2-3-5	Philippines	good grain quality, medium maturity
IR52	Vietnam	for drought- and submergence prone areas
Jagannath	Orissa	improved, short mutant, Bahal and Sarad crop, Orissa
Jaswa	Bihar	low yield, sensitive
Jaya	Maharashtra	high yield, medium duration
Jhili	Orissa	farmers' varieties
Jhilli	Madhya Pradesh	late
Kadaria	Malaysia	good adaptability
Kada 176-12	Gujarat	
Kalamdan	Bihar	25-50 cm water depth susceptible to BB, lodging
Kalaviya	Gujarat	
Kalimooch	Madhya Pradesh	medium duration, scented
Kavchi	Gujarat	
Khadasiya	Gujarat	
Khao Dawk Mali 105	Thailand	northern and northeastern Thailand, nonglutinous aromatic, drought tolerant
Khao Pahk Maw 148	Thailand	central and northeastern Thailand, harvest 3 Dec

Continued on opposite page

Appendix 4 continued

Variety	Country or states	Comments[a]
Koimurali	Assam	red rice, drought tolerant, short duration, moderately disease resistant, ahu season
Kolam (Halki)	Gujarat	
Kolpi	Gujarat	
Krueng Aceh	Indonesia	favorable and drought-prone areas
Lalu	Madhya Pradesh	early, medium slender grain
Latisail	Bangladesh	tall, moderately sensitive, transplanted aman crop
Leuang Pratew 123	Thailand	central Thailand, harvest 19 Dec
Leuang Yai 148	Thailand	northern Thailand, adapted to low-lying conditions
Luchai	Madhya Pradesh	late
Madhuri	Madhya Pradesh	early, semidwarf, scented
Mahakam	Indonesia	"waterlogged" areas
Mahsuri	Maharashtra Bihar West Bengal Malaysia Madhya Pradesh Assam	low inputs; BB susceptible, 0-25 cm water depth; lack of seed dormancy; poor submergence tolerance; susceptible to low temperature, drought, and Bl
Manoharsali	Assam	tall, can withstand late planting, BPH resistant
MTU 7029	Andhra Pradesh	stable yield at low, N fine grain, susceptible to GM and BPH
Muey Nawng 62 M	Thailand	northern Thailand, resistant to GM, early sensitive
M-141	Karnataka	weak stems, poor submergence tolerance
Nagra	West Bengal	
Nahng Mon S-4	Thailand	nonglutinous, central Thailand, harvest 26 Nov
Nahng Prayah 132	Thailand	southern Thailand, harvest 16 Feb
Nam Sagui 19	Thailand	northeastern Thailand, early drought and submergence tolerant
NC487/77	West Bengal	poor grain quality
NC488/78	West Bengal	poor grain quality
Ngakywe	Burma	low yield, good eating quality, sensitive
Ngwetoe	Burma	good yield, sensitive
Niaw San Pah Tawng	Thailand	glutinous, northern and northeastern Thailand, adapted to low-lying conditions, drought tolerant
Niwari	Madhya Pradesh	medium slender grain, early
Nizersail	Bangladesh	tall, sensitive, good grains, transplanted aman crop
NLR 9672	Andhra Pradesh	good grain quality, drought tolerant, susceptible to BPH, GM
Nungi	Madhya Pradesh	short, bold grain; early, drought tolerant
Padmakesasi	Orissa	farmers' varieties
Pankaj	Bihar West Bengal Assam	25-50 cm water depth
Parewa	Madhya Pradesh	short bold grain, early
Parmal	Madhya Pradesh	medium duration
Pawsanhmwe	Burma	low yield, aromatic, sensitive
Peuak Nam 43	Thailand	southern Thailand, harvest 22 Feb
Phalguna	Karnataka	

Continued on next page

Appendix 4 continued

Pokkali	Sri Lanka	grown in stagnant water areas
Poorwa	Madhya Pradesh	improved, early, long slender
Puang Rai 2	Thailand	southern Thailand, harvest 6 Feb
Purbachi	Bangladesh	early, high yield, susceptible to BB, RTV, ShR
Rasi	Assam	drought resistance, ahu season
Ratna	Maharashtra Ranchi, Bihar	high yield, early duration
RD6	Thailand	glutinous, mutant of Khao Dawk Mali, wide adaptation to low-lying conditions, drought tolerance
RD13	Thailand	southern Thailand, harvest 23 Feb
RD15	Thailand	northern and northeastern Thailand, early mutant of Khao Dawk Mali 105, aromatic, drought tolerant
RD27	Thailand	central Thailand
RP4-14	Maharashtra	high yield, acceptable grain quality
Sadang	Indonesia	favorable areas, RTV resistant
Safri Desi	Madhya Pradesh	late
Safri 17	Madhya Pradesh	medium duration
Samridee	Madhya Pradesh	GM resistant
Sathi	Madhya Pradesh	short, bold grain, very early
Sekembang	Malaysia	wide adaptability
Setanjung	Malaysia	
Shwetasoke	Burma	high yield, sensitive
Sita	Ranchi, Bihar	high yield, improved
SR26B	Orissa	salinity tolerant
Subang Intan	Malaysia	
Surekha	Andhra Pradesh	GM resistant, fine grain, susceptible to SB and BPH
Suresh (CN540)	West Bengal	insensitive, poor tillering
Tam ruot lua	Vietnam	stagnant flooded areas, tolerant of acidity and salinity
Tau huong	Vietnam	stagnant flooded areas, tolerant of acidity and salinity
Tellahamsa	Andhra Pradesh	fine grain, cold tolerant, susceptible to gall midge
Than nong do	Vietnam	favorable and stagnant flooded areas
Tilakkachari	West Bengal	
Trang chum	Vietnam	favorable and stagnant flooded areas
Trang lun	Vietnam	stagnant flooded areas, tolerant of acidity and salinity
T90	Orissa	
T141	Bihar Orissa	BB and lodging susceptible 0-50 cm water depth
T1242	Orissa	stagnant flood conditions
Vikram	Karnataka	
White Lychai-112	Maharashtra	traditional, medium slender grain, tall, cooked grain remains good overnight
Yebawsein	Burma	clear, long grain, low yield, sensitive
62-355	Sri Lanka	early (90 d), drought tolerant, red rice

[a]BB = bacterial blight, Bl = blast, BPH = brown planthopper, GM = gall midge, RTV = tungro, SB = stem borer, ShR = sheath rot.

DROUGHT RESISTANCE IN RAINFED LOWLAND RICE

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The world's rainfed rice crop covers highly diverse ecological conditions with wide ranges of photoperiod, temperature, solar radiation, and moisture regimes. Moisture deficit causes substantial yield losses in rainfed rice areas. Rice, however, has some adaptation to water stress. Its ability to maintain water uptake in relation to atmospheric demand is largely a function of its root system. A considerable knowledge gap exists in the interaction between rice roots and mechanical impedance due to the hardpan. Field screening at the International Rice Research Institute has identified moderate drought tolerance and excellent recovery ability of some rices at a soil moisture tension of 10 bars. From the promising materials, IR52 was recommended by the Philippine Seed Board for rainfed lowland rice areas. Besides yield and yield components, records of water level depths within and below the lowland field are a useful indication of field level hydrology. It is critical to combine basic information on hydrology and crop physiology to systematize selection of drought-tolerant parents for varietal development and breeding lines for possible release in drought-prone rainfed lowland rice areas. Research should emphasize varietal improvement and agronomic practices for specific soil chemical and physical properties and hydrological conditions.

The magnitude of the rainfed lowland rice area and the diversity of the physical and biological constraints to increased production are well documented in the papers for this conference. A vast area often referred to as shallow or drought-prone rainfed lowland is subject to yield losses from water deficits. We would like to emphasize in this paper the potential for yield increase and stability through development of new genetic technology coupled with concurrent advances in agronomic technology suitable to this region.

Many studies have evaluated the potential for production increases, given adequate research and extension, in this rice cultural type (1, 2, 5, 8, 15). The studies have focused on shallow rainfed lowland rice as second only to irrigated rice in its potential to respond to research and extension. Table 1 illustrates the potential for increasing yield and total production in shallow rainfed lowland areas. Researchers have also recognized that lack of water when required is probably the most widespread constraint to higher rice yields (15).

This paper reviews how a water deficit causes numerous interactions among ecological factors affecting the rice crop, focusing on primary adaptations in

Table 1. Underlying assumptions and projected benefits from research for rice production environments in South and Southeast Asia (15).

	Irrigated		Rainfed			
	One rice crop	Two rice crops	Shallow wetland	Deep water	Floating	Dryland
Area in each type of rice production (% of total)						
1980	21	19	30	12	5	12
2000	26	25	23	9	5	11
Yield (t/ha)						
1980 estimated means	3.0	3.0	1.8	1.4	1.0	1.0
Potential increase by 2000	1.2	0.9	0.8	0.8	0.5	0.5
Average number of crops/ha per year						
Rice, 1980	0.9	1.8	0.7	0.7	0.9	0.8
Upland crops 1980	0.3	0.2	0.4	0.3	0.3	0.5
Increase in no. of rice crops/yr by the year 2000	0.4	0.5	0.3	0.2	0.1	0
Increase in no. of upland crops/yr by the year 2000	0.2	0.2	0.1	0	0.1	0.3
Total benefits from increased production						
Million US$	9,300	5,300	4,600	1,400	370	840
% of total	43	24	21	6	2	4

rice germplasm for buffering the crop against water stress. Recent results in field screening of germplasm for drought resistance are discussed.

THE DROUGHT SYNDROME

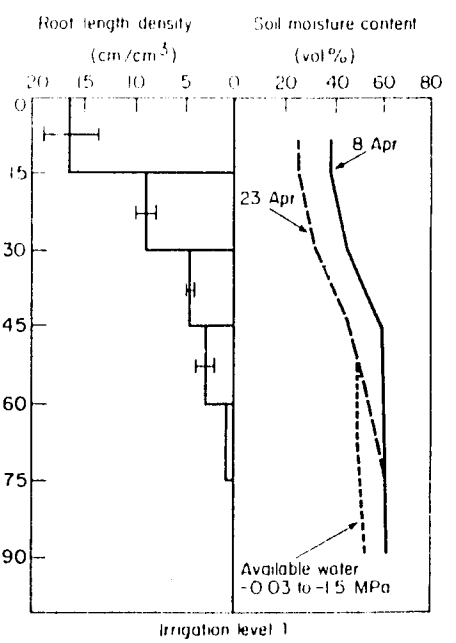
Definitions of drought are based primarily on climatic data and derived indices, although modern approaches to drought frequently utilize soil and crop water status (9). In rainfed lowland rice, observation of the rice crop during a rainless period must be tempered by information on local hydrological conditions, specifically the role of subsurface water. "Drought" as used here refers to a soil water deficit in the rainfed lowland ricefield brought about by subnormal rainfall in the watershed in which it lies. However, water, like light and N, is an extremely interactive ecological factor. Changes in soil and atmospheric water status not only bring about changes in primary physiological processes of the crop but also may be major contributors to secondary and tertiary factors leading to decreased growth and yield. It is not within the scope of this paper to discuss the complete array of changes in and interactions among the ecological factors directly or indirectly attributable to a water deficit in a rainfed lowland rice crop. Table 2 illustrates some of the interactive changes that occur. Among the physiological consequences of water stress, the following are discussed: decreased crop growth rate, decreased nutrient uptake, and the effect these changes have on weed competition.

One of the most sensitive physiological indicators of water stress is expansive growth (10), a turgor-dependent process that is responsive to even mild stress levels (4, 11). Drought damage as manifested by decreased

expansive drought growth contributed to the other problems mentioned above, i.e., nutrient uptake (19) and weed competition (22). A decline in leaf expansion reduces nutrient uptake in two ways. First, nutrient uptake responds to demand by the expanding shoot and will decline with decline in expansive growth. Second, water stress causes a decrease in crop transpiration, which is highly correlated with nutrient uptake (20). Increase in plant height, leaf area expansion, and nutrient uptake are highly competitive parameters where weed species are concerned. It is often noted that, in addition to the more direct effects of the drought syndrome on rainfed rice, a significant indirect effect is increased competition and eventual yield reduction from weeds (22). Cruz et al (3) illustrated the competitive advantage of several common weed species in relation to rice during water stress. The weed species were able to maintain higher leaf water potentials, presumably due to superior root systems that enhanced water uptake. Thus weed competition is a significant part of the drought syndrome in rainfed lowland rice.

ROOT SYSTEM DEVELOPMENT

The ability to maintain water uptake at levels determined by atmospheric evaporative demand during a rainless period appears to be a major attribute that confers increased drought resistance on traditional rice varieties and current and future breeding lines. We know very little about the root systems of successful rainfed lowland varieties. However, we may speculate that increased rooting depth and density would increase the capacity to extract available water (Fig. 1) as well as decrease the effects of poor soil-water



1. Root length density before harvest and moisture extraction of IR36 rice from a clay loam soil during a 15-d stress treatment at the reproductive stage. Level 1 was at field capacity before stress was imposed (R. T. Cruz and J. C. O'Toole, unpublished data).

Table 2. Generalized description of environmental factors[a] potentially interacting (directly or indirectly) with a rainfall deficit condition to create an array of complexes collectively referred to as "drought." The factors are considered in relation to their variability across location and through time and to the principal cultural systems in which rainfed rice is grown (21).

Variability[b] and factor	Characteristics of cultural system		
	Upland	Lowland	Deep water
• Edaphic			
Physical			
* Depth (potential root zone)	often deep	averaging 10-30 cm	usually deep
* Texture	light (sandy to clay loam)	heavy (clays, few loams)	heavy (clays)
* Physical obstruction (plow or hardpan	uncommon	present	absent
*† Hydraulic conductivity	high	low	low
Chemical			
*†‡ Biochemical	aerobic	anaerobic (possibly alternately aerobic)	aerobic → anaerobic
*†‡ Deficiencies or toxicities, e.g.,			
Fe deficiency	yes	no	no
Zn deficiency	no	yes	yes
Al toxicity	yes (at pH < 5.0)	no	no
* Native fertility	low	wide range	high
• Climatic			
*†‡ Rainfall			
Totals (crop season)	500-1500 mm	700-2000 mm	not relevant, influx is from surface flow
Distribution (crop season)	3-4 mo > 200 mm	3-7 mo > 200 mm	deficits in early stage associated with erratic onset of monsoon

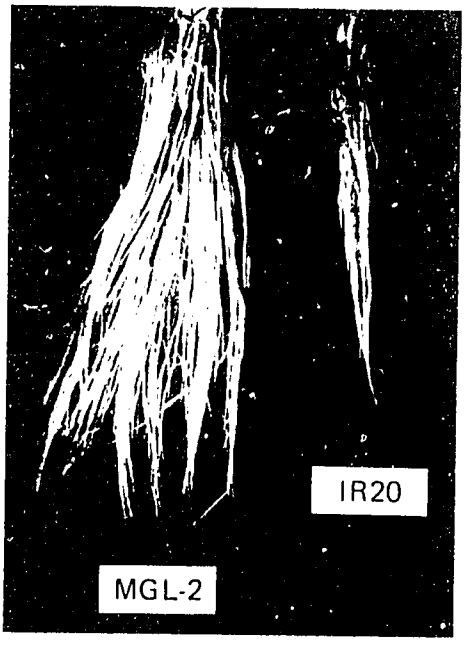
*†‡ Temperature			
Air	├── variable by geographic location — longitude, latitude, elevation ──		
Soil	and hydrological conditions		
*†‡ Atmospheric evaporative demand	├── determined primarily by macroclimatic conditions but respond ──		
*†‡ Wind	significantly to microclimatic modifiers		
*†‡ Solar radiation (crop season)	├── generalization on quantity or photoperiod not possible ──		
• Hydrologic			
*†‡ Water depth			
(surface)	rarely > 0	0-100 cm	1-6 m
(subsurface)	low	high (often perched)	become positive
*†‡ Occurrence of water excess (flood)	rare	rare to annual flooding	annually
• Biotic			
*†‡ Competitive plants (weeds)	severe	may be severe	severe during establishment
	├── drought accentuates the problem in all systems ──		
• Agronomic			
*† Land preparation	dry	wet	dry
*† Crop establishment	direct sown (dry)	direct sown or transplanted (wet)	direct sown (dry)
*† Use of agrochemicals	negligible	wide range related to water control	negligible

[a]The authors have not attempted an in-depth survey of environmental factors affecting rainfed rice growth, development, and yield but have concentrated on illustrating the large number of salient factors and attendant variability of each that may significantly interact (directly or indirectly) with rainfall deficit and thus modify the location-specific phenomena collectively termed "drought." [b]* = variable across locations, † = variable across seasons, ‡ = variable within seasons.

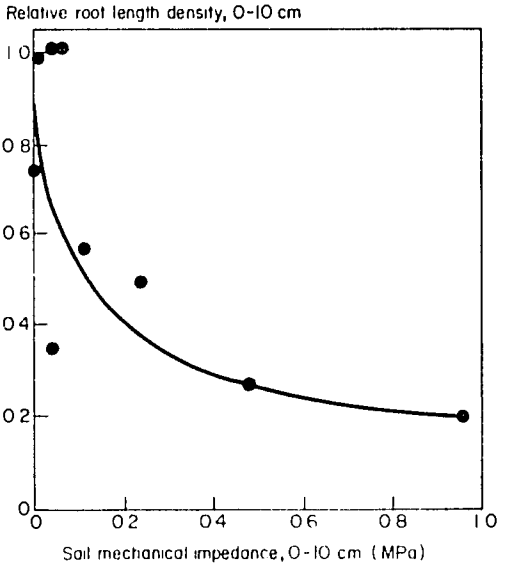
transmission properties characteristic of puddled clay soils (R. T. Cruz and J. C. O'Toole, unpubl. data). There appears to be ample genotypic variation for root system parameters in rice.

Figure 2 shows MGL-2 (a rainfed variety from India) and IR20, a cultivar selected for irrigated conditions and used as a susceptible check in screening for drought resistance. Ekanayake et al (6, 7) have illustrated the heritability of many root parameters and, more importantly, demonstrated that F_3 families of crosses involving MGL-2 could be selected for root parameters such as root length and thickness. These parameters are related to the maintenance of higher plant water potential and desirable visual drought-resistance scores in field screening.

Rooting depth in rainfed lowland rice is influenced by more than genotypic variation. In lowland ricefields the development of hardpans or traffic pans is to be expected, given the potential for soil compaction from numerous cultural practices requiring human, animal, or tractor traffic in the field. Hardpans may constitute a significant barrier to downward root expansion. In addition, soil drying associated with drought also increases the mechanical impedance of lowland rice soil coincident with the period when increased root exploration (vertical as well as horizontal) of the soil is desirable. During 1980-84 we investigated the effect of simulated hardpans and soil drying in rainfed lowland fields on rice root growth. Figure 3 illustrates the general trends for several experiments. It appears that even a slight mechanical impedance will decrease rice root growth. Mechanical impedance values between 0.1 and 0.2 MPa reduced root growth by 50% of the control, and these levels would certainly inhibit the exploitation of soil water in a water stress situation.



2. Deep and thick roots of MGL-2 from Andhra Pradesh, India, are capable of penetrating hardpan in rainfed lowland rice soils compared with IR20 with shallow and thin roots.



3. Relationship between root length density relative to control and soil mechanical impedance in a drying puddled lowland soil. The regression equation $\hat{Y} = (1.441+27.27x)^{-1}$ describes the relationship (R = 0.95**) (Thangaraj and O'Toole, 1984, unpublished data).

Although significant genotypic variation appears to exist for many root morphological characteristics, we still know very little about the interaction between rice roots and either hardpan development or drought-induced mechanical impedance. In many instances the level of mechanical impedance in rainfed ricefields in South and Southeast Asia was found to be extremely high (>0.4 MPa) (R. T. Cruz and J. C. O'Toole, unpubl. data) and would perhaps necessitate some form of deep tillage to open avenues for root penetration to the subsoil. Altering the physical properties of lowland soil is beyond the scope of this discussion, but in areas where water is a distinct limiting factor, alteration may be necessary. The reader may wish to consult IRRI's *Soil physics and rice* (17) concerning this subject.

EVALUATION OF BREEDING LINES FOR DROUGHT TOLERANCE

Through testing at IRRI and multilocation testing in farmers' fields, it is possible to evaluate rices (traditional varieties and new breeding lines alike) for drought tolerance.

Rainfed lowland rice drought screening

For the past 10 yr, IRRI has focused attention on improving the yield of rainfed lowland rice. The International Rice Testing Program (IRTP) established separate nurseries for rainfed lowland (shallow water) rice areas. The International Rainfed Lowland Rice Observational Nursery (IRLRON, now the International Rainfed Rice Shallow Water Observational Nursery — IRRSWON) was initiated in 1978, and the International Rainfed Lowland Rice Yield Nursery (IRLRYN, now the International Rainfed Rice Shallow Water Yield Nursery — IRRSWYN) in 1981. IRRI's Plant Breeding

Department now selects for adaptability to rainfed lowland rice conditions and has separate groups of observational (OYT) and replicated (RYT) yield trials.

Erratic rainfall distribution and subsequent soil moisture stress during dry spells necessitate selection of drought-tolerant rices with excellent recovery capability. Since the 1980 dry season, the Agronomy Department has annually screened, during the dry season, rices from IRRSWON, IRRSWYN, OYT, and RYT for vegetative stage drought tolerance.

Procedure. Thirty-day-old seedlings were subjected to soil moisture stress in the field. The plants were scored for drought tolerance 3 times — when soil moisture tensions (SMT) at 20-cm soil depth were 2, 5, and 10 bars. Drought recovery capability was determined 7-10 d after relief of soil moisture stress, following drought scoring at 10 bars SMT. The Standard Evaluation System for Rice (SES: 0-9 scale for drought tolerance and 1-9 scale for recovery) (12) was used in scoring.

Results. From 1980 to date, the Agronomy Department has screened 786 IRRSWON and IRRSWYN entries and 340 OYT and RYT materials for drought tolerance and recovery capability. Of these, 295 rices showed no or negligible drought effects at 2 bars SMT, normally reached after 20 d of imposed drought (Table 3). Only IR3259-P3-160, ITA119, IR9782-111-2-1-2, and ITA139 showed excellent tolerance at 5 bars SMT. At 10 bars SMT, the best drought score of 3 was exhibited by the first two of the four plus four others (Table 4).

RD19, a recommended deep water variety in Thailand, showed high drought tolerance in the 1980 and 1984 drought tests (Table 4). RD19 was entered as BKN6986-147-2 in the 1979 IRLRON and as RD19 in the 1983 IRRSWON.

Only 35 or 3% of the 1,126 entries showed 90-100% recovery from drought stress (Table 3).

Ten entries with 2-4 yr of drought tests performed similarly to the checks (Table 5). All the listed entries showed drought tolerance at 2 bars SMT. As SMT progressed to 5 bars, ITA186, Leuang Yai 148, and RD19 showed

Table 3. Frequency distribution of drought tolerance and recovery capability scores of rainfed lowland rices in observational and yield nurseries. IRRI, 1980-84.

Drought and recovery scores[a]	No. showing drought tolerance at SMT[b]			Recovered (no.)
	2 bars	5 bars	10 bars	
0-1	295	4	0	35
2-3	679	104	6	382
4-5	149	696	200	575
6-7	3	315	803	122
8-9	0	7	117	12
Total	1126	1126	1126	1126

[a]Standard evaluation system for rice 0-9 scale for drought: 0 = no visible effects of soil moisture stress, 1 = slight leaf tip drying, and 9 = all plants apparently dead; in 1980, 1 = no effects of soil moisture stress. 1-9 scale for recovery: 1 = 90-100% of plants recovered, and 9 = 0-19% of plants recovered. [b]SMT = soil moisture tension.

Table 4. Entries in rainfed lowland rice observational and yield nurseries with scores of 3 at 10 bars soil moisture tension (SMT), IRRI, 1980-84 dry seasons.

Designation	Year tested	Source	Drought score[a] at SMT of			Recovery score[b]
			2 bars	5 bars	10 bars	
IR3259-83-160-1	1980	1979 IRLRON	1	1	3	1
IR5793-55-1-1-1	1980	1979 IRLRON	1	3	3	3
BKN6986-147-2	1980	1979 IRLRON	1	3	3	3
IR21178-43-1-2-2-2	1984	1983 OYT	1	3	3	1
ITA119	1984	1983 IRRSWON	0	1	3	1
RD19	1984	1983 IRRSWON	0	3	3	3
Salumpikit (tolerant check)	1980		1	4	6	4
	1984		1	4	4	2
IRAT9 (susceptible check)	1980		3	7	9	7
	1984		4	9	9	8

[a]1980 SES 0-9 scale for drought: 0 = no visible effects of soil moisture stress, and 9 = all plants apparently dead; in 1980, 1 = no effects of soil moisture stress. [b]1980 SES 1-9 scale for recovery: 1 = 90 100% of plants recovered, and 9 = 0-19% of plants recovered.

Table 5. Lines and varieties selected for drought among rainfed lowland rice entries in observational and yield nurseries from 1979 to 1983. IRRI, 1980-84 dry seasons.

Designation	Period of testing (yr)	Drought score[a] at SMT[b] of			Recovery score[c]
		2 bars	5 bars	10 bars	
Selections from IRRSWON and IRRSWYN					
IR52	4	2	4	6	3
IR5853-198-1-2	4	2	4	6	3
IR18599-68-1	2	2	4	6	2
IR21040-4-P1	2	2	4	6	3
BKN6986-66-2	2	1	4	5	3
ITA186	2	1	3	6	2
ITA230	2	1	4	6	2
RD19	3	1	3	4	3
Selections from observations yield trials (OYT)					
CR1006	2	1	4	5	3
Leuang Yai 148	2	1	2	4	3
Drought checks					
Salumpikit (tolerant check)	5	1	3	5	3
IR442-2-58 (tolerant check)	5	2	4	6	3
IR20 (susceptible check)	5	3	6	7	6
IRAT 9 (susceptible check)	5	4	7	9	8

[a]1980 SES 0-9 scale for drought: 0 = no visible effects of soil moisture stress, and 9 = all plants apparently dead; in 1980, 1 = no effects of soil moisture stress. [b]Soil moisture tension. [c]1980 SES: 1-9 scale for recovery: 1 = 90 to 100% of plants recovered, and 9 = 0-19% of plants recovered.

higher drought tolerance than the rest. Leuang Yai 148 and RD19 were better than the drought-tolerant checks at 10 bars SMT. When soil moisture stress was relieved, IR18599-68-1, ITA186, and ITA230 recovered faster than the checks.

IR52, one of the 10 selected rices for high drought tolerance, has been recommended for rainfed lowland areas in the Philippines.

Table 6. Lines and varieties for drought reactions among entries in the 1983 rainfed lowland rice observational and yield nurseries. IRRI, 1984 dry season.

Designation	Source	Drought score[a] at SMT[b] of			Recovery score[c]
		2 bars	5 bars	10 bars	
IR9975-5-1E-P1	IRRSWON and IRRSWYN 1983	1	3	5	1
IR13224-26-3E-P1	IRRSWYN 1983	1	5	5	1
BPT3291	IRRSWYN 1983	1	3	5	1
ITA119	IRRSWYN 1983	0	1	3	1
ITA186	IRRSWYN 1983	1	3	5	1
IR20992-7-2-2-2-2-1-1-1	OYT 1983	1	5	5	1
IR21071-53-2-3-2E-P1	OYT 1983	1	5	5	1
IR21178-43-1-2-2-2	OYT 1983	1	3	3	1
IR26567-29-3-3-1-2	OYT 1983	1	5	5	1
IR33153-1-1-2	OYT 1983	1	5	5	1
IR33153-19-1-2	OYT 1983	1	5	5	1
Cisadane	OYT 1983	1	3	4	1
HTAFR77051-1	OYT 1983	1	5	5	1
Ngakwe	OYT 1983	1	5	5	1
Peykeo	OYT 1983	1	5	5	1
Salumpikit (tolerant check)		1	4	4	2
IR442-2-58 (tolerant check)		1	4	5	3
IR20 (susceptible check)		3	7	7	5
IRAT9 (susceptible check)		4	9	9	8

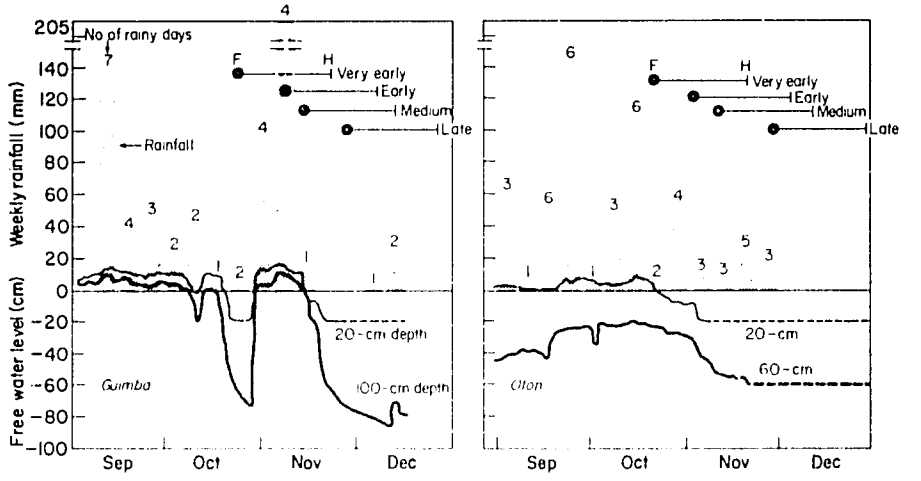
[a]1980 SES 0-9 scale for drought: 0 = no visible effects of soil moisture stress, and 9 = all plants apparently dead; in 1980, 1 = no effects of soil moisture stress. [b]Soil moisture tension. [c]1980 SES 1-9 scale for recovery: 1 = 90-100% of plants recovered, and 9 = 0-19% of plants recovered.

Table 6 shows the outstanding selections from the 1984 field drought screening. Fifteen of 421 rainfed lowland rice entries during the year had higher drought tolerance and recovery capability than the drought-tolerant checks. ITA119 was highly drought tolerant at 2 bars SMT and had only slight leaf tip drying at 5 bars. All the 15 rices showed excellent recovery capability.

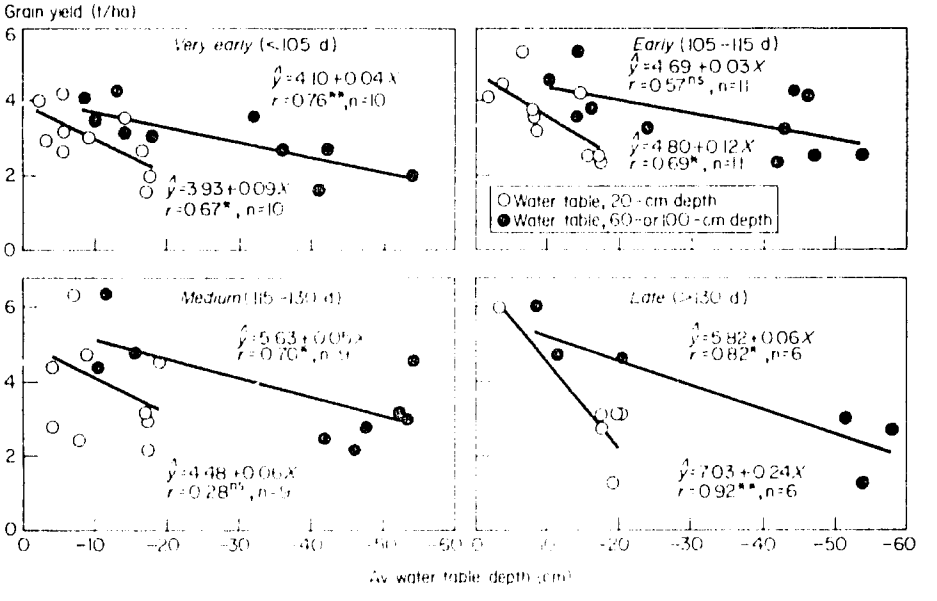
Philippine yield trials in rainfed shallow drought-prone environments

Since 1979 we have conducted yield trials of elite breeding lines from IRRI's Genetic Evaluation and Utilization Program and from the IRTP in selected drought-prone rainfed lowland sites in the Philippines. Initially, we experienced difficulty in measuring water status in rainfed lowland fields. A set of hydrological data is necessary to compare locations and seasons. We have evolved a relatively simple set of inexpensive measurements that describe the surface and subsurface hydrology of the lowland ricefield during the crop season. Figure 4 illustrates the use of these measurements (rainfall, surface water depth, and depth in 20-cm and in 60-cm observation wells) in combination with maturity groupings of varieties to describe two contrasting year and location situations in 1980 and 1981.

Figure 5 shows the relationship between average water table depth and grain yield for each maturity group. Each point is an average of the two highest



4. Water level and rainfall in lowland rice fields in Guimba (Nueva Ecija) and in Oton (Iloilo), Philippines, 1981 wet season. Water level was determined at 20- and 100-cm depth in Guimba and at 20- and 60-cm depth in Oton. F = flowering, H = harvest.



5. Relation between grain yield of the 2 highest yielding entries at each location and average water table depth below the soil surface in the root zone above the hardpan (0–30 cm) and below the paddy (0–60 or 100 cm) soil surface. The average water table depths were summed over the period 30 d before flowering to 20 d after flowering, based on mean flowering date of each maturity group.

yielding varieties or lines for each location. By using the highest yielding entries, we hope to negate the effects of other biological and physical-chemical factors determining growth and yield and focus on the role of subsurface water in determining crop yield response to rainfall in rainfed lowland culture.

Significant correlations were observed in the very early (0.67*), early (0.69*), and late maturing entries (0.92**). However, in the medium maturity group, the correlation coefficient of 0.28 was not significant for the shallow water table. For the deeper water table, the early maturity group had a correlation coefficient of 0.57, but significant correlations were observed in the early (0.76**), medium (0.70*), and late maturing (0.82*) entries, although grain yield generally decreased with decreasing water table depth. In some localities, water table depth during the crop season was very low; however, we also obtained high grain yield. This could be due to adequate amount and distribution of rainfall and not to total rainfall per se. For example, at Iloilo in the 1981 wet season (Fig. 4), rainfall was well distributed during the period 10 days before flowering to 20 days after flowering, with a total rainfall of 154 mm for the early maturing group and a mean grain yield of 3.9 t/ha. At Guimba during the 1980 wet season, however, rainfall was high (347 mm) during the same growth stages, but mean grain yield was rather low (2.1 t/ha) because of a short-term water deficit that followed flowering in mid-October.

Our results suggest that recording of water table depths within and below the lowland ricefield can be a useful indicator of field-level hydrology. When used in tandem with meteorological data, especially rainfall, these easily measured parameters allow interpretation of crop water stress at remote sites and are the only currently practical methods for use in large variety trials where conventional soil or plant water status measurement techniques are not feasible. The daily hydrological values allow interpretation of yield response to water stress for each entry or maturity group.

Although numerous other biological, physical, and chemical factors contribute to the site-specific stresses determining yield, the recording of hydrological conditions in lowland ricefields aids significantly in interpreting differences in nursery performance over years and locations.

Other examples of the use of this basic data set combining hydrology and crop phenology of rainfed lowland rice can be found in Maguling et al (18) and

Table 7. Rices that showed promising drought tolerance under rainfed lowland conditions.

Maturity	Designation	Days to flowering	Drought score[a]
Very early	IR10110-24-1	60	1.7
	IR19735-5-2-3-2-1	70	1.7
	IR13427-40-2-3-3-3-3	71	2.7
Early	IR19058-107-1	82	1.0
	IR21015-80-3-3-1-2	84	1.3
Medium	IR52	86	2.3
	Nam Sagui 19	89	1.7
	UPL Ri-5	90	1.0
	BPI-76 N.S.	93	1.0
	UPL Ri-3	93	1.0
	IR54	93	1.7
	IR18848-35	99	2.3

[a]Av of 4 replications. Based on 1980 SES 0-9 scale for drought: 0 = no visible effects of soil moisture stress, and 9 = all plants apparently dead.

IRRI annual reports (13, 14, 16). Since 1981 we have conducted yield trials at 3-5 locations each year. In some situations, there was ample rainfall with good distribution, and an estimate of yield potential was realized. We are, of course, more interested in entry reactions where drought occurs at the reproductive stages or postflowering spikelet-filling stages, as this most accurately simulates the situation in the drought-prone regions of South and Southeast Asia. Table 7 shows varieties and breeding lines that have shown significantly better performance when drought occurred. An effort has been made to group the entries by maturity group. However, the number of days to maturity is highly variable in drought-affected trials.

The results from the IRTP, specifically the IRRSWYN, were a part of the Philippine trials but are reported in a separate paper (23) at this conference.

RESEARCH PRIORITIES

Large areas in South and Southeast Asia are affected by drought or flooding and often by both stresses in the same season. Unless there is built-in tolerance for drought, improvement in grain yields will be limited. In these regions, shorter maturity rices will have greater chances of success than longer maturing varieties, irrespective of the duration of the rainy season. Both breeding and testing programs should clearly delineate the target environment. Rainfed lowland rice areas provide greater opportunity to improve yield and production than any other rainfed rice environment. Rices of intermediate stature with high lodging resistance and capability to penetrate the hardpan should be developed.

Agronomic practices such as weed control, minimum tillage, and optimizing N rate, sources, and timing should be developed to maximize farmers' limited resources, particularly purchased inputs. Varietal improvement and agronomic resources should address on-farm water management and soil fertility management specific to the soil chemical, physical, and hydrological conditions. Improved varieties and cultural practices should then be tested in farmers' fields using constraints methodology under various water and hydrological conditions. The successful rices can then be considered for multilocation farm-level testing and rapid adoption.

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BREEDING RICE VARIETIES FOR RAINFED LOWLAND AREAS

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Characteristics of rainfed lowland areas in India and the rice varieties grown there are described. Desirable traits for new varieties in waterlogged areas and breeding programs to produce them are proposed.

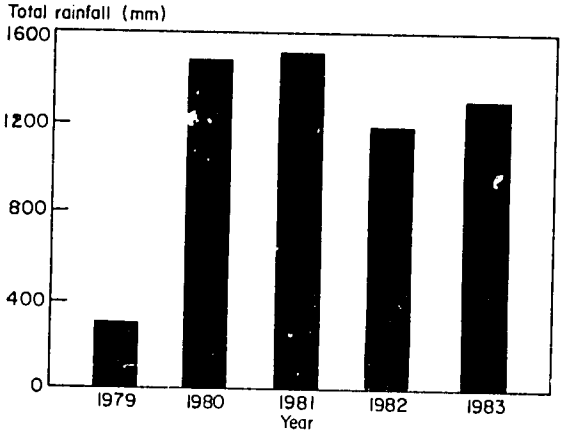
The erratic behavior of the monsoon (Fig. 1, 2) combines with low elevation and undulating topography to cause flooding or waterlogging in some areas of India and drought in others. The occurrence of drought over most of this century is shown below.

Season/stage	*Years*
Premonsoon (before Jul) — sowing time and early seedling stage	1926, 1935, 1957, 1982
Monsoon (Jul-Sep) — tillering and flowering stages	1908, 1924, 1926, 1928, 1929, 1931, 1932, 1935, 1942, 1943, 1944, 1951, 1954, 1965, 1966, 1977, 1979
Postmonsoon (Oct-Nov) — grain setting stage	1908, 1913, 1914, 1918, 1925, 1935, 1939, 1940, 1941, 1942, 1950, 1952, 1957, 1982

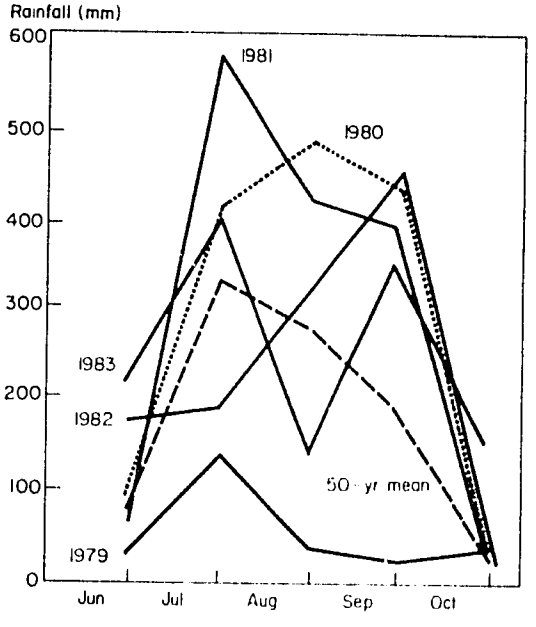
The pattern of drought in India during 1979 is shown in Figure 3, and the rainfall distribution in Uttar Pradesh over 12 yr (1971-82) is depicted in Figure 4.

The success of rainfed rice is fully dependent on variations in the onset, duration, distribution, and intensity of rain during the growing season. A prolonged drought generally causes severe damage to the crop.

The nature of the adverse effects of drought depends on the time of its occurrence. Drought at the beginning of the wet season delays tillage and sowing; if much prolonged it may depress productivity. Rice yields in India average around 1.2 t/ha. Partial drought in 1974-75 and in 1976-77 caused approximately 10% drops in national yields over the previous years, and acute drought in 1979-80 caused a 20% shortfall. Uttar Pradesh experienced severe drought in 1979-80, with a resulting 56% drop in yield. Prolonged drought during the wet season after the crop has been sown may completely stop crop development. Drought at the end of the wet season may wither a ripe crop and also create adverse conditions for the succeeding crop.

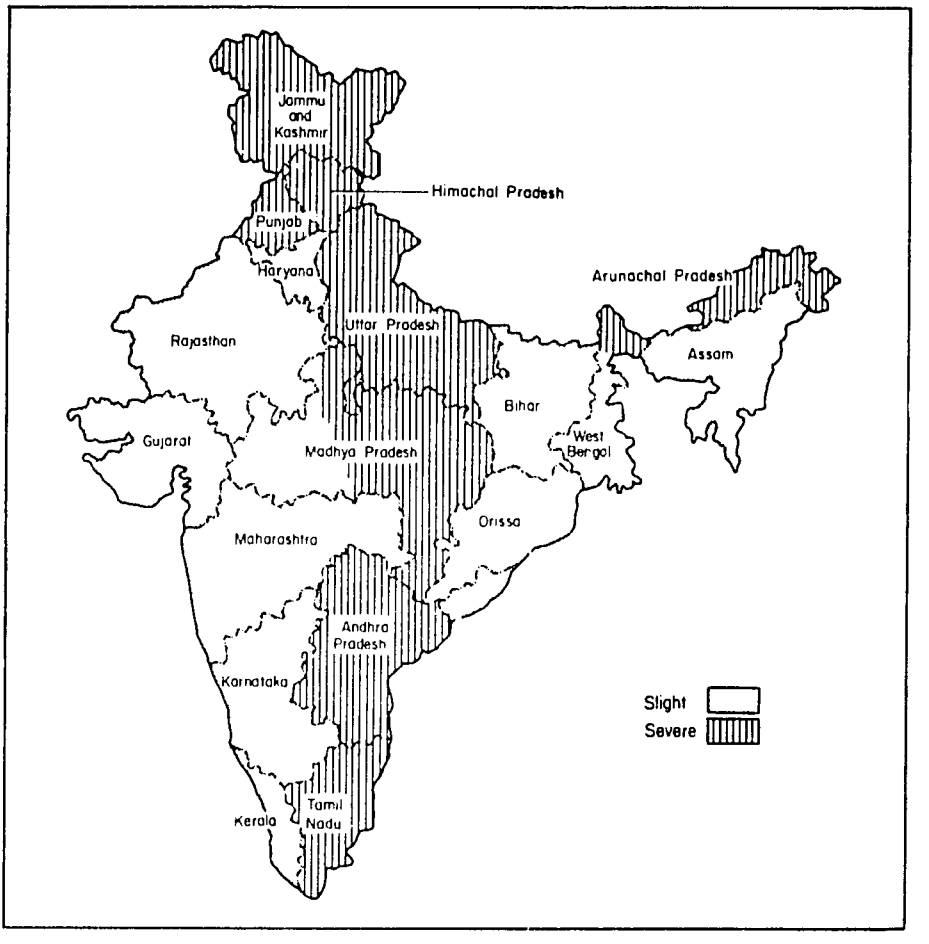


1. Total rainfall in India, 1979-83.



2. Rainfall pattern of Faizabad, India, during the rice-growing season, 1979-83.

A sizable portion of northeast India is under rainfed lowland rice culture, and in Uttar Pradesh alone, 2.1 million ha are subjected to inundation of various sorts and magnitude. Although rice fields can tolerate ordinary inundation, they sustain damage under abnormal flooding, as when water depths exceed 5-7 cm in the initial stage or when the crop is submerged completely beyond 5-7 d. In many cases a 15-20% yield loss goes unperceived, but loss exceeding that level makes farmers panic. Accumulated water is often hard to drain and is lost only by evaporation or percolation. The water stagnates during the rainy season and may remain some time afterwards.



3. Drought in India, 1979.

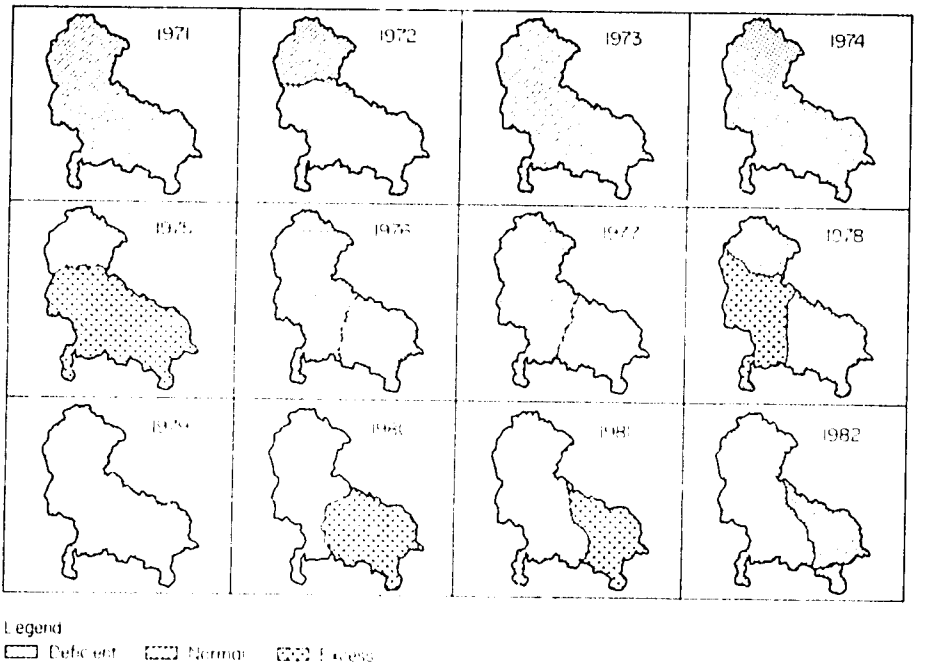
VARIETAL CHARACTERISTICS

Traditional varieties for waterlogged areas have longer leaves because of faster growth. They have tall stems, are lodging susceptible, and cause mutual shading. They have long growth duration and photoperiod sensitivity. They are cold tolerant at the reproductive stage and moderately tolerant of reduction products. Seed dormancy is adequate.

Dwarf rices in lowland areas lack submergence tolerance, elongation capacity, an appropriate degree of photoperiod sensitivity, and cold tolerance at the reproductive stage. They are susceptible to reduction products.

The ideal plant type for waterlogged conditions has:

- medium long leaves,
- internode elongation during the early vegetative stage,
- shorter individual internodes,



4. Rainfall distribution in Uttar Pradesh, 1971-82.

- the capacity to produce a higher number of internodes,
- stiff straw that prevents lodging,
- high tillering ability,
- branching at higher nodes,
- submergence capacity for at least 2 wk,
- photoperiod sensitivity matching best local types to ensure maturity after the danger of water rise in the field is over,
- adequate cold tolerance,
- resistance to reduction products, and
- adequate grain dormancy.

These characteristics are discussed in detail below.

Longer leaves

The rice plant avoids submergence by keeping some of its upper portion above water. The oxygen supply to its organs is maintained through special tissue called aerenchyma. Once the plant is completely submerged, the oxygen supply is cut off. If this situation remains for a few days, the plant dies. The higher the leaves, the greater are the chances that some of them will remain above water. In the initial stages, then, the leaves play the major role in submergence tolerance, and the stem — which appears around the panicle initiation stage — a minor role.

Internode elongation during vegetative stage

A certain amount of internode elongation occurs in photoperiod-sensitive varieties during the vegetative stage, usually in earlier sown crops. Such elongation enables the plants to attain greater height, hence greater submergence tolerance.

Tall stem

As the panicle develops on the stem apex, and panicle development and seed setting are hindered in submerged plants, the developing panicle should be above water as soon as possible. A tall stem is thus essential to ensure that the panicle remains above water in inundated fields. Traditional rice varieties generally have taller stems.

Lodging susceptibility

For submergence tolerance in waterlogged areas, favored varieties are tall, leafy, long-duration, and photoperiod-sensitive — features that are also responsible for lodging. Lodging susceptibility has long beenrecognized as a major constraint to higher production. The solution to this problem was sought by reducing the size of leaves and length of stems. In areas where adequate irrigation and proper drainage exist, leafy growth, tall stem, and long duration are not advantageous; they cause mutual shading and lodging. Improving lodging resistance at the cost of tolerance for inundation is not advisable. There is a need to improve lodging resistance and also retain tolerance for inundation of at least 1 m.

Long growth duration

For lowland areas, long growth duration is desirable because it enables varieties to compensate for the loss of tillers due to excess inundation when the conditions for tillering are favorable. In addition, longer duration allows the flowering and grain development stages to occur after the danger of further inundation is over.

Photoperiod sensitivity

Daylength during the main rice growing season varies most in high latitudes and least near the equator. Photoperiod affects the growth duration of different species and varieties. Photoperiod sensitivity, although now recognized as a factor responsible for narrow adaptability to regions and seasons, is a special mechanism allowing adaptation to a wide range of planting times. It is needed for growing rice crops when depending totally on uncertain and unpredictable monsoon rains. It also ensures the flowering and maturity of the crop at a fixed date after the danger of inundation is over.

Although photoperiod sensitivity is necessary for the rainfed lowlands, the problem arises as to how to ensure and incorporate the proper degree of photoperiod sensitivity for a particular location. A simple technique has been developed to select parents for use in crosses as well as segregants. The parents

and later the F_3-F_4 are sown at three dates —1.5 mo before normal time (D_1), normal time (D_2), and 1.5 mo late (D_3) — along with the most accepted photoperiod-sensiti ve varieties prevailing in the area. Generally, the standard varieties flower at the same time, irrespective of planting date. If the proposed parents and the newly generated line show the same flowering behavior, these materials possess identical degrees of photoperiod sensitivity. In photoperiod sensitivity tests (Table 1), most of the new lines from different sources, including Pankaj and Mahsuri, failed to flower on the third date (D_3 = 30 Jul sowing), while a few selections, including standard varieties, did flower and normal seed setting took place. This technique is simple enough and can be applied to screen material at any center (subtropical and subtemperate situations) with some adjustment in planting date.

Table 1. Photoperiod sensitivity test, 1982 kharif.

Variety	Days to 50% flowering[a]		
	1 May (D_1)	15 Jun (D_2)	30 Jul (D_3)
BR109-74-2-2-1	153.5	133.5	
BR161-2B-47	153.0	121.0	
IR135-40-56-3-2-1	136.0	129.5	
IR2053-375-1-1	119.0	114.5	
MS30	136.5	128.0	
FH559	120.0	118.5	
FH573	169.5	128.5	92.0
FH355	177.0	132.0	87.0
T1879	179.5	135.0	92.0
FH557	118.0	113.0	
FH567	144.5	134.0	
IET1648	146.0	128.0	
IET2703	144.5	127.0	
Co 12	138.5	118.0	92.0
FH563	141.0	126.5	
FH622	167.5	131.0	92.0
NDAU 22	168.0	128.0	88.5
Siam	168.5	126.0	87.5
IET6205	149.0	132.0	
IET5882	152.0	134.0	
MS6	128.5	120.0	91.0
FD69-1-1-3-2	120.0	114.0	
FD69-1-1-1-3-2	112.0	114.0	
WL 8	167.5	123.0	91.0
MS2	136.0	128.0	92.0
MS14-1-5	138.0	127.5	
MS18-7-2	136.0	121.0	
MS34-1-1	136.5	126.0	
MS5-3-4	134.0	127.5	
MS46-1-3	138.0	120.0	
Pankaj	151.0	133.5	
T100	166.5	127.0	90.0
Mahsuri	136.0	126.0	
T26	158.5	122.0	90.0
Cross 116	168.0	127.5	88.5
Madhukar	168.0	126.0	87.5

[a]D_1 = sown 1.5 mo before normal time, D_2 = normal sowing time, D_3 = sown 1.5 mo late.

Cold tolerance

In southern Indian states temperatures remain within safe limits even until the end of November, but in northern states the minimum air temperature reaches the critical level (below 18 °C) during October. Most varieties that lack resistance to lower temperatures show such symptoms as stunted growth, failure of panicle emergence, and high grain sterility due to poor seed setting. Therefore, in northern subtropical states the lowland varieties either must be temperature-insensitive or should possess adequate cold tolerance.

To test for cold tolerance, planting should be as late as farmers' practice in rainfed lowland areas. In some districts of eastern Uttar Pradesh, planting in waterlogged areas is done as late as the first week of September in 40-60 cm of standing water. The crop is ready for harvest by the end of November, by which time the temperature reaches as low as 13 °C. However, traditional varieties flower satisfactorily and show proper seed setting.

The delayed planting used in photoperiod sensitivity testing serves the purpose of cold tolerance testing as well. Often it is difficult to separate the effects of the two parameters under field conditions. The degree of panicle emergence and seed setting functions as a measure of cold tolerance.

Aerial branching at higher nodes

When the water level in the field increases beyond 10-12 cm, ground-tiller buds are suppressed. As a result, even if the plant survives, tillering, which is one of the most important determinants of yield, suffers. Crosses among floating and normal varieties have already indicated that aerial branching is a heritable trait and is correlated with early internode elongation. Typical floating varieties possess both characteristics. Several floating/normal tall and floating/dwarf crosses have showed that early internode elongation as well as aerial branching can be transferred easily.

In this way the plant will attain the same height as tall varieties but will have more of comparatively shorter individual internodes. The tall feature of the plant will enable it to rise above the water and the shorter internodes will impart lodging resistance.

Comparative studies of dwarf, normal tall, and floating strains show that in dwarf and tall types the numbers of internodes are more or less the same, but in floating strains the number is higher. Therefore, by combining short internodes of dwarf plants with higher number of internodes from floating varieties the desired type can be constituted.

Leaf size needs reduction. While longer leaves are beneficial for plants under stagnant conditions, they promote lodging and are disadvantageous. Any attempt to reduce the length will also reduce the plants' ability to tolerate inundation.

Studies of deep water varieties show that as water depth increases and leaves are no longer capable of elongating, internode elongation starts well before panicle initiation. Thus, the leaves attain apparent additional length and the plant can survive in deeper water than would otherwise be possible.

BREEDING EFFORTS

The primary breeding efforts needed are for improvement of the basic yield components — survival percentage, enhanced tillering ability, branching, panicle number, and lodging resistance. Many of these traits are complex and involve several physiomorphological traits. For instance, improvement of survival percentage depends on the growth rate of the leaves and stem before and after inundation as well as on the physiological ability to resist complete submergence, which in turn is regulated by complex biochemical features. Some features such as stem length and lodging resistance are negatively correlated, although correlation is not very strong.

Breeding to combine resistance to lodging and to waterlogging

Although lodging resistance is contributed by many features, the dwarf stem plays the major role. One of the simplest ways to retain tall stem height and also have shorter internodes is to evolve varieties that have higher numbers of internodes than tall ones. Early internode elongation can compensate to some extent for reduction in the size of leaves. New types for waterlogged conditions should have medium long leaves, shorter but more individual internodes, the ability to elongate internodes during the early vegetative stage, and the capacity to continue elongation for a longer time.

Multiple selection criteria for rainfed lowland situations

Selection for traits at F_2. Some traits such as height, number of internodes, and long growth duration, which are easily expressed and have high heritability, can be identified in early generations, and selection for desired types may be made.

Selection for traits at F_3. Such traits as photoperiod sensitivity, cold tolerance, and disease resistance, which are well defined, may be screened at the F_3 stage with small populations.

Selection for traits at F_4. Elongation features and submergence capacity, which require larger test populations, should preferably be screened at the F_4 stage, where many homozygous lines with enough seed are available and part of the seed may be spared to test for the presence of these traits.

BREEDING FOR DROUGHT- AND SUBMERGENCE-PRONE RAINFED LOWLAND RICE IN THAILAND

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Rainfed rice improvement experiments began in Thailand in 1916. Problems of shallow rainfed lowland rice are drought, flood, salinity, and acid sulfate and sandy soils. A large-scale rice improvement program was initiated in 1950. The present breeding program for the drought- and submergence-prone rainfed lowlands aims to incorporate tolerance for adverse soils into photoperiod-sensitive better plant types with disease and insect resistance and good grain and cooking qualities.

Irrigation canals were first constructed in Thailand in 1890 to improve rice production in selected areas in the central plain. In 1916, the Rangsit Rice Experiment Station was established, and eight improved rice varieties were subsequently recommended for distribution to farmers. There are indications that the varieties selected were for rainfed conditions according to the description of their characters (Table 1). In 1950, a large-scale rice improvement program was launched, and local collections were made. More varieties were recommended for rainfed areas.

With the development of modern varieties such as RD1 and RD3, the national average yields have risen and leveled off (1, 3). More attention must now be paid to the problems of rainfed rice.

GEOGRAPHY AND CLIMATE

Thailand is divided into four regions: north, northeast, central, and south. In most parts of the north and the upper part of the northeast, farmers grow glutinous rice. The rest of the country produces nonglutinous varieties. The rice area in the northeast is the largest, and its lowland rainfed area of 3.3 million ha is also the largest (5).

Rainfall in Thailand is mainly from the monsoons and cyclonic rains. Rainfall distribution is generally bimodal. The rainy season commences in mid-May with the southwest monsoon coming from the Indian Ocean on the western side of the peninsula. The monsoon trough gradually moves north, passing through the country from around mid-July to the end of August. It leaves a dry spell of 2-3 wk before it turns back, moving from north to south from August to the beginning of October.

Table 1. Recommended varieties from Rangsit Rice Experiment Station, 1921-36.

Variety	Collection site	Start of selection	Harvesting period[a]	Characters
Puang Ngern	Thonburi	1921	wk 4 of Oct	early, low yield if planted late
Tawng Rayah Dam	Chacherngsao	1922	wk 2 of Nov	early, stiff straw, high tillering, good taste and aroma
Khao Todlawng	Station field	1924	wk 4 of Nov	medium late, moderately drought-tolerant, suitable for higher elevation
Jampah Sawn	Nakorn Pathom	1922	wk 4 of Nov	medium late, moderately drought-tolerant
Pin Gaew	Chonburi	1921	wk 2 of Dec	late, first prize in World Rice Exhibition in Regina, Canada, 1933
Bahng Pra	Samut Sakorn	1921	wk 2 of Dec	late, not suitable for uplands, able to stand 1-m water depth
Nam Dawkmai	Lad Krabang	1921	wk 2 of Dec	late, for lowlands, able to stand deep water
Nahng Tahni	Prachinburi	1921	wk 2 of Dec	late, for lowlands, wide spacing in high fertility soils

[a]Nursery seeding third week of May.

Cyclonic rains originate from the South China Sea and move westward along the monsoon trough. The track appears in the north in August, moves to the northeast and the central plain during September-October, and moves further south in November. The passing or delaying of the cyclone influences the rainfed crop production of the country and can cause either drought or flood. The annual damage from drought and flood in 25 yr (1958-82) is estimated at 3.7 to 22.1% (Thai Department of Agriculture Extension, unpublished data).

PROBLEMS

Drought

Drought is the major problem in rainfed areas. From 1831 to 1957 the rice yield was affected in 60 years by drought and in only 4 years by flood (Thai Royal Irrigation Department, unpublished data). In drought-prone areas, rainfall distribution is bimodal, with a dry spell between the two peaks. Damage may occur at the seedling, transplanting, or vegetative stage. There have been occasions when damage was severe at the reproductive stage.

Drought stress is common in the north, northeast, and central regions. Although rainfall is abundant in the south, parts of the riceland, especially the light soils, are normally affected by drought.

Submergence

Although drought is the most severe problem, flooding can occasionally be devastating. The drought-prone area in the northeast is subjected to submergence from time to time. In the valleys and plains in the north, rice fields are usually flooded after heavy upstream rains. Overflow of the rivers causes floods in the central plain, sometimes submerging rice for more than 10 d. In the south, flash floods occur because of poor drainage in low-lying areas. Submergence is observed at different growth stages, but mostly during the reproductive stage.

Soils

The economically important soil problems in the rice areas are saline soils, acid sulfate soils, and sandy soils.

Saline soils. There are two types of saline soils: inland and coastal. The inland type (Fig. 1) occurs mostly in the northeast, where irrigation is limited. The area is estimated at 2.8 million ha (4). Rice yield in the saline area of Tung Kula Ronghai is 35% below normal (2). Coastal saline soils (Fig. 2) are tidal swamps, shores, and beaches. Tidal swamps are not recommended for rice cultivation since it is more profitable to raise coconut there (4).

Acid sulfate soils. Most acid sulfate soils are in the central region (Fig. 3), covering 0.9 million ha. Smaller areas are scattered along the peninsula, especially on the eastern coastline. Grain yield and quality are poor.

Peat soils are included in Figure 3. The reclaimed peat has been used with very limited success (4). Rice plants have poor root anchorage and are frequently washed away during floods. Yields are around 0.6-1.2 t/ha.

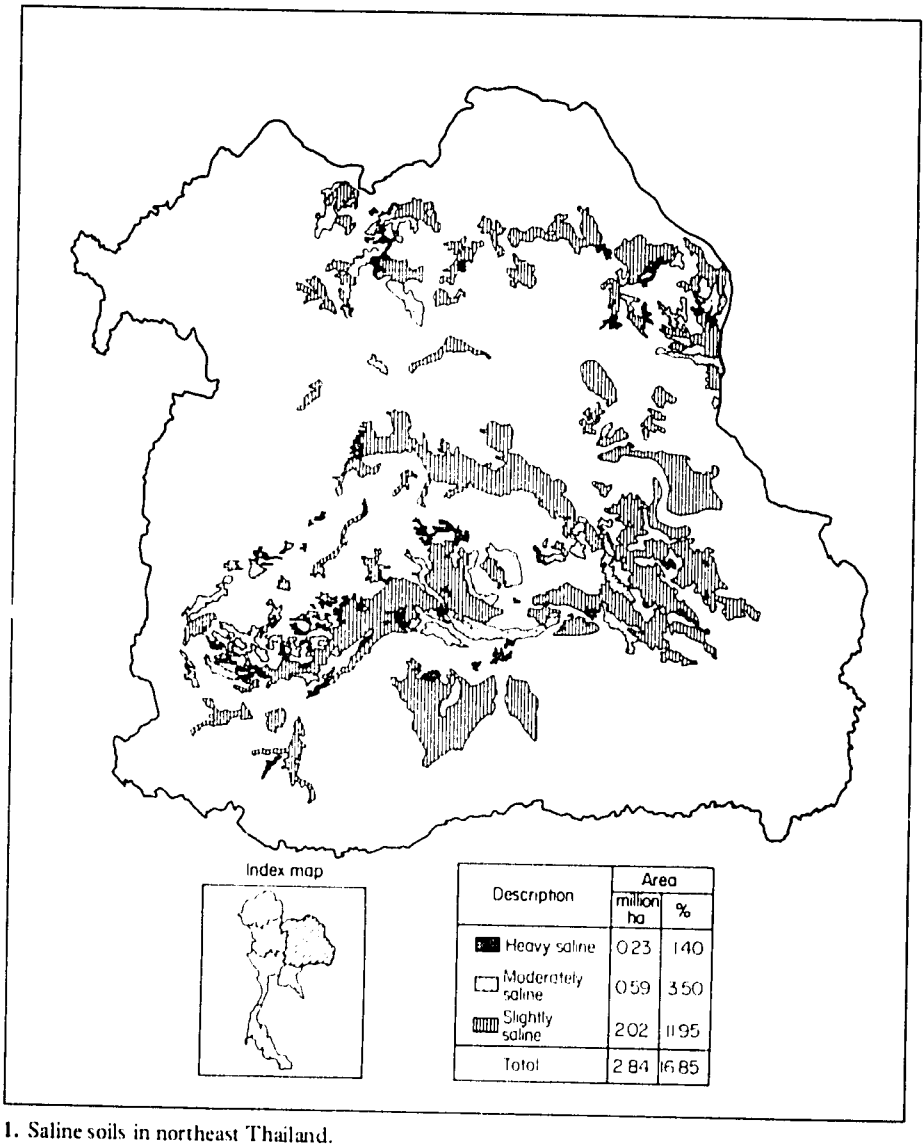
Sandy soils. The sandy area is estimated at about 1.0 million ha, scattered in the northeast (Fig. 4). The soil has very low fertility. The combined effects of drought and salinity on sandy soils make rice production in the northeast very low.

BREEDING WORK

Achievements

When the large-scale rice improvement program was launched in 1950, thousands of collections were made in different parts of the country. Pureline selection was done, and the first batch of recommended varieties was released in 1956. More varieties were recommended at 3-yr intervals until 1968.

There was no concrete screening technique for rainfed characters during that period. Promising lines were further tested in farmers' fields under rainfed conditions for three seasons before the Varietal Release Committee recommended them. Some of the varieties (Table 2) are still popular with farmers.



1. Saline soils in northeast Thailand.

In the 1950 program, not only was pureline selection conducted but hybridization as well; the breeding objectives included drought tolerance and better elongation ability. But the hybridization program was not very fruitful. Since the first cross was made in 1955, only two varieties were released: RD13 in 1978 and RD27 in 1981 (Table 3).

Present activities

The northeast has the poorest rice yield, although its planting area is the largest; this lowers the national average yield. Almost yearly, the region suffers

2. Coastal saline areas of Thailand.

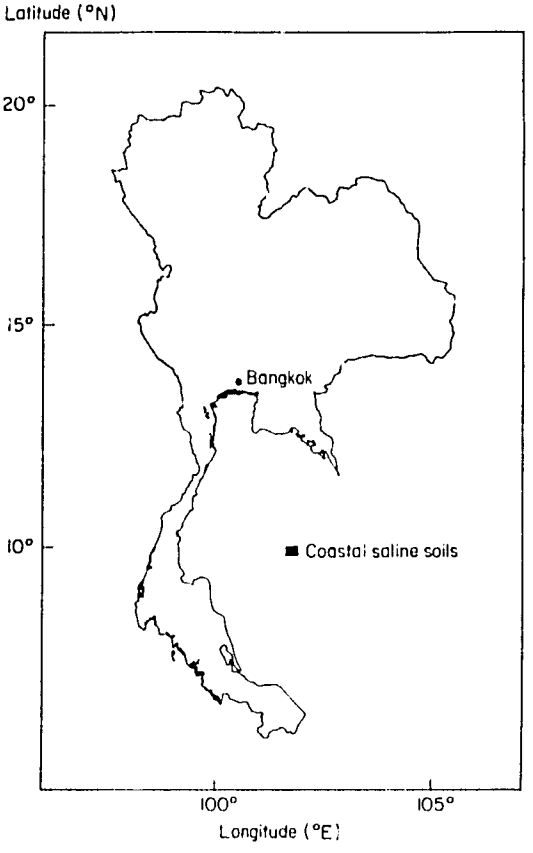
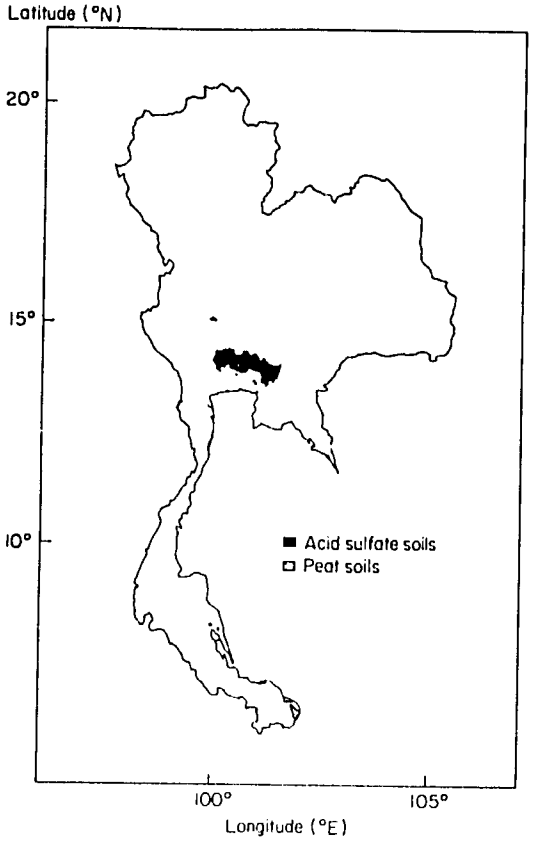


Table 2. Recommended varieties from the 1950 Rice Improvement Program still in use.

Variety	Flowering date	Region[a]	When recommended	Important characters
Nahng Mon S-4	late Oct	C	1956	early, good grain quality, aromatic
Muey Nawng 62 M	late Oct	N	1959	waxy endosperm, gall midge-resistant
Khao Dawk Mali 105	late Oct	N, NE, C	1959	early, good grain quality, aromatic, moderate drought-, salinity-, acid sulfate-tolerant
Niaw San Pahtawng	late Oct	N, NE	1959	waxy endosperm, wide adaptability
Nam Sagui 19	early Oct	NE	1968	drought- and submergence-tolerant

[a]C = central, N = north, NE = northeast.

from losses due to drought and flood in various degrees of severity. The World Bank recommended that something be done to improve the situation, and the Northeast Rainfed Rice Improvement Pioneer Project was initiated in 1973 with the Khon Kaen Rice Experiment Station as the key breeding location.



3. Acid sulfate and peat soils of Thailand.

Table 3. Rainfed lowland rice varieties released under the RD series and later.

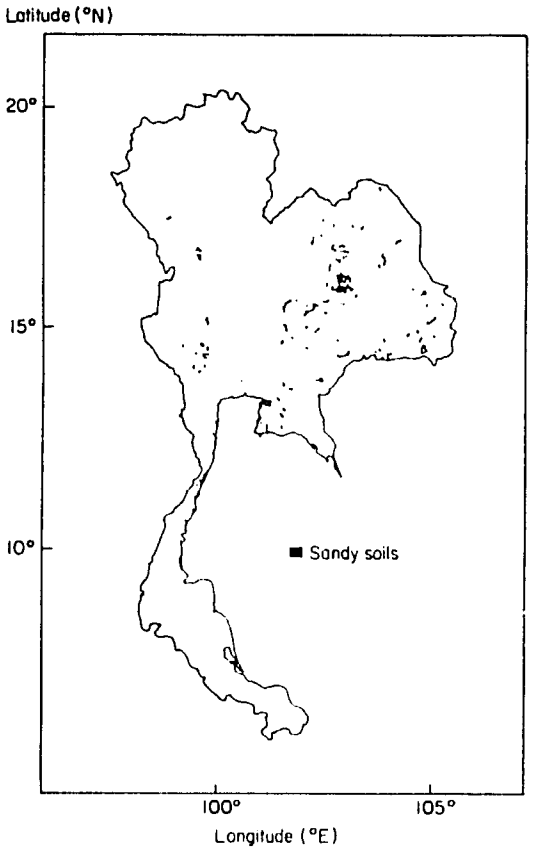
Variety	Year of release	Region[a]	Flowering date	Important characters
RD6	1977	N, NE	late Oct	waxy endosperm, good eating quality, slightly earlier than NSPT
RD8	1978	N, NE	late Oct	waxy endosperm, moderately resistant to drought
RD13	1978	S	late Feb	high yield
RD15	1978	N, NE	mid-Sep	earlier than KDML 105
RD27	1981	C	early Nov	late maturing
Niaw Ubon 1	1983	N, NE	mid-Oct	waxy endosperm, moderately resistant to drought, earlier than RD8
Gaen Jan	1983	S	late Feb	wide adaptability

[a]N = north, NE = northeast, C = central, S = south.

The breeding objectives for both glutinous and nonglutinous rice are

- wide adaptability for cultivation in rainfed lowlands in the northeast, including drought, flood, and salinity tolerance;
- photoperiod sensitivity, with different maturities to fit specific rainfall patterns and topography in different areas;

4. Sandy soils of Thailand.



- plant type preferably the same as that of modern varieties, medium to tall, and with sturdy culm; and
- combined resistance to diseases and insects with agreeable grain appearance and good cooking quality.

At the beginning of the project, several promising lines were already in the pipeline. As the project progressed, RD6, RD8, and RD15 were released (Table 3). Several progeny lines from crosses at Khon Kaen since 1972 are being evaluated in multilocation yield trials at all stations in the north and northeast.

In general, breeding objectives for the shallow lowland rainfed rice in other regions are the same as those in the northeast. There is a need to incorporate different traits such as tolerance to salinity and acid sulfate soils for specific locations.

THAI-IRRI RAINFED COLLABORATIVE PROGRAM

In 1978 the collaborative rainfed breeding program with IRRI was initiated with drought screening experiments of rainfed lowland cultures at two stations in the northeast. Pedigree lines from crosses made at IRRI were grown at four

stations, and IRRI breeders assisted in the selection of lines on the basis of plant type and vegetative growth, while Thai counterparts placed strong emphasis on grain quality. The attempts were not successful, because most of the crosses contained foreign parents with poor grain quality.

In 1982 a new collaborative effort began with the signing of a memorandum of understanding with IRRI. Thai breeders suggested traditional varieties and improved hybrid progenies of Thai origin — with acceptable grain quality, photoperiod sensitivity, stiff straw, good yield, and wide adaptation to northeast conditions — as parents for crossing with IRRI materials having disease and insect resistance and drought and submergence tolerance. Crosses were made and F_1 plants were grown at IRRI. F_2 populations were grown at the six stations in northeast Thailand according to endosperm type. Selections in different environments were made by IRRI breeders. Seeds from selected F_2 plants were sent to IRRI for generation advance. F_4 seeds were sent back to the five corresponding stations, and the pedigree lines were grown. At Phimai, the F_2 populations grown in the 1983 wet season were damaged by flood during the reproductive stage; they were thus naturally selected, and the surviving pedigree lines were planted. More F_2 populations were subsequently planted at the six stations.

RAPID GENERATION ADVANCE

Some rapid generation advance (RGA) materials were requested from IRRI in 1981. The materials were mostly crosses made in Thailand, and some had Burmese rainfed lowland varieties as parents. The materials were grown at Phitsanulok in the 1981 wet season. More materials were requested in the following years. In 1982 the F_2 seeds from crosses made at Suphanburi for the central plain were sent to IRRI for generation advance. The F_4-F_5 seeds were sent back and grown at Phitsanulok. The RGA lines were selected with strong emphasis on grain quality and photoperiod sensitivity with varying dates of flowering.

Several progeny lines of waxy endosperm were grown in multilocation yield trials in the northeast. The nonwaxy endosperm lines were evaluated at Phitsanulok.

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SCREENING FOR SUBMERGENCE TOLERANCE

D. HilleRisLambers, A.R. Gomosta, International Rice Research Institute, P.O. Box 933, Manila, Philippines; and T. Kupkanchanakul, Huntra Rice Research Station, Ayutthaya, Thailand

Methods for screening rice for submergence tolerance in breeding programs are discussed, along with genotypic and environmental factors influencing tolerance level. Three objective criteria for evaluating the efficiency of submergence tests are given: relevance, precision, and cost; some parameters for measuring them are suggested. Submergence tolerance screening has been concentrated in only a few breeding programs, most investigating tolerance of seedlings. The variety FR13A is most often used as the resistant check and donor of genes. There is a risk associated with this procedure, because it ignores other types and levels of tolerance. Desirable emphasis in future submergence screening is discussed. Recommendations include more exploitation in crosses of donors other than FR13A; development of tests at more advanced growth stages of the rice plant; exploitation of alternative predictors of submergence tolerance such as tolerance for prolonged darkness; accumulation of more data on flood characteristics, including hydrographs; and exploitation in breeding programs of lines that have been bred from submergence-tolerant donors.

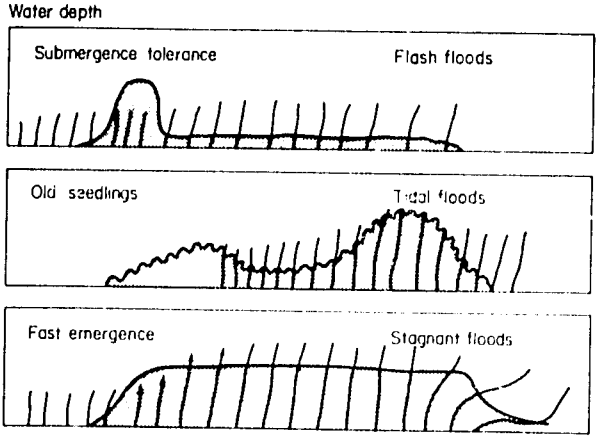
Submergence tolerance is defined here as the ability of a rice crop to survive complete submergence in flash floods that may or may not linger. These conditions have two aspects:

- a sudden surge in the supply of water to the field, and
- a drainage capacity that is (temporarily) inadequate.

FLOODING CHARACTERISTICS

The type of flood depends on the source of water and the specific landform. Figure 1 shows different deep water situations (10), some of which cause total submergence of the rice crop. We can distinguish two important types of flash floods, both characterized by a rapid increase in water level, which is the scope of this paper:

- Short-duration submergence, also sometimes called intermittent flooding (20), often occurs as a result of excess rainfall in areas where drainage is slow but not absent. Intermittent floods may also occur in a predictable, fortnightly cycle in coastal areas under the influence of the moon. Varieties such as FR13A can tolerate complete submergence for as many as 10 d.



1. Schematic hydrographs of three basic types of flash flooding and matching adaptive mechanisms of rice (10).

- Abrupt submergence, prolonged stagnation flooding lasting beyond 10 d usually kills rice unless it emerges through the water. Tolerance for short-duration flooding would not be appropriate here, as pointed out by many workers (6, 20). The rice varieties adapted to such long-duration flooding manage to emerge from total submergence through leaf or stem elongation (24).

Flash floods are widespread in the wet season in relatively level areas where localized excess rainfall and water supplied by nearby rivers interact with impaired natural drainage. Reports from the Indian states of Uttar Pradesh (19, 21), Bihar (28, 30, 36), West Bengal (24, 29), Orissa (29), and Assam (4); Bangladesh (1, 8, 27); Thailand (33); northern Vietnam (3); and the Philippines (2; and D.B. Marra, H.C. Gines, and D. HilleRisLambers, unpubl. data) all describe flooding events of this category.

CULTURAL TYPES

Submergence tolerance has relevance to a wider range of rice cultural types than those described as rainfed in the classification recently adopted as a working model (17). Thus, flash floods are often superimposed on the slowly increasing floods beyond 1 m in depth that characterize floating rice growing conditions (27), or on the stagnant floods of 50-100 cm that support deep water rice in Bihar, Assam, and Uttar Pradesh (4, 19, 21, 28). Part of the flood hazard in northern Vietnam affects irrigated rice (3). Submergence tolerance also concerns breeders of tidally submerged rice in Sri Lanka (13, 14) and Bangladesh.

Submergence tolerance is of special importance for rainfed rice because of the lack of water control in this cultural type. Flooding is an important constraint in transplanted aman rice in Bangladesh (8). In a survey on rainfed rice reported by Mackill (18), flash floods were recognized as the second most important physical stress after drought, and submergence tolerance was

among the five most important breeding objectives for programs serving almost 10 million ha of rainfed rice.

Combining increased submergence tolerance with intermediate or short stature may allow modern varieties to be grown in areas where they cannot now be used; genetic submergence tolerance may also replace plant height as a mechanism determining tolerance for submergence.

MECHANISMS OF SUBMERGENCE TOLERANCE

Breeding for submergence tolerance has not reflected the importance of this hazard to the rainfed rice farmer, perhaps because flash floods are highly unpredictable and their simulation is very expensive. Plant physiologists and breeders are now searching for the physiological basis of submergence tolerance so as to devise simpler tests.

Traits correlated with submergence tolerance

Mazaredo and Vergara (22) tested varieties reported to be tolerant of or sensitive to submergence but could not pinpoint any single mechanism responsible for varietal differences. One problem is the distinction between two mechanisms:

- survival under water until after drainage, and
- escape from submergence by emergence above the floodwaters.

Table 1 lists the varietal traits and environmental factors postulated by various authors as contributing factors to submergence tolerance. Adaptation to prevailing soils is mentioned and should be seen as a general condition for healthy seedling growth, leading both to taller seedlings and to more carbohydrate accumulation. Conceptually, all traits listed in Table 1 are supposed to affect submergence tolerance in one or more of the following ways:

- building up or conserving carbohydrate reserves before or during flooding,
- maintaining physical structure during submergence, and
- avoiding submergence by emerging above the water.

Traits like tallness are assumed to affect both submergence tolerance and ability to emerge through flooding equally. Other traits affect the two characteristics differently or even in opposite ways, as in the case of elongation during submergence, which is undesirable for survival in short-duration floods but essential for escaping long-duration flooding. Many suggestions are speculative or, like leaf sheath overlap and air spaces in the stem, have subsequently been shown to be of no use in selection for submergence tolerance in segregating populations (15).

A few factors deserve more explanation. One of us is evaluating survival in darkness as a tool for screening rices for submergence tolerance. This approach is based on the hypothesis that an important aspect of submergence tolerance may be the ability to cope with lack of assimilation, which happens to

Table 1. Rice traits and environmental factors cited as important for submergence-tolerance in various studies.[a]

Trait or factor	Tolerance (1)	Tolerance (2)	Emergence (3)	References
Rice traits				
Tallness	•		•	22
Rapid elongation during submergence			•	6, 19
Slow elongation during submergence	•	•		12, 20
Short erect leaves		•		27
Glabrous leaves	•		•	7
Leaf sheath overlap		•		15
Air spaces in stem	•			15
Survival in darkness	•			[b]
Adaptation to soil	•		•	[b]
Silica in leaves against silt		•		22
Low P/R rate while submerged at 30 lux		•		22
High nitrate in culm		•	•	22
Carbohydrate conservation	•			22
Stiff and rigid culm			•	22
Carbohydrate before submergence	•		•	25
Environmental factors				
Shallow water depth	•		•	26, 34, 35
Low turbidity	•		•	26, 35
Cold water	•			35
Short duration	•		•	26, 35
Plant age	•		•	26, 35
Low nitrogen fertility		•		26, 35

[a](1) = carbohydrate reserves, (2) = physical structure, (3) = escape from submergence.
[b]Discussed in this paper.

Table 2. Yellowing symptom of 9 rice entries as affected by dark treatment (3, 7, and 10 d) of 30-d-old seedlings.[a]

Variety	Recovery from Submergence[b]	Yellowing symptom (%) 3 d	7 d	10 d
FR13A	1	5	20	35
Thavalu 15314	1	10	25	40
BKNFR76106-16-0-1	3	10	15	35
BKNFR76109-1-2-1	3	10	20	40
IR8234-OT-9-2	5	15	40	65
T442-57	7	20	60	90
RD7	7	20	50	90
NSG19	7	25	75	100
KDML 105	9	30	70	95

[a]Av from 2 experiments, 4 replications. Source: Kupkanchanakul, unpubl. data. [b]By the *Standard evaluation system for rice* scale.

be one of the consequences of darkness. Varietal differences in response to darkness, which are of interest in their own right, are found (Table 2). However, their correlation with submergence tolerance needs to be established, and environmental variation in results from different tests must be resolved.

So far, no test has been adopted for screening submergence tolerance without submerging the plants.

Genetics

Since submergence tolerance is dependent on so many component traits, it is difficult to elucidate its genetics. However, submergence tolerance as shown by FR13A, FR43B, Kurkaruppan, and Goda Heenati was found to behave as a dominant character, with at least one major gene active (23). The dominance is encouraging for breeders, since it means that screening for submergence tolerance derived from these parents can start from the F_2 without unduly narrowing down the population. Furthermore the major-gene hypothesis corresponds with our experience of the relative ease of transfer of submergence tolerance in crosses with FR13A.

SCREENING METHODS AND BREEDING PROGRAMS

The literature abounds with accounts of experiments in which natural or induced flooding was a main factor, but that is not necessarily screening. Screening denotes testing of large numbers of varietal entries in a breeding program. Depending on the capacity of the testing facilities, such screening can evaluate the following in order of increasing capacity:

1. Genetic stock. Successful entries are used as progenitors in the breeding program.
2. Breeding lines. Small samples of pedigree lines are planted in the test. Results are noted and used to help decide on selection or rejection of each line.
3. F_2 or other segregating populations in rapid generation advance. The test is used as a selective seedbed; only surviving plants are transplanted for further selection. Notes are also taken but are not strictly necessary once confidence in the test has been established from the response of the check varieties.

Submergence screening in practice

Submergence tolerance is not adaptation to a permanent condition such as disease or poor soil. During submergence, tolerant entries are characterized by a slower onset of mortality than the susceptible entries. While in progress, the test cannot easily be inspected because of strong and unpredictable environmental influences on mortality. Often the test destroys all plants, including the resistant checks, or too few plants — even susceptible checks — survive. Breeders have to cope with serious screening difficulties.

Specifications of tests. Table 3 summarizes testing procedures now used in breeding programs in Asia. Only two programs regularly use a submergence test as a selective seedbed for bulk F_2 populations. The test in Indonesia uses natural tidal fluctuations, and as such may differ from other tests.

The use of resistant and susceptible checks deserves emphasis. All programs except those in Indonesia and Sri Lanka use FR13A as a resistant check, and a prevalent local variety without submergence tolerance as a susceptible check. Nine to ten rows of varieties to be checked are always flanked on one side by FR13A and on the other side by the susceptible variety. The checks are used to

Table 3. Screening for submergence tolerance.[a]

Characteristic	IRRI-1	IRRI-2	IRRI-3	INDO	THAI	BDSH	SRIL
Establishment[b]	ds	ws	ws	30 d	ws	35 d	ds
Water[c]	tb	tb	cl	tb	tb	tb	tb
Age at submergence (d)	30	10	10	30	30	40	5
Submergence duration (d)	9[d]	10[d]	7	?	100	15	10
Water depth (cm)	90	45	30	alt	1/10	1/15	30
Scoring (d after drainage)	10[e]	7	5				[e]

[a]IRRI-1 = selective seedbed on F_2s and bulk populations before transplanting (Plant Breeding). IRRI-2 = greenhouse test on pedigree lines and rapid generation advance populations (Plant Physiology). IRRI-3 = greenhouse test under controlled light (400 lux continuous) and temperature (30 °C) for genetic stock and genetics experiments (35). Clear water. INDO = Kalimantan (Indonesia) tidal swamp experiment on genetic stock (32). THAI = Huntra (Thailand) field test on pedigree lines (31). BDSH = BRRI (Bangladesh) concrete tank test on genetic stock (6). SRIL = Bombuwela (Sri Lanka) tank test on segregating F_2 populations before transplanting (15). [b]ds = dry seeded, ws = wet seeded, a number plus d (days) indicates seedling age if transplanted. [c]tb = turbid, cl = clear. [d]Or less, if weather is cloudy. [e]The result sought here in the first place is surviving plants for further breeding work.

verify the validity of the test in the following way: If FR13A checks are destroyed, then the test was too severe. In contrast, good survival of the susceptible checks will cause the breeder to be skeptical and at times lead him to submerge the trial again.

Scoring methods. Results can be scored as survival percentage if there is differential survival. Most tests allow the crop to recover for several days after draining the water. There is merit in combining observations immediately after drainage with those after 10 d recovery. Immediately after drainage, identify entries with excellent survival ability — scored 1 or 3 — without considering as yet entries scored 5 to 9. After recovery, a very clear reading can be made of survival and recovery, and the final scoring can be done using the day-after scores to distinguish among scores 1, 3, and 5.

However, if the test did not give much difference in mortality, survival percentage scoring is insufficient, and scoring of other symptoms is in order (slightly modified from 6), as follows:

Score	*Description*
1	Erect, little or no elongation
3	Erect, green, considerable elongation
5	Elongated and bent at the middle
7	Elongated and lodged flat
9	Elongated and apparently dead

In the same test, some entries may survive by emerging from the water and others by their physical structure or their ability to conserve carbohydrates. This can be a source of confusion if breeders interpret the data without having observed the test while it was in progress, and it leads to elongating, floating, and deep water rices all receiving relatively favorable scores at times.

Varieties and lines from past screening tests

Some of the results of the many small-scale submergence trials, large-scale screening tests, and observations in farmers' fields are given in Table 4. These data are limited to varieties identified more than once. An encouraging degree of overlap exists, especially in the varieties FR13A, FR43B, and Kurkaruppan plus their offspring. Some tests also favored varieties known mainly for their elongation ability. The lines identified here could be further used in breeding programs.

Table 4. Varieties, lines, and progenitors with good survival after submergence in various screening programs.

Designation[a]	Reference
B1050-MR-44-3	3, 32
BKN6986-108	32, 35
BR118-3B-17	3, 32
BR118-3B-37	10
BR4	5
Chenab 64-117	10, 34
FR13A	5, 6, 11, 20, 23, 26, 31
* BKNFR76106-16-0-1	31
* FR26702-111	
* FR26702-155-2-3	
* IR26702-25	
* IR26708-2-2-3-1-1	
* IR28884-26-3-505-1-1	
* IR28884-6-1-502-1-2	
* IR31031-43	
FR43B	20, 23, 26
* BKNFR76109-7	35
* IR6402-7-1	31
FRG2	19, 20
* IR33279-1-501-1	
* IR33284-4-503-1-1	
FRG7	3, 32
Goda Heenati	23, 35
* IR26721-135-2-6-1-3	
* IR28905-10-1-3	
* IR28930-5T	
IR8234-OT-9-2	11, 23, 31, 35
KURKARUPPAN	
* IR31406-333-1	
* IR31432-6-2-2-3	
* IR31442-1-503-1-2-1	
Kaharamana	35
Karamana	14
Madhukar	3, 10, 20
RAU21-168-1-2	32, 34
Thavalu 15314	9, 35
Thavalu 15325	9, 35
Tilockachari 33-754	

[a]An asterisk (*) indicates lines having the preceding variety as one of the parents, screened by IRRI's Plant Physiology Department.

EVALUATION OF SCREENING TECHNIQUES

Submergence tests must be judged by their precision, relevance, and cost. These three criteria are discussed below, along with parameters for their evaluation.

Precision

Distinctions among varieties should be possible on visual observation. Furthermore, replications cannot be numerous, so the response should be rather uniform.

In simple submergence survival tests, the F-value for the varietal component from an analysis of variance can be used in judging precision (9, 33). A high F-value may be obtained by reducing environmental variance through adequate design and replication of the experiment, but the F-value is also high when the genetic variance increases through inclusion of highly resistant and very susceptible entries. Thus, clearcut results were obtained in the Thailand program only when FR13A, FR43B, and lines from crosses with these as a parent were included as checks and parents (31, 33).

Another parameter is repeatability, an intraclass correlation (16) that can be calculated as the ratio of the variance estimate attributed to genotypes divided by the phenotypic variance. The use of repeatability is equivalent to the use of the F-test if tests with the same number of replications are compared. Repeatability can actually be calculated from the F-value for genotype variance as follows:

$$r = \frac{(F - 1)}{(F - 1 + R)}$$

in which r = repeatability, F = F-value from the analysis of variance for genotypic differences, and R = the number of replications per entry.

Relevance

Precision is not all. One can think of tests with high precision that measure a type of submergence tolerance useless to farmers, or that measure too high or too low a level of tolerance.

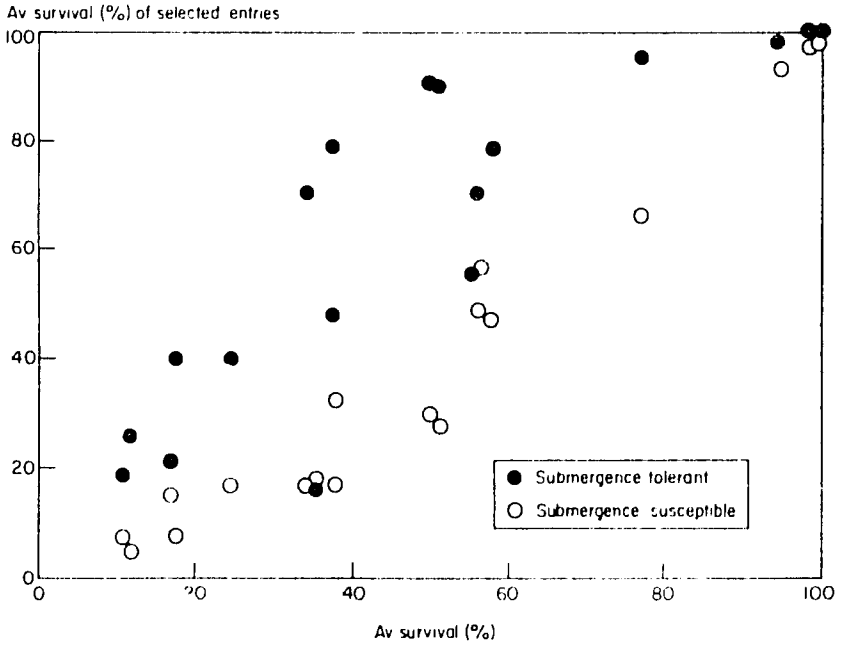
Correlation with results in farmers' field. The test conditions should relate to submergence as it occurs in the target area of the breeding program. Whether this is so can be checked — the varieties favored by the test should include those favored in the local field situation. This approach is important, given the different types of submergence. On the other hand, it is also important that conditions of a test need not precisely duplicate those of the field. For example, direct seeding can be substituted for transplanting; age of plants when tested can be different from that in usual natural flooding; and clear water can be substituted for silted water. Another important point (in using clear-water tests for turbid-water farming situations, etc.) is that screening should not

pretend to replace testing under farmers' conditions but rather should preselect breeding populations in earlier generations for higher probability of success later.

Parameters. When evaluating a test for relevance to farming conditions, one can take the simple correlation coefficient between results obtained on-farm and those obtained in the submergence test. Often on-farm data are difficult to obtain, in which case entries in a submergence test can be divided into two classes: those reputedly submergence tolerant, and those known by farmers to lack tolerance. Their performance in the deep water test can then be examined with an analysis of variance.

Severity of the test. Submergence tolerance is of finite duration unless it involves escape by emerging from the water. This means that resistant and susceptible varieties differ in the time it takes for the first adverse symptoms to appear after applying the stress and in the time until subsequent death. There may be few differences between very tolerant and very susceptible entries both if the stress is too weak (too short duration of submergence, water too shallow, etc.) and if it is too strong (duration too long, water too deep, etc.). In the first case all plants will be alive; in the second case all will be dead.

Figure 2 (11) shows, for 18 tests with different specifications, the average survival percentages of tolerant and susceptible entries as a function of the average survival percentage of all entries in the test. At high severity all entries die, without difference between resistant and susceptible entries; likewise,



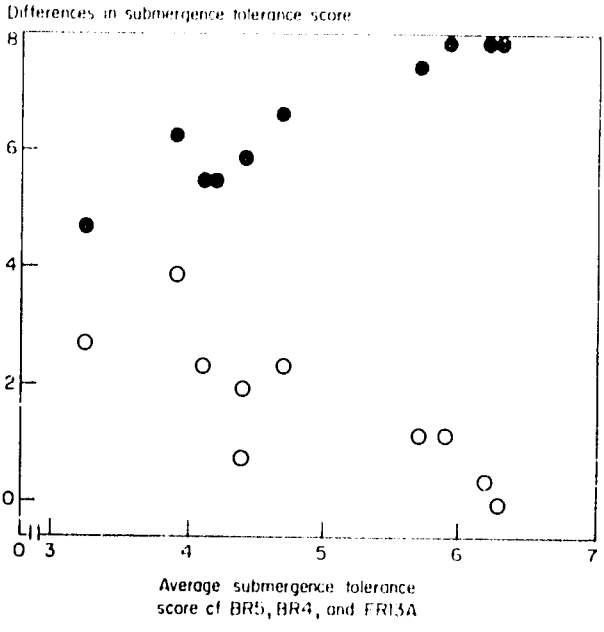
2. Average survival percentage of 4 submergence-tolerant and 8 susceptible entries in 18 tests, plotted against average survival percentage of all test entries.

there is no difference at extremely low severity, when nearly all entries survive. The useful test is somewhere between the above extremes, depending on two factors: first, whether the test is supposed to yield survival scores or actual, surviving plants; second, the level of tolerance of the relevant farmer varieties.

When submergence scores are used, high survival rates of both susceptible and resistant entries are acceptable, as long as differences can be seen and rated. For a selective seedbed, however, susceptible plants must actually die in order to derive any benefit from the exercise. Theoretical calculations (11) illustrate the dependence of selection efficiency on the difference between mortality rates of resistant and susceptible entries.

An important problem is the danger of excessively severe tests. Figure 3 compares submergence scores of highly susceptible BR5, highly resistant FR13A, and moderately resistant BR4. In these tests, either seedling age or recovery period between transplanting and flooding was varied. FR13A was superior to BR5 in all tests in Bangladesh, where BR4 tolerance is known to be useful to farmers. The difference between BR4 and BR5 was minimal in the more severe tests, whereas it was maximized in tests using old seedlings and longer periods between transplanting and submergence. The latter conditions are more representative of farmer conditions than the specifications of the more lethal tests.

Thus, by designing submergence tests to highlight only varieties with the exceptional tolerance of FR13A, one is denied the opportunity of identifying moderate and more agronomically sensitive submergence tolerance such as that of BR4 and, possibly, many other farmer varieties with established reputations for submergence tolerance.



3. Differences in submergence tolerance scores between BR5 and FR13A (•), and between BR5 and BR4 (○), as a function of average submergence survival scores of the 3 varieties (from 10 tests using different seedling ages or seedling recovery periods).

Cost

Facilities and labor requirements for the test should be minimal. It is not necessary to use fishponds for submergence testing, since water depths as low as 30 cm have been successfully used with correspondingly lower seedling ages of around 10 d (Table 3).

FUTURE RESEARCH NEEDS

Screening methods. The screening methods we discussed are biased toward the use of young seedlings. There is som justification in this for logistical reasons and because test results and information from farmers' fields have shown significant correlation. However, many varieties known for submergence tolerance in their areas of origin perform poorly in the tests.

As was suggested in Figure 3, by tuning a test to highlight only FR13A-caliber submergence tolerance, one may identify perfectly adequate submergence tolerance that might have been identified by using, for example, older seedlings.

More experiments are needed to design tests for submergence tolerance of adult plants.

Target submergence type. In many tests that evaluate submergence tolerance, the rice crop stays completely submerged. In practice, tolerance based on the emergence of plants above the water also occurs (24). Testing specifically for this strategy is difficult, because this type of tolerance interacts with plant height, water depth, and growth stage. Precise tests that consider such interactions should be developed.

Mechanisms of submergence tolerance. More knowledge is needed of the physiological basis of submergence tolerance and its relation to the carbohydrate assimilation or respiration pattern in the plant. Resistance to darkness as a supplementary test should be evaluated.

Exploitation of donors for submergence tolerance. There seems little point in further direct exploitation of FR13A and some other frequently crossed varieties. Lines of improved plant type now available for further breeding (Table 4) have already combined the submergence tolerance of these sources with improved plant types. On the other hand, many of the available alternative donor varieties have no submergence-tolerant descendants with improved plant type; this gap should be filled.

Role of submergence tolerance. It is striking how few programs on submergence screening exist despite the appreciation of submergence tolerance as an important limitation on rainfed rice yields. It would be useful if every rainfed rice variety had submergence tolerance. However, that would not be practical, since a cost is associated with every trait that is used for serious selection in breeding programs. Perhaps submergence tolerance should be a necessary precondition to the introduction of improved (shorter) plant types to replace tall traditional rices. Some evidence of this has been obtained in flood-prone areas in northern Luzon, Philippines (2). This line of thought may be developed for other areas as well, possibly in tidally flooded areas where tall

stature protects current rices from floods. More studies of actual flooding, including hydrographs, should be undertaken in specific rice growing areas, preferably combined with survival tests of key rice plant types.

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BREEDING FOR SUBMERGENCE TOLERANCE IN RICE IN INDIA

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Submergence-tolerant rice varieties are needed for flash flood-prone lowlands. Early breeding work in India led to the release of flood-tolerant varieties, among which FR13A and FR43B, along with Kurkaruppan of Sri Lanka, are the best donors for submergence tolerance. Intensification of breeding work in the 1970s produced Janaki, Jalaj, Suresh, and Biraj for semideep water situations. They are still to be critically assessed for submergence tolerance and elongation ability. So far no serious breeding efforts have attempted to incorporate submergence tolerance into the genetic background of the popular shallow lowland varieties. It would be rewarding to use the breeding lines BKNFR76106-16-0-1, IR6402-OT-7, and IR31406-333-1 as sources of submergence tolerance. The breeding program can be sped up by using seeds of the F_2 population of crosses involving appropriate parents produced and freely supplied by IRRI. There is urgent need for improvement in screening for submergence tolerance. The national evaluation trials PVT 4, UVT 4, PVT 5, and UVT 5 should include flood submergence at early and midgrowth stages at some of the test sites. The present efforts for screening local germplasm should be intensified.

Flood submergence is a serious constraint to our efforts to minimize the annual fluctuation in rice production. About one-third of India's total rice area of about 40 million ha is exposed to the hazards of monsoonal floods. Deep flooding occurs once or twice in [illegible].

No rice crop, when submerged, [illegible] escape damage. Damage may vary from less than 10% to complete crop loss depending upon the growth stage of the rice, floodwater height above the crop, f[illegible]od current, and water turbidity. To a considerable extent, the observed varietal differences in adaptation to flooding (7, 13, 17) are under genetic control.

In India, as elsewhere, breeding efforts since the 1930s have been directed to exploit flood tolerance in the development of rainfed lowland rice varieties.

FLOODING PATTERN AND VARIETAL ADAPTATION

There are distinct mechanisms of varietal adaptation to flooding —elongation ability and submergence tolerance — corresponding to the two distinct categories of flood-prone situations.

Elongation ability is observed in very deep water rices growing in lands of stagnant flooding where the sustained water depth during most of the life cycle of the crop may be 100-600 cm or deeper. Very deep water rices have the unique capacity to elongate internodes and leaves to keep a sizable part of the upper plant above the rising water. This is, strictly, a mechanism of submergence avoidance. In India, very deep water rices are grown on about 3 million ha, mostly in Assam, Bihar, and West Bengal.

Submergence tolerance is found in some rice varieties grown in flash flood-prone lands where the sustained water depth may be up to 100 cm but where the crop is submerged under intermittent flooding for 1-10 d or longer. The mechanism of adaptation is the inherent ability of rice tissue to survive and function underwater, in an atmosphere of light and oxygen stresses. Varieties with strong submergence tolerance do not usually exhibit much elongation ability. The total flash flood-prone rice area in India may be around 10 million ha in the floodplains of the major river systems.

Between the two broad categories of flood patterns, a continuous array of situations exists, and the rice varieties adapted to these conditions show combinations of elongation ability and submergence tolerance according to their past selection history. Rice breeders desire to incorporate submergence tolerance into deep water rices to enhance their adaptability to situations where their rate of elongation may not be adequate to keep pace with the rapid rise in floodwater. However, 20- to 30-d-old seedlings of most rice varieties can stand submergence for 3-4 d, while tolerant strains have the ability to survive submergence for up to 10 d without much damage.

VARIETAL TYPES NEEDED

Choice of rice varieties depends on the topographical and the hydrological characteristics of the land, which are, in fact, beyond precise description. However, farmers' understanding of their ricelands is reflected in their choice of varieties of appropriate maturity period varying from less than 80 (for upper uplands) to more than 160 d (lower lowlands). This section describes the varietal requirements of different flood-prone lowlands.

Shallow lowlands (0-30 cm water depth)

Shallow lowlands comprise about 5 million ha and include Khush's 'c' and 'd' categories of lowland (11). Varieties with a maturity period of 140-150 d are grown. Other varietal requirements are short to intermediate plant height (80-120 cm), moderate to high photoperiod sensitivity, and seed dormancy. The crop is either direct seeded in May-June or transplanted in June-July. Adequate drought tolerance at the early seedling and postflood stages is essential. Adaptation to flooding should be through submergence tolerance. Internode elongation is highly undesirable, as it aggravates lodging following recession of the floodwater. Regeneration ability is helpful in reestablishment of the stand of the crop following flooding.

Semideep water lands (30-60 cm)

Semideep water lands occupy 3 million ha and include Khush's 'e' category of ricelands (11). Varieties with maturity periods of 155-165 d are grown. Other varietal requirements are intermediate plant height (100-130 cm), high photoperiod sensitivity, and seed dormancy. The crop is generally direct seeded in May-June and often faces the problem of early seedling establishment due to drought or flooding. Varietal adaptation to flooding should be through submergence tolerance and elongation ability, particularly at the early seedling stage.

Deep water lands (60-100 cm)

The area under deep water rices may total about 2 million ha. Varieties maturing in more than 165 d are grown. Other varietal requirements are tall plant height (more than 130 cm), strong photoperiod sensitivity, and seed dormancy. The crop is direct seeded in May, and early seedling establishment may be adversely affected by drought or flood. Adaptation to flood should be through submergence tolerance and elongation ability.

Tidal swamplands

The area of tidal swamplands close to the coast is about 2 million ha. These lands are subjected to monsoonal flooding as well as tidal inundation. The varieties should have tolerance for submergence and for salinity.

In addition, lowland rice varieties should have adaptability to adverse soil conditions associated with waterlogging and resistance to stem borer, gall midge, bacterial leaf blight, and sheath rot.

EARLY RESEARCH

Varietal evolution during the decades prior to 1970 was primarily by pureline selection from farmers' varieties in flood-prone rice areas and only occasionally by hybridization. The work was carried out mainly at Karimganj (Assam), Pulla (Andhra Pradesh), Pottambi (Kerala), Coimbatore and Aduthurai (Tamil Nadu), Sabour (Bihar), and Kujang (Orissa) (16, 18, 20).

Some of the important varieties tolerant of flash flood-prone situations are listed in Table 1. These traditional types have been selected for their tolerance for submergence in natural flooding or in field tanks. Subsequently, critical evaluation in the greenhouse as well as in field tanks has shown high levels of submergence tolerance in FR13A and FR43B (4, 14, 15). Systematic screening of the world's genetic stock of rice at IRRI highlighted FR13A, followed by Kurkaruppan of Sri Lanka, as the best available sources for submergence tolerance (9, 10).

The cultivation of these traditional flood-tolerant varieties is confined to a limited area where crop survival is at stake because of regular deep flooding. They are not accepted in most lowland rice areas because of their poor yield and inferior grain quality. The two top submergence-tolerant varieties FR13A

Table 1. Traditional flood-tolerant rice varieties in India.

Variety	State	Parentage	Maturity (d)	Suitability
FR13A	Orissa	Dhullaputtia	145	shallow lowlands
FR43B	Orissa	Bhetnasia	160	semideep water lands
Chin 31	West Bengal	Tilakkachari	180	deep water lands
Jalaplaban	West Bengal	Gabura	160	semideep water lands
Chakia 59	Uttar Pradesh	Chakia	150	semideep water lands
Madhukar	Uttar Pradesh	Madhukar	150	shallow lowlands
Adt 17	Tamil Nadu	Mutusamba	165	semideep water lands
Co 14	Tamil Nadu	Hybridization	200	deep water lands
Pla 4	Andhra Pradesh	Burma Akkulu	150	semideep water lands
Ptb 15	Kerala	Kavingin Pothales	165	semideep water lands

and Kurkaruppan are near wild types in having long awns, red kernels, and a tendency for high grain shedding. In most of the rainfed shallow lowlands where deep floods occur once or twice in 5 yr, farmers prefer the traditional tall varieties T141, NC1281, Br 8, and GEB24, or the modern intermediate varieties Mahsuri, Pankaj, Jagannath, Swarna, and Savitri. These lowland varieties lack adequate tolerance for flood submergence and suffer heavy yield loss in deep flooding.

PRESENT STATUS OF BREEDING WORK

Since the mid-1970s, breeding work on deep water and flood tolerance has been intensified at a number of research stations: Chinsurah (West Bengal), Gograghat (Uttar Pradesh), Pusa (Bihar), and Cuttack (CRRI). Those stations have improved facilities such as field and greenhouse submergence tanks with water control devices. Excellent facilities for screening under natural flooding are available at Gograghat. Fresh collections of local germplasm and their evaluation have received increased emphasis. Hybridization with crosses produced at the station or from the IRRI-Thailand program was taken up at a number of centers. The All India Coordinated Rice Improvement Project (AICRIP) initiated UVT 4 (previously UVT 5) for multilocation evaluation of promising entries for rainfed shallow lowlands and UVT 5 (previously UVT 6) for semideep water selections. IRDWON (IRTP) nurseries for flood tolerance (subset I) and deep water (subset II) were evaluated at a number of test sites in India. Breeding and evaluation work led to the identification and release of a number of promising breeding lines, particularly for semideep water and deep water situations.

RECENT BREEDING RESULTS

Chinsurah

Chinsurah released two promising selections — CN540 (IR262/Khao Nahng Nuey) or Suresh, and CNM539 (mutant of OC1393) or Biraj — for semideep

water lands (3). The station also developed two more promising lines — NC492 (a pureline selection) and CN505-5-32-9 (IR26/SMI40-10-4) — for semideep water situations. The breeding program has been further intensified with production of many complex crosses involving shallow lowland and semideep water varieties and a number of donors of diverse genetic origin for different lowland traits, including submergence tolerance (Biswas, personal communication). But none of the crosses used FR13A or any of its derivatives.

Bihar

Breeding projects are in operation at Pusa, Sabour, and Patna stations of Rajendra Agricultural University. Two varieties — Janaki (C64-117, a selection from Chenab) and Jalaj (IR8/BR8) — have been released for cultivation in semideep water and deep water lands (19). Thakur (21) at Pusa identified a number of promising selections such as BIET452 (IR8/BR34), BIET724 (IR8/BR14), and BIET1048 (Jaya/Mahsuri) for deep water conditions. Chaudhary (personal communication) at Patna developed a number of male-sterile-facilitated composites in collaboration with IRRI to upgrade different traits, including submergence tolerance in lowland rice varieties. One such composite, IR38500/CP104, is the product of 21 donors of diverse genetic origin.

Gograghat

Screening of local germplasm in Gograghat led to the identification of promising flood-tolerant selections FRG7 and FRG10 for shallow water and semideep water lands (12).

Bhubaneswar

The station at Bhubaneswar selected four promising lines — OR1104 (sel. Badakalasura), OR1105 (sel. Khajuriachauer), OR117-8 (T141/Jagannath), and OR143-7 (Pankaj/W1263) — for semideep water conditions. Recently, the station developed a number of advanced breeding lines from crosses involving popular lowland varieties such as Jagannath, CR1009 (Savitri), and RD19 (of Thailand) with the submergence-tolerant donors FR13A, FR43B, and Kurkaruppan.

Cuttack

The shallow lowland variety Savitri developed at the Central Rice Research Institute (CRRI) lacks an adequate level of submergence tolerance but compensates for flood damage to a considerable extent by its ability for rapid regeneration of tillers after recession of flood (unpublished results at Bhubaneswar). Another selection, CR1030 (Waikoku/CR1014-211), has already been released for semideep water lands in Orissa. Screening of local germplasm led to the identification of a number of lines — NCS2031, NCS2062, and NCS2067 — that showed high survival under submergence through elongation of leaves and leaf sheath (5). However, the lines were not evaluated for submergence tolerance.

Table 2. Mean yield of 11 varieties in 1982 and 1983 UVT5 at 5 locations, AICRIP, India (1, 2).

Variety	Yield (t/ha)												
	Bhubaneswar		Chinsurah		Patna		Pusa		Pulla		Mean		Overall mean
	1982	1983	1982	1983	1982	1983	1982	1983	1982	1983	1982	1983	
BIET724	4.98	1.25	3.92	0.63	3.45	2.35	2.33	1.17	2.10	0.55	3.36	1.19	2.27
Janaki	1.83	0.31	4.00	1.50	2.18	3.43	2.48	1.89	3.01	1.41	2.70	1.71	2.20
BIET807	3.02	0.86	4.08	1.93	1.50	3.34	2.00	1.81	1.71	1.37	2.46	1.86	2.16
OR143-7	4.66	1.25	3.46	0.90	1.18	1.82	1.85	1.03	1.64	0.75	2.56	1.15	1.85
BIET821	2.39	0.40	3.58	1.27	0.95	1.68	1.25	1.08	2.14	1.54	2.06	1.19	1.63
CN499-160-2-1	3.07	1.26	4.47	2.60	2.72	1.55	1.75	0.89	2.19	1.04	2.84	1.47	2.15
CN499-160-13-6	3.09	0.97	4.78	2.63	2.86	1.14	1.42	1.11	2.49	0.89	2.93	1.35	2.14
CN505-5-32-9	3.24	0.98	5.87	2.33	3.08	1.14	1.80	0.47	3.28	1.40	3.45	1.26	2.36
CN506-147-14-2	1.96	1.08	5.52	1.77	3.53	2.35	2.10	0.58	2.33	0.60	3.09	1.28	2.18
NC492	4.59	0.76	6.25	3.07	3.18	2.64	2.67	1.36	3.17	2.39	3.97	2.04	3.01
Tilakkachari	2.35	0.94	4.34	1.67	2.86	2.02	2.18	0.89	1.89	1.60	2.72	1.42	2.07
Mean	3.20	0.92	4.57	1.85	2.50	2.13	1.99	1.12	2.36	1.23	2.92	1.45	2.19
Overall mean	2.06		3.21		2.32		1.56		1.80		2.19		

National testing program

The results of UVT 4 trials comprising entries for rainfed shallow lowlands are of limited value for this review, as the experimental crops were not subjected to flood submergence.

The mean yields of 11 UVT 5 entries at 5 test locations each in 1982 and 1983 show that NC492, CR505-5-32-9 (both from Chinsurah), and BIET724 were promising for semideep water lands (Table 2). There were, however, high yield fluctuations over both locations and years. The analysis of variance of the data showed significant interaction of the varieties with the location and the year (Table 3). This suggests the need not only for a location-specific breeding approach but also for evaluation over a number of years to identify varieties having high yield and high yield stability. Among the three top yielders, BIET724 appeared to be most stable in performance in the sense of Eberhart and Russell (6). The two top yielders, NC492 followed by CN505-5-32-9, showed high responsiveness to environment and are to be preferred where crop growth conditions do not fluctuate very much (Table 4).

It may be added that at none of the test sites were the UVT 5 trials scored for submergence tolerance or elongation ability. Water level was maintained at around 50 cm.

Table 3. Analysis of variance for mean yield (t/ha) of 11 entries of UVT 5 at 5 locations in 1982 and 1983, AICRIP, India (1, 2).

Source	DF	MS[a]
Location (L)	4	8.99
Year (Y)	1	59.83*
Error I (L × Y)	4	5.39
Variety (V)	10	1.15**
V × L	40	0.58**
V × Y	10	0.68**
Error II (V × L × Y)	40	0.27

[a]Significant at 5% (*) and 1% (**).

Table 4. Stability parameters for 11 varieties in UVT 5 in 1982 and 1983, AICRIP, India (1, 2).

Variety	Mean yield (t/ha)	Regression coefficient (b)	Variance due to deviation from regression
BIET724	2.27	1.10	0.83
Janaki	2.20	0.72	0.61
BIET807	2.16	0.75	0.39
OR143-7	1.85	0.89	0.72
BIET821	1.63	0.72	0.20
CN499-160-21	2.15	0.95	0.16
CN499-160-13-6	2.14	1.06	0.27
CN505-5-32-9	2.36	1.36	0.36
CN506-147-14-2	2.18	1.22	0.48
NC492	3.01	1.38	0.16
Tilakkachari	2.07	0.86	0.14

International program

HilleRisLambers and Seshu (8) critically analyzed the results of the 1976-80 IRDWON nurseries in different countries including India and concluded that submergence tolerance was an important factor in the survival and overall performance of entries in deep water situations. Among the breeding materials recommended for use in the hybridization program were BR118-3B-37 for submergence tolerance, Chenab 64-117 (Janaki) in crosses for situations with erratic water level, and RD19 for good plant type, photoperiod sensitivity, and moderate elongation ability. In the 1981 and 1982 IRDWON, FR13A and BKNFR76106-16-0-1 consistently exhibited high levels of tolerance for submergence.

FUTURE BREEDING STRATEGY

There is need to reorient breeding objectives to develop rice varieties having appropriate mechanisms of adaptation to different land situations in flash flood-prone areas: submergence tolerance for shallow lowlands, submergence tolerance plus early seedling elongation for semideep water situations, and submergence tolerance with moderate elongation ability for deep water lands.

Considerable progress has been made in evolving varieties such as Janaki, Jalaj, Suresh, and Biraj for semideep water and deep water lands. They should be critically evaluated for submergence tolerance and elongation ability.

It is apparent that rice breeders in India have neglected development of rice varieties with an adequate level of submergence tolerance for rainfed shallow lowlands. The presently cultivated varieties, both the traditional tall and the modern intermediate plants, are nontolerant of flash floods of even moderate intensity. As deep floods visit these lands at least once every 5 yr and cause widespread damage, it is essential to intensify breeding work to incorporate submergence tolerance into the genetic background of the presently grown intermediate varieties such as Mahsuri, Pankaj, Jagannath, Swarna, Savitri, or any of the promising breeding lines in UVT 4.

Flood-tolerant traditional types FR13A, FR43B, and Kurkaruppan are desirable sources of submergence tolerance. It is possible to combine a high level of submergence tolerance with other desirable traits, including yield and grain quality (unpubl. data). The cumbersome process of eliminating undesirable traits from the above donors could be bypassed by using derived lines BKNFR76106-16-0-1, IR6402-OT-7, and IR31406-333-1, which combine a high level of submergence tolerance with good plant type (HilleRisLambers, personal communication), or any such line from IRDWON.

For semideep water and deep water situations, varieties such as Suresh, Janak, and RD19 (of Thailand) may be used in crosses with appropriate donors for submergence tolerance or elongation ability.

For tidal lands, the breeding projects should aim at combining submergence tolerance with salinity tolerance. The breeding program may use traditional varieties such as SR26B, Pokkali, Getu, and Damodar.

There should be free exchange of early segregation material among breeders. National institutes such as CRRI and AICRIP (now the Rice Directorate of Research) are expected to take the lead in such exchanges. Breeders should take advantage of the facility at IRRI under which seeds of the F_2 population of appropriate crosses are produced and supplied for national programs.

There is an urgent need for improving the facilities and for screening breeding lines for submergence tolerance and elongation ability at different research stations located in flood-prone areas.

Test locations with adequate screening facilities for submergence should be identified for evaluation of AICRIP trials PVT 4, UVT 4, PVT 5, and UVT 5. The experimental crop should be exposed to submergence for 10 d at the seedling age of 30 d, or for 15 d at the age of 60 d.

The present work of collection and evaluation of rice germplasm from flood-prone areas should be intensified to identify new and better sources of submergence tolerance and elongation ability.

Breeding for submergence tolerance should be adequately supported by research in the genetic and physiological aspects of this complex trait and in the development of more dependable screening methods.

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- 201 -

TOLERANCE OF RICE VARIETIES FOR STAGNANT FLOODING

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The performance of several rice varieties under stagnant flooding in West Bengal was studied. The 577 entries broadcast seeded in a lowland field showed striking differences in survival and grain yield. Sudden submergence at the seedling stage adversely affected seedling survival, yield, and yield components of surviving entries. Of 156 entries that flowered, 21 produced sterile panicles. No panicles were produced by 136 entries. Only Gerikalma showed good survival, grain yield, and yield components with low grain sterility. SR26B showed the least sterility, and Bhimsail produced the highest number of fertile grains/panicle. Bhimsail and Hamai gave maximum grain yield/plant. Flood-resistant varieties failed to grow well under stagnant flooding. Flood-resistant and lowland varieties performed differently. The study suggests that tolerance of varieties for stagnant flooding is influenced by a combination of environmental, genetic, and physiological factors.

Stagnant floods in the rice areas of West Bengal are caused primarily by heavy and almost continuous rainfall for a number of days between mid-June and early October. Insufficient waterways for drainage of floodwater and runoff from adjacent areas contribute to the intensity of stagnant flooding.

There is no periodicity in the occurrence of floods. Water accumulates to a depth of 20-120 cm or more at different phases of plant growth. Stagnation persists until harvest. Lowland rice varieties that have moderate stem elongation ability and that can also survive under prolonged submergence thrive best (1,6,14,18).

The submergence of plants in stagnant floods adversely affects growth, yield, and stand of the rice crop depending upon the variety, age of the crop, time of occurrence, rate of water rise, soil fertility, and depth and duration of flood.

Earlier studies (5,8,16,19) showed that older seedlings show better resistance to submergence. Semidwarf genotypes have been found suitable for low-lying situations that are prone to submergence early in the growing season (3,15,19). Generally, submergence at the early seedling stage, which sometimes destroys the entire crop, cannot be avoided at any sowing date. Therefore, a search for suitable varieties capable of tolerating stagnant flooding at the early seedling stage seemed logical (9,17,18). To provide a convenient test for tolerance for stagnant flooding in the field and to allow

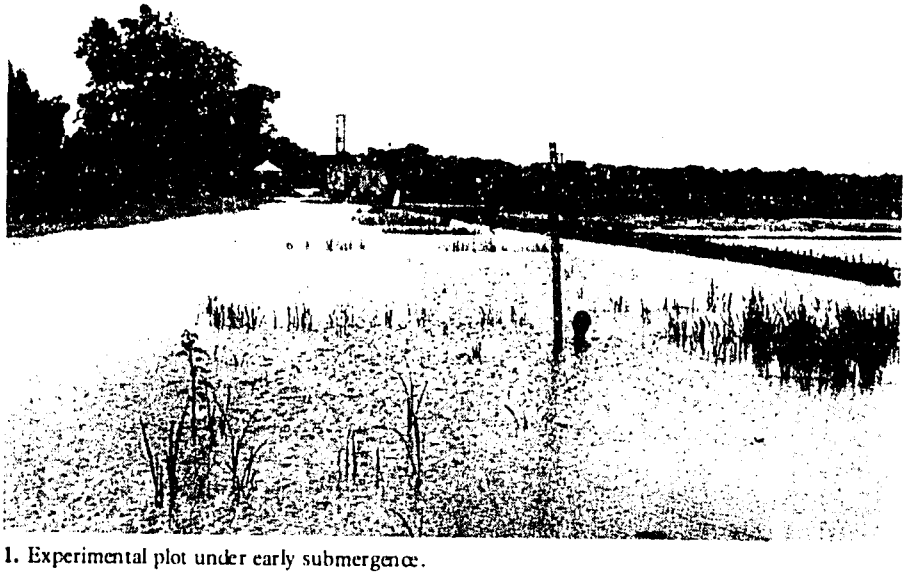
selection of better varieties for lowland flood-prone areas, the performance of several varieties at the seedling stage was studied in areas of sudden submergence.

MATERIALS AND METHODS

The experiment at the Chinsurah Rice Research Station in West Bengal screened 577 germplasm entries, including standard varieties FR13A and FR43B, for submergence tolerance at the seedling stage under varying depths and durations of stagnant flooding. The experimental area was situated in the low-lying part of the station and was connected with main drainage channels so that during the rainy season the whole area was in a stagnant, waterlogged condition. The experimental plot was submerged in a flood caused by unusually heavy rainfall when the seedlings were 35 d old. The seedlings remained completely submerged for 19 d at varying depths and durations (Fig. 1). Monthly variations in water level at different growth periods in the low-lying submerged plot are shown in Table 1.

Direct seeding was in wet soil in late July. Harvest was from November to December in nonreplicated plots. Each entry occupied 1.0 m^2, and a distance of 25 cm was maintained between plots. The soil was heavy clay with pH ranging from 6.5 to 7.2. Farmyard manure at 10 t/ha was applied basally to all plots. Seeds were sterilized by soaking in 0.2% formalin for 4 h before sowing. On the average, the entries took 4-6 d to germinate, after which the number of seedlings in each plot was recorded.

Stand was counted before harvest. Five randomly selected plants gave the average of grains/panicle, sterility of grains, and grain yield/plant.



1. Experimental plot under early submergence.

Table 1. Monthly water depths in low-lying plots at Chinsurah Rice Research Station, India.

Month	Rice growth stage[a] (WS)	Water depth (cm)
Aug	2-5	2-5
Sep	6-9	25-145
Oct	10-13	20-30
Nov	14-17	50-70
Dec	18-21	20-30

[a]WS = weeks after sowing.

RESULTS AND DISCUSSION

Stagnant flooding at the seedling stage adversely affected survival and grain yield of the surviving entries by reducing the number of fertile grains and increasing grain sterility in all 577 entries. In general, flowering was delayed, and 285 entries died in the flash flood that prolonged water stagnation.

The flash flood at the early stage inflicted heavy damage. Floodwater caused complete submergence at 25-145 cm for 19 d. Four factors — deep early submergence, flood duration, restricted light, and limited oxygen — seemed to be the principal problems.

After the flood receded, the plants remained almost buried under the waterlogged mud from the floodwater, and many leaf surfaces were coated with a thick layer of mud. The 292 plants that survived (50.6%) showed certain morphological changes such as considerable elongation and swelling of the leaf sheath and formation of secondary aquatic tillers at the upper internodes. Moreover, the plant tissues became soft and lost their productivity. One hundred thirty-six of the survivors failed to flower. Of 156 entries that flowered, 21 were sterile. The 40 most promising entries are described in Table 2. Only 13 exhibited more than 45% plant survival; 6 gave more than 29 fertile grains/panicle; 18 showed less than 44% grain sterility; and 13 produced more than 5.0 g grain/plant. Only Gerikalma showed good survival, grain yield, and low grain sterility (Table 2).

Entries Kalawriji 1, Kaimsail, NC1281, Nizersail, Auskali, Alakkachari, Bhelki, Meghi, Motajata, Asgo, Badrasail 2, Jabra, IR442-2-24-1-2-3, Kariwai 1, and Kaiputur showed high survival but produced low grain yield and yield components. They remained alive despite complete submergence under anaerobic conditions. Auspanjali, Kalamkati, Pokkali, Ghatakalma, Sadakalma, Bongota, Hamai, Sitabhog, Peshwari, Patnai 23, Bhimsail, Begunbichi, and Bokra showed higher grain yield/plant but lower survival rate. Survival and yield seem to be controlled by distinct genotypes (13,14).

Among the flowering entries, Kalamkati and Bhimsail had low grain sterility and good yield; NC678 and Bhasamanik, lowest survival rate; SR26B, lowest sterility; and Bhimsail, highest number of fertile grains/panicle. Bhimsail and Hamai gave maximum grain yield/plant (Table 2). In general, the beneficial effects of tolerance for stagnant flooding were noticed in the yield attributes (i.e., higher number of fertile grains/panicle and lower sterility of grains), which resulted in considerably higher grain yield in some local

Table 2. Important attributes of 40 outstanding entries[a] in stagnant flooding trials at Chinsurah Rice Research Station, India.

Variety	Survival (%)	Fertile grains/panicle	Grain sterility (%)	Grain yield (g/plant)
Gerikalma	91.6	34.2	26.6	8.4
Kalawriji 1	82.8	11.4	45.9	2.5
Kaimsail	75.6	16.1	45.8	3.3
NC1281	74.0	5.0	81.8	1.6
Nizersail	68.0	7.0	67.9	1.4
Auskali	66.8	16.0	65.0	3.0
Alakkachari	58.8	0.0	100.0	0.0
Bhelki	55.6	9.8	71.3	1.7
Meghi	50.8	7.8	75.5	2.1
Motajata	46.4	0.0	100.0	0.0
Asgo	45.6	12.7	67.9	3.6
Badrasail 2	45.6	17.0	50.0	2.5
Jabra	44.8	16.0	64.0	3.4
IR442-2-24-1-2-3	48.6	14.8	22.9	3.5
Kariwai 1	42.0	10.2	42.0	2.2
Kaiputur	40.8	0.8	96.7	0.4
Auspanjali	38.4	18.4	58.7	5.0
Kalawriji 2	38.4	10.4	26.8	2.1
Kalamkati	34.0	34.0	20.0	7.7
Kariwai 2	29.2	19.1	34.8	4.1
Gazal	28.8	12.8	34.7	2.3
Pokkali	28.4	20.8	52.1	5.9
Ghatakalma	21.2	23.2	42.0	7.6
Badrasail 1	20.4	21.8	39.1	4.2
Sadakalma	18.8	26.5	55.5	6.3
Bongota	14.0	30.2	41.7	6.8
Hamai	13.2	38.4	31.2	9.0
Nagra	12.8	18.7	17.6	3.3
Sitabhog	10.8	23.0	68.1	6.7
Peshwari	10.8	20.5	61.7	6.1
Patnai 23	10.4	24.5	75.3	5.7
SR26B	9.6	21.6	14.6	3.4
Bhimsail	9.2	41.8	27.0	9.0
Kumargore	9.2	4.5	27.4	1.0
Begunbichi	6.8	22.5	55.4	5.1
Bokra	6.4	36.0	32.9	7.5
NC678	4.4	17.0	33.3	3.3
Bhasamanik	4.4	6.2	29.6	1.6
FR13A	34.0	9.6	51.5	1.4
FR43B	30.4	4.2	84.2	1.2

[a]Total entries = 577.

lowland varieties such as Gerikalma, Kalamkati, Hamai, Bhimsail, and Bokra (Table 2). Total number of flowers/panicle had no definite relationship with yield. However, the number of fertile grains was directly associated with yield increase in most entries.

The standard flood-resistant varieties FR13A and FR43B did not perform well under prolonged stagnant flooding (11), and some local lowland varieties were superior to the two. Our previous results showed that FR13A and FR43B can perform well only in typical flood-prone areas (5,8).

The overall results show a distinct genetic difference in physiology between the flood-resistant and lowland varieties, strengthening the suggestion that some local lowland varieties such as Gerikalma, Kalamkati, Bhimsail, and Hamai can be successfully cultivated only in rainfed, low-lying, stagnant, submerged areas, whereas flood-resistant varieties can be grown in tracts that are occasionally flooded. Flood-resistant varieties are not suited to cultivation in chronically waterlogged and ill-drained areas.

The lowland varieties showed changes in stem structure when grown in waterlogged areas (2,4,16). Other variables such as genetic tolerance for prolonged waterlogging, soil fertility, and various environmental factors may also play important roles (7,10,12,14,16).

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INTEGRATED BREEDING PROGRAM FOR MEDIUM-DEEP, STAGNANT-WATER, RAINFED RICE IN INDIA

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Approximately 50% of the total rice area in eastern India is medium-deep, stagnant-water, rainfed lowland. Severe environmental stress, disease and pest pressure, and lack of proper genotypes limit productivity. The main centers for research in this problem area are in Bihar (Patna and Pusa), Orissa (Cuttack and Bhubaneswar), Uttar Pradesh (Faizabad), and West Bengal (Chinsurah), where intensive breeding efforts were initiated in the early 1970s. Breeding objectives have been established, and field screening and evaluation techniques have been developed. Progress in varietal improvement, especially under the national program and through international collaboration, has been made toward the development of superior rice genotypes for rainfed lowlands. The future breeding program includes a survey of medium-deep water areas; disease and insect survey; basic studies on characterization of deep water germplasm, submergence tolerance, and photoperiod sensitivity in different regions; use of improved breeding techniques; and collaborative efforts toward exchange of material and extension of facilities for rapid generation advance.

Rice production in India increased about 3% annually from 1972 to 1979 with better irrigation facilities, increased fertilizer use, and adoption of modern varieties and production technologies. The increase occurred mainly in northern India (up to 4 t/ha) and southern India (3 t/ha). In contrast, average productivity in eastern India — comprising West Bengal, Bihar, Orissa, and Assam — remains well below 2 t/ha. Of 40 million ha of riceland in India, 17.5 million are in eastern states. Nearly 50% is medium-deep, stagnant-water, rainfed lowland, where water depth remains around 50 cm during the major growth period. Yields are generally poor because of excess moisture associated with inadequate crop stand, poor tillering, soil problems, and disease and pest pressure.

Intensive efforts toward breeding rice varieties for this situation started in the early 1970s. Farmers' varieties were screened and selected at experiment stations, and promising ones were isolated. Varietal development through conventional and mutation breeding was intensified at different centers in the mid-1970s.

ACCOMPLISHMENTS

Research centers

Research on lowland rice is done at research centers like Patna, Pusa, Sabour, and Sindri in Bihar; Cuttack and Bhubaneswar in Orissa; Faizabad and Ghaghraghat in Uttar Pradesh; Chinsurah in West Bengal; Karinganj in Assam; Arundhutinagar in Tripura; and Pulla in Andhra Pradesh. But only Chinsurah, Patna, Bhubaneswar, Cuttack, and Faizabad are actively involved in developing new materials suited to medium-deep, stagnant-water, rainfed situations.

Water depth study. Chinsurah has shallow (25 cm), medium-deep (50 cm), deep (100 cm), and very deep (more than 100 cm) lowlands. Recording water depth during the growth period is essential to obtain a clear picture of a lowland situation. Lands cannot be grouped according to maximum water depth in the field, as water depth depends on time and intensity of rainfall. Daily and periodic measurements in rainfed lowlands during crop growth, initiated at the Chinsurah Rice Research Station in the 1976 crop season, show greatest water depths of 120 cm in Sep 1978, 50 cm in Aug 1979, 55 cm in Aug 1980, 60 cm in Jun 1981, 40 cm in Sep 1982, 50 cm in Aug 1983, and 60 cm in Jun 1984. The plot was flooded to a depth of around 50 cm during the major crop growth period except in 1982.

Breeding objectives. Although breeding objectives are influenced by location-specific requirements, some common features are discernible. Early attempts at varietal improvement aimed to transfer elongation ability into high yielding varieties. But elongating types suitable for very deep areas (above 100 cm) were not useful for the medium-deep situation, where water depth fluctuates during crop growth. A different breeding strategy has been developed (5, 6, 7, 8, 9, 10, 11, 12, 15), emphasizing the following characters:

- seedling vigor,
- drought tolerance at the early vegetative stage,
- semitall (120-140 cm) plant type,
- stiff culm,
- good basal tillering,
- long panicles,
- submergence tolerance,
- resistance to stagnant water,
- photoperiod sensitivity,
- seed dormancy,
- good grain quality, and
- resistance to major diseases and pests.

Identification of superior genotypes. Through a series of screening trials in the field and under controlled conditions a large number of materials with one or more desirable traits has been identified (Table 1, 2). They are used directly as varieties or as donors in crossing programs. Natural calamities like flood and drought also help in identifying superior genotypes for problem areas. For example, the unprecedented precipitation in Sep 1978 and the resultant flood

Table 1. Promising rice varieties with characteristics suitable for rainfed lowland conditions.

Character	Variety
Seedling vigor	NC492, Janki, NC493
Drought tolerance at early vegetative stage	CN506-147-2-1, CN506-147-14-2, Janki, NC487, NC488, BIET821
Semitall plant type	CN505-5-32-9, CR301-3066, OR143-32, FPAR 7809, OR142-99
Stiff culm	OR330-40-3, FPAR7809, CN506-147-14-2, NC496, OR142-193
Good basal tillering	CN499-160-2-1, CN499-160-13-6, CR320-9, BIET724, OR117-8, CN505-5-32-9
Long panicles	OR143-7, CN643, BIET807, TCA4, FRG7
Submergence tolerance	FR13A, CN643, CN540
Resistance to stagnant water	CR292-7050, OR117, CR1030, NC492, CN506-147-2-1, BIET807, NC490, Tilakkachari
Photoperiod sensitivity	CNM539, CN505-5-32-9, NC492, Janki, CR1030, BIET821, TCA48, TCA808
Seed dormancy	CN499-160-13-6, NC492, CN499-160-2-1, FR13A
Good grain quality	CNM539, CN540, CN499-160-2-1, CN691-1, Mahsuri

Table 2. Best entries in different IRTP[a] nurseries at Rice Research Station, Chinsurah.

Experiment[b]	Entry	Height (cm)	Time to flowering (d)	Survival[c] (SES)	Yield/ plot (g)
Flood-tolerant	KAU2039	70	141	3	900
	BR118-3B-17	120	131	3	700
Rice	IR13610-72-2-2E-P2	100	145	3	600
Screening	Nam Sagui 19 (check)	117	124	3	300
Set 1981	CN643 (local check)	150	143	1	1100
Medium	IR17643-1-5	129	177	3	500
Deep Water	HTA7403-110-1-5	135	167	6	400
Rice	IR13437-5-3-4E-P3	74	164	5	300
Screening	IR42 (check)	69	147	7	150
Set 1981	CN540 (local check)	118	136	3	700
IRRSWYN 1983	Mahsuri	147	134	3	1267
	IR19431-72-2	109	124	5	767
	IR18599-68-1	97	107	5	717
	IR52 (check)	102	115	5	617
	NC492 (local check)	146	135	3	1630
IRDWON 1983	IR11141-6-1-4	105	108	3	—
	IR11185-R-0-7	134	129	1	—
	SPR7292-151-2-1-B-B	142	115	3	—
	RD19 (check)	90	133	5	—
	NC492 (local check)	114	104	3	—

[a]International Rice Testing Program. [b]IRRSWYN = International Rainfed Rice, Shallow Water Yield Nursery, IRDWON = International Rice Deepwater Observational Nursery. [c]SES = Standard evaluation system for rice.

enabled Chinsurah researchers to select superior lines from farmers' fields as well as from the germplasm collection. Seventy materials that survived the severe environmental stress were identified.

Hybridization and evaluation of breeding materials. Several crosses between well-adapted tall indica varieties and high yielding breeding lines and varieties

have received major emphasis since the mid-1970s. The F_1's are generally grown in shallow water to prevent loss of genotype. From the F_2 onwards the segregating materials are grown under natural field conditions and also under controlled conditions when facilities are available.

At Chinsurah the breeding materials (Table 3) were screened in the field (14) from 1976 to 1983. The breeding lines experienced drought, flash flood, waterlogging, and disease and pest pressure. Preliminary yield evaluation started with fixed cultures at the F_5. The early generation materials received from other collaborating centers like that in Thailand and from IRRI were evaluated through the same procedure.

After the F_6, replicated yield trials in lowland situations were conducted at the experiment station, followed by multilocational adaptive trials at regional stations and then by minikit trials in farmers' fields.

Breeding strategy. To develop a sound breeding strategy for the medium-deep, stagnant-water, rainfed lowlands, the nature of gene action involving some important quantitative characters was studied at Chinsurah (13). The findings may be summarized as follows:

- The genetic system involved in adaptability to the lowlands is not simply inherited. Many of the characters require individual evaluation; most are conditioned by a small number of genes, thus limiting the spectrum of desirable recombinants.
- Narrow-sense heritability values indicate that selection should be based on individual plant phenotype.
- As few genes, primarily with additive effects, are involved, a selection procedure to utilize both types of gene action would be advantageous.
- Lines with increased level of tolerance for greater water depth could be selected from crosses between adaptable and high yielding parents.
- A breeding approach maximizing the accumulation of favorable genes for lowland adaptability would be more effective.
- The method of multiple crossing and intercrossing of the desirable lines in segregating generations is likely to produce more desirable genetic recombinants.

National program

At the group meeting of breeders during the Annual Rice Workshop at Coimbatore in Apr 1979, it was felt necessary to undertake multilocational

Table 3. Rainfed lowland breeding lines tested under field conditions at RRS, Chinsurah, 1976-83.

Generation	Lines (no.)	Some of the parents used in crossing
F_1	212	Patnai 23, OC1393, Jaladhi 2, Jhingasail, NC491, CN503, NC488
F_2	369	FR13A, FR43B, NC487/77, SR26B, NC496, Bashpair, Bura Kalma, Rupsail, Bhasamanik, CNL 214, CR1006
F_3	2842	Jalaplaban, Pankaj, Mahsuri
F_4	418	CR1002, CN540, IET3257, CR1009
F_5	431	CN 643, CNM539, CN644

Table 4. Promising entries in rainfed lowland trials in India, 1979-82.

Experiment[a]	Entries (no.)	Locations (no.)	Water depth range (cm)	Promising entries
1979 SDWVT	20	4	40-90	CN540, CN643, CN603, Achra 108/1, CNM539
DWVT	18	3	50-130	CNL 231B/B, Jaladhi 2, CNL 31, CNL 108, RAU21-168-1-2
1980 SDWVT	20	6	55-90	NC487/77, CN540, OR1104, CN643, OR1105
LLSN	60	4	50-75	NC488/78, CR256-6-436-507-96, Meta, Tilakkachari, Achra 108/1
1981 SDWVT	20	4	56-90	BIET724, OR117-8, NC491, OR143-7, Janki, NC437/77
LLSN	120	3	60-65	IET6900, Acc. 8200830, OR117-30, OR142-24, CN505-5-3-1, CN506-147-14-2
1982 SDWVT	16	7	50-70	NC492, CN505-5-32-9, CN506-147-14-2, CN499-160-13-6, BIET724
LLSN	80	5	50-70	NC491, NC496, TCA177, TCA62-31, IPAR7360, IPAR7511, DPAR7356, NC493, NC490, NC497

[a]SDWVT = Semi-deep Water Variety Trial, DWVT = Deep Water Variety Trial, LLSN = Lowland Screening Nursery.

coordinated trials for lowland situations (after more than a decade of emphasis on the semidwarf breeding program) and focus attention on lowland rice breeding in the national program in India. Promising materials identified during 1979-82 are listed in Table 4 (1, 2, 3).

Under the integrated national program for development of lowland rice, materials developed at cooperating centers are nominated for testing in the Lowland Screening Nursery (LLSN). The best performing and most promising LLSN entries are promoted to the preliminary variety trial (PVT 5) the next year. Elite materials from PVT 5 finally pass through to the uniform variety trial (UVT 5), the stage at which performance is judged for recommendation as new varieties. Each state or center may have its own varieties to recommend for specific areas, but testing under the national program is obligatory.

In 1983 there were three trials — LLSN, PVT 5, and UVT 5 — for depths below 100 cm.

Twenty entries from different states were tested at 11 locations in UVT 5 using Tilakkachari as the check. Water level was minimum (36.5 cm) at Karimganj and maximum (62.5 cm) at Sabour. On overall performance, CN505-5-32-9 (IET8967) ranked first (2.8 t/ha) and NC492 (IET8970) second (2.7 t/ha). Both showed high percentages of seedling survival at CRRI-Cuttack, Karimganj, Pusa, Sabour, and Faizabad. The All India Rice Workshop has recommended large-scale testing of the two varieties in Orissa, Bihar, Andhra Pradesh, Uttar Pradesh, West Bengal, and Assam because of

their consistently good performance (3, 4) during 1982 and 1983 (Tables 5-7). Other promising entries that yielded higher than the check (Tilakkachari, 2 t/ha) are listed in Table 8.

Detailed characteristics of some promising varieties are given in Table 9.

PVT 5 with 35 entries and Tilakkachari as the check was conducted at 7 locations. Varietal reaction differed from place to place. On the basis of mean performance over all locations, NC490 ranked first (2.7 t/ha). The yield of 10 other top entries varied between 2.5 t/ha and 2.2 t/ha (Table 10).

In LLSN, 70 entries were tested at 5 locations: Chinsurah, Bhubaneswar, CRRI, Pulla, and Ghagraghat. Ten top entries on the basis of mean performance are listed in Table 11.

INTERNATIONAL COOPERATION AND VARIETAL IMPROVEMENT

The rainfed lowland rice varietal improvement program in India has been strengthened by close collaboration and cooperation with IRRI through the

Table 5. Performance of CN505-5-32-9 (IET8967) in state and national trials, under medium-deep water conditions.

Year	Locations (no.)	Experiment	Location	Yield (t/ha)	
				CN505-5-32-9	Tilak-kachari
1979-81	6	State adaptive trial	Chinsurah, Nalhati, Majhian	5.0	3.5
1982	6	National semideep water trial	Pulla, Patna, Sindri, Bhubaneswar, Chinsurah, Arundhutinagar	4.2	2.8
1983	11	UVT 5 (national trial)	Pulla, Bhubaneswar, CRRI, Ranitul, Chinsurah, Karimganj, Patna, Pu a, Sindri, Sabour oghraghat	2.8	2.0
		Mean		4.0	2.8

Table 6. Performance of NC492 (IET 8970) in state and national trials in medium-deep water situations.

Year	Locations (no.)	Experiment	Locations	Yield (t/ha)	
				NC492	Tilak-kachari
1979-82	6	State adaptive trial	Chinsurah, Majhian, Bishnupur, Kakdwip	4.7	3.4
1982	7	National semideep water trial	Pulla, Patna, Pusa, Sindri, Bhubaneswar, Chinsurah, Arundhutinagar	3.8	2.6
1983	8	UVT 5 (national trial)	Ranital, CRRI, Pulla, Chinsurah, Patna, Pusa, Sindri, Sabour	2.8	1.8
		Mean		3.8	2.6

Table 7. Performance of NC492 (IET8970) in the physiology screening trial for waterlogged conditions under the national program

Location	Yield (t/ha)					
	NC492		Tilakkachari		Other check[a]	
	1982	1983	1982	1983	1982	1983
Baruipur (West Bengal)	4.5	4.5	3.9	3.8	2.9 (M)	1.0 (P)
Chinsurah (West Bengal)	4.9	5.8	3.1	4.7	4.3 (N)	4.2 (C)
Cuttack (Orissa)	3.4	4.7	3.2	3.7	3.1 (M)	3.1 (M)
Patna (Bihar)	4.2	3.2	4.6	4.0	2.6 (P)	2.1 (B)
Mean	4.2	4.5	3.7	4.0	3.2	2.6

[a]M = Mahsuri, N = NC488, P = Pankaj, C = NC487, B = BR34.

Table 8. Yield of top 10 entries in UVT 5 conducted over 11 locations during 1983 kharif.

Entry	Parentage	Yield (t/ha)
CN505-5-32-9	IR36/SML 40-10-4	2.8
NC492	Pureline selection from Boyan	2.7
CN506-147-14-2	IR30/LMNIII/IR1514A-E666	2.7
PLA1100	Mahsuri/Vijaya	2.7
CN506-147-2-1	IR30/LMNIII/IR1514A-E666	2.6
CR292-5258	Pankaj/Mahsuri	2.5
OR117-215	T141/Jagannath	2.5
CR292-7050	Pankaj/Mahsuri	2.4
CR221-1030	Waikukku/CR1014	2.3
BIET724	IR8/BR14	2.2
Tilakkachari (check)		2.0

exchange of early generation breeding material, screening and evaluation in International Rice Testing Program (IRTP) nurseries, and joint monitoring of the nurseries and experiments. The performance of some elite material from IRTP nurseries is presented in Table 2.

In a multiple crossing program for gene pyramiding, a collaborative program with the Fertilizer Promotion and Agricultural Research Division of the Hindustan Fertilizer Corporation, Ltd. was initiated in 1982 at Chinsurah. In this program eight parents have already been combined; their F_1's were grown during 1983 kharif (wet season), and the F_2's were grown during 1984 kharif in lowland situations. The crossing program included 20 varieties, and a breeding program with a number of parental lines is in progress. The parental varieties involved are Dular, Badkalamkati 65, Seetasail, Jhingasail, Nagra 41/14, Latisail, Bhasamanik, Patnai 23, SR26B, CB1, CB2, NC1281, OC1393, Kumargore, Tilakkachari, NC678, Pankaj, Mahsuri, IR36, and Jaya.

FUTURE PROGRAM

The future breeding program includes the following:

- detailed survey of medium-deep water areas to classify them according to water depth, to gain an understanding of the plant problems through

Table 9. Characteristics of some promising lowland rice cultivars.

Variety	Cross	Duration (d)	Height (cm)	Panicles (no./m^2)	Panicle length (cm)	Exsertion (cm)	Grain characteristics			
							Length (mm)	Breadth (mm)	L/B ratio	1,000-grain wt (g)
CN499-160-2-1	IR34/KLG6987-143-2-P//IR2070-2-5-6/HBj DW8	179	151	312	26.33	3.00	7.7	2.5	3.08	17.5
CN505-5-32-9	IR26/SML 40-10-4	190	113	252	21.00	0.50	7.7	3.2	2.40	24.8
CN506-147-2-1	IR30/LMN//IR1514 A-E666	184	163	200	27.50	3.50	7.6	3.4	2.23	25.9
NC492	Pureline selection	179	166	192	26.00	5.00	10.9	2.9	3.75	31.9
NC487/77	Pureline selection	197	161	228	24.67	1.83	8.6	3.4	2.52	28.6
Janaki (C64-117)	Pureline selection	171	214	198	26.50	9.17	9.3	3.3	2.76	29.5
BIET724	IR8/BP.34	167	170	258	27.17	4.17	8.3	3.1	2.68	26.2
OR117-8	T-141/Jagannath	179	148	222	24.50	5.50	7.8	2.6	3.02	18.4

Table 10. Yield of best entries in PVT 5 in 7 locations under the national program during 1983 kharif.

IET no.	Entry	Yield (t/ha)
8987	NC490	2.7
8996	NC519	2.5
7971	Janki	2.4
8998	Bhasakalma	2.4
8017	VPAR7360	2.4
8992	NC497	2.4
8989	NC493	2.3
8982	IET720	2.3
8997	NC678	2.2
	Tilakkachari (check)	2.2

Table 11. Best entries over 5 locations under the national program LLSN during 1983 kharif.

Entry and IET no.	Parentage
CN704-7-3 (IET9060)	Pankaj/CN540
Acc. 30074 (IET9072)	Pureline selection
MTC6/A (IET9016)	Pureline selection
TC6 (IET9020)	Pureline selection
OR(M)1103-42 (IET9040)	Mutant of Katakchandi
Dalkhani 36-21 (IET9055)	Pureline selection
CN697-3-13 (IET9063)	NC487/Jalaplaban
CN691-1 (IET9059)	IR2070-423-2-5-6/SML Temerin
CN705-18 (IET9065)	Mahsuri/CN643
19MTC5/A (IET9075)	Pureline selection

contacts with farmers, and to determine the extent of different soil problems;

- disease and insect survey to assign priorities;
- basic studies on characterization of deep water germplasm according to desirable traits, physiogenetics of submergence tolerance, and photoperiod sensitivity of locally adapted deep water varieties from different regions;
- breeding techniques for gene pyramiding through multiple crossing using as many parents as possible, and use of male sterile facilitated composites for continuous and free flow of genes; and
- collaborative efforts toward exchange of parent materials, sharing of early generation materials, and generation advance with the help of the rapid generation advance system of IRRI or other centers where facilities are available.

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INTEGRATED BREEDING PROGRAM FOR MEDIUM-DEEP, STAGNANT-WATER, RAINFED RICE IN BANGLADESH

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Rainfed rice culture in Bangladesh depends on the monsoon. It includes the aus and the transplanted (T) aman rice crops. Short-duration aus, and photoperiod-sensitive and long-duration insensitive aman varieties with submergence tolerance at the vegetative stage and tolerance for low temperature at the reproductive stage are required for rainfed culture. Resistance to pests is also a prerequisite. In most situations, tall seedlings and intermediate to tall plants are desirable. Most varieties of the Bangladesh Rice Research Institute are performing well as rainfed aus and T aman crops. Some traditional rice varieties also occupy a considerable area and demand special attention by breeders. Entries from local and IRTP nurseries that show superior performance in Bangladesh have been isolated and are being evaluated in different trials. Some are used as parents. Programs have started to develop varieties with tolerance for submergence and drought, which frequently cause crop loss. Work is in progress to develop varieties with broad-spectrum pest resistance.

Bangladesh grows rice on about 10.3 million ha, of which 4.8 million ha are rainfed lowlands. Table 1 shows the area under different types of rice culture. Rainfed rice culture is subject to the vagaries of the unpredictable monsoon that causes year-to-year fluctuation in total production. Figure 1 shows the year-round distribution of rainfall and daylight and the crop seasons.

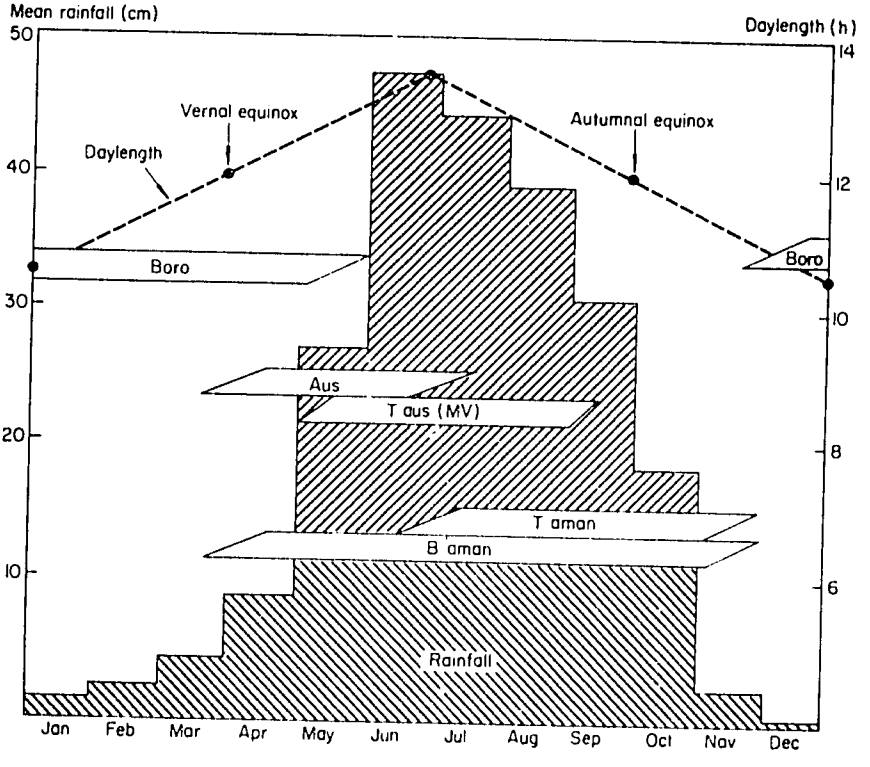
Rainfed rice includes T (transplanted) aus and T aman (photoperiod-sensitive and long-duration photoperiod-insensitive varieties). Ahmad and Nasiruddin (1) included direct seeded drought-prone upland rice and deep water rice under rainfed rice culture. In the light of recent classification (5), direct seeded upland rice and deep water rice are excluded from the rainfed lowland group in this paper. Parts of Khulna, Barisal, and Patuakhali districts and small pockets in other districts fall under the medium stagnant water situation; as this area is relatively small, our discussion deals mainly with the overall rainfed culture.

Depending on demand, pest-resistant rainfed lowland rice varieties with the following characteristics are required:

- short duration to escape early floods in June and July for the T aus crop;
- low-temperature resistance at the reproductive stage for the T aman crop;

Table 1. Area under different types of rice culture in Bangladesh.

Cultural type	Area (million ha)	
	Photoperiod sensitive	Photoperiod insensitive
Boro	—	1.20
Aus (upland and mixed with B. aman)	—	2.50
T aus	—	0.60
Rainfed (T aman)	3.40	0.60
B. aman	1.60	0.20
Tidal wetland	.20	
Total	5.20	5.10



1. Rice crops of Bangladesh (6).

- intermediate to tall stature with photoperiod-sensitivity to fit the rainfed shallow to medium-deep situation; and
- long duration and photoperiod-insensitivity, semidwarf to medium tall stature with submergence tolerance.

Major problems that limit the yield of rainfed rice in Bangladesh are:

- uneven distribution of rainfall during the monsoon months covering the aus and T aman seasons;

- poor seedling establishment due to occasional submergence;
- low photosynthetic efficiency due to low light intensity during the monsoon; and
- an environment favorable to pests.

MAJOR CROPPING PATTERNS

The existing major cropping patterns related to rainfed rice culture in Bangladesh may be categorized as follows:

- T aus/jute - T aman - rabi crops or fallow;
- single T aman - rabi crop;
- T aman - boro crop; and
- late T aus/early T aman -rabi (recommended).

These patterns influence the research program to develop varieties for the near future. For example, the first pattern demands short-duration varieties, but photoperiod sensitivity is an additional requirement for T aman. Long-duration photoperiod-insensitive varieties are more appropriate for the single T aman pattern than short-duration varieties, which are usually lower yielding. In the third pattern, photoperiod sensitivity is a must to escape cold weather during flowering (late November) and also to make room for the following boro crop. For the fourth pattern, long-duration aus varieties or short-duration to medium-duration but photoperiod-insensitive T aman varieties are suitable.

PRESENT STATUS OF RAINFED RICE RESEARCH

There are significant topographical variations in rainfed riceland, and variations exist between seasons. In most situations tall seedlings and intermediate to tall plants are desirable, but semidwarf varieties such as BR3, BR6, and Chandina are also suitable for the higher elevation fields where the water remains shallow.

Modern varieties (MVs) such as BR7, BR8, BR9, and BR14, which were bred for rainfed aus culture, are all intermediate in height with relatively tall seedlings and within 95-d field duration. They cover about 18.8% of all rainfed areas.

Among the MVs, BR4, BR10, and BR11 are excellent as rainfed T aman varieties. In addition, a few widely adapted photoperiod-sensitive traditional varieties (Nizersail, Latisail, DA29, Tilockkachari, Patnai 23) and some regional varieties occupy a substantial rainfed area for which breeders need to strengthen their program; if MVs can be introduced there, total rice production will be significantly increased. Table 2 lists promising breeding lines for rainfed rice culture.

Since 1979, the Bangladesh Rice Research Institute has been participating in the International Rice Testing Program (IRTP) rainfed program with the nomination of nine varieties or breeding lines for testing in the international rainfed lowland rice nurseries (2, 3, 4). BR51-282-8 and BR4 occupied 4th and

Table 2. Promising breeding lines and their agronomic characters.

Line	Seedling ht range (cm)	Plant ht (cm)	Maturity (d)	Panicles/m²	Yield (t/ha)	Reaction[a] to Bacterial leaf blight	Reaction[a] to Brown planthopper	Suitable for
IR50	20-22	80	106	402	3.60	7	9	aus
IR9708-51-1-2	22-24	81	101	402	3.09	7	7	aus
IR9729-67-3	24-25	82	102	402	3.22	5	5	aus
IR13429-109-2-2-1	32-35	94	116	340	3.84	5	5	aus
BR171-2B-8	28-35	92	118	272	3.37	4	—	aus
BR14	35-38	116-121	120	—	4.50	3	—	aus (rice tungro virus resistant)
BR51-282-8	28-31	114	132	240	5.28	5	9	T aman
BR51-74-6-J1	42-45	116	141	213	5.27	5	9	T aman
BR236-10-2-2-1	34-39	116	141	296	4.66	5	9	T aman (photoperiod sensitive)
BR315-12-1-4-1	34-37	117	136	267	5.20	3	—	T aman
BR316-15-4-4-1	40-44	120	123	242	4.50	5	—	T aman
BR593-676-4-1-2	45-50	95	147	240	4.54	3	9	T aman
BR593-676-4-1-6	31-34	104	147	210	4.31	5	5	T aman (photoperiod sensitive)
BR593-698-5-1-8	34-36	89	149	293	4.88	5	9	T aman (photoperiod sensitive)
BRC16-127-4-3	31-35	116	142	213	4.93	5	9	T aman
Cisadane	32-37	115	138	240	5.10	3	5	T aman
BR1045-232-5-3	49-57	124	139	198	3.56	5	9	T aman
BR734-1-2-2	44-56	110	141	206	4.70	5	9	T aman
BR847-76-1-1	57-70	102	147	257	4.51	5	5	T aman
BR736-20-20-3	47-71	117	142	211	3.76	5	5	T aman
BR850-9-1-1	40-47	129	149	197	4.71	3	9	T aman

[a]By the 1980 *Standard evaluation system for rice* scales.

Table 3. BRRI varieties or lines nominated for the International Rainfed Lowland Rice Observational Nursery and International Rainfed Lowland Rice Yield Nursery, 1979-83.

Variety/line	Parentage	Year
BR4	IR20/IR5-114-3-1	1979-80 1981-83
BR160-19-2-1	IR272-4-1-2-J1/IR570-39-2	1979
BR166-2B-8	IR272-4-1-2-3-10/IR305-3-17-1-3	1979
Mala-J11	IR272-4-1-2-3-10/IR305-3-17-1-3	1979
Chanda Aman	local	1979
Goda	local	1979
Goirol	local	1979
Surjamukhi	local	1979
BR51-282-8	IR20/IR5-114-3-1	1980, 1981, & 1983
BR10	IR20/IR5-114-3-1	1980 & 1981
BR52-90-2	IR20/IR5-47-2	1981
BR111-140-1-1	DA29/IR20	1981
BRB11-461-1	IR8/SR26b (transplanted)	1981

5th positions in 1981 with a yield of 4.4 and 4.2 t/ha. BR111-140-1-1 was rated good for submergence tolerance (Table 3). BR166-2B-8 showed tolerance for whitebacked planthopper and BRB11-461-1 for leaffolder. Entries from other countries, such as Cisadane, IR8192-166-2-2-3, IR10781-75-3-2, and IR13358-85-1-3, that have shown superior performance under local conditions are being evaluated in the replicated trials. They are also being used as parents in the hybridization program.

FUTURE BREEDING STRATEGIES

Past experience with rainfed rice culture shows that the crop occasionally suffers from inundation or submergence due to excess rainfall or flash flood during the early growth stage. Drought in September and October when the crop is in the reproductive stage results in drastic yield reductions. In some years, damage is so great that the farmers leave the unharvested crop in the field.

Genes for submergence tolerance and drought resistance should be incorporated in future varieties to fit them to the rainfed situation. FR13A is used as a donor parent for submergence tolerance, and some progeny lines are being tested for tolerance.

Bacterial leaf blight, rice tungro virus, sheath rot, and sheath blight are most prevalent in the aus season. Leaf scald and brown planthopper are a menace to the rainfed T aman crop. Other minor problems are the green leafhopper, mealybug, and gall midge. The environment of the aus and T aman seasons is favorable for insect pests. Attempts should be made to develop varieties with broad-spectrum pest resistance.

Due to continuous cropping, soil problems such as Zn and S deficiencies are appearing and need close attention. The use of materials from local gene pools and IRTP nurseries that have resistance to pests and tolerance for soil

problems will strengthen the national breeding program. Inasmuch as rainfed rice occupies a substantial area of land in Bangladesh, development of varieties that will perform well under low inputs and produce relatively high yields would be an additional advantage for farmers.

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BREEDING PROGRAM FOR MEDIUM-DEEP WATERLOGGED RAINFED LOWLAND RICE IN BURMA

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Approximately two-thirds of the rice area in Burma is rainfed lowland, concentrated in the high-rainfall deltas and along major rivers in the south. Water in the fields accumulates at depths ranging from shallow to medium deep during the monsoon season (May-October). In those areas traditional tall, photoperiod-sensitive varieties are best adapted, but yields are generally low. To improve yields the adapted varieties are being crossed with high yielding varieties of improved plant type. Criteria for selection are seedling vigor, medium tillering ability, resistance to or tolerance for prevalent insects and diseases, lodging resistance, medium to tall plant stature, medium to long growth duration, and good grain appearance. The performance in 1983 yield trials of medium to tall, medium to late maturing selections from the earlier crosses indicates that fairly high yielding types with good lodging resistance and desired grain characters can be recovered from progenies of such crosses. Selection X72-8-22 from IR24/Kaukhmwe was released in 1984 and named Sin Ekari. Two other selections, X72-7-1 and X72-7-15 from IR24/Yebawsein, were subsequently released.

Rice is the main food and chief export crop of Burma. Over 80% of the population depend on it for their livelihood. It is grown on 4.8 million ha, mostly in the deltas of southern Burma, where annual rainfall ranges from 2,500 to 5,000 mm. Rice is an important crop even in the Central Plains, where annual rainfall is as low as 760 mm, and in the hilly regions (about 1,200 m or higher), which have more or less adequate rainfall but low temperature during the reproductive stage. In the latter two regions, rice is generally a subsistence crop.

Because of the great diversity in rainfall and soil in which rice is grown, practically all the agroecological types are cultivated (1):

Agroecological type	*Percentage of total rice area*
Irrigated lowland	17
Rainfed lowland	67
Deep water	9
Upland	4
Saline	3

Most of the rainfed lowland rice is grown in the high rainfall deltas where soil is naturally fertile. But, mainly because of excessive water in the growing season and the use of many low yielding, traditional varieties, yields are modest.

Improvement in crop yields in the lowlands during the monsoon season is being attained in at least two ways. Embankments and flood control structures are built along rivers to minimize the inflow of excess water into the fields during the monsoon season. They not only control floods during the monsoon but also provide irrigation during the dry season. Improved cultural management, including increased use of appropriate fertilizers, is another strategy to improve yields. However, development of varieties better adapted to these growing conditions is the cheapest means of increasing yield.

VARIETIES GROWN IN WATERLOGGED LOWLANDS

Waterlogged rainfed lowlands considered here refer to areas subject to stagnant floods ranging from 25 to 50 cm deep during the growing season. Usually these fields are situated between the river banks and the middle of the "islands" formed by rivers The middle parts of these islands are generally low and are either grown to deep water rice or left idle if too deep. Rainfall usually starts in May with the onset of the monsoon, reaches its peak in August-September, and ends in late October. Occasionally, heavy off-season rains in November and December cause substantial damage to the maturing or harvested crop in the fields.

Varieties used under these growing conditions are usually the traditional tall and photoperiod-sensitive types, although recently a few late maturing photoperiod-insensitive varieties have been used. Rice is sown in nursery beds in June and transplanted in July-August. If water in the field is too deep for transplanting, 6- to 8-wk-old seedlings are transplanted with sticks. The crop is harvested from late October to December.

The most popular varieties grown in these areas and their yields are shown in Table 1 (1).

STATUS OF RICE BREEDING FOR MEDIUM DEEP WATERLOGGED LOWLANDS

Breeding for adaptation to medium deep, waterlogged rainfed lowlands is part of the ongoing breeding program for favorable rainfed lowlands at Yezin and for high-rainfall rainfed lowlands at Hmawbi.

Varietal improvement for favorable rainfed lowlands

Breeding work for favorable rainfed lowlands is being done at the Agricultural Research Institute (ARI), Yezin. The national rice collection comprising some 1,500 accessions was evaluated in short rows yearly from 1975 to 1978 for adaptation to favorable growing conditions; 405 vigorous accessions that were tall and relatively free from prevalent insects and diseases were selected and

Table 1. Most popular rice varieties grown in Burmese waterlogged lowlands and their yields.

Variety	Harvested area (thousand ha)	Yield (t/ha)
	Late maturing[a]	
Ngakywe (black)	113	2.7
Pawsanhmwe	63	2.9
Meedon group	263	2.6
Emata group	35	2.3
Ngasein group	57	2.3
	Medium late[b]	
Meedon group	41	2.5
Shwebo Khunni	1	2.0
Taungdeikpan	15	2.2
Zeera group (Hnanga, Meegauk, etc.)	180	3.4
Shwetasoke	527	3.9
Emata group	405	2.8
Ngasein group	601	2.2
Phokawgyi	26	3.4
Ngweto	52	3.5
Total	2379	2.9
National total	4661	3.1

[a]In fields with water depth of 30-60 cm. Varieties matured in late December. [b]In fields with water depth of 0-30 cm. Varieties matured in early December.

grown again in 1979 in the observation nursery for further evaluation. Fifty entries were ultimately selected in 1981, from which selections were either included in uniform performance tests or used in hybridization work. In 1983, the variety Shwetasoke was the highest yielder. It is moderately photoperiod-sensitive, tall, and fairly lodging resistant. In that year, it gave an average yield of 3.9 t/ha on 527,000 ha, the largest area occupied by a single photoperiod-sensitive variety.

Shwetasoke, along with a number of other good performing, traditional tall varieties, has been crossed and is still being crossed with high yielding selections having good grain quality and improved plant type. The objective is to develop high yielding varieties with good grain quality adapted to rainfed lowlands with excessive water. The segregating generations are grown in low-lying lowland rainfed fields at Yezin that are difficult to drain in the monsoon season. The parental varieties used in crosses and the number of cross combinations grown in different generations in the 1984 monsoon season are summarized in Table 2. Criteria in the selection of plants and lines are seedling vigor, medium tillering ability, resistance to or tolerance for prevalent insects and diseases, lodging resistance, medium to tall plant stature, medium to long growth duration, and good grain appearance.

Several uniform lines were selected from segregating generations of the above crosses in the 1983 monsoon season and are presently grown in an observation nursery (Table 3). Selection in this nursery uses the criteria for selection in segregating generations.

Table 2. Parental varieties used in crosses between traditional tall, photoperiod-sensitive varieties and improved selections. Yezin, Burma, 1984 wet season.

Traditional tall varieties	Improved plant type varieties	
	Crossed, 1984 wet season (150 crosses)	
Shwetasoke	IR21836-90-3	RD17
Shwedinga	IR9129-7-1	BKN6874-40
Yebawlat	IR22277 Yn-3	Shwethwelay
Inmayebaw	IR18146 Yn-1	X72-7-1
Yebawyoesin	CR1024	RD15
Yebawpinto	IR21848-65-3-2-2	IR24609-32-3-2
Tetnanbatingasein	IR48	IR22277 Yn-3
Yebawsein	Kulu	IR18151 Yn-4
	529C-Md-10-3-6	IR18372 Yn-13
	X72-7-15	IR3646-9-1-1
	X73-20-19	IR18152 Yn-1
	F_1 generation (105 crosses)	
Shwetasoke	X72-822	IR54
Yebawsein	IR18151 Yn-4	Sinshwethwe
Yebawpinto	IR18372 Yn-18	Manawhari
Shwetasoke	C168	Shwewelay
Yebawlat	IR18152 Yn-1	Palenthe
Yebawyoesein	IR22277 Yn-3	BR51-54-2
Inmayebaw	IR21848-65-3-2-2	X70-16-38
Shwedinga	IR8	Sinthiri
Ngakywe	IR36	Sintheingi
Pawsanhmwe	IR44	Kyawzeya
Pawsanyin	IR46	C22
Pawsanbaykyar	IR50	Shwethwetun
Ngakywetaungbyan	IR52	Shwewartun
		MRC603-303
	Segregating generations (F_2-F_8) (51 crosses)	
Shwetasoke	YR237-13	YR303-304
Aungzeya	YR303-D126-6-80	YR72078-19
Ngweto	YR71014-1	YR2097-4-8
Yebawyoesein	YR72161-6	YR72136-1
Pawsanhmwe	YR72164-25-6	YR72164-25-6
Ngakywe	YR228-33	Sinthiri
	IR28	IR36
	Basmati	IR13427-69-1-2-2
	Seintalay	X72-7-8
	Shwewartun	C4-63
	Kyawzeya	IR2053-442-1-2-3
	Shwethwetun	IR2053-78-1-3-2-3
	Manawthuka	Mahsuri
	Palethwe	IR1626-225-2-3
	Segregating generations (F_2-F_4) at Hmawbi (37 crosses)[a]	
Yebawsein	Hmawbi 2	
Hnanwamegauk	IR24	
Meegauk	C4-63	
Shwedinga	MA-68-1	
Hnanga	CNM-31	
Shwechigyin	IR42	
Pendosein		
Inmayebaw		
Aungzeya		
Nam Sagui 19		
Ekarin kewa		
Kaingsaba		

[a]Personal communication, dated 4 Sep 1984, from U Saw Stanley, assistant general manager, Hmawbi Agricultural Experiment Station, Hmawbi, Burma.

Table 3. Number of uniform lines selected from crosses between traditional tall varieties and improved selections and grown in the 1984 monsoon at Yezin, Burma.

Cross no.	Cross combination	Lines selected (no.)
Yn 54	Yebawsein/IR34	1
Yn 116	Pawsanhmwe/IR1626-225-2-3	1
Yn 114	Aungzeya/Pelita I-1	2
Yn 260	Shwetasoke/IR28	3
Yn 261	Shwetasoke/IR36	2
Yn 297	Pawsanhmwe/C4-63	1
Yn 301	IR2053-442-1-2-3/Pawsanhmwe	1
Yn 116	Pawsanhmwe/IR1626-225-2-3	5
Yn 117	Pawsanhmwe/Pelita I-1	2
Yn 114	Aungzeya/Pelita I-1	4
Yn 44	Hanwamegauk/IR34	4
Yn 46	Pindosein/IR28	2
Yn 50	Shwedinga/IR34	2

Promising lines are entered in preliminary performance tests at Yezin under growing conditions similar to those in the breeding nursery. In the subsequent monsoon season, selections from those tests are entered in national uniform performance tests at Yezin and at two other stations in the high-rainfall zone for at least 2 yr. Water depths in the other test locations vary from 20 to 40 cm, and the fields can be waterlogged for 3-4 mo. Outstanding selections in the second year of uniform performance testing are also entered in a few farmers' trials supervised by agricultural extension township managers.

The performance of medium to tall, medium to late maturing, photoperiod-sensitive or -insensitive selections from the 1983 monsoon season performance tests are shown in Tables 4 and 5. Grain yields of medium-tall to tall selections compared favorably with checks C4-63 and Shwewartun, which are medium-short to medium-tall. Plant height and duration of each selection were similar in the monsoon season at the various locations.

In the eight farm trials supervised by agricultural extension township managers in the high-rainfall zone in the 1983 wet season, all medium to tall, medium to late maturing selections yielded higher than IR42, a medium maturing, short variety used as the check (Table 6). The highest yield was from Shwewartun, a gamma ray-induced mutant selected from IR5 in Burma and released in 1974. Two X72-7 selections and X72-8-22 were derived from local crosses involving Yebawsein and Kaukhmwe, both tall, late maturing traditional varieties that were used as males, with IR24 as the female parent. X72-8-22 was released early in 1984 and renamed Sin Ekari. X72-7-1 was released in 1985.

Performance testing is a multidisciplinary activity involving the active participation of plant breeders, agronomists, plant pathologists, entomologists, and chemists of ARI, the Applied Research Division (ARD), and the Agricultural Extension Division (AED). The ARI plant breeders provide the leadership and guidance in the multilocation testing that is carried out collaboratively with the ARD experiment stations and selected AED-

Table 4. Performance of tall, medium- to late-maturing selections in shallow to medium deep waterlogged lowlands. ARI, Yezin, Burma, 1983 monsoon season.

Entry no.	Selection	Grain yield (t/ha)	Days to heading	Plant ht (cm)	Field stress reaction[a]	Kernel		
						Chalkiness[b]	Length (mm)	Length:width
212	Shwedingayin	4.23	101	137	0	0-wc	6.5	2.9
243	Yn 174-6	3.56	100	151	blb	0-wc	6.3	3.3
252	C4-63 (medium early check)	3.47	100	111	blb, dh, wh	0	6.0	3.3
269	Yn 169-3	4.41	113	137	blb	0	6.3	3.1
272	Yn 116-13	4.36	115	139	dh	0	6.3	3.1
	Pawsanhmwe/IR1626-225-2-3							
274	Yn 116-18	4.36	116	147	dh, wh	0	6.2	3.0
280	Yn 169-2	5.01	116	141	DH	0-gl	6.3	3.0
294	Yn 50-7	4.65	113	129	blb, dh	—	—	—
	Shwedinga/IR34							
295	Yn 50-8	4.36	113	132	0	—	—	—
299	Yn 50-11	4.36	106	131	blb, dh, wh	—	—	—
303	Yn 107-11	4.54	113	128	wh	0-wc	6.2	3.0
304	Shwewartun (medium maturing check)	4.71	120	132	blb, dh	0-wc	6.3	3.3
308	Yn 83-8	4.93	121	129	DH	0	6.3	2.9
313	IR15166 Yn-16	5.07	119	137	0	0-wc	5.9	2.9
324	Yn 63-2	5.28	124	119	blb	0-wc	6.0	3.1
	Shwechigin/IR34							
326	Yn 63-3	6.10	124	136	blb	0-wc	5.8	3.1
329	Yn 106-2	4.15	129	141	0	0	6.3	3.0
332	IR14718 Yn-10	4.73	127	131	blb	—	—	—
338	Shwewartun (medium maturing check)	5.17	124	131	blb	0-wc	6.2	2.8

[a]Stress abbreviations (capitals = serious, lowercase = moderate, 0 = none or slight incidence): blb = bacterial leaf blight, dh = stem borer deadhearts, wh = stem borer whiteheads. [b]wc = chalkiness between 10 to 20% of kernel, gl = glutinous, 0 = chalkiness absent or negligible.

Table 5. Performance of tall, medium- to late-maturing selections in uniform performance tests in shallow to medium deep waterlogged lowlands, 3 stations in Yezin, Burma, 1983 monsoon season.

Entry no.	Selection	Grain yield (t/ha)	Days to heading	Plant ht (cm)	Field stress reaction[a]	Kernel		
						Chalkiness	Length (mm)	Length:width
24	X72-7-107	3.19	106	135	DH, wh	0	6.6	3.0
26	X72-8-39	3.24	109	141	uf, dh, WH, lg, blb	0	6.6	3.0
33	Yn 18-2	3.46	112	140	uf, dh, WH, lg	0	6.0	2.7
35	Yn 1808	3.42	114	146	uf, DH, wh	0-wc	6.6	3.0
36	X72-10-44	3.39	114	141	uf, dh, wh, lg	0	6.8	3.1
30	Shwewartun (medium maturing check)	3.64	122	134	B, uf, dh, wh, HLS, blb	0-wc	6.4	2.9
122	X72-7-114	3.84	106	138	uf, dh	0	6.5	2.9
123	X72-7-115	3.46	108	135	uf, DH, wh	0	6.5	3.0
124	X72-12-20	3.29	107	137	dh, wh	0-wc	6.4	2.9
127	C4-63 (medium early check)	3.70	98	111	blb, b, uf, DH, wh, hls	0-wc	5.8	2.8
137	X72-10-30	3.50	111	148	uf, dh, wh	0	6.5	3.2
138	IR15164-3	3.37	107	137	uf, blb, hls	0	6.2	3.0
139	X72-12-18	3.24	107	141	DH, blb	0	6.4	3.0
140	X72-7-128	3.48	107	132	dh, blb	0	6.4	3.2
141	X72-7-137	3.34	106	135	uf, dh, WH, blb	0	6.3	3.0
142	Yn 25-7	3.30	110	137	uf, dh, his	0	6.3	3.1
147	Yn 116-16	3.02	114	135	uf, WH, blb, hls	0	6.4	3.0
148	Yn 116-17	3.12	113	140	uf, dh, hls	0	6.3	2.9
145	Shwewartun (medium maturing check)	3.46	120	130	B, uf, dh, WH, HLS, blb	0-wc	6.2	3.0

[a]Field stress abbreviations (capitals = serious, lowercase = moderate incidence): dh = stem borer deadhearts, wh = stem borer whiteheads, uf = ufra nematode, blb = bacterial leaf blight, b = rice blast, hls = Helminthosporium leaf spot, lg = lodging. [b]wc = chalkiness between 10-20% of kernel, 0 = chalkiness absent or negligible.

Table 6. Performance of tall, medium- to late-maturing rainfed lowland selections in agricultural extension supervised farms in high rainfall townships in Yezin, Burma, 1983 monsoon season.

Entry no.	Selection	Grain yield (t/ha)	Days to heading	Plant ht (cm)	Field stress reaction[a]	Kernel[b]	
						Length (mm)	Length:width
2	X72-7-1	3.40	97	113	blb, sb	7.0	3.5
3	X72-8-22	3.03	105	128	blb, sb	6.8	3.3
5	X72-7-15	3.27	96	112	b, blb, sb	6.6	3.5
6	Shwewartun	3.73	107	124	b, blb, bls	6.3	2.9
8	BKN6874-40	3.40	104	106	b, blb, bls	6.8	3.5
7	IR42 (check)	2.91	100	91	b, REB, blb, bls	5.7	2.9

[a]Stress abbreviations (capitals = serious, lowercase = moderate incidence): blb = bacterial leaf blight, bls = bacterial leaf streak, b = rice blast, sb = stem borers, REB = rice ear bug. [b]Chalkiness score for all entries was 0 = chalkiness absent or negligible.

supervised farms. Performance data on all important agronomic and grain traits are summarized by the plant breeders at ARI and then presented and discussed during a meeting of the Rice Varietal Improvement Group, which is composed of the leaders of each of the disciplines involved in the testing. This group recommends outstanding selections to the National Technical Seed Committee for eventual release and seed increase.

Varietal improvement for high-rainfall rainfed lowlands

Varietal improvement for adaptation to medium deep waterlogged lowlands in the high-rainfall zone has been carried out at Hmawbi Agricultural Experiment Station since 1981. Thirty-seven crosses between selected traditional tall, photoperiod-sensitive varieties and improved plant type selections have been made (Table 2). The F_2 and F_4 of those crosses are presently grown in Hmawbi and are being handled similarly to those at Yezin. No uniform line has been selected so far.

Promising uniform lines will be entered in preliminary performance tests at this station, after which selections will be included in the national uniform performance tests coordinated by the Rice Varietal Improvement Group.

PLANS FOR VARIETAL IMPROVEMENT

Since the 1983 monsoon season, performance testing of selections intended for use in the medium deep waterlogged lowlands has been carried out in low-lying fields subject to waterlogging at high-rainfall stations. Entries for these trials should have strong plant vigor, lodging resistance, medium-tall to tall plant stature, resistance to or tolerance for prevalent insects and diseases, and good grain appearance. They could be late maturing or medium-late maturing, and photoperiod insensitive or moderately photoperiod sensitive so they can be planted in June and harvested in November-December. Preferably, selections should come from crosses involving at least one parent adapted to the target environment.

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233

PROGRESS IN BREEDING RICE FOR MEDIUM DEEP WATER RAINFED LOWLAND AREAS IN VIETNAM

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Medium deep water rainfed lowland areas occupy about one-tenth of the total rice hectarage in Vietnam. Two main constraints of rice production in these areas are uncertain rainfall — both amount and frequency — and temperature differences in the Red River and Mekong River Deltas. Suitable varieties should have the following characteristics: appropriate seedling height at the transplanting and tillering stages, medium to late maturity, and resistance to major pests. To improve yields, scientists have been screening newly introduced promising lines and varieties, and simultaneously selecting from segregating materials from their own breeding programs. Several well-adapted varieties have been identified.

The major rice-growing areas of Vietnam are the Red River Delta in the north and the Mekong River Delta in the south, with a total of 5.8 million ha of rice fields. The rice seasons in Vietnam, as in other Southeast Asian countries, depend mostly on climate. Varieties with different maturity periods are grown in different seasons (Fig. 1, 2); those grown in the two deltas are listed in Table 1. This paper discusses the rice seasons and varieties for medium deep water rainfed areas in the deltas.

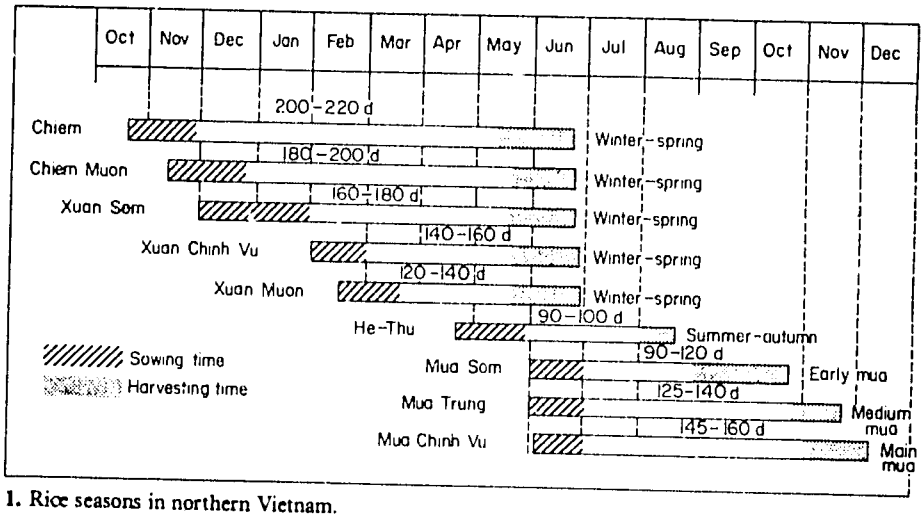
VARIETIES FOR RICE CULTIVATION IN VIETNAM

Red River Delta

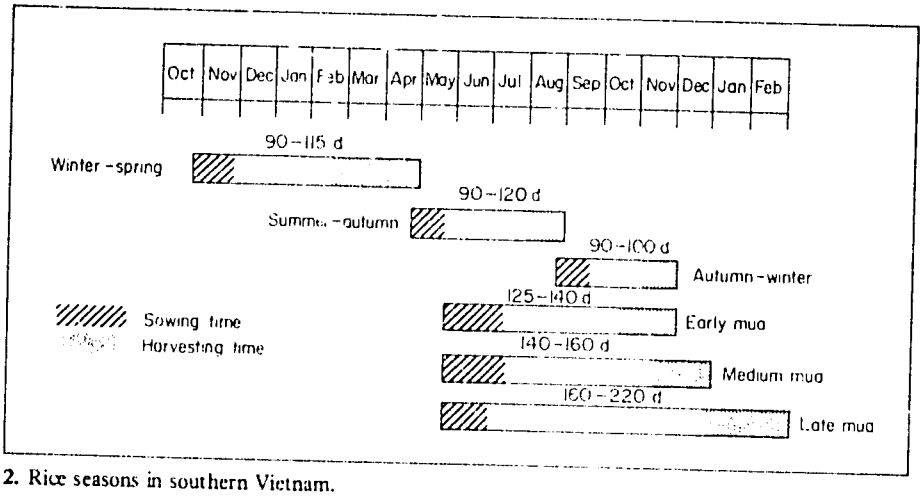
In the Red River Delta in northern Vietnam, the annual average rainfall ranges from 1,300 to 2,000 mm and the bulk of rain falls from June to September. Flooding causes great damage to 0.3 million ha of medium deep water rice and 0.2 million ha of deep water rice (3, 4). At the peak of the rainy season, typhoons are common; about four to five hit the Red River Delta annually.

The average temperature ranges from 16.5 °C in January to 29 °C in June-July. From December to March, the mean temperature ranges from 16.5 to 19 °C. During this period, sudden cold weather sometimes causes the temperature to drop below 10 °C for a week or longer (Fig. 3) (1).

In medium deep water areas, only two crops of rice have traditionally been grown each year — the chiem and mua crops — using adapted traditional varieties.



1. Rice seasons in northern Vietnam.



2. Rice seasons in southern Vietnam.

Chiem crop (winter-spring). For the chiem crop, sowing starts between late October and late November, transplanting is in January-February, and harvest is in June. During the seedling stage and the early stages of transplanting, the crop may suffer from cold weather. The harvesting period is often a time of rain and high temperatures, causing lodging of the plants at harvest and germination of grains right on the panicles. Rice blast is the only major disease during this season. The varieties used have maturity periods ranging from 180 to 220 d. Other varietal traits are required for medium deep water lowland areas in this season (2):

- seedlings and early transplanted crops with tolerance for cold temperature and lack of solar radiation for periods lasting 7-10 d;

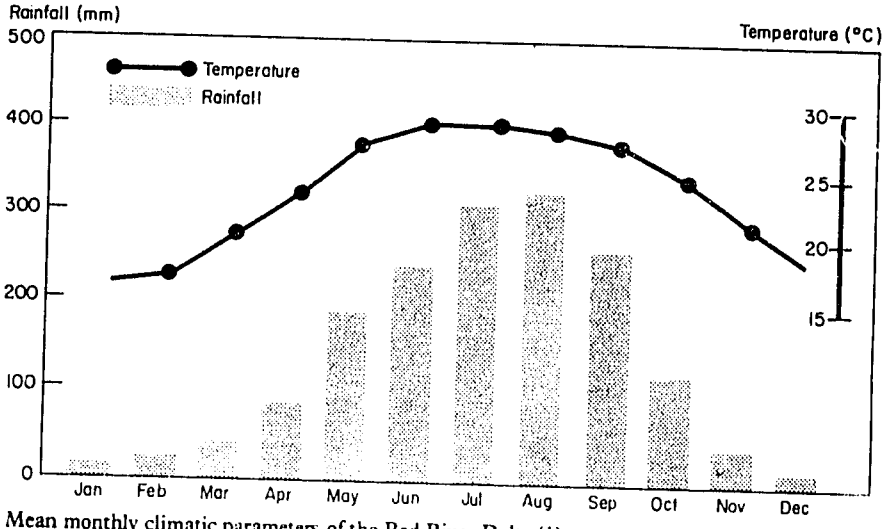
Table 1. Rice varieties grown during different seasons in northern and southern Vietnam.

Months	Maturity (d)	Varieties
	Northern Vietnam	
Late Oct-Nov to end of May-Jun	200-220	314, Sai duong, Tetep, Cut, Ba la, NN75-1, NN75-2
Nov-Dec to end of May-Jun	180-200	NN75-2, NN75-1, Xuan-2
Dec-Jan to end of May-Jun	160-180	NN75-6, V13, X_1
Feb to end of May-Jun	140-160	TH2, Tran chau lun, NN75-6, CR203, NN75-10
Mar to end of May-Jun	100-140	NN-1 A, TH2, NN75-6, NN75-10
Apr-May to Aug	90-100	TH 2, NN1A
Jun to Oct	90-110	NN75, NN75-10, NN1-A, NN23, IR1561-1-2, CR203
Jun to Nov	125-150	NN-22, BR52, NN27, Bao thai, Moc tyuen, Mockham, Nep Du, Di huong
Jun to Nov	140-160	Tam 4, Nep 4, Moc, Tuyen, NN750-8, NN75-9
	Southern Vietnam	
Oct-Nov to Mar-Apr	90-115	NN3A, NN6A NN7A, NN8A
Apr-May to Aug	90-120	NN3A, NN6A NN7A, NN8A
Aug to Nov	90-100	NN7A, IR13240-10-1
May-Jun to Oct-Nov	120-145	NN4B, NN5B, Sa quay, Nep nu u, Trang lun
May-Jun to Dec	140-160	Ba thiet, Chum ruot lua, Than nong do, Trai may cut, Trang lun
May-Jun to Jan-Mar	160-220	Trang chum, Trang tep, Chet xanh, Chau nang vo, Trang lua

- seedlings at least 30 cm high at transplanting;
- tolerance for adverse soils, especially those with phosphorus deficiency;
- nonlodging habit;
- grain dormancy;
- resistance to blast;
- plant height of at least 120-140 cm; and
- tolerance for high temperature and dry and hot winds during flowering.

Of the modern varieties introduced by IRRI since the late 1960s, none can be grown as medium deep water rice in northern Vietnam.

Mua crop (June-November). Rice yields in the medium deep water rainfed lowland areas of the Red River Delta depend on prevailing conditions. The



3. Mean monthly climatic parameters of the Red River Delta (1).

seedling stage occurs during the drought period. Tillering of the rice about 1 mo after transplanting often coincides with sudden heavy showers. For 24 h, whole fields may be submerged in 10-20 cm of water or deeper. Rice plants for medium deep water areas in this season have (2)

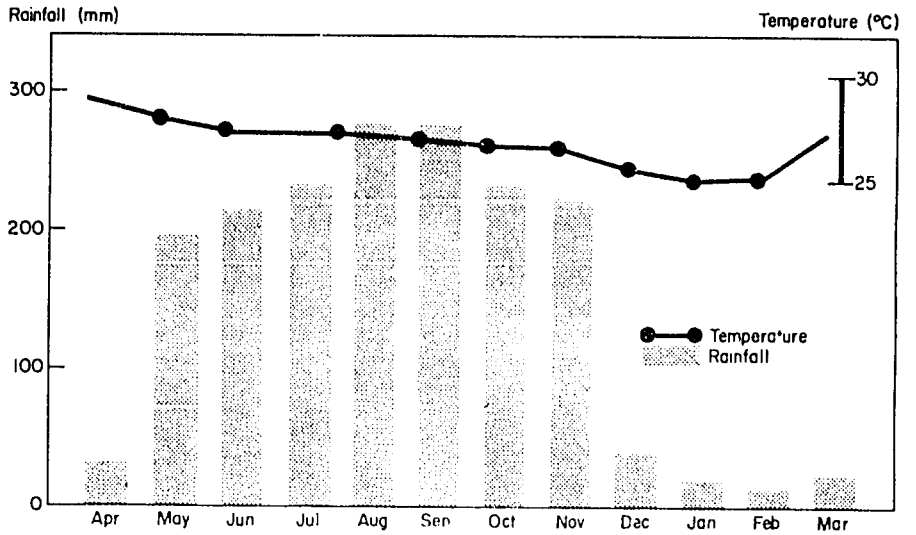
- tolerance for drought at the seedling stage,
- survival or emergence during flooding periods of 5-10 d or longer at the tillering stage,
- kneeing ability after water has drained off,
- nonlodging habit,
- tillering ability in water of 40 cm depth,
- plant height from 110 to 140 cm,
- photoperiod sensitivity,
- cold tolerance for temperatures below 20 °C at the flowering stage, and
- resistance to bacterial blight, stem borers, and brown planthopper.

To date, none of the modern varieties from IRRI have been found to fit the mua crop in the medium deep water rainfed lowland areas of the Red River Delta.

Mekong River Delta

In the Mekong River Delta, average annual rainfall is 1,500-2,000 mm with a peak in August-September. The water level rises quite high in the rice fields, which become flooded in August, damaging 0.3 million ha of deep water and 0.4 million ha of medium deep water crops. Temperatures do not vary greatly, the average ranging from 25 to 28 °C (Fig. 4) (1).

Most of the medium deep water rainfed lowland rice areas are confined to the western province of Vietnam. The main rice crops in this region are the summer-autumn, early mua, and late mua crops. Conditions in which rice



4. Mean monthly climatic parameters of the Mekong River Delta (1).

grows vary widely. Water level in the fields in September can be from 60 to 100 cm. Varieties that may be grown in these areas are:

- photoperiod-insensitive modern varieties and early maturing varieties for the summer-autumn crop;
- medium maturing and photoperiod-sensitive rices for short days; or late-maturing varieties for the early, medium, and late crops;
- semitall or tall, with nonlodging habit,
- tolerant of drought at the seedling and early transplanting stages;
- suitable for single transplanting;
- submergence tolerant;
- medium elongating; and
- resistant to brown planthopper, bacterial blight, and stem nematode (2).

The traditional rice varieties are adapted to medium deep water rainfed lowlands; average yields are 1-1.5 t/ha. Varieties include Tetep, Sai duong, Chiem ba la, Bau, and Nhang in the Red River Delta. The average yield is 2-2.5 t/ha for the country as a whole (1).

Apart from these areas of low and unstable yields are irrigated areas of potentially high cropping intensity with yields of 6-8 t/ha per crop; 8-10 t/ha per crop could be attained over areas of 100 ha or more (1).

BREEDING RICE FOR MEDIUM DEEP WATER RAINFED LOWLANDS

Rice varieties for medium deep water regions were improved in the late 1970s through the efforts of rice breeders working at the Food Crops Research Institute and the Vietnam Agricultural Science Institute in the north, as well as by the foundation of the Mekong Delta Centre of Agricultural Techniques and Can Tho University in the south.

Table 2. Characters of some traditional varieties for medium deep water areas in northern Vietnam.

Variety	Parents	Maturity period (d)		Plant height (cm)	Resistance[a] to			Yield potential (t/ha)	Notes
		Chiem crop	Mua crop		Lodging	Blast	Bacterial leaf blight		
Tetep	Traditional varieties	180-220	135	140-150	S	R		2-2.5	Grown as chiem crop only
Sai duong		180-220	135	140-155	S	R		2-2.5	
Chiem bau		180-220	135	140-160	S	R		2-2.5	
Du	Purelines		145-150	135-145	S	R	R	1.5-2.0	Photoperiod-sensitive and good quality
813			150-155	140-150	R	R	R	3.5-4.0	
828			150-150	140-145	R	R	R	3.5-4.0	
314	Doanket/ Saiduong	180-220	135	140-150	R	R	M	3.0-3.5	
NN75-1	IR8/813//NN1	180-220	130-135	120-130	R	M		4.0-5.0	
NN75-2	IR5/314	180-220	135-140	130-140	R	R	R	4.5-5.0	
U9	IR1529-680-3-2 /SLM18	180-200	135-140	120-125	R	R		4.5-5.0	
U14	IR1529-680-3-2	180-200	135-140	110-115	R	R	R	4.5-5.0	
U17	IR5//IR8/ IR1529-680-302	180-220	140-145	125-130	R	R	R	4.5-5.0	
CI0	IR8/DU//IR24[2]		150-160	115-120	R	R	R	5.0-6.0	Photoperiod-sensitive
CI5	IR8/813//C4		150-160	115-120	R	R	R	4.5-5.0	

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

Until the late 1960s in the north and the late 1970s in the south, breeding work for medium deep water rice was limited to pureline selection from traditional varieties. In the north, such varieties were Chiem bau, Chiem chanh, Chiem ba la, Tetep, and Sai duong for the chiem crop; and Moc tuyen, Moc kham, Bao thai lun, 813, 828, Du, Di huong, and Nep for the mua crop. In the south, sources were Ba thiet, Than nong do, and Hoa binh for the main mua crop; and Trang chum, Trang tep, Chet xanh, and Chau nang vo for the late mua crop.

Most of these varieties are indica types that possess suitable plant height; they include photoperiod-sensitive and insensitive varieties with different maturity durations and low yields, and they have been adopted as they were found suitable for the socioeconomic conditions of Vietnam.

In 1968 the Chiem 314 variety, selected from the cross Doan ket/Sai duong, was the first variety released to cooperative growers under the crossing program. By 1970 it had replaced the old varieties being grown in northern Vietnam, as it possessed better characteristics such as stable culm, good lodging resistance, and higher yields.

In 1977, following the cultivation of Chiem 314, two varieties — NN75-1 and NN75-2 -- were released. They are high yielding types that have significantly contributed to rice cultivation, they possess good resistance to diseases and are especially tolerant of acid and saline soils in medium deep water areas.

Many new varieties for medium deep water areas are entries in the national rice testing program. Most of them are released by the Food Crops Research Institute; they include lines of U_1, U_9, U_{14}, and U_{17} for chiem and medium mua crops and C_{10} and C_{15} for main and late mua crops in the north. The characteristics of these varieties are given in Table 2.

In the Mekong River Delta, the traditional varieties are mainly for medium deep water and deep water areas. Pureline selection for hybridization and other breeding methods are being used at agricultural institutes and universities.

CONCLUSIONS

Rice production in Vietnam still faces many problems, including deficiencies in chemical fertilizers, pesticides, insecticides, and electrical power, as well as the difficulty of constructing irrigation systems. Much rice cultivation is still performed by human labor. The introduction of new varieties of the high yielding type for cultivation over large areas does not seem possible in the near future.

Breeding rice for medium deep water areas is a major project. Varieties suitable for different ecological regions are needed. The crossing of traditional and tall plant types with good elongation ability to produce new varieties and the introduction of high yielding types from IRRI and other countries are practical and effective ways to achieve a rice variety structure for medium deep water areas.

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VARIETAL IMPROVEMENT AND RESISTANCE TO INSECT PESTS

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Insect pests cause sufficient yield loss in rainfed lowland areas to justify development and adoption of resistant varieties. Research toward this goal in Bangladesh, India, the Philippines, and Thailand was initiated for glasshouse and field evaluation of rice varieties against all major insect pests. Active screening and breeding programs have led to the identification and utilization of promising donors, culminating in the release of varieties with resistance to gall midge, brown planthopper, stem borer, and green leafhopper. Several breeding lines, particularly promising in rainfed lowland rice situations, are also resistant to insect pests. Some released varieties possess resistance to more than one major pest. The nature of resistance in these varieties is fairly well understood. Existence and development of spatial and temporal biotypic variations in pest populations have been the major constraints to widespread and prolonged cultivation of resistant varieties. Resistant varieties such as IR36 and Phalguna have had a great impact on pest populations in areas of adoption. More research must be carried out to meet the requirements of rainfed lowland areas.

With the availability of modern varieties possessing high yield potential, insect pests have drawn attention to rainfed lowland rice ecosystems. Major insect pests of rainfed areas are stem borers (SB), gall midge (GM), green leafhopper (GLH), rice hispa, brown planthopper (BPH), rice bug, ear-cutting caterpillars, caseworm (CW), leaffolder (LF), and rice thrips. Coordinated trials conducted at several locations in India have shown an average 28.8% gain in yield after protection against insects (14). In rainfed areas of northern Bihar, estimates of crop loss have ranged from 14.5 to 46.6%, the average being 22.5% (6). Average losses in Assam are 48% and in Orissa 35% (14). Crop loss assessment trials conducted at the Bangladesh Rice Research Institute (BRRI) from 1977 to 1979 have shown yield losses of 13% in boro, 24% in aus, and 18% in T. aman due to attacks by major insect pests. Thus, the importance of insect control in rainfed lowland rice cannot be overemphasized.

Varietal resistance forms an important low-cost component of pest management, particularly advisable in rainfed lowland areas. However, separate breeding programs for insect resistance, specifically for rainfed areas, have not been initiated. Varieties evolved through glasshouse and field screening under irrigated conditions have been found suitable for rainfed

cultivation. In this paper, the status of the work on varietal resistance to insect pests in Bangladesh, India, the Philippines, and Thailand is briefly reviewed.

DEVELOPMENT OF RESISTANT VARIETIES

Screening methodology

As a prerequisite to identification of resistance donors, greenhouse screening methods have been developed for several of the major insect pests. Simultaneous field screening under natural infestation or under artificially enhanced levels of infestation has been also adopted. Glasshouse screening is done against BPH and GLH in Bangladesh; against BPH, GLH, WBPH (white-backed planthopper), GM, thrips, and LF in India; against BPH, WBPH, GLH, zigzag leafhopper, whorl maggot (RWM), LF, CW, thrips, black bug, and rice bug at IRRI in the Philippines; and against GM, BPH, GLH, and LF in Thailand. A standard 0-9 scale for evaluating these pests has been developed (8) and adopted in all countries.

Identification of donors

Table 1 presents the status of screening and identifies donors against nine of the major pests in four countries. Resistant, moderately resistant, or tolerant rice varieties have been identified. Work on breeding varieties with resistance has been initiated. Only screening programs under coordinated trials are listed for India; results depict multilocation testing and overall performance of the entries across locations. Besides coordinated trials, varietal evaluations under both greenhouse and field conditions are done at the Directorate of Rice Research (DRR) headquarters (Hyderabad), the Central Rice Research Institute (Cuttack), and at agricultural universities. At DRR, more than 32,000 germplasm materials and cultures have been screened against BPH and about 800 donors have been identified (Table 2) (12). Details of donors identified against GM (11, 14, 16), GLH (24), and other pests (15) have been reported elsewhere and are summarized in Table 2. In all, resistance sources for 33 insect species have been identified (5). Besides *Oryza sativa* germplasm, 328 wild rice accessions have been evaluated at IRRI to identify additional sources of resistance to 10 pests (5).

Utilization of donors

Several of the identified donors have been utilized in breeding resistant varieties. A list of important donors utilized and the status of the development of resistant varieties are presented in Table 3. A brief account of the progress made in individual countries is given here.

Bangladesh. The breeding program for insect resistance in Bangladesh resulted in the identification of modern varieties suitable for irrigated as well as rainfed conditions (4). BR1 (Chandina) possesses moderate field resistance to yellow stem borer and tungro virus disease (RTV). BR12 (Moyna) is moderately resistant to RWM and thrips. BR14 (Gazi) is tolerant of RWM,

Table 1. Status of screening of rice germplasm for resistance to major insects in different countries.

Insect[a]	Country	Type of screening[b]	Start of screening	Germplasm (no.)	
				Tested	Resistant
BPH	Bangladesh	G	1976	5,147	126
	India	G, F	1974	2,668	159
	Philippines				
	biotype 1	G	1967	42,355	363
	biotype 2	G, F	1975	15,068	258
	biotype 3	G	1975	16,402	267
	Thailand	G	1972	6,290 (1983)	42
WBPH	India	G, F	1979	248	48
	Philippines	G	1970	46,488	391
	Thailand	G	1978	702	45
GLH	Bangladesh	G	1976	2,361	44
	India	G, F	1971	1,690	122
	Philippines	G	1967	47,944	1,196
	Thailand	G	1978	1,975 (1983)	186
GM	Bangladesh	F	1971	3,206	70
	India	G, F	1968	9,725	500
	Thailand	G, F	1962	900/yr	14
SB	Bangladesh	F	1970	4,929	222
	India	F	1969	5,998	710
	Philippines	G, F	1962	19,961	43
	Thailand	F	1965	1,500/yr	16
LF	Bangladesh	F	1973	1,482	18
	India	G, F	1972	900	169
	Philippines	G	1979	17,914	28
	Thailand	G	1982	31	7
RWM	Bangladesh	F	1970	2,451	599
	India	F	1972	3,890	94
	Philippines	F	1965	15,787	1
Thrips	Bangladesh	F	1975	1,389	485
	India	F	1982	28	5
	Philippines	G	1983	79	11
Hispa	Bangladesh	F	1972	499	71
	India	F	1983	40	11

[a]BPH = brown planthopper, GLH = green leafhopper, WBPH = whitebacked planthopper, GM = gall midge, SB = stem borer, LF = leaffolder, RWM = whorl maggot. [b]G = greenhouse, F = field.

Table 2. Greenhouse evaluation of rice germplasm and breeding material at the Directorate of Rice Research (AICRIP), Hyderabad, India.

Insect	Start of screening	Entries screened (no.)	Resistant or tolerant entries (no.)
Brown planthopper	1974	32,959	826
Gall midge	1975	4,585	1,000
Whitebacked planthopper	1976	2,005	119
Green leafhopper	1975	212	82
Leaffolder	1981	18	4

Table 3. Important donors utilized and resistant varieties released against major insect pests in different countries.

Insect	Country	Donors utilized in breeding varieties	Varieties released
Brown planthopper	Bangladesh	Swarnalata, ARC6650, ARC10550, Ratu Heenati, Neera, Ptb 33	to be released
	India	Leb Mue Nahng, Manoharsali, Ptb 33, ARC6650, Veluthachera, Andrewsali, ASD11, ARC10550, NLR9674	Co 42, Jyothi, Bhandra, Pavizham
	Philippines	Mudgo, ASD7, Ratu Heenati, Ptb 33	IR26 to IR62
	Thailand	W1252, W1256, IR26, IR32	RD4, RD9, RD21, RD23, RD25
Stem borer	Bangladesh	—	BRI (Chandina)
	India	TKM6	Sasyasree, Ratna
	Philippines	TKM6	IR20, IR26, IR30 to IR44, IR50 to IR56
	Thailand	TKM6, IR20, IR36, IR531-E-239, IR1820-52-2, W1263	to be released
Gall midge	Bangladesh	BG12-1, BR308-3-2-9-A	to be released
	India	Eswarakora, Siam 29, Leuang 152, Ptb 21	IR36, Phalguna, Vikram, Kakatiya, Surekha, Dhanyalaxmi, Rajendra dhan 202, Usha, Asha, Samaridhi, Shakti, Samalei, Kunti
	Thailand	MN62 M, W1252, W1256, W1259	RD4, RD9
Green leafhopper	Bangladesh	Ptb 18	BR6
	India	Ptb 2, ADT21	to be released
	Philippines	Pankhari 203, Ptb 18	IR5 to IR20, IR24 to IR62
	Thailand	RD1, RD9, W1263, IR28, IR30, IR32, IR34, IR36, IR42	RD21, RD23, RD25

thrips, and hispa. BR15 (Mohini) is moderately resistant to thrips. Five advanced breeding lines identified as resistant to BPH are under testing in farmers' fields. The breeding program is developing varieties resistant to BPH, GLH, GM, and thrips. BJ1 is the thrips-resistant donor. Among the breeding lines tested in the 1979 IRLRON, IR4432-103-6-4 was found to be resistant to BPH in Bangladesh.

India. Breeding for GM resistance in India was initiated in 1964. On the basis of regional performance through a coordinated program, 13 varieties have been released (Table 3) and are being grown in endemic areas. The breeding material being evaluated against GM will be used in developing varieties in different duration groups, with suitable grain types and combining resistance to other major pests. Some promising breeding materials are IET6080 (CR44-35/W12708), IET6131 (Vijaya/Ptb 10), IET6187 (Vijaya/Ptb 21), IET6290, IET6729 and IET7008 (Surekha/Kakatiya), IET6721 (Ptb 21/Ptb18//IR8), IET6725 (CR94/Vikram), IET6747 (Kumar/CR57, and IET7918 (Surekha/CR141-7369). A moderate level of resistance to SB (*Scirpophaga incertulas*) has been realized through TKM6 in two varieties: Ratna and Sasyashree. Attempts to identify better donors and to evaluate more breeding materials were resumed in 1980 under the coordinated program. Preliminary evaluation has produced a few promising cultures.

Against BPH, Co 42, Jyothi, Bhadra, and Pavizham have been released in Tamil Nadu and Kerala. IET6314 (Co 42) inherited a moderate level of resistance from Leb Mue Nahng and is excellently suited to rainfed lowland areas (3). Several advanced cultures (IET6315, IET7568, IET7569, and IET7575 derived from the cross Sona/Manoharsali, and MTU5995, MTU5249, and DR190-103s) are in the final stages of testing. Against GLH and RTV, the advanced breeding material in the prerelease stage includes IET7301, IET7302, IET7303 (RPW 6-13/Ptb 2), IET7562, and IET7563 (Rasi/ADT21). Breeding material against WBPH originating from crosses IET6288/RPW 6-17, TN1/Ptb 33, and IET5656/Veluthachera are in advanced stages of development.

Philippines (IRRI). Breeding programs at IRRI have aimed at systematically adding resistance to the pest complex in successive steps. IR20 was the first variety to possess moderate resistance to SB (*Chilo suppressalis*) and to GLH. IR26 has combined resistance to BPH biotypes 1 and 3. Most of the IR varieties subsequently released have resistance or moderate resistance to these insects, and a few are also resistant to GM and to diseases such as blast, bacterial blight (race 1), and grassy stunt. IR36 has been the most widely cultivated variety in the Philippines, southern Vietnam, and Indonesia.

Thailand. Screening rice varieties for resistance to GM, the most important pest in Thailand, was initiated in the early 1960s. Glutinous dwarf variety RD4 and nonglutinous RD9 have resistance to GM. These two varieties, released during 1973 and 1975, are also resistant to BPH and GLH. During 1983, 23 breeding lines were identified as promising against GM, with W1252, W1256, and W1259 as additional sources of resistance. Against SB (*C. polychrysus*), selections from the cross RD1/IR532-E-239 — CNT7246-

4-2-1 and CNT7256-4-2-3 — have been found promising. Recently, 20 breeding lines from 6 crosses involving 4 possible sources of resistance (IR36, IET2911, IR2863-38-1-2, and IR1820-52-2) were identified as promising against SB. Three more varieties were released in 1981 against BPH and GLH. Further evaluation (1983) identified 66 breeding lines with good BPH resistance, involving one or more of the 11 resistant sources IR26, IR28, IR30, IR32, IR34, IR36, IR42, IR262, IR2061, RD9, and W1263. Some of them have also contributed resistance to GLH in 28 breeding lines in similar evaluation. Screening programs against WBPH and leafhopper have also identified a few donors against both pests.

Insect resistance in rainfed lowland rice breeding material

No serious attempt has been made specifically to incorporate insect resistance in rainfed lowland rice. In some instances, however, breeding material generated for rainfed lowland conditions has been routinely evaluated against a few major insect pests, and promising entries have been identified. Screening at IRRI has brought out good levels of resistance to BPH biotypes 1 and 2 in 12 entries, to GLH in 3 entries, and to WBPH in more than 12 entries from among the 261 of the first 1978 IRLRON materials (6). Likewise, 48 entries in the 1979 IRLRON were rated good against BPH at IRRI, and one entry — CR1001 — against RWM in India (7). Among the 40 early-maturing entries of the 1981 IRLRON, 24 fared better against BPH biotype 2, 22 against biotype 3, 3 against GLH, and 1 against WBPH. IR4744-295-2-3 was rated resistant to GLH and BPH biotypes 2 and 3 (10). From the late-maturing group, IR10781-143-2-3 was found resistant to LF (in Thailand), WBPH, and BPH biotypes 1 and 2, while the total number of promising entries against those pests was 11 (LF), 6 (WBPH), 39 (BPH biotype 1), and 21 (BPH biotype 2).

In National Screening Nursery II in India, breeding materials generated for rainfed lowland rice (PVT 4 and UVT 4) were evaluated against insect pests in 1980-83. Four entries — IET8009, IET8022, IET8037, and IET8549 — were found moderately resistant to GM at Raipur. IET8009 (CNM3-2) was also found good against BPH at Hyderabad and against SB at Maruteru in 1983. All four have performed well in yield trials. Similarly, IET7494 (CNM603) was rated good against BPH and WBPH at Hyderabad.

Multiple resistance

Several varieties released from IRRI/Philippines (Table 4) and from Thailand (RD4, RD9, RD21, RD23, and RD25) have combined resistance to more than one major insect pest. In India a coordinated program on multiple resistance screening initiated in 1980 and the greenhouse screening at Hyderabad have identified several donors with combined resistance to two or more major pests (3, 13, 23). Some of the multiple resistance donors (Veluthachera, Ptb 33, and IET6288) have been utilized in breeding programs, and promising cultures are in various stages of evaluation. In Bangladesh, donors such as Hondarawala 502, Sinna Sivappu, and Rathu Heenati have shown resistance to both GLH and BPH.

Table 4. Multiple resistance[a] to major insect pests[b] in selected IR rice varieties in different countries.

Variety	Reaction in														
	Philippines						Thailand				India[c]			Bangladesh[c]	
	BPH biotype			GLH	WBPH	SB	BPH	GLH	WBPH	GM	BPH	WBPH	GM	BPH	GLH
	1	2	3												
IR5	S	S	S	MR	S	S	S	R	S	S	S	S	S	S	S
IR8	S	S	S	MR	S	S	S	R	S	S	S	S	S	S	S
IR20	S	S	S	MR	S	MR	S	S	S	S	S	S	S	S	S
IR26	R	S	R	MR	S	MR	R	MR	MR	S	S	S	S	S	S
IR36	R	R	MR	MR	S	MR	R	R	R	S	S	S	MR	S	R
IR42	R	R	S	MR	S	MR	R	MR	MR	S	S	S	—	S	—
IR50	R	MR	R	R	S	MR	R	R	R	S	S	S	R	S	—
IR52	R	R	MR	R	MR	MR	R	R	R	—	S	MR	S	—	—
IR56	R	R	R	R	S	S	R	R	R	—	S	—	S	S	—
IR58	R	R	R	R	S	S	R	R	MR	—	S	—	—	S	—
IR60	R	R	R	R	MR	S	R	R	R	—	R	—	—	—	—

[a]R = resistant, MR = moderately resistant, S = susceptible, — = not tested. [b]BPH = brown planthopper, GLH = green leafhopper, WBPH = whitebacked planthopper, SB = stem borer, GM = gall midge. [c]Screened in glasshouse at AICRIP, Hyderabad, and BRRI, Bangladesh.

MECHANISMS OF RESISTANCE

A vast amount of literature is available on the nature of resistance. The general pattern of rice resistance to hopper pests includes nonpreference by nymphs and adults for shelter, food, and oviposition; antibiosis manifested in reduced survival, prolonged development, and decreased fecundity; and tolerance of certain rice varieties for moderate levels of pest populations without obvious yield reduction. Resistance to BPH is by blocking a set of amino acids acting as feeding stimulants, while organic acids such as oxalic acid, trans-aconitic acid, and salicylic acid act as feeding or oviposition deterrents. Against GM, resistance appears to be due mainly to antibiosis involving inhibition of molting in first-instar maggots, with consequent mortality. SB resistance appears as nonpreference and antibiosis, including the mechanical damage caused to larvae by high silica contents of resistant varieties.

BIOTYPIC VARIATIONS

The existence and development of spatial and temporal biotypic variations in pest populations have been the major constraints in widespread and prolonged cultivation of insect-resistant varieties. Geographic variations in rice reaction patterns to GM within India were pointed out in 1969 (21). Further variations in the Asian countries have been highlighted through IRTP trials (9). A distinct response of BPH in South Asia was first brought out in 1974-75 when IR26 was found damaged in the field in Kerala and also under greenhouse conditions at Hyderabad (17). Introduction into Bangladesh of insect-resistant modern varieties from other countries was found ineffective in some cases due to the presence of insect biotypes. The GLH biotypes in Bangladesh and India are different from those of the Philippines (24). Genes for resistance —*Glh 1*, *Glh 2*, *Glh 3*, *glh 4*, and *Glh 5* — are susceptible in Bangladesh (18). Similarly the BPH biotype in Bangladesh is different from that of the Philippines, Taiwan, and Japan but has some similarities with the Sri Lanka and Indian biotype (1).

A clear understanding of such geographic variations has been attempted for BPH and GM through international collaborative studies under the IRTP (9, 22). In India, GM biotype studies conducted since 1974 under the coordinated program have distinguished three biotypes on the basis of reaction to two groups of differentials (22). Biotype 1, prevalent in Andhra Pradesh, Tamil Nadu, and Madhya Pradesh, is characterized by its inability to damage the donors and derivatives of either the Eswarakora or Siam 29 group. Only the former group is damaged by biotype 2 in Orissa, Maharashtra, and Karnataka. The Siam 29 group is damaged by biotype 3 in Bihar and Manipur. By reaction pattern, biotype 3 resembles the one in Thailand. More recent coordinated studies on BPH in India failed to show the variation in reactions noted earlier at Pantnagar in Uttar Pradesh and in the rest of the country (2). Besides the noted difference in reactions to varieties by BPH, GLH, and GM among Asian countries, differences have also been observed for WBPH (20) in India

and the Philippines. These differential reactions have been outlined in Table 5. Continued international collaborative studies are, therefore, imperative for better understanding of the situation.

Of more concern, however, is the record of development of new biotypes of BPH within the population in the same area as a result of its prolonged exposure to resistant varieties. IR26, the first BPH-resistant variety released by IRRI, became susceptible 2-3 yr after its release in the Philippines, Indonesia, and Vietnam. IR36, released in 1975, is currently grown on more than 13 million ha, primarily in the Philippines, Indonesia, and Vietnam. After 8 yr, reports of BPH attacks have come only from Mindanao in southern Philippines and North Sumatra in Indonesia. In North Sumatra IR36 and IR42 showed hopperburn. Whether this represented selection of yet another biotype of BPH or was a consequence of insecticide-induced resurgence or other unknown causes is being investigated at Bogor, Indonesia.

STABILITY OF RESISTANCE

Biotype selection has been a problem primarily in BPH control. GLH-resistant varieties have been grown for almost 20 yr and continue to control the hopper and RTV successfully. Although in the laboratory, GLH populations that fed on resistant varieties could be selected, this has not been reported in the field, probably because of several alternate host plants available for hopper selection pressure. Likewise, varieties with a moderate level of SB resistance have been grown in the Philippines for about 15 yr since the release of IR20, and GM-resistant varieties have been grown in India and Thailand for many years. There is no conclusive evidence to indicate any decrease in levels of resistance of these varieties to GM except for the decrease in the resistance level of Muey Nawng at Chieng Rai, Thailand.

IMPACT OF RESISTANT VARIETIES

High yielding, insect-resistant varieties have been accepted as a major component in pest management in all rice-growing countries. Insect-resistant varieties have been released in China, Colombia, Costa Rica, Cuba, Japan, Korea, Malaysia, the Solomon Islands, Sri Lanka, and Vietnam, besides the countries dealt with in detail in the preceding section. The most widely cultivated resistant variety is IR36, which is planted on more than 13 million ha and makes up 56% of the rice grown in the Philippines, southern Vietnam, and Indonesia. It is also cultivated in Malaysia, Kampuchea, Laos, Sri Lanka, and India.

In Warangal, Andhra Pradesh, an endemic area for GM, cultivation of GM-resistant varieties Phalguna and Surekha in more than 70% of the area during kharif since 1976 has reduced pest incidence to only traces compared with more than 50% incidence before 1976 (19). A similar situation exists in other GM-endemic areas of India.

Table 5. Variations in major insect pest reactions to some donors in different countries.

Insect pest	Donor	Reaction[a]										
		Bangladesh	Hyderabad	Pantnagar	Andhra Pradesh	Orissa	Manipur	Philippines Biotypes 1	Philippines Biotypes 2	Philippines Biotypes 3	Thailand	Sri Lanka
BPH[b]	ASD7	S	S	S				R	R	S	R	S
	Mudgo	S	S	S				R	S	R	R	S
	Ratu Heenati	R	R	S				R	R	R	R	S
	Ptb 33	R	R	S				R	R	R	R	V
GLH[c]	Intan 2400	S	S						R		—	—
	MAS	—	S						R		—	—
	Pankhari 203	S	S						R		R	—
	IR8	S	S						MR		R	—
	ASD7	S	—						R		R	—
WBPH[d]	ARC13349		S						S			
	8895		S						R			
	IR781-144-1/ IR842		R						S			
	T16		R						S			
GM[e]	Eswarakora				R	S	R				R	S
	Siam 29				R	R	S				S	R

[a]R = resistant, MR = moderately resistant, S = susceptible, V = variable reaction, — = information not available. [b]BPH = brown planthopper; based on 1976-78 IRBPHN tests. [c]GLH = green leafhopper; based on 18, 24. [d]WBPH = whitebacked planthopper; based on 20. [e]GM = gall midge; based on 2, 11.

FUTURE STRATEGIES

We have shown the advantages and limitations of resistant varieties in pest management in rice. It is imperative to develop or adopt insect-resistant varieties for rainfed lowland situations, particularly in view of their low cost. As was pointed out earlier, insect resistance has been identified incidentally in several rainfed lowland rice breeding lines, and many insect-resistant varieties for irrigated conditions are also suitable for cultivation in rainfed lowlands. They should be used initially in incorporation of resistance in more acceptable varieties for the situation.

Development of resistant varieties, in general, should aim at greater stability rather than higher level of resistance. This requires a better understanding of factors responsible for relative stability of resistance in varieties such as IR36 and incorporating them in breeding lines. Innovative breeding techniques involving tissue culture and genetic engineering may allow greater utilization of resistance in wild rices and expedite incorporation of resistance in hybrid rice, enhancing the level, broadening the base, and combining existing resistance to major pests. Identification of new genes for resistance to major as well as minor pests would continue to be a basis for such exploration.

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DISEASE RESISTANCE IN RAINFED LOWLAND RICE

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Changing situations in rice ecosystems led to the emergence of disease problems such as bacterial blight, rice tungro virus, sheath blight, and sheath rot in rainfed lowland rice areas in South and Southeast Asia. Available information on distribution patterns of diseases is summarized and the efforts of various national institutions and the International Rice Research Institute to identify donors of resistance to major diseases and to develop resistant varieties for rainfed lowland areas are discussed. The importance of national and international cooperation for containing disease problems is emphasized.

Disease management in rainfed lowland rice received limited attention until recently, as other production constraints such as drought, floods, and management problems were considered more important. It is now being increasingly realized that in rainfed lowland areas, disease problems are more intense and consequently more important than before because of changes in cropping intensity, intensive use of chemical fertilizers, improved management levels, and use of modern varieties that are susceptible to diseases. The magnitude of the disease problems associated with rainfed lowland rice has been emphasized by several researchers (8, 9, 10, 16, 21, 22). In this paper, we review the work on disease resistance in rainfed lowland rice at IRRI, in India, and in Bangladesh.

MAJOR DISEASE PROBLEMS

The major disease problems reported on rainfed lowland rice in Asia are bacterial blight (BB), rice tungro virus (RTV), blast (Bl), sheath blight (ShB), brown spot (BS), and sheath rot (ShR) (8, 9, 10, 13, 16, 21, 22). Their occurrence depends upon the distribution pattern of rainfall in the monsoon season and on varietal susceptibility. In some years in the riverine districts of India (Assam, West Bengal, Bihar, and eastern Uttar Pradesh) the rice crop is subjected to high rainfall and resultant floods, favoring epidemics of BB and RTV, while in drought years severe outbreaks of BS and ShR occur (2, 4, 22).

In the following sections the distribution patterns of BB, RTV, BS, Bl, ShB, and ShR in rainfed lowland rice in different countries are considered along with varietal resistance and crop improvement in relation to disease resistance.

Bacterial blight

BB caused by *Xanthomonas campestris* pv. *oryzae* (Ishiyama) Dye is an important production constraint in both irrigated and rainfed lowland rice. In India, a severe form has been observed in Faizabad, Gorakhpur, and Basti districts of eastern Uttar Pradesh (2, 10); Bhajpur, Shabad, Muzaffarpur, Darbhanga, and Samastipur districts of Bihar (2, 8, 10, 21); and Burdwan and Hooghly districts of West Bengal. BB also occurs in isolated areas of Assam, Orissa, and Andhra Pradesh (Table 1). In Bangladesh, BB is a major problem in rainfed lowland rices (10, 16). Outbreaks have also been reported in several other Asian countries (16, 18).

During the past two decades, extensive research at IRRI and in India, Bangladesh, and other countries has focused on the identification of BB-resistant germplasm and incorporation of resistance genes in otherwise productive genotypes (12, 13, 14, 19, 23, 25, 26, 29).

In IRRI's breeding program, diverse gene sources such as TKM6, Sigadis, DZ192, B589 A4, Malagkit Sungsong, Zenith, Wase Aikoku, and Nam Sagui were used, and resistant varieties were developed (13, 14, 18, 19). BB-resistant IR20, IR26, IR36, IR50, and IR54 are now grown in Asia and have also served as parents in numerous crosses at IRRI and in several national programs. IRRI breeding lines released in other countries — Chandina (IR532-1-1-76) and Mala (IR272-4-1) in Bangladesh and TN73-2 (IR1561-228) in Vietnam — are also resistant to BB (13).

In India, BB-resistant donors used in breeding programs at the All India Coordinated Rice Improvement Project (AICRIP), the Central Rice Research Institute (CRRI), and other institutes are TKM6, MTU15, Lacrosse/Zenith-Nira, Sigadis, Zenith, Nira, Wase-Aikoku, Chinsurah Boro II, DV85, BJ1, Sayaphal, Java 14, Hashikalmi, and a few IRRI breeding lines. BB-resistant varieties developed in these programs are IET2815, Ramakrishna, Saket 4, Prasad (TKM6 derivative), and IET4141 (BJ1 derivative), which are grown in irrigated conditions (25). Other promising cultures with a high degree of resistance in AICRIP multilocation testing and suitable for rainfed lowland conditions are presented in Table 2. A few varieties or cultures reported resistant in rainfed lowland conditions are CN539 and CN540 in West Bengal (6) and BR51-91-6, BR52-87-1, RP1491-20, and TCA177 in Bihar (8, 30).

In Bangladesh, the BB-resistant donors are DZ192, Rayada 16-06, R16-12, and Gochi Boro; improved varieties are BR4, IR20, Mala, BR6, BR8, and

Table 1. Distribution and intensity of diseases on rainfed lowland rice in India (2, 3).[a]

State	Bl	BS	ShB	ShR	BB	RTV
Andhra Pradesh	S	L	S	L	M	L
Assam	S	L	S	L	M	M
Bihar	L	M	L	M	S	S
Orissa	L	M	L	M	S	M
Uttar Pradesh	L	M	L	L	S	M
West Bengal	L	M	L	M	M	S

[a]L = low, M = moderate, S = severe.

Table 2. High yielding varieties grown in Bihar, West Bengal, Orissa, and Andhra Pradesh in lowland conditions and their reaction to major diseases of rice (1).

Variety or culture	State	Reaction[a] to					
		Bl	BS	ShB	ShR	BB	RTV
Pankaj	Bihar, West Bengal, Orissa	MS	S	MS	S	S	S
Mahsuri	Assam, Bihar, Orissa, West Bengal, Andhra Pradesh	S	MS	S	MR	MS-S	MS
BR34[b]	Bihar	R	MS	—	S	S	MS
Janaki[b]	Bihar	—	S	—	R	S	R
Jagannath	Orissa	R	MR	S	—	S	S
CNM539	West Bengal	MR	MR	MS	MR	MR-MS	MR-MS
CNM540	West Bengal	R	MR	MS	MS	MR	MR
Savithri	Orissa	S	MS	MS	MS	S	—
Swarna	Andhra Pradesh	S	S	S	—	S	S
Phalguna	Andhra Pradesh	S	S	S	S	S	S
Swarnadhan	Andhra Pradesh	R-MR	MS	MR-MS	MS	S	—
NLR9672	Andhra Pradesh	R	—	S	—	S	S
NLR9674	Andhra Pradesh	R	—	S	—	S	S
Vijaya Mahsuri	Andhra Pradesh	MR	MS	S	MR	S	—
Soubhagya	Andhra Pradesh	MS	MS	MS	MS	S	—

[a]R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, — = not tested. [b]Source: 30

Chandina (10, 13). In other countries, IRRI breeding lines have been used to incorporate resistance in lowland rice varieties (13).

Rice tungro virus

Epidemics of RTV have been reported in rainfed lowland rice in India, Bangladesh, and other Asian countries (10, 11, 16, 18, 22). In India, RTV is an important production constraint in eastern Uttar Pradesh, Bihar, and West Bengal (Table 1). Anjaneyulu et al (5) observed that slow progress in RTV resistance breeding programs in several countries is due to lack of sufficient and compatible resistant plants with desirable agronomic characteristics. However, IRRI and national institutes in India, Bangladesh, and Indonesia have identified a large number of donors (5, 15, 18, 19, 27, 28, 29).

In the IRRI RTV breeding program, use of resistant varieties Intan, Sigadis, TKM6, HR21, Ptb18, Pankari 203, BJ1, and others led to the release of IR20, IR26, IR30, IR32, IR36, and IR50 and to the development of more breeding lines with resistance. These have also been used in national programs (13).

At AICRIP, CRRI, and other institutes in India, Ptb2, Ptb18, Ptb21, ADT21, BJ1, Kataribhog, ARC15570, ARC11554, ARC13804, and Ambemohar have been used in breeding programs (5, 27, 28). RTV-resistant or -tolerant varieties (Triveni, Ratna, Pusa 2-21) reported in the country (5) are of limited value in rainfed lowland areas; however, resistant or tolerant varieties that have gained wide acceptance in rainfed lowlands are CNM 539 and CNM 540 in West Bengal (6) and IET7970 and Janaki in Bihar (7, 30). Improved lines that could be useful in endemic areas are IET7956, IET7958, and IET8558 (Table 3).

Table 3. Promising cultures with resistance to major rice diseases (4).

IET no.	Designation	Cross	Susceptibility index[a]	Mean days to flowering	Grain type[b]
		Bacterial blight			
7296	IR54	Namsagui 19/IR20718/IR2051-243-3-6	5	110	LS
8323	RP2151-175-1	IET4141/CR98-7216	4	127	LB
8324	RP2151-192-2	IET4141/CR98-7216	4	135	LS
8328	RP2151-224-1	IET4141/CR98-7216	4	122	LS
8584	RP2151-173-1	IET4141/CR98-7216	4	110	LB
8592	RP2136-43-2	IR8/IET4140	5	109	LB
	TN1 (susceptible check)		9	90	SB
	IET4141 (resistant check)		5	109	LB
		Rice tungro virus			
8559	RP1570-11-5-1	Rasi/ADT21	4	117	MS
7956	RP1125-46-3-2-1-1-2-1	RPW6-13/PTB2	3	113	MS
8122	RP1125-21-665	RPW6-13/PTB2	4	111	SB
7958	UPR231-28-1-2	Ratna/YR13-89-11	3	93	LS
8558	CR146-7003		3	106	LS
	Ratna (resistant check)		4	85	LS
	Jaya (susceptible check)		9	101	LB

		Sheath blight			
6903	RP1057-35-1-4	RS5-32/Pankaj	5	120	LB
7191	RP1057-184-5-3-2	RP5-32/Pankaj	5	112	LB
7193	RP1057-184-5-3-4	RP5-32/Pankaj	5	120	LB
7893	RP1821-5-1-3	OS4/Phalguna	5	113	MS
7895	RP1821-5-5-2-2	OS4/Phalguna	5	105	LS
6261	BR51-91-6	IR20/IR5-114-3-1	5	112	MS
6272	CR210-1017-607	Pankaj/Jagannath	5	116	SB
7300	CR149-7249-CRR-29	MNP36/CR12/Pankaj	5	115	MS
	Pankaj (resistant check)		5	117	LB
	TN1 (susceptible check)	*Blast*	8	90	LB
7252	RP1057-184-5-3-6	RP5-32/Pankai	3	131	LB
7591	RP1057-393-1	RP5-32/Pankaj	3	129	SB
7592	RP1057-394-1	RP5-32/Pankaj	3	128	SB
7521	RP1465-655-139	RP348-/IET2815	3	127	LS
8003	RP1854-266-4-4-23	Mahsuri/Beunjing	2	114	MS
8516	RP1883-873-6-1-2	IET5122/IR9168-13-1	3	118	LS
8556	RP125-625-939-1	RPW6-13/PTB2	3	119	MS
5912	RP1017-76-1-3-2	Sona/Mahsuri	2	120	MS
7191	RP1057-184-5-3-2	RP6-32/Pankaj	3	125	LB
6903	RP1057-35-1-4	RP6-32/Pankaj	3	125	LB
6466	TNAU17005	Dasal/IR20	2	115	SB
7296	IR54	—	3	107	LS
7283	IR52	—	3	100	LS

[a]Breeding lines with confirmed resistance in 2-3 seasons. Average disease scores recorded at 10 locations for BB, 2 for RTV, 2 for ShB, and 2 for Bl in 1983 kharif.
[b]LS = long slender, LB = long bold, MS = medium slender, SB = short bold.

In Bangladesh, RTV-resistant varieties Kataribhog, Habiganj Aman VIII, Ambemohar 159, ARC4236, ARC11353, ARC13904, Mala, J15, and Utrimesh were identified (15). Improved varieties include BR4, IR20, Mala, and Chandina (13).

Sheath blight

An increased incidence of ShB caused by *Rhizoctonia solani* Kuhn [*Thanatephorus cucumeris* (Fr) Donk] in India and other countries is attributed to susceptible modern varieties grown under better management practices. In India, ShB is gaining importance in Assam, Andhra Pradesh, West Bengal, and Orissa (Table 1). Unfortunately, resistant donors have yet to be identified, and most varieties reported to date have only a moderate level of resistance (17, 19, 24, 26). Some moderately resistant varieties that have been used in breeding programs are Pankaj, Ramadja, T141, and OS4. Among the released rainfed lowland varieties in India (Table 2), Pankaj and Swarnadhan have tolerance. IET6261, IET6272, IET7193, IET7300, and IET7895 — derivatives from crosses involving Pankaj — possess a moderate degree of resistance (Table 3) and should prove useful in the rainfed lowland areas.

In view of the nonavailability of highly resistant varieties and the polyphagous nature of the pathogen, breeding strategies suggested by Khush (13) might be useful for the development of ShB-resistant varieties for the rainfed lowland areas.

Blast

Bl caused by *Pyricularia oryzae* Cav. is one of the important diseases of rainfed lowland rice in many countries. In India, the late crop suffers from neck blast in isolated areas of Assam, Bihar, West Bengal, Orissa, and Andhra Pradesh. Many of the modern varieties currently grown in rainfed lowland areas are resistant or moderately resistant (Table 2). Rapid progress has been made in incorporating Bl resistance in high yielding varieties at AICRIP, CRRI, and other institutes. Local resistance donors (BJ1, MTU5, Co 4, ARC1250, MNP36, Manoharsali) and introduced donors (Sigadis, Zenith, Tetep, Tadukan) have been used. Multilocation testing in nationwide coordinated trials has facilitated the identification of improved breeding lines with a broad spectrum of resistance. Some promising lines for rainfed lowland conditions are presented in Table 3.

The breeding program for Bl resistance at IRRI has emphasized the use of diverse gene sources. Many resistant lines are derived from H105, Dawn, B589A4, Kan Bau Ngan, Gampai, Sigadis, Tetep, and Tadukan (13). Highly resistant varieties developed at IRRI include IR20, IR26, IR36, IR52, and IR54. These and other breeding lines developed at IRRI have been widely utilized in many national programs.

Sheath rot

ShR caused by *Sarocladium oryzae* (Sawada) Gams and Hawksworth has been reported in a fairly severe form in Bihar, West Bengal, Orissa, and Andhra

Pradesh (Table 1). In other countries, the economic importance of the disease has been identified (19). Most modern varieties are susceptible to ShR. Often the disease problem is aggravated by cold temperature at flowering or when plants are infected with other diseases such as RTV or BB. Among the released varieties in India, Mahsuri, CNM539, and Vijaya-Mahsuri are resistant or moderately resistant (Table 2). Due to the nonavailability of adequate and effective inoculation techniques to induce the disease in breeding nurseries, observations are made in endemic areas. Some of the promising cultures resistant to ShR in AICRIP multilocation testing are IET8144 (TNAU4691), IET8843 (RR123-2), IET8862 (NDR450), IET778 (CR280-4), IET7789 (MGL11), and IET8252 (Mahsuri/MR30).

Brown spot

BS caused by *Helminthosporium oryzae* Breda de Haan is a serious problem in rainfed lowland rice. It is widespread in eastern Uttar Pradesh, northern Bihar, and West Bengal in India (Table 1). Several resistance donors such as BAM10, CH45, and T141 have been identified (18, 20). As part of the AICRIP program, advanced breeding lines are evaluated in multilocation testing for their reaction to BS. Some promising lines are IET4106 (CR155-5029-21), IET6755 (NDR91), IET8252 (OR367-OP-11), and Rasi.

Multiple disease resistance

In different rice ecosystems, various diseases attack at different growth stages of the crop; furthermore, the incidence of certain diseases predisposes crops to other diseases. For example, RTV or BB infections in the early growth stages weaken the plants and predispose them to ShR infection. The synergistic action of two or more diseases causes extensive crop losses, indicating the need to develop resistance for more than one disease.

DISEASE RESISTANCE IN INTERNATIONAL RAINFED LOWLAND NURSERIES

It was only during the late 1970s that rice scientists began feeling that research efforts should be directed to the development and improvement of rainfed lowland rice. At a conference at IRRI in 1978, it was emphasized that varieties should be developed to suit particular agroecological situations in rainfed lowland rice areas. IRRI initiated the International Rainfed Lowland Rice Observational Nursery (IRLRON) in 1978 and the International Rainfed Lowland Rice Yield Nursery (IRLRYN) in 1981 to identify suitable varieties.

In 1978, 12 of 261 test entries of IRLRON were found resistant to Bl, 19 to BB, 6 to BS, and 18 to RTV. A few of the promising entries were IR32, IR3511-39-3-3 (resistant to BS and RTV), BR51-91-6 (resistant to BB and RTV), IR3518-106-2-25-3, IR5537-20-1-3-2, and IR5853-162-1-2-3 (resistant to BB and RTV). In 1980, 12 of 220 test entries of IRLRON were resistant to Bl, 11 to BS, 13 to BB, and 15 to RTV.

During 1981, test entries of IRLRYN and IRLRON were evaluated. The promising cultures having resistance to different diseases are listed in Table 4.

During 1982, 30 IRLRYN entries were evaluated against major diseases. Ten had resistance to one or more diseases (Table 5). Among 119 IRLRON entries, 10 were resistant to Bl, 12 were tolerant of ShB, and 38 were resistant to BB. Some had resistance to more than one disease (Table 6).

Table 4. IRLRYN and IRLRON entries with resistance to 3 diseases, 1981.

Varieties resistant to		
BB	RTV	BS
BR51-282-8	IR8073-65-6-1	IR4744-295-2-3
IR10751-143-2-3	C242	IR8073-65-6-1
IR10781-75-3-2-2	IR10199-12-8-2	IR36
IR13419-35-1	IR13365-253-3-2	IR42
IR10781-K 18-143-1-1	IR13419-35-1	
IR1414 753-86-2		
IR14875-98-5		
IR19083-22-2-2		
IR19431-72-2		
IR4819-77-3-2		

Table 5. Disease-resistant entries of 1982 IRLRYN.

Entry	Resistant to diseases in respective years		
	BB	RTV	Bl
BR4	1978	1978	
C168		1980	1980
IR10781-75-3-2	1980		1981
IR13146-45-2-3	1981		
IR13358-83-1-3			1981
IR46			1981
IR4819-77-3-2	1981		1981
UPLRi-3		1980	1980
RP975-109-2		1980	
BR51-282-8	1981		

Table 6. 1982 IRLRON entries with multiple disease resistance.

Entry	Resistant to[a]		
	Bl	BB	ShB
IR5931-110-1	•	•	—
IR7732-B-A 96-3	•	•	—
IR7732-RGA-B-A 96-1	•	•	—
Kabra	•	•	•
BR10	—	•	•
IR13146-45-2	—	•	•
TCA183-1	—	•	•
Mahsuri	—	•	•
IR13564-95-1	—	•	•
IR21178-39-PI	—	•	•
IR15853-89-7E-P3	—	•	•
IR4829-89-2	—	•	•

[a] • = disease score (SES) of 4 or less, — = score greater than 4.

OUTLOOK

Existing disease resistance breeding programs of national institutes and of IRRI are concerned primarily with the improvement of irrigated rice. Much of the available information on disease resistance in rainfed lowland rice is too sketchy. Concerted efforts of pathologists and breeders are needed to improve rainfed lowland rice varieties for disease resistance. This could be achieved by formulating disease screening nurseries exclusively for rainfed lowland areas. Existing breeding programs have to be strengthened. Many diseases such as false smut, narrow brown leaf spot, and leaf scald, which were hitherto minor problems, are gaining importance in isolated situations. Care must be taken to avoid increasing susceptibility to these diseases in future varieties. The old and the new problems could be contained effectively by dovetailing the efforts of national institutes and IRRI.

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BREEDING FOR SOIL STRESSES

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Soil toxicities are the most important constraints on rainfed rice production. The main soil toxicities in rainfed areas include coastal salinity, acid sulfate conditions, iron toxicity, peat soil conditions, and deficiencies of N, P, and Zn. In cooperation with national agencies, IRRI has organized attempts to develop varieties with tolerance for soil stresses. Since 1969, over 120,000 rices have been screened at IRRI. Tolerant donors and breeding lines have been identified, and a few varieties have been developed. To breed high yielding varieties with increased tolerance for soil stresses, more information is required, particularly on genetics, plant growth and stress interactions, mechanisms of tolerance, and screening techniques. Current procedures use conventional breeding methods in transferring tolerance from known donors. To accelerate varietal improvement work, a few breeding strategies and innovative methods have been proposed.

Although selecting and breeding for desirable agronomic characteristics and resistance to diseases and insects have been going on for decades, it was only recently that organized attempts were made to select and breed rice for resistance to soil stresses (42, 43). The main soil stresses are chemical, physical, and hydrological. This paper deals with chemical stresses.

SOIL STRESSES

The main chemical stresses are toxicities and nutrient deficiencies. Common toxicities in rainfed lowland areas are coastal salinity, acid sulfate conditions, peat soil conditions, and iron toxicity. The main nutrient deficiencies are those of N, P, and Zn.

Salinity. Salinity is a major obstacle to high yields on about 27 million ha of lands in deltas, estuaries, and coastal fringes in Asia, which are physiographically and climatically suited to rice production. About 1 million ha of shallow, rainfed, saline lands are currently cultivated. A saline soil is one that contains sufficient salt to impair plant growth. Saline soils have an electrical conductivity of the saturation extract (EC_e) exceeding 4 dS/m at 25 °C and usually a pH below 8.5. They vary widely in their chemical, physical, and hydrological properties. The salt content may range from <1 dS/m to >35 dS/m, pH from 2.5 to 8.5, organic C content from 1 to 50%, nutrient

status from low to moderately high, texture from sandy to clayey, and water regime from dry to deep flooding (3). These differences have important implications for breeding salt-tolerant rice varieties.

Acid sulfate soils. Acid sulfate soils are extremely acid clays with a high content of sulfate and a pH that is less than 3.5 in some layers in the upper 50 cm of the profile. They are derived from marine sediments high in sulfides (pyrites) and poor in bases. When submerged and anaerobic, they are nearly neutral in reaction and support salt-tolerant marsh plants. But when the water recedes or the land is drained, the pyrites are oxidized to sulfuric acid and the soils become extremely acid. Acid sulfate soils underlie some coastal peats. Of the 2 million ha of cultivated acid sulfate soils, about 0.6 million ha are shallow, rainfed ricelands. The chief growth limiting factors are toxicities of Al, Fe, and H_2S; P deficiency; and salinity. Breeding should aim at conferring tolerance for these conditions, with emphasis depending on site characteristics. Use of tolerant varieties will improve yield on current rice soils and enable the cultivation of idle lands where potential acidity is not severe.

Peat soils. Peat soils contain >12% organic C. Unless drained, they are submerged or saturated with water. The pH ranges from 3.5 to 7.5. Coastal peats are saline; inland ones are usually nonsaline. Peat lands cover about 30 million ha of lowlands in the humid tropics, mostly uncultivated. Because of land scarcity, Indonesia has planted to rice about 0.8 million ha of coastal peat lands. The main growth limiting factors include deficiencies of N, P, K, Cu, and Zn; and excess salt, H_2S, and water-soluble organic substances of unknown composition. Breeding for tolerance for peat soil conditions is determined by the nature of the peat soil and its hydrology.

Iron toxicity. Iron toxicity is caused by excess water-soluble Fe. It usually occurs on lowland soils whose aerobic pH is <5.0. About 7 million ha of shallow rainfed riceland in South and Southeast Asia may have the problem. Symptoms of the disorder are stunted growth, drying of the leaves, death, and a purple, reddish brown, orange, or yellow discoloration of the leaves. It is aggravated by interflow and low supplies of K, P, Ca, and Mg. Iron toxicity can be alleviated by drainage or liming. Since often neither is feasible, varietal tolerance should be exploited.

Nitrogen deficiency. Over 75% of the ricelands of Southeast Asia are N deficient. About 16 million ha are shallow rainfed ricelands. Although varietal differences in efficiency of N utilization exist (22), use of N fertilizer is still the best solution.

Phosphorus deficiency. Phosphorus deficiency limits rice growth on Ultisols, Oxisols, Andepts, Vertisols, Histosols, and acid sulfate soils. It may be due to a low total P content or to low availability or fixation of P fertilizer. About 12 million ha of shallow rainfed lowland rice are P deficient. Use of P-efficient varieties will permit adequate yields without P fertilizer on marginally deficient land and with less P fertilizer on strongly deficient soils.

Zinc deficiency. After N and P deficiency, Zn deficiency is perhaps the most important factor limiting wetland rice yields. The disorder occurs on calcareous, sodic, peat, poorly drained soils, and on most soils with pH >6.5.

Over 3 million ha of shallow rainfed ricelands are Zn deficient. Zn deficiency is characterized by chlorosis of the base of the emerging leaf, followed by the appearance of brown spots as the leaf matures. The spots coalesce to give the leaf a reddish brown color. Zn deficiency can be easily corrected by applying Zn to the soil or plant. Since Zn deficiency is due mostly to low availability rather than low total content, use of Zn-efficient varieties is feasible.

Implications of alternate flooding and drying. One characteristic of rainfed ricelands is alternate flooding and drying. Apart from drought tolerance, rainfed wetland rices should have tolerance for some aerobic soil problems — Fe and Zn deficiency in alkaline soils and Al and Mn toxicities in acid soils.

BREEDING FOR SALT TOLERANCE

More than 120,000 rices have been screened for tolerance for salinity, strong acidity, peat soils, Al and Mn toxicities, and deficiencies of P, Zn, and Fe; tolerant varieties and breeding lines have been identified (Table 1, 2). Major breeding efforts, however, have gone into selection and breeding for salinity.

Breeding for the development of salt-tolerant varieties is carried out by various institutions. Progress is slow because of lack of resistant sources, inadequate knowledge of the genetics and physiology of these traits, and inadequate screening and breeding techniques (2). Furthermore, plant growth and other environmental factors greatly affect the tolerance response. Most varieties grown on problem soils are traditional pureline selections very well adapted to local stress conditions; however, they have not been bred for improved grain quality and high yield. Therefore, breeding strategies should be focused to combine the adaptability of local varieties and genes for high yield, higher stress-tolerance, and pest and disease resistance. Stress-tolerant varieties must have ample tolerance genes to cope with all adversities.

Screening and selection criteria

Tolerance for salinity differs among rice genotypes (7, 9, 10, 14, 21, 23, 28, 30, 37, 39, 44) as shown by grain yield differences. Various screening and selection procedures have been proposed for isolating salt-tolerant varieties. The varieties are usually classified as tolerant or sensitive on the basis of

Table 1. Summary of screening of rices for soil stresses in rainfed lowlands, 1969-83.

Stress	Rices (no.)	
	Screened	Tolerant
Salinity	81,865	16,685
Iron toxicity and acid sulfate conditions	4,611	300
Peat soils	2,180	449
P deficiency	5,863	643
Zn deficiency	16,396	1,111
Fe deficiency	751	136
Al and Mn toxicities	613	71
N deficiency	12	5

Table 2. IR rices with tolerance for adverse soils.

TOXICITIES		
1. *Salinity*	2. *Alkalinity*	3. *Iron/acid sulfate*
IR36	IR36	IR36
IR42	IR46	IR46
IR44	IR52	IR52
IR46	IR54	IR4683-54-2-2
IR52	IR58	IR8192-200-3
IR5657-33-2	IR60	IR9217-58-2-2
IR8073-65-6	IR8073-65-6-1	IR9764-45-2-2
IR9764-45-2-2	IR8192-200-3	IR13149-43-2
IR9884-54-54-3	IR9736-16-1-2	IR13423-10-2
IR10198-68-2	IR9764-45-2-2	IR29385-1-1
4. *Peat soils*	5. *Boron*	6. *Aluminum/manganese*
IR34	IR42	IR36
IR36	IR46	IR43
IR42	IR48	IR46
IR46	IR50	IR48
IR52	IR8192-200-3	IR127-80-1
IR54	IR8608-298-3	IR577-11-2
IR2071-88-8	IR9129-209-2	IR661-1-170
IR8192-31-2	IR9217-58-2	IR2797-105-2
IR8192-200-3	IR9884-54-3	IR4432-52-6
IR9764-45-2-2	IR13426-19	IR6023-10-1

DEFICIENCIES			
1. *Phosphorus*	2. *Zinc*	3. *Iron*	4. *Nitrogen*
IR40	IR34	IR24	IR5
IR42	IR36	IR36	IR36
IR44	IR50	IR43	IR42
IR48	IR52	IR52	
IR50	IR54	IR3839-1	
IR54	IR4683-54	IR44[illegible]-52-6	
IR8192-200-3	IR8192-31-2	IR8[illegible]2-166-2	
IR9129-209-2-2-2-1	IR8192-166	IR9129-456-2	
IR9217-58-2-2	IR8192-200-3	IR9209-181-2	
IR9764-45-2-2	IR9764-45-2-2	IR13168-143-1	
IR14632-21-3			
IR15791-163-1-3			

germination tests (11, 12, 38, 40, 46, 48, 49), seedling survival (17, 27, 51), root growth (13, 29), and yield (7, 14, 37). In all tests except those involving yield, young seedlings (8-14 d old) are used.

Efforts have sought to identify a single parameter that could be used as the criterion for mass screening. Parameters generally proposed are leaf injury rate (26, 27, 41, 45), Na and Cl accumulation (18, 19, 24, 26, 31, 37, 39, 50), and development of phloem tissue under saline conditions (15). Salinity effects in the rice plant are very complicated. Plants under saline conditions suffer from morphological, physiological, and nutritional effects that in turn are modified by various environmental factors (35, 42, 47), so it may not be feasible to select a single parameter. Selection of salt-tolerant donors on the basis of one criterion could jeopardize a breeding program. Salt tolerance is not a constant property but varies with age of the rice plant. Salt-tolerant varieties Jhona 349 and Getu, for example, had less tolerance at the early seedling stage but

exhibited considerable tolerance beyond 3 wk (37). Varieties such as Nona Bokra and Pokkali were highly tolerant at EC 10 dS/m during the seedling stage but showed a 30% seed set when grown in solution culture at EC 10 dS/m under controlled conditions and a 45% seed set in a saline field at EC_e 10 dS/m. It seems that the response of rice plants to salinity is directly related to salt concentration, plant growth stage, and duration of salinization. Therefore, it is necessary to evaluate tolerance in relation both to salt concentration during the growing season and to grain yield.

Genetics of salt tolerance

The few studies conducted so far on the genetic behavior of salt-tolerant rice have shown that F_1 hybrids of tolerant/sensitive and tolerant/tolerant varieties have a higher degree of tolerance than the parents (5, 36). Transgressive segregation occurred in the F_2 (1), and salt-tolerant progenies could be selected in the F_3 and F_4 (4). Resistance to delayed-type panicle sterility induced by salinity was found to be a dominant character controlled by a few genes (6). Assuming that a genotype with a combination of many tolerant genes from different sources will cope better with adversities in saline conditions, pyramiding of genes from different sources is suggested.

Breeding strategies

Before planning any breeding strategy, it is necessary to recognize the following points reported in the literature:

- Saline soils vary widely in their physical, chemical, and hydrological properties.
- Genetic variability for salinity exists among rice varieties.
- Tolerance varies with the age of the rice plant and its stage of development.
- The early seedling and flowering stages are more sensitive than the germination and vegetative stages.
- Grain yield is much more affected than straw yield.
- Accumulation of K in the plant decreases with increase in salinity.
- The discriminating level of salinity is around EC 8 dS/m.
- No single parameter confers salt tolerance.

Interdisciplinary breeding approach. At IRRI, an interdisciplinary breeding approach (GEU — Genetic Evaluation and Utilization — Program) was started in 1973 to build tolerance for biological as well as soil stresses into varieties. It combines efforts of plant breeders and soil chemists to select and breed rices for adverse soil conditions. All breeding materials — i.e., progenies, advanced lines, and elite lines, including those not particularly developed for stress conditions — are exposed to salinity. Three lines — IR5657-33-2, IR9764-45-2-2, and IR11418-19-2-3 — that perform well have been selected. They were derived from complex crosses involving as many as 16 parents and do not have any known tolerant parent in their pedigrees.

Screening and testing in target areas. Rice is moderately susceptible to salt injury (34). Yields start decreasing above EC_e 3 dS/m and are significantly

decreased at EC_e 8-10 dS/m. This range of salt concentration may be used for identifying salt-tolerant donors. Because of low repeatability of results due to wide environmental fluctuations from season to season, year to year, and location to location, it is suggested that donors be tested under controlled conditions from seedling to maturity, and then rigorously tested in fields in target areas under different climatic conditions in collaboration with national programs. Genotypes possessing tolerance at the seedling and flowering stages should be identified and used to develop elite genotypes with enhanced salt tolerance.

Breeding methods

Pedigree method. The pedigree method has been used widely at IRRI for salt stress breeding. Well-known tolerant donors such as Pokkali, Nona Bokra, Kalarata, Jhona 349, and Damodar are hybridized with parent of superior characteristics; progenies are screened in artificially salinized soil (EC_e 8 dS/m) in greenhouse and in field conditions. Promising lines are then tested for yield performance in saline areas of the Philippines. Elite lines are further tested for adaptability and yield through the International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON). The following salt-tolerant strains have been developed:

Source	*Salt-tolerant strain*
Pokkali	IR4630-22-2-5-1-3
Pokkali	IR4630-22-2-17
Pokkali	IR4595-4-1-13
Nona Bokra	IR10198-66-6
Nona Bokra	IR9884-54-3

Male-sterile-facilitated recurrent selection. With the availability of genetic male sterility in indica rice IR36, it is now possible to use population breeding methods such as male-sterile-facilitated recurrent selection. Male sterility facilitates crossing in population improvement schemes. There is free flow of genes or gene combinations as in cross-pollinated crops (20). Thus, it is possible to recover even the rarest combination of characters. By this method, salt tolerance could be considerably increased by combining the various donors to produce a population with a broad genetic base from which salt-tolerant genotypes adapted to various agroclimates could be selected.

Biparental mating approach in selected crosses. The biparental mating approach is used to break undesirable linkages. It seems particularly useful for breeding salt-tolerant rice varieties where an undesirable linkage is common between the low yield of the salt-tolerant local parent and the high productivity of the other, low-tolerance parent. Biparental mating involves intermating of selected plants in the F_2. Such intermating has been found to change the population means in the F_3 and break the genetic linkages, especially in crosses showing heterosis in the F_1 and least reduction in the F_2.

Biparental mating in breeding high yielding rice varieties has been emphasized (32).

Haploid breeding. The haploid breeding method has the advantage of fixing the genetic recombinants in the immediate generation. The major steps are

- selecting crosses showing heterosis for salt tolerance,
- following anther culture of the desirable F_1's,
- obtaining true breeding lines by doubling the chromosomes of the haploids,
- evaluating the doubled haploid progenies for salt tolerance and other agronomic characteristics, and
- selecting true breeding and better yielding lines possessing a high degree of salt tolerance.

Somaclonal variation and mutant isolation. Tissue culture per se is an important source of somaclonal variation. Somaclonal variation for disease resistance and other agronomic characteristics has been reported in sugarcane, potato, and other crops (33). The method needs to be exploited in rice, particularly to derive salt-tolerant lines. High yielding insect- and disease-resistant varieties lacking salt tolerance must be used to improve salt tolerance through somaclonal variation. It is easier to incorporate a single trait in an otherwise good variety than in a variety having high salt tolerance but low yield potential and undesirable agronomic characters. The method is promising, as each cell is a potential plant; large populations of cultured cells could be advantageously used to regenerate salt-tolerant mutant plants. Somaclonal variants for salt tolerance and Al toxicity through somatic cell culture have been obtained (25).

The cultured cells could be mutagenized to further increase the frequency of salt-tolerant plants. Mutagenized cells proliferate and are grown in a medium supplemented with high salt concentration. The surviving cells are selected and the plants regenerated. The progenies of the regenerated plants are screened for salt-tolerant mutants.

Another approach — mutagenizing the fertilized egg of rice — needs to be explored for isolating salt-tolerant mutants. At IRRI this method has been shown to induce salt tolerance in the sensitive Taichung 65 variety (8).

Wide hybridization. Most varieties and breeding lines developed at IRRI have the same degree of tolerance as known salt-tolerant donors such as Pokkali and Nona Bokra. To increase the salt tolerance of rice varieties, it is necessary to evaluate the genetic potential of wild species and to consider the possibility of wide crosses such as of the halophyte *Sclerophyllum coarctatum* with *O. sativa*. Anther culture of such wide crosses could be used to fix the desirable gene combinations. Salt tolerance has successfully been transferred from the wild species *Lycopersicon chessmanii* to the cultivated tomato (16).

The following points need to be considered when formulating breeding strategies for various stress conditions:

- An ideal high yielding plant type for the various stresses has not been clearly defined.

- Adaptability and productivity traits possess negative correlation; hence, the problem of a repulsion phase genetic linkage has to be overcome.
- The genetics of tolerance for various stresses is complex and is not understood adequately.
- Mechanisms of tolerance for various stresses are also not understood clearly.
- Selection for local adaptability needs to be done by screening and evaluating the breeding material in target areas.
- Tolerance for various stresses varies according to the stage of plant growth and is influenced by environmental conditions. Germplasm/ breeding materials should be screened under controlled and field conditions, preferably from seedling to maturity.
- Innovative breeding methods such as anther culture, somaclonal variation and mutant isolation (cultured cells and fertilized egg treatment), and wide hybridization need to be explored for increasing the salt tolerance of otherwise high yielding varieties.
- A shuttle breeding approach must be adopted for screening and evaluating breeding materials in cooperation with national program rice scientists in the target areas.

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SOIL, CROP, AND WATER MANAGEMENT

SOIL FERTILITY AND FERTILIZER MANAGEMENT FOR RAINFED LOWLAND RICE

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Soil nutrient availability to rice in rainfed lowlands is affected by mineralization-immobilization, oxidation-reduction, osmotic imbalances, and toxicities and deficiencies associated with chemical changes in the soil due to alternate wetting and drying. In relation to soil fertility and fertilizer use, management regimes consider such factors as prevailing cultural practices, rainfall patterns, and crop duration as well as soil conditions. Methods of application and forms of N, P, and K are discussed. Effective and efficient N management is the key measure. Ways to optimize N availability in shallow and medium rainfed lowlands are described, and suggestions are made to increase P and K availability to plants.

At least three factors distinguish lowland from upland soils: soil texture is heavier in the lowlands than in the uplands, lowland drainage is poorer, and moisture fluctuations in the lowlands lead to alternate wetting and drying.

With regard to management, rainfed lowland rice can be classified into four situations based on the amount and reliability of rainfall received during rice growth (4): rainfall during the vegetative and reproductive stages is adequate and assured, rains during the vegetative stage are inadequate and unreliable, rains are adequate and reliable during the vegetative stage but inadequate and uncertain in the reproductive stage, and rainfall is inadequate and uncertain during both vegetative and reproductive stages.

Rice-growing practices in an area vary with the situation. In areas where the monsoon comes late in the season, a system of dry-wet lowland rice is followed (4). In heavy-textured soil, lowland rice can be broadcast under dry conditions and later submerged; in coarse-textured soils, the practice is to transplant rice in wet fields.

MANAGEMENT IMPLICATIONS OF RAINFED RICE FARMING

Uncertainty of rainfall — too little at the proper time or delay in the onset — often forces the farmer to develop the rice nursery at the wrong time and to delay puddling and transplanting. The delay shortens the growing season, and the transplanted crops may run out of moisture during the reproductive stage, ultimately resulting in yield loss. Late transplanting of rice can cause a yield decline of 0.5-0.8 t/ha (14). See Table 1.

Table 1. Effect of date of planting on rice yield in India (14).

Center	State	Year	Av yield for given planting date					
			1		2		3	
			t/ha	Date	t/ha	Date	t/ha	Date
Kalyani	West Bengal	1980-81	3.3	28 Jul 1980	2.8	13 Aug 1980	2.1	30 Aug 1980
		1981-82	3.7	4 Jul 1981	3.3	21 Jul 1981	2.9	6 Aug 1981
Kharagpur	West Bengal	1980-81	3.3	1 Jul 1980	3.0	18 Jul 1980	2.7	31 Jul 1980
		1981-82	3.9	7 Jul 1981	3.7	23 Jul 1981	3.6	7 Aug 1981
Titabar	Assam	1980-81	4.0	4 Jul 1980	4.0	22 Jul 1980	3.5	1 Aug 1980
		1981-82	2.6	23 Jun 1981	2.9	7 Jul 1981	2.8	27 Jul 1981
Varanasi	Uttar Pradesh	1980-81	4.0	10 Jul 1980	4.4	23 Aug 1980	2.1	9 Aug 1980
Maruteru	Andhra Pradesh	1981-82	5.1	27 Jun 1981	5.1	7 Jul 1981	4.7	22 Jul 1981
Nandyal	Andhra Pradesh	1981-82	4.2	8 Sep 1981	3.6	18 Sep 1981	3.5	28 Sep 1981
Raipur	Madhya Pradesh	1981-82	3.9	13 Aug 1981	2.7	28 Aug 1981	0.9	10 Sep 1981

A slightly increased dose of fertilizer may often mitigate the loss by providing a more nutrient-rich soil environment. However, the farmer is not encouraged to invest in additional fertilizer for an expectedly subnormal crop. Using a five-village survey, Pal (9) analyzed the constraints to optimum productivity in some typical rainfed rice areas in Bihar and West Bengal — traditional wet season rice-growing states of India. He found that the high risk has discouraged the use not only of photoperiod-insensitive rice varieties, but also of modern inputs like chemical fertilizers for traditional rice.

From a soil chemist's viewpoint, rainfed lowland rice culture can be seen as managing a soil that is vulnerable to extremes — from a near dry to a submerged condition. Fertility and fertilizer use management are serious issues because nourishment of the crop has to be provided where the soil itself is destabilized. Nutrient availability to the crop remains a gamble on the balance of mineralization-immobilization, oxidation-reduction, osmotic concentrations, and toxicities and deficiencies associated with chemical and electrochemical changes due to variable soil moisture conditions caused by alternate wetting and drying. The nature and severity of the problems depend upon soil properties and the time and duration of drying.

Ponnamperuma and Ikehashi (13) summarized the nutrient deficiencies and toxicities that are likely to be associated with the chemical and electrochemical changes in completely reducing as well as in alternately reducing and oxidizing conditions. When the rains fail and the soil dries, redox potential increases, and if the situation continues for more than 2 wk, rice may suffer from Fe deficiency in neutral and calcareous soils and Mn toxicity in acid soils (12). Drying of the soil imposes other kinds of problems: Al toxicity and P deficiency in strongly acid soils, severe osmotic stress leading to specific Fe toxicities, and increased N loss due to nitrification-denitrification.

Optimum management of rainfed lowland rice in relation to soil fertility and fertilizer use must take into account such factors as prevailing cultural practices, rainfall amount and distribution during the crop season, crop duration, and soil conditions such as texture, organic matter content, salinity-alkalinity, nutrient deficiencies, and toxicities.

NITROGEN MANAGEMENT

N management of lowland rice is intimately linked with water management. Besides runoff losses from any topdressed material, there are established channels for chemical and microbiological losses of N, including volatilization, leaching, and denitrification. The latter two generally occur only after nitrification has taken place; nitrate formation is thus a prerequisite.

Leaching causes major loss only in highly permeable soils where urea itself can leach without going through the stages leading to nitrification. Under most lowland rice situations, the major loss seems to be caused initially by NH_3 volatilization and thereafter by denitrification. Any management technique for efficient N use and reduced N loss must necessarily look for ways to control or retard nitrification. Placement of ammoniacal fertilizer such as urea super-

granules (USG) in the reduced soil layer is one such technique; others are use of nitrification retarders or inhibitors along with urea, and application of slow-release fertilizers like sulfur-coated urea (SCU).

Management in shallow lowlands

Most shallow lowland soils are productive, and problems are comparatively few. Rice is generally transplanted, and the technology for fertilizer management in irrigated situations can be adopted. Split application of urea is often recommended, but placement of USG has a distinct advantage. Summarizing the results of trials under the All India Coordinated Rice Improvement Project (AICRIP) at 19 locations during 1980-83, Rao (15) concluded that USG is superior to best split urea (Table 2). According to him, on the 12 million ha of shallow lowlands growing rainfed rice it is possible to obtain an additional 10 kg of grain from every kg of N applied as USG. Analyzing the results of trials at the Central Rice Research Institute (CRRI), Cuttack, and those under AICRIP, Rao (15) observed that USG could be applied 15 d after transplanting (DT) on early or medium-duration varieties and 30 DT on long-duration ones without any significant yield decrease (Table 3).

Alcantara et al (1) summarized the results of N management in farmers' fields in Tarlac and Camarines Sur, Philippines, where about 46% of the rice area is rainfed. Best split urea had an advantage over deep placed USG, but SCU was as good. The poor performance of USG was attributed to drought during the reproductive stage. An important observation made by these

Table 2. Efficiency of urea supergranules (USG) in lowland transplanted rice (15).

Treatment[a]	Grain yield[b] (t/ha)				
	1980(2)	1981(4)	1982(4)	1983(8)	Mean
No N	3.2	3.2	2.8	2.8	3.0
28 kg N/ha as urea, basal and incorporated	3.7	3.8	—	—	—
28 kg N/ha as urea, split	—	4.0	3.5	3.3	—
28 kg N/ha as USG, placed 7 DT	3.9	4.3	4.0	3.6	4.0
56 kg N/ha as urea, basal and incorporated	4.0	4.0	—	—	—
56 kg N/ha as urea, split	—	4.2	4.0	3.9	—
56 kg N/ha as USG, placed 7 DT	4.7	4.6	4.7	3.9	4.5

[a]DT = days after transplanting. [b]Numbers in parentheses indicate number of locations.

Table 3. Effect of time of application of urea supergranules on rice grain yield (15).

Time of application (DT)[a]	Grain yield[b] (t/ha)		
	1981 (5)	1982 (13)	Mean
5	4.7	4.1	4.4
10	4.7	4.1	4.4
15	4.5	4.0	4.3
20	4.2	4.0	4.1

[a]DT = days after transplanting. [b]Numbers in parentheses indicate number of locations.

authors is that fertilizer contributes about 50-80% toward the improvement of rice yields on rainfed farms.

Fertilizer management under different systems of rice culture should consider the following points:

- Deep placement of USG is superior to broadcast and incorporated urea + dicyandiamide (DCD) or to three split applications of urea because N loss is minimal. Floodwater NH_4^+-N concentration was lowest with USG point placement and highest with urea + DCD, suggesting higher N loss through volatilization with the latter treatment.
- Addition of DCD to urea or ammonium sulfate (AS) did not show any yield advantage over split application of urea or AS alone (Table 4), perhaps because DCD degradation is faster under tropical conditions.

Table 4. Effect of source of N and application technique on grain yield of irrigated and rainfed IR36.[a] IRRI, 1982 wet season.

Nitrogen treatment[b]	Grain yield (t/ha)	
	Irrigated	Rainfed
No N	3.6 b	2.1 f
At 45 kg N/ha		
PU, basal, surface broadcast	3.6 b	2.6 ef
PU, farmers' split	3.7 ab	2.8 de
PU, researchers' split	3.9 ab	3.2 cd
PU + 10% DCD, basal, surface broadcast	3.6 b	2.8 de
PU + 10% DCD, basal, B&I	3.9 ab	3.2 cd
AS, researchers' split	4.1 a	3.4 bc
AS + 10% DCD, basal, surface broadcast	3.8 ab	2.8 de
AS + 10% DCD, basal, B&I	3.8 ab	3.1 cde
SCU, basal, B&I	3.9 ab	3.8 ab
At 75 kg N/ha		
PU, researchers' split	3.8 ab	4.1 a
AS, researchers' split	4.1 a	4.2 a

[a]Av of 4 replications. In a column, means followed by a common letter are not significantly different at the 5% level by DMRT. [b]PU = prilled urea, farmers' split = ½ topdressed at 10 d after transplanting and ½ 5-7 d after panicle initiation, researchers' split = 2/3 broadcast and incorporated (B&I) just before transplanting + 1/3 topdressed 5-7 d before panicle initiation, DCD = dicyandiamide, AS = ammonium sulfate, SCU = forestry-grade sulfur-coated urea.

- In rainfed lowlands, N efficiency was higher when 50% urea was basal and incorporated and 50% topdressed 5 d before panicle initiation than when urea was all basal and surface broadcast. The farmers' practice (in the Philippines) of applying the whole dose of N fertilizer 30 DT was consistently inferior.
- In rainfed lowland rice trials, in the absence of any water stress during the growing period, grain yield from best split urea was comparable to that from nonconventional sources such as SCU, USG, urea + DCD, and AS + DCD. Where rainfall distribution was erratic and the crop suffered from water stress, particularly at the reproductive stage, crop response to N was poor and there was hardly any difference among the sources or their method of application.

The results obtained by AICRIP have not provided any conclusive evidence to support the superiority of USG over urea. Split application of urea tended to be better than root zone placement of USG when water control was adequate. USG was better in areas of poor water control, particularly in eastern India.

Reviewing the results of a study on N efficiency for rice production in nine countries during 1975-79 under the INPUTS (Increasing Productivity Under Tight Supplies) programs, Yamada et al (17) observed that a single deep application of urea (as USG) is better than its split application when the cation exchange capacity of the soil is higher than 10 meq/100 g and growth duration is shorter than 120 d.

Nitrogen management for medium-deep rainfed lowlands

Medium-deep rainfed lowlands occupy about 6 million ha in India. The rice crop is invariably direct seeded, and virtually no N is applied for fear of fertilizer loss due to water stagnation and runoff. On the basis of results obtained at CRRI during 1979, coordinated trials were initiated by AICRIP in 1980 and continued up to 1983. Available data from 14 locations are summarized in Table 5. Varieties were mostly tall indicas such as Mashuri, T141, Aijong, Nogoba, Samridhi, and Himdhan, although semitalls such as CR1018 and IET5882 were also included at some locations.

The benefits of fertilizer application to medium-deep rainfed lowlands were substantial. However, fertilizer must be applied subsurface and in one application at seeding time. Even the simplest way of broadcasting the fertilizer, plowing it in, and then sowing could increase the yield by 0.4 t/ha (25%), which is substantial for this type of rice culture (15).

Wherever seed is drilled or sown behind a plow (which is recommended), urea can be safely placed in the same furrow as the seed. This practice does not involve extra expenditure on fertilizer application; nor does it adversely affect seedling emergence. In fact, it further enhances fertilizer efficiency and leads to an increase of 0.6 t/ha (33%) in the yield. This practice is a better economic proposition than broadcasting fertilizer at seeding

The utility of USG for this situation appears spectacular, regardless of whether it is applied in the same furrow as the seed, between seed rows at

seeding, or between seed rows when plants emerge and water accumulates to a shallow depth. Yield increase with these three methods is around 1 t/ha, or 55% over unfertilized conditions.

Delayed planting and fertilizer dose

Application of an optimum fertilizer dose often somewhat offsets yield reduction due to delayed planting. A typical illustration, given in Table 6, is based on results obtained at Kalyani (West Bengal, India) under the All India Coordinated Agronomic Research Project.

Under severe and prolonged drought conditions due to irregular rainfall distribution, rainfed fields undergo frequent drying and reflooding, resulting in considerable N loss through sequential nitrification-denitrification. For such conditions, nitrification inhibitors may have a special significance and advantage. Under conditions of stagnant floodwater, point placement of USG should have an added advantage in that it will reduce not only denitrification loss but also NH_3 loss through volatilization. Leaching loss is generally negligible in typical lowland rice soils but can assume importance in coarse

Table 5. Effect of methods of N application on direct seeded rice in rainfed lowlands (15).

Treatment	Grain yield[a] (t/ha)				
	1980 (2)	1981 (5)	1982 (3)	1983 (4)	Mean
No N	1.8	1.8	1.9	1.7	1.8
40 kg N/ha as urea broadcast and incorporated before sowing	—	2.5	2.2	2.0	—
40 kg N/ha as urea in the same seed furrow	2.3	2.4	2.7	2.2	2.4
40 kg N/ha as USG in furrows between 2 seed rows	3.7	3.0	2.5	2.1	2.8
40 kg N/ha as USG between 2 seed rows in shallow water	3.7	2.9	2.8	2.2	2.9

[a]Numbers in parentheses indicate number of locations.

Table 6. Effect of date of planting and fertilizer dose on rice grain yield (2).

Treatment[a]	Grain yield (t/ha)
D_1F_1	3.7
D_1F_2	2.7
D_2F_1	3.0
D_2F_2	1.0

[a]D_1 = normal date of sowing (29 Jul 1982); D_2 = delayed planting (30 Aug 1982); F_1 = 100-26-33 kg NPK/ha; F_2 = 50-13-17 kg NPK/ha.

soils, particularly with alternate wetting and drying. Since leaching loss can be greater with USG under such situations, its application should strike a balance between the advantages and disadvantages. A combination of point placement of USG at planting followed by a suitable dose of urea as topdressing at or before panicle initiation might be the best approach under such conditions.

PHOSPHORUS MANAGEMENT

It is well documented that flooding increases the availability of P. Release of P in a flooded soil is accompanied by a decrease in redox potential because of 1) reduction of insoluble $FePO_4$ to more soluble $Fe_3(PO_4)_2$, 2) release of occluded P by reduction of hydrated Fe_2O_3 coating, 3) displacement of P from $FePO_4$ and $AlPO_4$ and from clay by organic anions, and 4) hydrolysis of $FePO_4$ and $AlPO_4$ (5).

Rainfed lowland rice soils undergo alternate drying and wetting. The increased availability of P under flooded (wet) conditions ceases once the soil becomes dry; and prolonged alternate wetting and drying reduces the percentage of P in the Al form and increases that in the Fe form (6, 11, 18).

Application of farmyard manure might help in keeping higher availability of P under situations of alternate wetting and drying. Another possibility is split application of P, half at transplanting and half topdressed along with N at tillering and mixed with the soil. However, no critical investigation has been done and therefore no specific recommendation can be made.

POTASSIUM MANAGEMENT

Available data show that variable soil moisture content, particularly that of alternate wetting and drying conditions, may result in either an increase in available K content (3, 8, 16) or greater fixation of K (10). The increase or decrease in K availability depends greatly on the clay mineral composition of the soil, but no reliable data on rainfed lowland rice soils are available.

Management of K does not appear to be a serious problem, but it would be advisable to make a basal application at transplanting to guard against any likely deficiency; K is also known to have some beneficial role against drought conditions and diseases.

CONCLUSIONS

Soil fertility and fertilizer use management for rainfed lowland rice center around effective and efficient N management. Application of liberal quantities of organic manure and placement of USG or use of urea in splits at appropriate times appear to be the key management strategies. Considering soil test and crop response, P and K must be applied along with micronutrients, especially Zn, particularly in neutral to calcareous soils.

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MANAGEMENT TECHNIQUES TO OVERCOME SOIL SALINITY PROBLEMS IN COASTAL RAINFED LOWLAND RICE

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Salinity is a serious problem, adversely affecting crop production in an estimated 2.5-3.0 million ha along the coastline of India. The affected states include West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Maharashtra, and Gujarat, and the Andaman and Nicobar Islands. The principal factors favoring salt accumulation in the profile are groundwater flows, inundation of soils by tide actions, wind sprays, and intrusion of seawater through rivers, estuaries, and creeks. The soils are generally medium- to heavy-textured, and NaCl is the dominant soluble salt. Coastal soils of Kerala have low pH and contain appreciable quantities of Na_2SO_4. In most coastal areas, high rainfall from June to September causes severe waterlogging. The areas are mostly monocropped with rice in kharif. Management approaches to increase rice production include provision of protective embankments and control structures to prevent intrusion of seawater while allowing drainage of excess rainwater. Proper bunding of the fields, provision of a system of surface drains, and the storage of excess rainwater in farm ponds provide relief from waterlogging. Raising of a second crop in winter or summer, and practices such as mulching favor the reduction of root zone salinity, thus enhancing production of kharif rice. Breeding rice varieties tolerant of environmental stresses peculiar to coastal conditions will further enhance and stabilize production from coastal salt-affected soils.

Soil salinity is a serious problem in areas along the 6,000-km coastline of India. The problem occurs in varying degrees in the states of West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Maharashtra, and Gujarat, and the Andaman and Nicobar Islands. While data on the extent of the area affected by salinity are lacking, the problem area is estimated at about 2.5-3.0 million ha. Table 1 shows the approximate distribution of affected areas in the different states and their rainfall. Rice is a major crop in the coastal areas in Gujarat, particularly the Saurashtra and the Kutch regions, where rainfall is low. This paper describes the nature of the salt problem and the management techniques being adopted to overcome it.

COASTAL SALT-AFFECTED SOILS

Formation

Salt-affected soils occur within a narrow strip of land adjacent to the coast and up to 50 km wide. The areas generally have an elevation of less than 10 m above

Table 1. Distribution and extent of coastal salt-affected soils.

State	Affected districts	Approximate area (thousand ha)	Rainfall (mm)	
			Jun-Sep	Oct-Dec
West Bengal	24 Parganas (North and South), Midnapore (East), Howra	800	1,325	177
Orissa	Balasore, Cuttack, Puri, Ganjam	400	1,140	180
Andhra Pradesh	Visakhapatnam, West Godavari, Krishna, Guntur, Nellore	40	570	330
Tamil Nadu	Madras, Chingalpet, Thanjavur, Ramnathpuram	4	310	480
Kerala	Ernakulam, Alleppey, Canannore	16	2,010	550
Maharashtra	Kolaba, Thana	40	2,700	130
Gujarat	Surat, Kaira, Ahmedabad, Surendranagar	720	930	30
Gujarat (Kutch region)			450	20
Andman and Nicobar Islands		15		
Area under mangrove vegetation		570	—	—

mean sea level and include the low-lying land of river deltas, estuaries, and depressions close to the coast. Soil salinity is attributed to the ingress of seawater along estuaries, creeks, drains, and rivers and to frequent tidal inundation of the land. The groundwater table is shallow, has high salt content, and contributes significantly to soil salinization in the dry periods.

The effect of tides is manifested in the regular rise and fall of the water level of the estuarine channels and creeks. The tidal flow repeatedly inundates the soils and impregnates them with salts. On the eastern coast in the Sunderbans (West Bengal), the highest tide inundates the lands to a depth of 2 m.

In almost all the coastal areas affected by salinity, high rainfall is received from June to September (kharif). As long as there are frequent rains, crop growth is not adversely affected. But any long break in the monsoon enhances the salinity of seawater and canal water substantially. With the receding monsoon and with the periodic inundation of the fields, the soil becomes more and more saline from October onwards.

The quality of groundwater depends on proximity to the sea and extent to which good quality water flows through the region. The coastal areas are also occasionally subjected to cyclonic storms, which, when accompanied by high tides, can severely damage the standing crops and inundate vast areas. For example, the Sunderban areas were inundated on 10-11 Dec 1981 with floodwaters having an electrical conductivity of 22 dS/m, resulting in

complete crop loss and raising the salinity of surface soil to 18 dS/m inland to a distance of several kilometers.

Characteristics

The coastal tract shows wide variations in soil characteristics; the soils are generally medium- to heavy-textured; NaCl is the dominant soluble salt except in Kerala, where the soils also contain large quantities of Na_2SO_4 (Table 2). While the salt-affected soils in the high rainfall areas tend to be slightly acidic (pH 6.5-7.0), those in the low rainfall regions tend to be neutral or alkaline (pH 7.5-8.0). The coastal salt-affected soils in Kerala are of acid sulfate type, and their pH is much lower (2.5-5.0).

The salinity of the coastal soils varies with the season and is at its maximum in May. Salinity decreases with the onset of the monsoon and is generally lowest during September. Figure 1 shows the variations in salinity of surface soil at the experimental farm at Canning, West Bengal.

Depth to groundwater and salinity of groundwater also show seasonal variation. In most of the coastal areas, subsoil water is encountered 1-2 m below ground level in the premonsoon season. It rises to the soil surface in the monsoon season and gradually falls in the dry season. The salinity of subsoil water ranges from less than 3 dS/m in the monsoon to over 13 dS/m in summer (Table 3).

Agricultural problems

Soil and water salinity, and lack of good quality irrigation water are the principal constraints affecting crop production in the coastal areas. The areas are mostly monocropped with rice grown in the rainy season, leaving the land fallow in winter until the onset of the next monsoon. The soils have impeded surface and subsurface drainage. The surface drainage problem is very acute because of heavily concentrated rainfall in the 4 mo of the monsoon season, flat topography, low infiltration rates, and the lack of a well-defined drainage system. Deep submergence during the monsoon season adversely affects growth of the rice crop, especially high yielding varieties. These factors, together with prevalent cultivation of traditional low yielding rice varieties and low level of management inputs, are responsible for low production in these areas.

MANAGEMENT PRACTICES

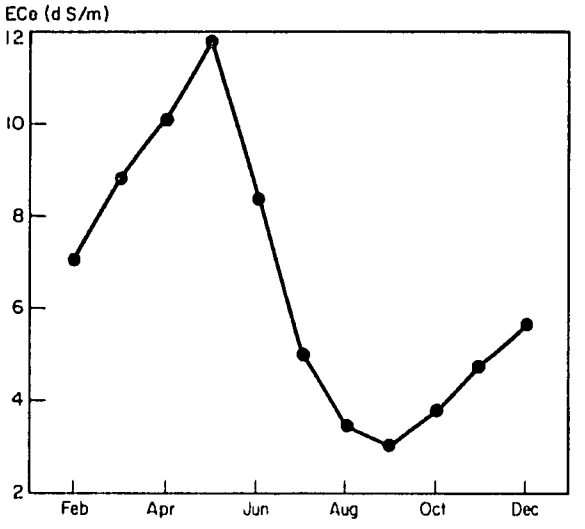
Management practices in the coastal areas can improve agriculture in general and rice production in particular.

Water management

Protective embankments. An age-old method for controlling salinity in coastal areas is the construction of embankments to stop the ingress of seawater. The recommended practice is to provide a freeboard of about 1 m above the high

Table 2. Characteristics of typical salt-affected soils.

Depth (cm)	Mechanical composition (%)				pH	ECe (dS/m)	CEC (meq/100 g)	Composition of the saturation extract (meq/litre)					Sodium absorption ratio
	Organic matter	Clay (2 μ)	Salt (2-50 μ)	Sand (50 μ-2 mm)				Na^+	Ca^{++}	Mg^{++}	Cl^-	$SO_4^=$	
Coastal saline soil, Canning, West Bengal													
0-12	0.4	34	26	40	7.2	27	15	156	29	120	213	16	18
12-28	0.3	45	38	17	7.5	7	18	38	11	17	57	8	10
28-80	0.3	46	38	16	7.5	7	20	43	17	19	73	9	10
80-105	0.3	40	44	17	6.7	8	16	48	16	16	75	9	12
Acid saline soil, Calicut, Kerala													
0-9	4.8	50	21	29	4.4	44	19	320	30	93	354	102	41
9-20	3.6	40	31	29	4.8	13	20	100	8	30	106	36	23
20-36	2.4	47	33	20	4.8	12	15	82	10	25	86	53	17
36-70	2.6	65	24	11	4.5	8	26	76	6	20	58	65	21
Coastal saline soil, Andhra Pradesh													
0-21	0.8	40	35	26	8.4	10	33	90	7	11	56	48	30
21-74	0.8	32	39	22	8.1	14	36	157	13	21	101	89	38
74-104	0.8	36	39	19	8.2	13	36	100	10	18	93	68	27
104-125	0.7	40	33	21	8.3	13	44	130	10	16	90	81	36



1. Seasonal changes in the salinity of surface (15 cm) soil at Canning, West Bengal, India.

tide level with a 3:1 slope on the sea or river side and 2:1 slope on the inland side. The width of the top of the embankment ranges from 1 to 3 m. The embankments require one-way sluice gates so that the ingress of seawater into the land is prevented during high tide and excess fresh water may be drained during low tide. A flume of 90-cm diameter with a manually operated screw gate on the inland side and a flap gate on the sea or river side effectively drains an area of about 2.5 km^2 at the rate of 30 cm/d. Operation of sluice gates more frequently and for longer periods during heavy storms helps in maintaining desired water levels for optimum crop growth.

Such embankments are constructed at huge cost. Their maintenance is demanding because of the constant erosive action of waves. There is need to identify appropriate trees and grasses that could be planted around the bunds to minimize wave action. Shelter belts also prevent the drifting of saline sands into the inland areas, thereby protecting the land from salinity.

Table 3. Seasonal variations of depth to water table and groundwater salinity at Canning, West Bengal.

Month	Rainfall (mm)	Depth to water table (cm)	Groundwater salinity (dS/m)
Jan	0	97	10.8
Feb	12	95	13.1
Mar	35	98	11.2
Apr	25	105	10.3
May	370	88	4.6
Jun	287	53	6.1
Jul	225	17	4.4
Aug	224	0	2.7
Sep	384	0	3.9
Oct	191	20	4.8
Nov	77	56	6.1
Dec	173	78	9.0

Field level control. Many coastal areas have practically no field boundaries, making on-farm water management almost impossible. Rao and Narayana (3) suggested the need for peripheral bunds to clearly demarcate the catchment and the various fields so that inflow of excess water into the catchment and the flow from one field to another are regulated. This would also provide field-level control of water level. About 25-30 cm peripheral bunds are recommended such that a minimum of 15 cm of standing water can be retained in the field to meet water requirements during probable dry spells. Channelization of the catchment — to route the excess rainwater from different zones directly to the outlet — and more frequent opening of the sluice gate for longer periods to maintain the desired water level in the catchment are recommended for effective water control at the field level.

Field studies at the Canning Research Station have shown that subsurface drains at a depth of 1.75 m and spaced 15-30 m apart are effective in lowering the water table and reducing root zone soil salinity. However, cost considerations preclude large-scale subsurface drainage installations.

Creating additional irrigation potential. Lack of irrigation is the major constraint in growing a second crop in many coastal areas. Storing excess rainwater in dugout ponds at the farm level for use during dry spells or for raising a subsequent crop appears to be a promising way to improve agricultural conditions in these areas. Excess rainwater can also be stored in the main drainage channels, in the re-excavated derelict natural channels at the catchment level, and in closed minor rivers and creeks. Data in Table 4 provide typical specifications of a pond for a 1-ha farm. The economics of farm pond development are favorable, and this practice needs to be taken up in a major way. Storing excess water in the pond can reduce the drainage needs of the area considerably. Raising the level of adjacent cultivated land can reduce the waterlogging problem, allowing cultivation of high yielding rice varieties.

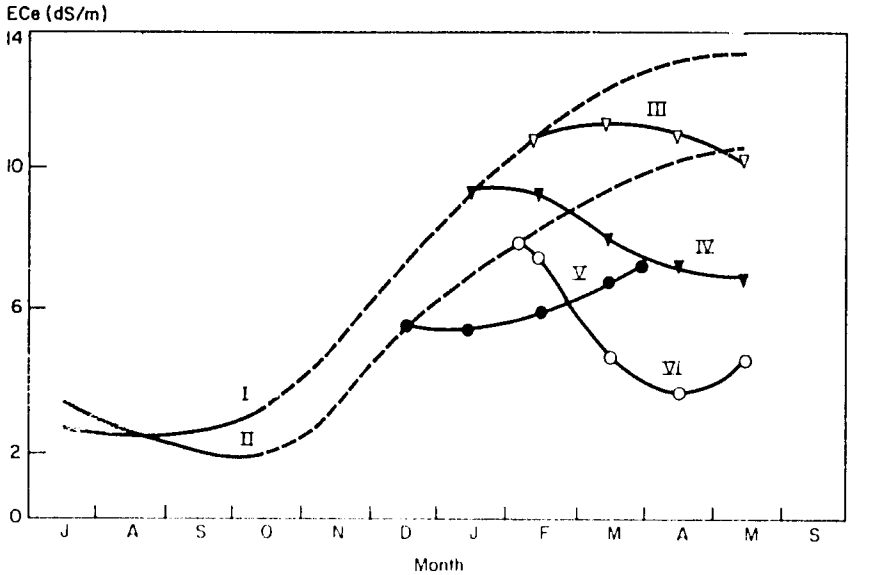
Soil management

Management practices that encourage leaching of soluble salts or prevent the accumulation of salts after the monsoon season ensure higher production of the subsequent rice crop. Proper land leveling and bunding ensure uniform leaching and drainage of excess water.

Salinity of the soil gradually increases during the postharvest period of wet season rice (Fig. 1), reaching a maximum before the onset of the monsoon.

Table 4. Typical farm pond specifications.

Size of holding	1 ha
Pond size at surface	42.3 m × 42.3 m (1,790 m^2)
Pond depth	3 m
Side slope	1:1
Depth of water that could be utilized for irrigation	1.5 m
Area that can be brought under irrigation for crops like chilies, watermelon	8,000 m^2
Volume of earth excavated	4,700 m^3
Height to which the remaining area can be raised	50 cm

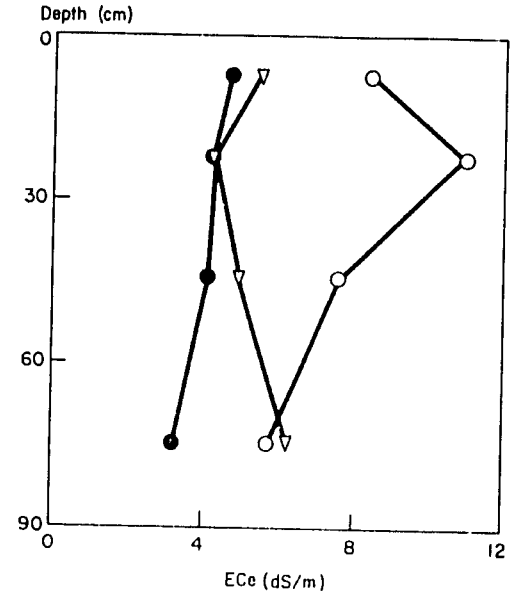


2. Changes in the salinity of surface (15 cm) soil due to different cropping sequences. I, II = rice in kharif followed by (fb) fallow, III = rice in kharif fb chili, IV = rice in kharif fb cotton, V = rice in kharif fb barley, VI = rice in kharif fb rice.

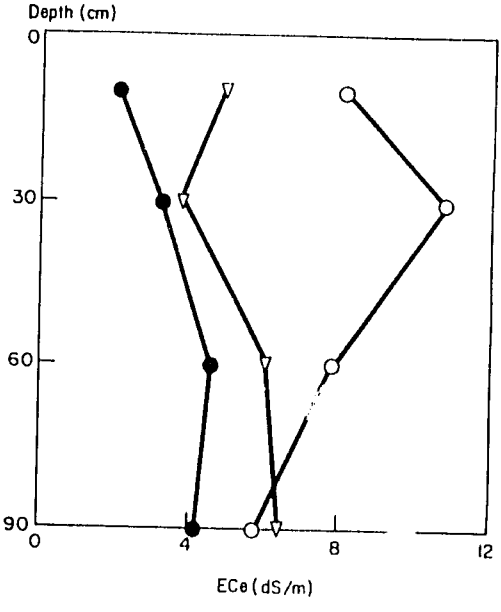
Soils are strongly salinized if the groundwater table is shallow and the salt content of groundwater is high, as is the case in most coastal areas. As far as possible, summer fallowing should be avoided. This can be accomplished by growing a second crop following kharif rice (Fig. 2). If sufficient water is available, the second crop should be rice, not only for additional production but also to increase the yield of the subsequent kharif rice (Table 5), because salts are leached from the root zone. If sufficient water is not available, crops needing less water such as chili, cotton, and barley can be grown. Figure 3 depicts changes in the salinity of surface soil when kharif rice was followed either by fallow, chili, and cotton, or by rice and barley in winter or summer. In the absence of winter cropping, soil mulching with such materials as rice husk, rice straw, or other organic wastes after the harvest of rainy season rice resulted in more favorable salt distribution in the soil (Fig. 4) and in increased yield of the following rice crop (Table 5). When other measures are not

Table 5. Grain yield of kharif rice as affected by land treatment during preceding winter or summer season.

Treatment	Grain yield (t/ha)		
	1st crop	2d crop	3d crop
Fallow	3.56	4.93	3.02
Rice	3.59	5.69	4.00
Mulching with rice husk at 10 t/ha	4.89	5.29	4.15
CD at P = 0.05	0.64	0.46	0.89



3. Distribution of salts in the soil profile initially (-o-) and after rice crops were grown in the rainy season (-∇-) and in winter (-•-).



4. Distribution of salts in the profile initially (-o-) and following monsoon rice with (-•-) and without (-∇-) application of rice husk.

possible, creation of a soil mulch by plowing the fields and leaving them as such will reduce salinization of surface layers to some extent and help obtain better yields of kharif rice.

Crop management

Tolerant varieties. Despite the adoption of proper soil and water management practices, salinity and waterlogging will remain major constraints in the

Table 6. Improved rice varieties suited to different salinity statuses and water regimes as recommended by Central Soil Salinity Research Institute.

Depth (cm) of standing water in the field	Sail salinity level[a]	Seed-to-seed duration[b] (d)	Varieties
< 15	low salinity	early	— Ratna, Cauvery, IET1444, CSR4 (Mohan)
		medium	— Jaya, RP6510
	moderate salinity	early	— CSR4 (Mohan)
		medium	— CSR1,CSR2, CSR3
	high salinity	early	— CSR4 (Mohan)
		medium	— CSR1, CSR3
15-25	low salinity	medium	— Jaya
		late	— Mahsuri, Pankaj, NC1281
	moderate salinity	medium	— CSR1, CSR2, CSR3
		late	— SR26B, Nona Bokra, CSR6, Malabati, Hamilton, Matla
	high salinity	medium	— CSR1, CSR3
		late	— Nona Bokra, SR26B, CSR6, Hamilton, Matla
25-50	low salinity	late	— SR26B, NC1281, Kalamota (Sel.), BKN6986 3(NS)
	moderate salinity	late	— SR26B, NC1281, CSR6, Hamilton, Matla, Kalamota (Sel.), NC540, IET6905

[a]Low = 5 mmho/cm, moderate = 5-8 mmho/cm, high = 8-10 mmho/cm. [b]Early = 110 d, medium = 120-130 d, late = 130 d.

coastal regions. Selection and breeding of rice varieties for tolerance for these adverse conditions has tremendous potential for increasing and stabilizing rice production. Efforts are under way at the Central Soil Salinity Research Institute Research Station at Canning and other stations to identify and breed varieties tolerant of one or more adverse environmental factors. A number of outstanding genotypes have been identified (1, 4): Damodar (CSR1), Dasal (CSR2), Getu (CSR3), Lalrani, ARC10399, Sadamota, and Nonasail. All are tall, photoperiod-sensitive indicas being used as parents in breeding programs. Some difficulties in obtaining desirable plant types for the coastal conditions include:

- paucity of information on the nature, extent, and seasonal variations in soil-related problems during the growth period of the crop;
- general nonavailability of multiple stress-tolerant varieties;
- insufficient information on the interaction of climate and soil stress; and
- general inadequacy of level of salt tolerance found in rice varieties.

Table 6 lists some improved rice varieties identified on the basis of their adaptation to three different maximum sustained water depths and three levels of salinity. Future breeding efforts must aim to incorporate desirable plant characters specifically suited to the environmental conditions prevalent in different coastal areas.

Plant population and time of transplanting. Rice transplanting is normally done after the onset of the monsoon. Since soil salinity is high in the initial period, it is advisable to increase the plant population by 20-25% to compensate for mortality and reduced tillering. Similarly when soils are highly saline, it is advisable to postpone transplanting for a few days until salts from the upper 8-10 cm have leached out.

Balanced fertilization. Balanced fertilization is necessary to optimize yields. Results of some of our experiments in the coastal areas show that the rice crop did not respond to P and K (2). However, there is a need to continuously monitor the changes over a period of time to make sound recommendations. Application of N split in three doses has resulted in optimum yields. Use of S-coated urea or lac-coated urea as N sources has also shown some promise. The micronutrient needs of rice grown in the coastal areas have not been studied in detail.

In conclusion, combining reclamation measures with proper soil, water, and crop management practices should break the stagnant yield barrier now prevalent in most coastal areas.

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EFFICIENT USE OF WATER FOR RAINFED LOWLAND RICE

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Extreme variations in the amount and distribution of rainfall in the humid tropics are major constraints to improving the productivity of rainfed lowland rice. The efficiency of rainwater utilization can be increased by proper soil and crop management techniques, and rainwater storage. The choice of available technology for efficient use of water in rainfed lowland rice depends on environmental as well as socioeconomic considerations. Under conditions of short wet season and high rainfall intensity and on heavy textured soils, puddled transplanted rice is desirable. Puddled, wet seeded rice may be best for areas where labor is scarce. Under conditions of long wet season and high rainfall intensity over a short period and on medium to light textured soils, nonpuddled, dry seeded (later bunded) rice may be used to increase cropping intensity, provided short duration and adapted rice varieties tolerant of changes in soil moisture conditions are used. Only a small portion of rainwater is effectively used for crop production during the peak of the wet season. Runoff water can be impounded in small farm ponds for use when the water supply is limited.

Rainfed lowland rice is grown on about one-third of the world's riceland, mostly in shallow water (15 cm) (4). In contrast to the advances that have taken place in the productivity of irrigated lowlands, there has been only a slow upward trend in the productivity of rainfed lowlands, mainly because of drought and flooding. These and other water-related constraints cause rainfed rice farmers to be more conservative in the use of modern technology.

This paper reviews research findings in rainfed lowland rice production that may be important in improving the productivity of rainfed lowlands through better utilization of available water.

WATER RESOURCE LIMITATIONS OF RAINFED LOWLAND RICE

Rainfall pattern and its limitations

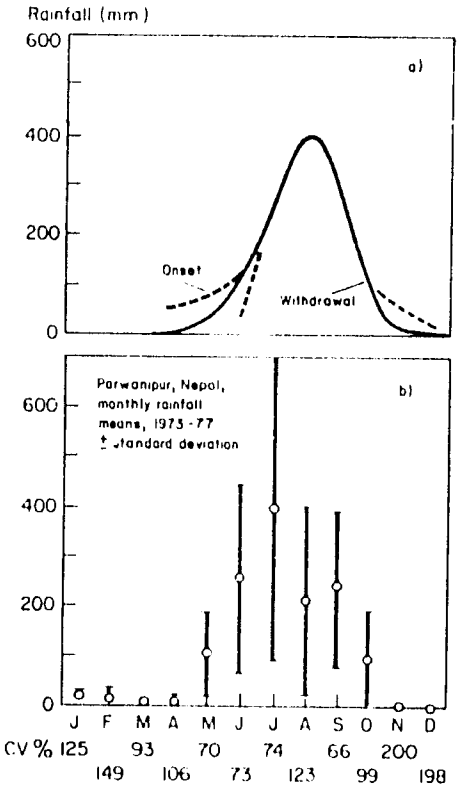
About 50-90% of annual rainfall over most parts of monsoonal Asia occurs during May-September. In the zone between 10° N and the equator, there are usually two peaks of rainfall — around February and October. South of the equator, the wet season usually starts in October and lasts until April or May.

Spatial and temporal fluctuations of monsoon rainfall are well known. The variations in the time of the onset and withdrawal of the monsoon are critically important. Figure 1 shows an example of the extent of such variations for the Terai of Nepal (8). Considering the recurrence of periods of highly deficient rainfall, every part of India except Assam and the adjacent states faces the probability of a drought at least once in 5 yr (Table 1) (17). Some regions like Gujarat, Rajasthan, Rayalaseema, and Telengana are subject to drought once in about 3 yr.

A breakdown of the climatic zones of the rice-growing regions of Southeast Asia was developed by IRRI (Table 2) based on monthly rainfall and the number of months with at least 200 mm rainfall (14). If monthly rainfall of 200 mm is the lower limit for lowland rice, and 100 mm the lower limit for secondary crops, the rainfed areas belonging to climatic zones II-3, III-1, III-2, and IV are the focus of efforts for increasing the efficiency of use of rainwater, particularly if year-to-year fluctuations in the monthly rainfall are sharp.

Other water-related limitations

The topographic sequence of rice production areas in relation to water supply has been described by several authors (13, 23). Most of the rainfed lowland rice



1. a) Annual rainfall distribution illustrating the extent of variability (dotted line) associated with monsoon onset and withdrawal periods, and b) rainfall distribution and variability common to the Terai of Nepal and northern India (8).

Table 1. Approximate probability of deficient rainfall during the monsoon in the various meteorological subdivisions of India (17).

Meteorological subdivision	Recurrence of highly deficient rainfall[a]
Assam	Very rare, once in 15 yr
West Bengal, Madhya Pradesh, Konkan, coastal Andhra Pradesh, central Maharashtra, Kerala, Bihar, Orissa	Once in 5 yr
Southern interior Mysore, eastern Uttar Pradesh, Vidarbha	Once in 4 yr
Gujarat, eastern Rajasthan, western Uttar Pradesh, Tamil Nadu, Kashmir, Rayalaseema, Telengana	Once in 3 yr
Western Rajasthan	Once in 2.5 yr

[a]Rainfall deficiency equal to or greater than 25% of normal.

Table 2. Climatic zones in Southeast Asian rice growing regions (14).

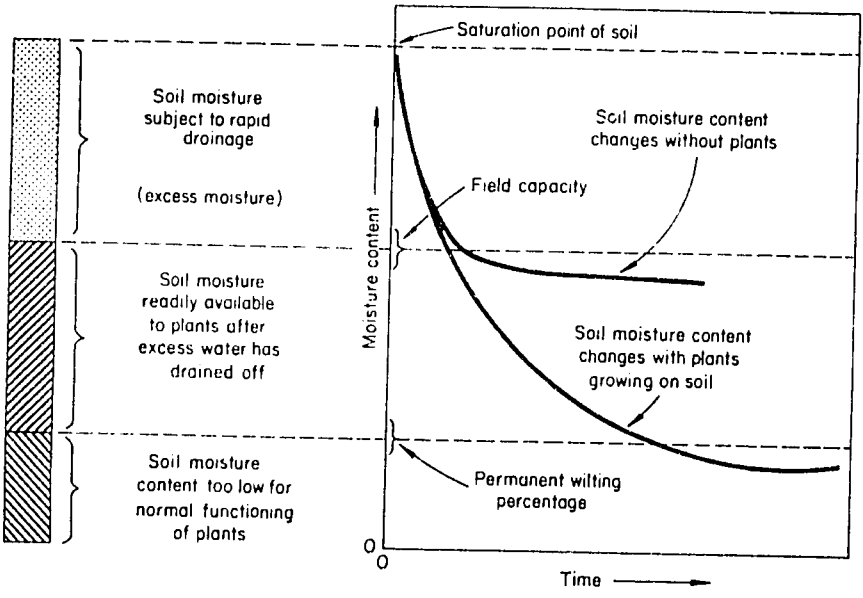
Climatic zone	Description	Utilization
I	more than 9 consecutive wet mo with 200 mm rainfall/mo	year-round cropping with two crops of puddled rice
II-1	5-9 consecutive wet mo with 100-200 mm rainfall/mo	year-round cropping with one crop of puddled rice
II-2	5-9 consecutive wet mo with 100-200 mm rainfall/mo during the remaining part of the year, and with another rainfall peak	suitable for multiple cropping; farmers are likely to grow two crops of puddled rice
II-3	5-9 consecutive wet mo with at least 2 mo of < 100 mm	possible to grow two crops in a year
III-1	2-5 consecutive wet mo with at least 100 mm rainfall/mo during the remainder of the year	limited possibility of growing two crops in a year
III-2	2-5 consecutive wet mo and a pronounced dry season with at least 2 mo < 200 mm rainfall/mo	limited possibility of growing two crops in a year
IV	less than 2 consecutive wet mo	not suitable for any type of agriculture

areas fall in the fluxial and phreatic parts of the landscape, and only some fall in the pluvial category. Drought usually occurs in the pluvial and phreatic parts, while flood may occur in the fluxial parts (Table 3).

Rainfed lowlands absorb rainwater either as stored water between the soil particles or water absorbed by soil particles. There are three practical parameters of soil moisture status as illustrated in Figure 2 (5) to which rainfed lowland rice may be subjected when water is scarce. Rice plants can tolerate soil moisture levels at field capacity and yield normally. Therefore, cultivation

Table 3. Topographic sequence for rainfed lowland rice in South and Southeast Asia and possible constraints to crop production (13, 23).

Topographic sequence	Water source	Constraints
Pluvial (upland plateau)	mainly rainfall	drought that may occur throughout the growing period
Phreatic (sloping plateau, sloping terraces, lowland plateau, lowland plains, river floodplains)	rainfall, seepage water, water table	less drought; drought may occur during the early growth period
Fluxial (floodplains)	rainfall, seepage water, water table, runoff	flood; prolonged submergence



2. Relationship among permanent wilting percentage, field capacity, range of readily available moisture, drainage, and moisture content (5).

techniques should be directed toward maintaining soil moisture as close as possible to field capacity when available water is limited.

Although there are no specific relationships between soil type and topographic sequence of agricultural lands (7, 14), the soil orders Entisols, Vertisols, Oxisols, and Inceptisols receive most attention in the management of crops and soil in rainfed agriculture.

Entisols that have aquic moisture regimes are very important for lowland rice production. The suitability of these soils for rainfed lowland rice production depends on changes in the water depth over time. Data from

Orissa, India (4), show water depth fluctuations with rainfall for different land categories (Fig. 3). The cultural practice necessary to grow rainfed lowland rice successfully must match the conditions resulting from not only rainfall but also topography.

Vertisols have high percentages of expanding clays, have very low water infiltration rates, and are very sticky when wet in contrast with their characteristics when dry. In some regions of India, the lands are fallowed during the monsoon, and then dryland crops are sown at the end of the rainy period and are grown on stored soil moisture (14).

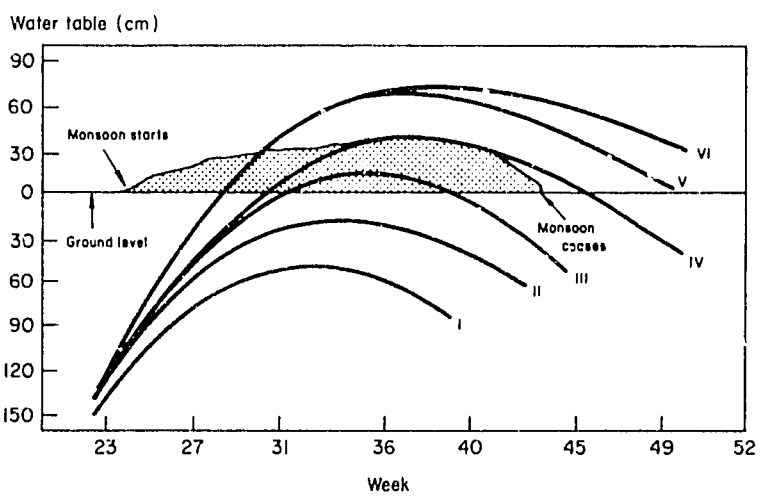
Oxisols have very high water infiltration rates. While puddling these soils tends to develop a layer of low permeability, some deep percolation may still occur even after puddling if a hardpan has not yet developed (18). To prevent water losses due to percolation, deep plowing may not be recommended on these soils in long established rainfed ricefields.

Rainfed lowland rice is widely grown on Inceptisols that are derived from pyroclastic materials if surface water is available and the terrain is suitable. In Southeast Asia many of these soils are porous, very permeable, and deficient in P (25). If managed properly, they can be highly productive.

Thus, knowledge of the characteristics of soils in rainfed rice areas is important to determine the kinds of technology for improving water use efficiency.

EFFECT OF WATER SHORTAGE ON RAINFED LOWLAND RICE

Variations in the onset and termination of the monsoon have technical as well as production consequences. Late onset delays land preparation and crop



3. Variation of water table in ricefields of various land categories in Orissa, India (4). Land category: I = highland, II = medium high, III = medium, IV = medium low, V = low, VI = very low.

establishment of rainfed lowland rice, and early termination causes drought stress at the reproductive stage.

The stress concept was used to help in deciding proper planting dates for maximum production of rainfed lowland rice. The number of days in excess of 3 without standing water in the field determines the number of stress days. A model used to estimate yields of rainfed lowland rice in Central Luzon, Philippines, with respect to N level and the number of stress days was developed (15):

$$Y = 2197 + 16.2\,N - 0.06\,N^2 - 47.8\,S^2 - 0.39\,NS$$

where Y is yield (kg/ha), N is the optimum level of N use (43 kg N/ha, which is defined as the point at which the marginal value of rice is twice the marginal cost of N), and S is the number of stress days during the growing season. Yield decreases as the number of stress days increases. Rice plants develop escape mechanisms to tolerate a certain degree of soil moisture stress, e.g., by closing the stomata and reducing the rate of evaporation. Rice yields are positively correlated with evapotranspiration rates (10).

Using the equation, yields of rainfed lowland rice planted at three different dates in Central Luzon were estimated (6). On the average, a 25% yield loss resulted from shifting the transplanting date by 26 d from 11 Jul, by which time cumulative rainfall equalled or exceeded the requirement for early crop establishment with a probability of 0.5 (Table 4). Similarly, 35% loss resulted from shifting 20 d from 1 Aug at a rainfall probability of 0.75. The growing

Table 4. Estimated yield losses for 6 yr (1969-74), resulting from delayed transplanting at 2 levels of rainfall probability, Cabanatuan, Central Luzon, Philippines (6).

Year	Yield loss (%) due to delayed transplanting		
	0.5 probability of rainfall[a]		
	11 Jul vs 7 Aug	*7 Aug vs 19 Aug*	*11 Jul vs 19 Aug*
1969	32	11	39
1970	0	8	0
1971	0	4	4
1972	36	46	75
1973	41	75	85
1974	29	12	37
Av	25	26	44
	0.75 probability of rainfall[b]		
	1 Aug vs 20 Aug	*20 Aug vs 31 Aug*	*1 Aug vs 31 Aug*
1969	36	45	64
1970	12	55	60
1971	0	18	21
1972	56	48	77
1973	82	100	100
1974	12	0	0
Av	35	30	55

[a]"Early" start = 11 Jul, "average" start = 7 Aug, "late" start = 19 Aug. [b]"Early" start = 1 Aug, "average" start = 20 Aug, "late" start = 31 Aug.

Table 5. Correlation coefficients between rice yield/ha and monthly or seasonal rainfall (24).

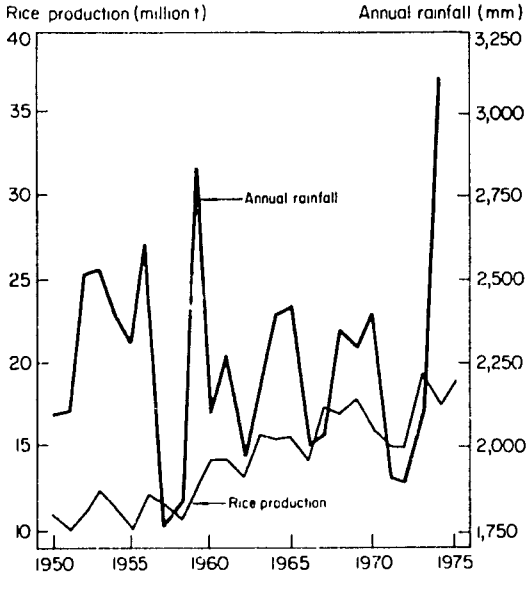
District	Rainfall for	No. of pairs of observation	Value of correlation coefficient	Level of significance (one-tailed test), if any
Chanda	Jun	34	0.17	0.005
	Jul	34	0.02	
	Aug	34	0.44	
	Sep	34	0.19	
	season	34	0.43	0.005
Ratnagiri	Jun	56	0.20	
	Jul	56	0.15	
	Aug	56	0.11	
	Sep	56	0.02	
	season	56	0.24	0.05

seasons starting from later planting suffered from more stress days during the critical stages of growth.

Table 5 shows that in Chanda and Ratnagiri, India, rainfed lowland rice yields fluctuated synchronously with the annual rainfall (24). The production of rice from 1950 to 1975 in Bangladesh (Fig. 4), where rainfed lowland rice is dominant, fluctuated in response to changes in annual rainfall (21).

AVAILABLE TECHNOLOGY FOR EFFICIENT USE OF WATER IN RAINFED LOWLAND RICE

A number of studies to improve the efficient use of water for rainfed lowland rice have been reported. The results are reviewed and discussed separately in



4. Bangladesh rice production from 1950 to 1975 plotted against annual rainfall (21).

this paper according to the crop production systems and objectives of the study: 1) a one-rice-crop-per-year system, and 2) a two-rice-crop-per-year system.

Water use efficiency refers to the ratio of crop yield and water supply. For example, in a one-rice-crop-per-year system under a rainfed environment, proper crop and soil management can 1) raise the yield of rainfed lowland rice under normal rainfall conditions, or 2) prevent yield loss when the rainfall falls below normal. In a two-rice-crop-per-year system, raising the total crop yield by increasing cropping intensity means more efficient use of rainwater per crop year. Research results are discussed based on these arguments.

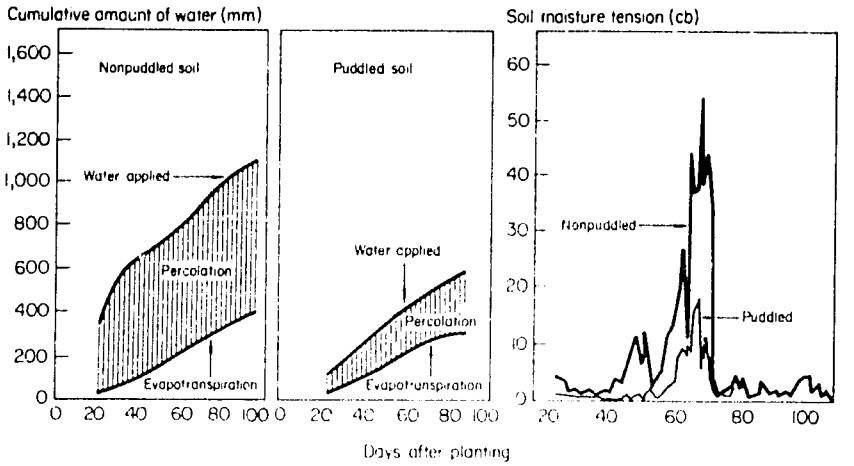
One rice crop/year

Puddled transplanted rice. The traditional method of preparing ricefields for planting consists of plowing and puddling the soil. Studies at IRRI (isohyperthermic, clayey mixed Aquic Tropudalf) showed that rice grown on puddled soil uses half as much water as rice grown on nonpuddled soil. Rice production on puddled soil was 2.5 times more efficient in water use than rice grown on nonpuddled soil because of decreased water losses through percolation and greater soil moisture retention in puddled soil (9). The soil moisture content of puddled soils stayed within the range of saturation and field capacity throughout the growing period of rainfed lowland rice (Fig. 5). Later studies at IRRI have differentiated among the degrees of puddling by classifying soil into granulated, paste, and muddy conditions based on the changes in apparent specific volume. In muddy soil, soil moisture was more available and rice yields were highest (12).

To puddle the soil, however, a large quantity of water is needed. Farmers may have to wait for heavy rains to impound water to facilitate puddling. In Central Luzon, Philippines, where farmers often transplant rainfed rice late in the season, there are frequent problems with water stress in the crop during the reproductive stages of growth, and consequent yield loss (6). Late plantings are often aggravated in light-textured soils because the water holding capacity is too low to sustain the rice crop over drought periods. Consequently, it may be best not to puddle such soils for rainfed lowland rice (11), particularly in areas where the wet season is short. In addition, when a puddled soil is exposed to dryness, soil cracks are wider and deeper than those for nonpuddled soils (11). Greater amounts of water are needed to saturate the soil (2).

Puddled wet seeded rice. For puddled wet seeded rice the fields are prepared as in the puddled transplanted system, and seeds are broadcast on the surface of the puddled soil. Despite its disadvantages — greater seed and weeding requirements — direct seeding requires less labor for planting. Therefore, the system is found in rainfed areas where labor is scarce.

Bangladesh has four crop seasons: March-September, March-December, June-December, and November-May. A combination of puddled transplanted and puddled wet seeded rice cultivation systems may be found in the same region. The first system is practiced in the shallow rainfed areas using



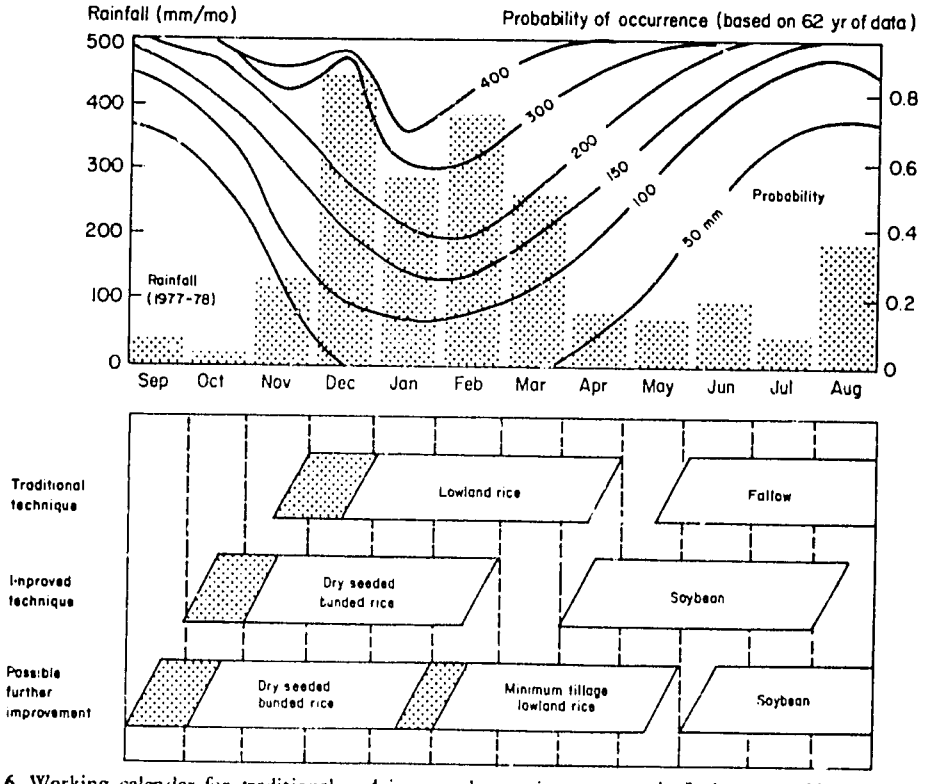
5. Comparison of cumulative water applied, evapotranspiration, and percolation loss in puddled and nonpuddled soils continually flooded at 5 cm; and soil moisture tension at 20-cm depth in puddled and nonpuddled soils. IRRI, 1972 wet season (9).

photoperiod-insensitive rices (1). The same procedure is followed in Burma (22) to better utilize available water.

Two rice crops/year

Nonpuddled, dry seeded, bunded rice. In rainfed areas where the onset and termination of rainfall are unpredictable, farmers have developed the system of nonpuddled, drop seeded, bunded rice, known in Indonesia as the gogorancah system. Rice seeds are dibbled or broadcast on a well-pulverized dry soil at the beginning of the wet season or a few days before it starts (27). The rice crop grows under dry soil conditions for about 5-6 wk after seed germination. Then the soil is flooded throughout the rest of the growing period by impounding rainwater in the field. If the amount of rainfall is less than usual, the soil may be kept dry up to harvest time as in the case of upland rice.

Agronomists in Indonesia have successfully introduced the gogorancah system into rainfed areas that have long wet seasons with high rainfall to increase the cropping intensity. A comparison of farmers' system and an introduced system of growing rainfed rice is given in Figure 6. Traditionally, farmers in Indramayu, West Java, Indonesia, puddle the soil (Vertic Tropaquepts) and transplant seedlings. About 250 mm water/ha over 20-30 d is needed for puddling. To fill this water requirement, farmers start cultivating the fields in the middle of November so that planting time falls not later than the third week of December. Because of late planting and use of long-duration rices, they successfully grow only one rice crop in a year. Using the gogorancah system, rice can be planted in the middle of November and harvested in February. Legumes or other suitable secondary crops may be planted after gogorancah rice and thus utilize the remaining rainfall. Cropping intensity

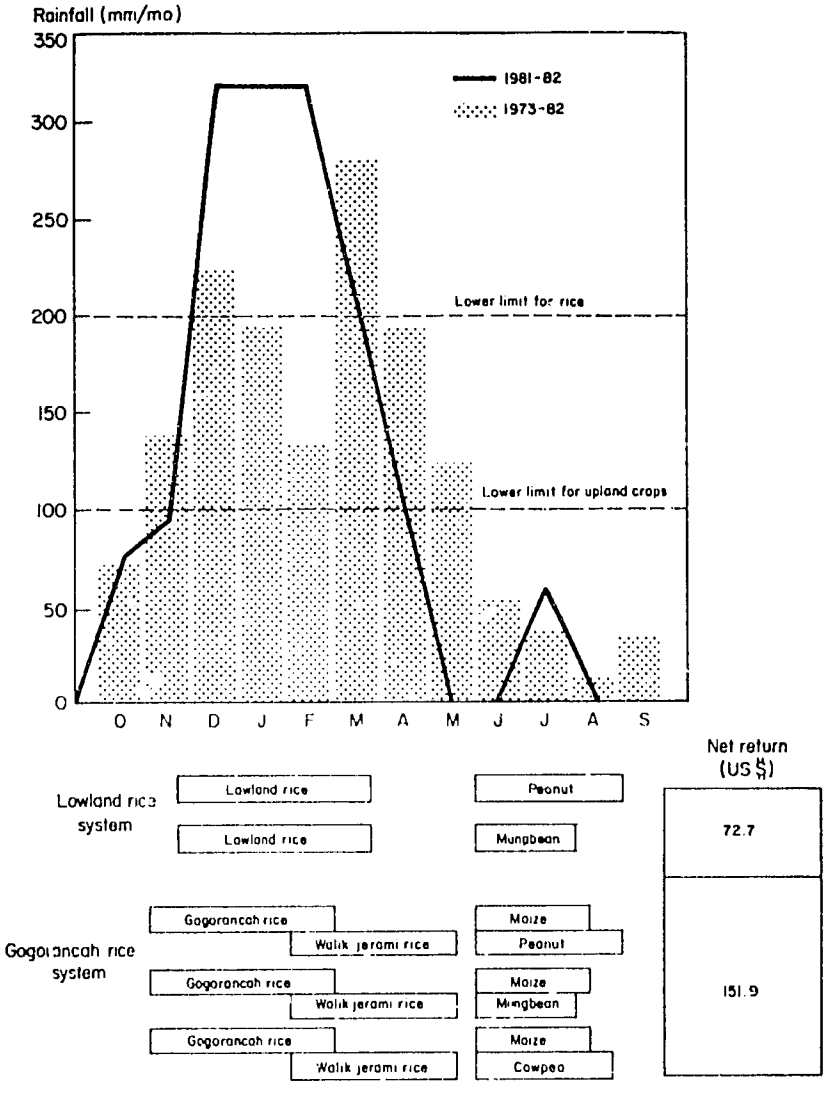


6. Working calendar for traditional and improved cropping patterns in Indramayu, West Java, Indonesia.

may be further increased by planting short-duration rice varieties in October, followed by walik jerami (minimum tillage, transplanted) rice in January. Legumes can be grown after the second rice crop using zero-tillage techniques. Rice straw mulch for secondary crops conserves soil moisture, as was effectively demonstrated at IRRI (M.P. Singh and S.K. De Datta, personal communication).

In recent years, the gogorancah system has been brought to other rainfed areas of Indonesia with less rainfall. Figure 7 shows that increases in cropping intensity by the use of the gogorancah system produced twice as much income as that from one puddled transplanted rice crop in Madura (19). On Lombok Island, wide adoption of the gogorancah system (about 30,000 ha) has changed the situation from food shortage to food surplus.

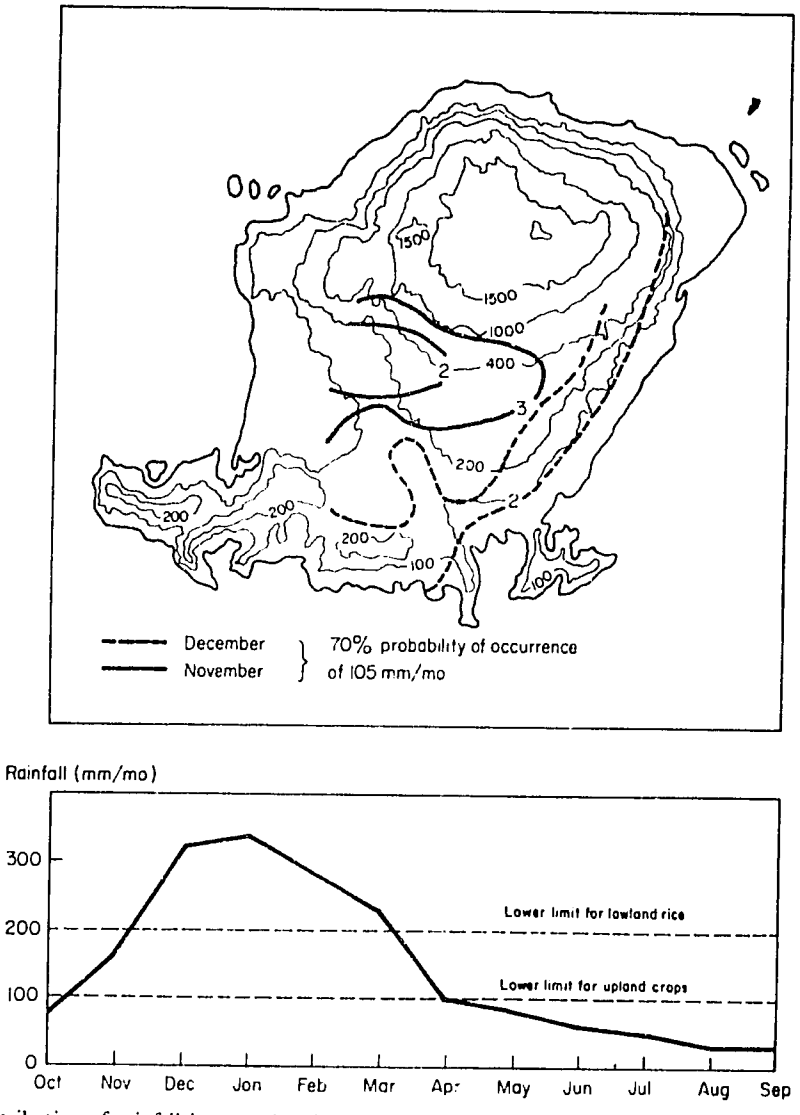
Environmental considerations. It can be predicted that with the two-rice-crop-per-year system at relatively high elevation in Central Luzon, Philippines, the second rice crop will fail in 3 out of 7 yr because of inadequate rainfall (6). To solve a similar problem in Indonesia, a system of using pondwater has become popular. About 70% of rainfall is effective at the beginning of the wet season, but only 20% at the peak of the wet season (29). The remainder of the rainwater is wasted in the form of runoff. In some cases,



7. Working calendar for traditional and introduced cropping patterns in Sampang, Madura, Indonesia, 1981-82 crop season (19).

runoff creates floods in the floodplains. The conventional flood control approach is to construct levees along the riverbanks to contain the water and to accelerate the flow of runoff water to the sea. In such an approach, many of the areas that are flooded in the wet season also suffer from drought during the following dry season (3).

Successful pond systems have been demonstrated in Sengkon, Lombok Island, Indonesia. A total of 1,700 mm rainfall/yr is adequate for rainfed lowland rice and secondary crops in that area (Fig. 8). The present cropping pattern includes gogorancah rice followed by secondary crops and takes 210 d



8. Distribution of rainfall in central and southern parts of Lombok Island, Indonesia, with 70% probability of 105 mm rainfall/mo in November and December, and monthly rainfall in Sengkon, where the pond system is implemented (28).

using only 1,050 mm rainwater. Small farm ponds with a storage capacity of 400 m^3 water cost about $400-600, and can increase the efficiency of rainwater utilization from 55 to 70% (28).

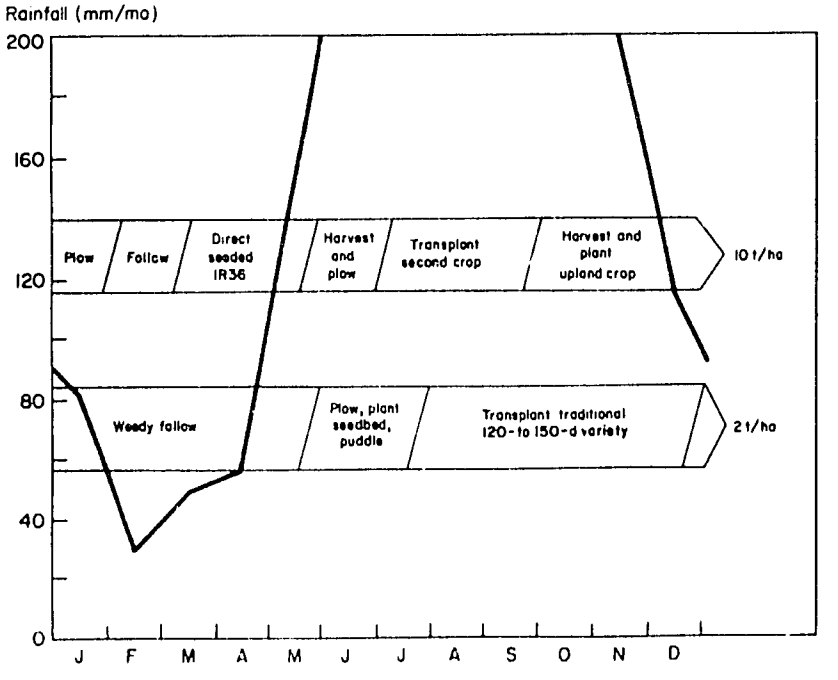
In addition to supplying water in case of drought, farm ponds can be used for aquaculture and can help minimize erosion.

Biotechnical considerations. Direct seeded rice in puddled soil followed by transplanted rice is suitable for rainfed areas that have long wet seasons and

high rainfall intensities. In Iloilo, Philippines, the practice of direct seeding rice and planting earlier was successfully implemented in the Kabsaka project (16). At the project sites, rainfall was efficiently utilized, cropping intensity was increased, and farm productivity increased by five times that of the traditional method (Fig. 9).

Use of short-duration, modern rice varieties is an important consideration in both the gogorancah and Kabsaka rice production systems. In the gogorancah system, the adaptability of rice varieties to changes in soil moisture status (oxidized soil conditions during vegetative growth and reduced soil conditions during reproductive growth) is critical. Tests of the adaptability of rice varieties and lines to gogorancah conditions conducted at Sukamandi (isohyperthermic Vertic Tropaquults), Indonesia, showed that several varieties such as IR36, IR32, IR26, Berantas, and Asahan (Table 6) gave higher and comparable yields, showing good adaptation to gogorancah soil conditions (26). Among upland rice varieties, C22 was most adapted to gogorancah soil conditions.

Weeds are a major problem in direct seeded rice (16). Herbicides effective in controlling weeds in rainfed lowland rice have been identified (20); however, they are not available in rural markets. Thus, hand weeding is still a popular method of controlling weeds but is labor-intensive. For example, the two-rice-crop-per-year farmers in Central Luzon, Philippines (direct seeded followed



9. Old system vs the new as practiced by Iloilo (Philippines) farmers who adopted a two-crop system for rainfed rice in the Kabsaka project (16).

Table 6. Grain yields of rice varieties and lines of lowland and upland origin planted under gogorancah system at the Sukamandi Experimental Farm (Vertic Tropaquults), 1979-80 wet season (26).

Variety and line	Grain yield[a] (t/ha)
Lowland origin	
IR36	5.5 ab
IR32	4.8 abc
IR26	4.8 abc
IR38	3.8 cde
Berantas	6.0 a
Serayu	2.9 de
Asahan	5.3 abc
Citarum	3.8 cde
Upland origin	
C22	5.2 abc
S55c-13	3.0 de
S55c-31	3.1 de
IRAT 9	3.9 bcd
IR3880	3.8 cde
Dular	2.3 e

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

Table 7. Effects of time of hand weeding at various N levels on grain yield of IR36 under the gogorancah system. Indramayu, Indonesia, 1980-81 wet season (A. Subardjo and A. M. Fagi, unpublished data).

N level (kg/ha)	Yield[a] (t/ha) with various hand weedings					Av yield[b] (t/ha)
	36 DAS	15+36 DAS	15+56 DAS	15+36+56 DAS	No weeding	
0	3.9	5.3	4.4	5.4	2.0	4.2 d
45	5.1	5.7	5.6	6.9	2.3	5.1 c
90	6.8	6.8	6.8	7.7	1.3	5.9a
135	6.3	6.8	7.2	7.4	0.9	5.7ab
180	5.3	7.2	6.7	7.6	0.9	5.5 bc
Av[b]	5.5 c	6.3 b	6.1 b	7.0 a	1.5 c	

[a]DAS = days after seeding. [b]In the column or row, means followed by common letters are not significantly different at the 5% level by DMRT.

by transplanted rice), produced 33% more rice than the one-rice-crop-per-year farmers, but their net farm income was about the same because of the higher labor requirement for weeding in the direct seeded first rice crop (6).

Field studies in Indramayu, Indonesia, on the interaction between N level and time of weeding (A. Subardjo and A.M. Fagi, unpubl. data) showed that IR36 yield decreased tremendously without weeding, particularly at high N levels (Table 7). This finding suggests that both nutrients and water are inefficiently utilized by rice.

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PHYSICAL CHARACTERISTICS OF LOWLANDS AND PROMISING TRADITIONAL AND NEW CROPPING PATTERNS

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The geomorphology and hydrology of lowland rice areas in India are described. The major cropping systems and patterns in the different soil-climatic regions are given, and promising traditional and new patterns are discussed.

Rice yield trends show that modern rice technology has largely bypassed the rainfed lowlands. Sharp year-to-year yield variations due to weather patterns are observed. During the past several years scientists have tried to understand the effect of unfavorable soil-water conditions on rice performance. Considerable efforts have been made to define and describe rainfed lowland rice-growing environments with emphasis on water depth (shallow rainfed lowlands, deep water, etc.). The information has been used to estimate the area under rainfed lowland rice. In India this is 20 million ha; in eastern India alone it is 10 million ha. It would be presumptuous, however, to state with certainty the amount of rice grown in each condition. The variable landforms and the hydrologic, climatic, and edaphic factors make a specific definition of rainfed lowland rice-growing systems very difficult. A better approach is through understanding the geomorphology and hydrology of lowland rice areas.

GEOMORPHOLOGY AND HYDROLOGY OF LOWLANDS

The distribution of the world's rice crop and its historical diffusion show that rice is mainly a wetland crop. The major rice areas are the extensive lowlands of southern and eastern Asia, which are exclusively river basins and deltas with their contiguous coastal plains. Rice-based cropping systems are thus clearly lowland systems. Rice is grown in these lowlands without much in the way of drainage and flood protection. Because of their hydromorphic nature, these lands are specifically suited to rice; no other food crop can be grown on them.

Lowland water regimes are not uniformly optimal for rice. Leveling and bunding have improved the distribution of water by collecting excess water from streams and the overflow from higher land in the bunded ricelands and distributing it by overflow to the lower ricelands, which have slowly permeable soils.

The physical characteristics and landforms of the lowlands are diverse, and their surface relief varies from place to place; no detailed geomorphological, soils, or hydrologic studies are available. The hydrophysical characteristics of these ricelands are directly related to the specific geomorphology of the landscape.

Major landforms in eastern India are meander floodplains and marine floodplains in coastal areas. Meander floodplains are found mostly in the middle course of major rivers and their tributaries; they are characterized by river beds with stream channels, river levees, and river basins. River levees are coarse textured. Away from the river, the soils are finer textured and hydromorphic because of slow sedimentation. There is a gradient away from the river, starting with medium-textured, well-drained soil where upland crops are grown, to very fine, clayey, poorly drained soil where lowland rice is the main crop. There are numerous meander floodplain patterns. In the Gangetic basin, the river channel commonly shifts, cutting away the levee. Often, meanders are abandoned when a river cuts a new bed and the old channels form into a lake. In eastern Uttar Pradesh and northern Bihar, numerous tributaries of the Ganges crisscross the plains; the floodplains show wide belts of abandoned river beds. Sometimes the river abandons its bed completely, forms a new bed, and builds a new river levee system where there was a basin.

The monsoon season is the annual flood period when river water overflows and floods the lowlands. The nature of flooding in the river floodplain depends upon the overall gradient, the rainfall regime of both plain and watershed or catchment area, and the degree to which the river bed and adjacent levees have been built up in relation to lower basin areas. Villages are located in the highest parts of the levees. There is a textural gradient from levees to basin. This transition of soil type from levee to the basin is used for growing a range of rice varieties varying from medium lowland to deep water rice.

In coastal areas, the transition between meander floodplains and the coastal plains is generally gradual, and it is difficult to draw a boundary between riverine and marine parts. In the Sundarbans in West Bengal, the presence of sediment deposits in a brackish water environment shows this kind of transition.

Generally, three physiographic-hydrologic types of ricelands are recognized (3): pluvial, phreatic, and fluxial. Since pluvial lands have free drainage, the lowlands are either phreatic or fluxial.

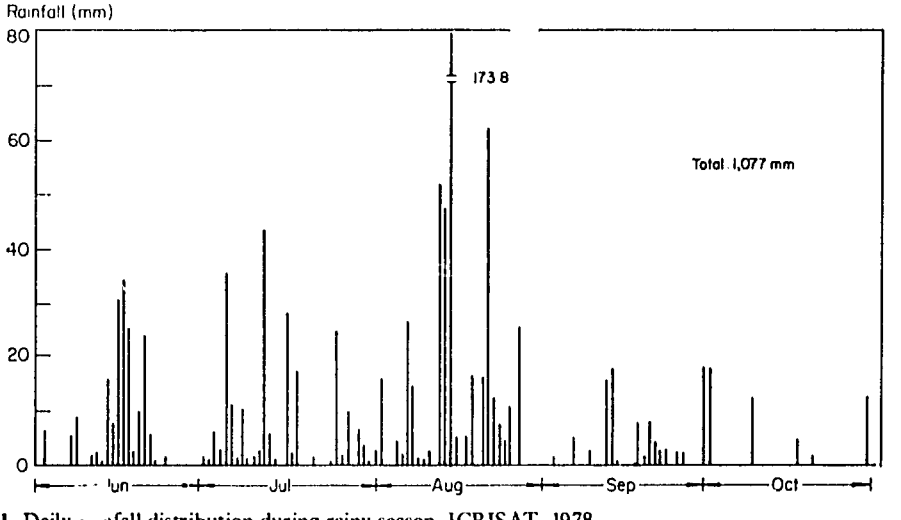
In phreatic lands, the water requirement of the rice crops is met by both rain and groundwater. The water table remains shallow at least during part of the cropping season. Water availability in the root zone during the growing cycle is influenced by the nature and distribution of rainfall, inherent soil characteristics, and soil management. In a given toposequence, the lower area is continuously influenced by water flowing laterally at shallow depth, and this interflow water is available in the root zone. In phreatic lands, rice can be grown with less drought risk.

Fluxial ricelands receive water wholly or partly from the surface flow —runoff or floodwater from rivers, streams, etc. These lands remain inundated during the cropping season. The duration of flooding precludes the growing of other upland crops in the rainy season. In fluxial ricelands, floodwater availability depends on the rainfall pattern and the runoff from the catchment areas of these lands. Heavy rains in the catchment can cause prolonged and deep flooding, while during failure of the monsoon little rainwater is available in the catchment. During drought years, floodwater is not a dependable source of water for rice growing, and both shallow and deep water rice suffer. During wet years, on the other hand, excessive rains in the catchment cause widespread flooding, damaging the standing crop. The rice plants may be drowned or uprooted and land damaged by scouring.

FLOODING REGIMES

In lowlands, the flooding pattern may vary from season to season and also within a single season. Several types of flooding regimes have been recognized (3): shallow, irregular, and brief or prolonged flooding; shallow and continuous uncontrolled flooding; shallow to moderately deep natural flooding; and deep seasonal flooding followed by shallow flooding. The flooding regime in the lowlands depends on the intensity and distribution of rainfall as is clear from ICRISAT weather data.

Weather data collected at ICRISAT, Hyderabad, show the problems of monsoon-based cropping, even in a semiarid region (2). During 1978, both the arrival and departure of the southwest monsoon were late. A total of 1,077 mm of seasonal rainfall (56% above normal) was received from June to October. Rainfall distribution data (Fig.1) show that of the five rainy months, four



1. Daily rainfall distribution during rainy season, ICRISAT, 1978.

—June, July, August, and October — received above-normal rainfall while September rainfall was below normal. The rainfall data collected at ICRISAT from 1977 to 1983 show that August rainfall was above normal in 5 yr and below normal in 2 yr, while the opposite was the case with September rainfall.

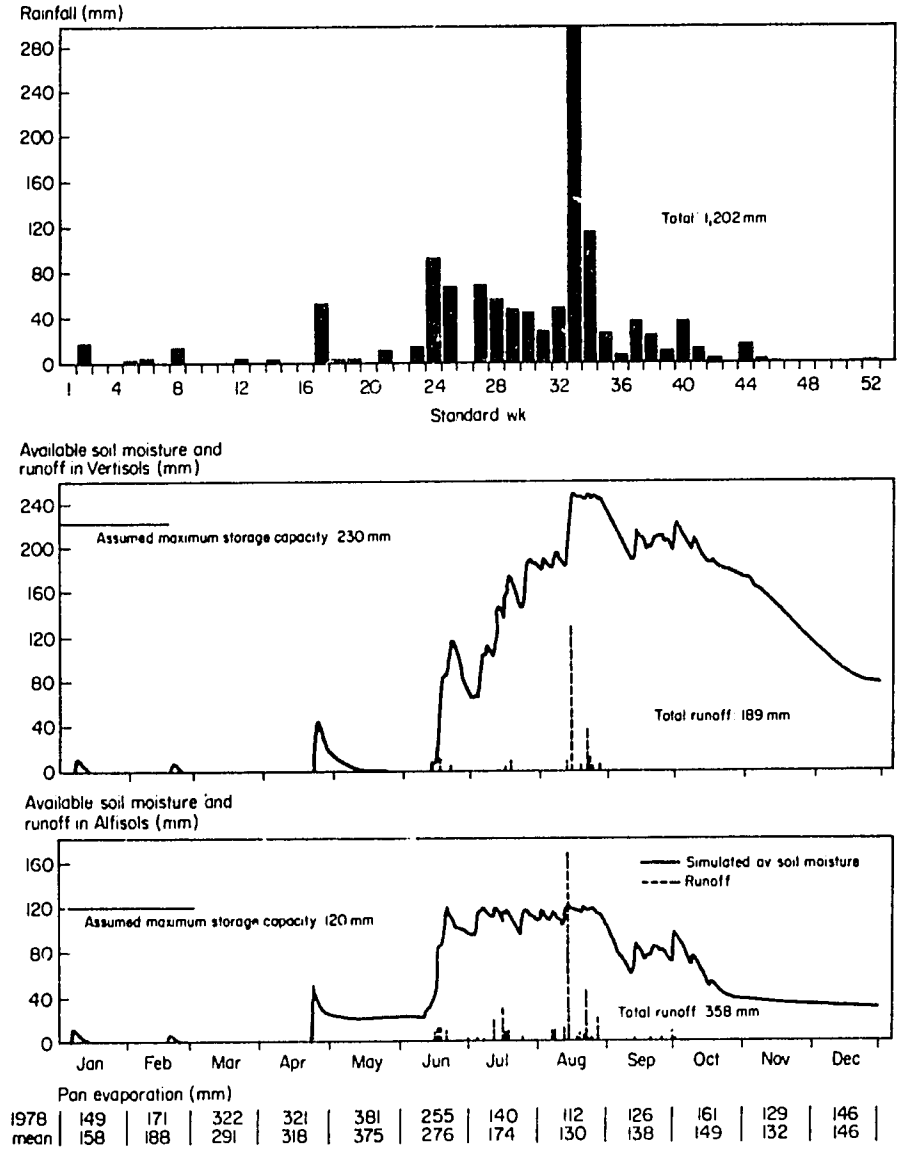
Data on rainfall associated with storms of different durations are presented in Table 1. In the 1978 rainy season several high-intensity, high-volume storms occurred. The most significant was the 15 Aug storm in which 85 mm of rainfall was received with an average intensity of 28 mm/h. During this spell a maximum intensity of 60 mm/h was recorded. These storms caused considerable runoff as shown in Figure 2.

In flood-prone lowlands, rice is normally seeded or transplanted in April-July and is harvested in October-December. Table 2 shows the rainfall pattern at Faizabad in eastern Uttar Pradesh during the rice growing season for the years 1976-79. Within 4 yr, rainfall can vary from 300 mm to 1,100 mm; rainy days can number from 24 to 46; and about 540 mm of rainwater is normally available in 15 d. Table 3 shows the occurrence, duration, and depth of water during the cropping season over 4 yr. The occurrence of 4-9 floods lasting 1-15 d and leading to water depths of 0.28-1.25 m in the fields is a common feature of lowlands. In the drought year of 1979 (300 mm rain), heavy flooding in July followed by low August rainfall completely submerged the rice crop to a depth of 86 cm for 15 d. Thus the depth of inundation varies considerably, depending upon the history of earlier flooding regimes.

Table 1. Duration and amount of intensive rain spells recorded during the 1978 rainy season, Hyderabad, India (2).

Date	Duration (min)	Rainfall[a] (mm)
16 Jun	15	10.5
	15	6.5
17 Jun	15	22.0
5 Jul	15	12.5
12 Jul	15	6.0
16 Jul	30	23.5
18 Jul	15	7.0
25 Jul	5	7.0
30 Jul	5	3.0
2 Aug	10	3.5
7 Aug	10	18.0
8 Aug	15	11.5
13 Aug	25	41.0
15 Aug	15	15.0[b]
18 Aug	10	4.5
19 Aug	15	9.0
23 Aug	15	12.0
14 Sep	15	5.0
1 Oct	15	8.0
2 Oct	15	10.8
10 Oct	15	9.0
30 Oct	15	9.5

[a]High intensity spells recording >5 mm/15 min are considered. [b]This was the highest intensity spell on that day; total amount of rainfall recorded was 174 mm.



2. Weekly rainfall, available soil moisture, and runoff at ICRISAT, 1978.

Table 2. Rainfall patterns at Faizabad, India, 1976-79.

Month	1976		1977		1978		1979		50-yr/mean	
	Rain (mm)	Days	Rain (mm)	Days	Rain (mm)	Days	Rain (mm)	Days	Rain (mm)	Days
Jun	30.2	1	—	—	132.0	5	27.2	2	113.5	5
Jul	211.4	7	334.0	14	501.2	14	182.2	12	338.6	14
Aug	538.8	15	147.4	5	180.8	12	31.2	4	280.7	13
Sep	312.8	6	65.4	4	196.2	13	21.2	2	196.3	8
Oct	20.6	1	171.4	4	15.2	2	39.0	4	46.7	2
Total	1113.8	30	718.2	27	1025.4	46	300.8	24	975.8	42

CROPPING PATTERNS

Several major cropping patterns are recognized in the rainfed lowlands. They are linked to the topography, soil water regime, and depth and duration of flooding.

As 70% of India's rice area is rainfed, good performance depends on timely and uniform June-August rainfall. In a year of good rainfall (1978-79), total rice production was 54 million t, while in a bad year (1982-83), production was 46 million t despite increased inputs.

Table 4 shows promising traditional and new rice-based cropping systems in the major soil-climatic regions of India. Average rainfall and soil taxonomic units are also indicated. In the Himalayas and northern alluvial plains the dominant cropping pattern is rice during kharif and some winter crops (wheat, pulse, vegetable, oilseed, or fodder crop) during rabi. In the humid eastern and southern regions the dominant cropping pattern is rice - rice or rice - millets (1).

The production potential of some promising cropping patterns is shown in Table 5. Data on economics and food energy produced are also presented (1).

At Pantnagar (recent organic rich alluvium), the rice - wheat - cowpea + maize sequence recorded the maximum grain yield of 8.5 t/ha, with maximum net returns of over Rs 10,800/ha (US$1 = Rs 10.06). The digestible carbohydrates from rice and wheat alone in this sequence accounted for 5.7 t/ha.

In the alluvial soil of Kalyani, the rice - wheat - maize sequence recorded a total grain yield of 10.3 t/ha, with an average net return of almost Rs 9,200/ha. This crop sequence accounted for 6.3 t/ha of digestible carbohydrates and 1.0 t/ha of digestible proteins.

The rice - wheat - green gram sequence recorded a total grain production of 11.7 t/ha at Ludhiana (old coarse-textured alluvium). At Masodha, the best results were recorded in rice - potato + wheat - green gram: 8.4 t/ha of grain in addition to 12.7 t/ha of potato. Although highly input oriented, this sequence recorded the maximum net return of over Rs 21,000/ha. This was also the best in terms of digestible carbohydrates and proteins harvested per unit area. The calorific value of the total food production was also maximum under this crop sequence. At Varanasi, the rice - wheat - green gram sequence recorded the maximum productivity, with high biological value of the food harvested. This was also the case at Nandyal. At Rudrur, the rice - groundnut - black gram sequence appeared to be most remunerative.

In the deep black soils of Navsari, the rice - wheat - green gram sequence appeared to be the best. In Banswara, the rice gram and rice - green gram rotations gave the best results, while at Hanumangarh, a groundnut - wheat - fallow sequence appeared to be more promising. At Karjat in the Konkan region, the rice - wheat - green gram sequence appeared to be the best.

The data reported from Thanjavur (medium black soils) clearly indicate the superiority of rice - rice - cotton and rice - rice - groundnut sequences there. In the rice - rice - groundnut rotation, 9.6 t rice/ha and 2.2 t groundnut/ha were

Table 3. Date of inundation, duration of submergence, and depth of water during crop season, 1976-79.

Month	Week	1976			1977			1978			1979		
		Date of inundation	Duration (d)	Depth (m)	Date of inundation	Duration (d)	Depth (m)	Date of inundation	Duration (d)	Depth (m)	Date of inundation	Duration (d)	Depth (m)
Jul	1	—	—	—	—	—	—	—	—	—	—	—	—
	2	—	—	—	11 Jul 1977	4	0.40	8 Jul 1978	7	0.60	—	—	—
	3	—	—	—	15 Jul 1977	3	0.40	15 Jul 1978	7	0.86	15 Jul 1979	3	0.28
	4	2 Jul 1976	1	0.30	26 Jul 1977	1	—	22 Jul 1978	10	0.90	23 Jul 1979	8	1.25
Aug	1	7 Aug 1976	1	0.40	6 Aug 1977	—	—	1 Aug 1978	7	0.95	3 Aug 1979	4	0.38
	2	8 Aug 1976	2	0.40	—	—	—	8 Aug 1978	7	0.91	10 Aug 1979	15	0.86
	3	18 Aug 1976	4	0.50	16 Aug 1977	5	0.60	15 Aug 1978	2	0.65	—	—	—
	4	22 Aug 1976	1	—	27 Aug 1977	5	0.25	—	—	—	—	—	—
Sep	1	4 Sep 1976	3	0.40	1 Sep 1977	2	0.25	—	—	—	—	—	—
	2	—	—	—	14 Sep 1977	—	—	—	—	—	—	—	—
	3	—	—	—	14 Sep 1977	2	0.20	—	—	—	—	—	—
	4	—	—	—	—	—	—	—	—	—	—	—	—

Table 4. Rice-based cropping systems in major soil-climatic regions of India.

No.	Region	Average annual rainfall (mm)	Major soil type	Rice-based cropping systems
1	Humid western Himalayas	1,000-2,000	Udic Haplustalfs: very deep (> 90 cm) red soils	rice - barley rice - oats
		Jammu, Kashmir, Himachal Pradesh	Typic Haplustalfs: very deep (> 90 cm) grey brown podzolic soils	rice - peas rice - berseem
	Subtropical plateaus	Rs. Pura	Eutrochrepts: very deep (> 90 cm) lowland clayey soils	rice - potato - wheat rice - wheat - green gram rice - mustard rice - toria - wheat
	Subhumid temperature			rice - wheat - rice - berseem rice - wheat

Continued on next page

Table 4 continued

No.	Region	Average annual rainfall (mm)	Major soil type	Rice-based cropping systems
2	Humid eastern Himalayas and Gangetic plains	1,700-1,800 West Bengal, NE region Gangetic Plain	Udic Ustochrepts: very deep (> 90 cm) lateritic Fluventic Eustrochrepts: very deep (> 90 cm) alluvial Udifluvents-Haplaquepts association: very deep (> 90 cm)	rice - jute - rice rice - rice jute - rice - wheat jute - rice - potato rice - cucurbits/vegetables rice (monocrop) rice - wheat rice - potato rice - fallow - rice rice - rice - rice rice - potato - jute rice - mustard - rice
3	Subhumid Satlej-Ganges alluvial plain	700-1,400	Typic Ustochrepts: very deep (> 90 cm) alluvial, fine and coarse loamy soils Udifluvents-Fluvaquents association: coarse loamy soils Haplaquents-Haplaquepts: deep (45-90 cm) alluvial soils Eutrochrepts: very deep (90 cm) lowland clayey soils Ultic Paleustalfs and typic Haplustalfs: very deep (> 90 cm) red loamy soils	rice - wheat rice - potato - wheat rice - wheat rice - grain rice - mustard rice - maize jute - rice rice (monocrop) rice - wheat - green gram rice - potato - green gram
4	Subhumid to humid eastern and southeastern uplands	1,500	Aeric Haplaquepts: red and lateritic clayey, poorly drained alluvium	rice - potato - rice rice - mustard - rice rice - potato - wheat rice - maize - green gram

			rice - vegetables jute - rice rice - cowpea rice - rice
	1,310	Ochraqualfs-Ochraquults association: fine loamy soils	rice - rice rice - gram rice - lentil
	1,000-11,000	Typic Chromusterts, deep (45-90 cm), medium, to deep black, red, and mixed red and black soils	rice - jowar rice - ragi - rice rice - rice rice - rice - rice sugarcane - rice rice - jowar/bajra rice - wheat - mung rice - mung
Humid to semiarid western Ghats and plateau region	1,728	Ustropepts, very deep (> 90 cm) laterites	rice - rice - rice rice - rice - ragi rice - rice - cowpea rice - okra rice - groundnut/cowpea
	3,000	Typic Tropofluvents, very deep (> 90 cm) sandy loam laterite and coastal alluvial	rice - rice - fallow rice - rice - vegetables rice - rice - sasamum rice - rice - tapioca
	1,136	Typic Pellusterts, very deep (> 90 cm) deep black soils of deltaic origin	rice - rice rice - rice rice - rice - rice rice - groundnut - rice rice - millet - groundnut rice - rice - cotton groundnut - ragi - rice - ragi

Table 5. Production potential of some promising cropping patterns.[a]

Location	Crop sequence			Yield (t/ha)			Total grain yield including pulses and oilseeds (t/ha)	Total fertilizer input (kg N-P-K /ha)	Net returns[b] (Rs/ha)	Digestible carbohydrates (t/ha)	Digestible proteins (t/ha)	Crop yield in food energy (10^6 K cal/ha)
	Kharif	Rabi	Summer	Kharif	Rabi	Summer						
Pantnagar	rice	wheat	cowpea + maize (F)[c]	3.8	4.7	29.3	8.5	260-180-27	10,835	5.7	0.8	33.3
Kalyani	rice	wheat	maize	4.1	3.5	2.7	10.3	340-180-120	9,179	6.3	1.0	35.7
Masodha[d]	rice	potato + wheat	green gram	4.4	12.7	0.8	8.4	403-220-190	21,024	8.7	1.1	48.0
Varanasi	rice	wheat	green gram	4.8	3.4	1.1	9.3	310-160-140	10,592	6.2	1.0	37.2
Ludhiana	rice	wheat	green gram	6.0	5.0	0.8	11.8	256-130-60	15,487	8.0	1.2	47.8
Nandyal	rice	wheat	green gram	2.7	1.4	1.0	5.1	250-150-150	5,940	3.6	0.6	20.2
Rudrur	rice	groundnut	black gram	4.2	2.0	0.9	5.1	150-130-105	13,774	4.2	1.0	30.0
Banswara	rice	gram	green gram	3.9	1.4	0.1	5.4	155-150-0	7,936	4.0	0.6	19.8
Karjat	rice	wheat	green gram	3.4	2.0	0.6	6.0	230-160-130	6,245	4.2	0.6	23.8
Thanjavur	rice	rice	groundnut	6.1	3.5	2.2	9.6	258-123-160	16,464	8.0	1.3	47.2
Karaiyi-ruppu	ground-nut	rice	ragi	2.9	4.6	3.9	8.5	245-175-140	17,376	6.9	1.5	45.7
Bhavanisagar	rice	rice	rice	3.3	2.6	2.9	8.8	360-180-180	7,140	7.1	0.6	32.4

[a]AICRIP data pooled over 1979-80 to 1982-83. [b]US$1 = Rs 10.06. [c]Cowpea + maize (F) and cotton are not taken for calculations. [d]Values include the potato crop.

produced with maximum net returns of almost Rs 16,500/ha. The digestible carbohydrates accounted for more than 8.0 t/ha, while protein was more than 1.2 t/ha. Similarly, at Karaiyiruppu, the best results were recorded by a groundnut - rice - ragi sequence, with maximum net returns of about Rs 17,375/ha. At Siruguppa, the green gram/cotton - sunflower sequence recorded maximum returns. At Bhavanisagar, a sequence of rice - rice - rice recorded the maximum grain yield of 8.8 t/ha with a high level of agronomic productivity. In terms of net returns, however, this sequence was not as remunerative as those at Thanjavur or Karaiyiruppu.

The yield levels presented clearly show that agronomic productivity as well as physiological energy output are high in completely cereal-based sequences, although the quality of the food produced in such cases suffers from low production of protein. Inclusion of a pulse crop as reported in Varanasi, Ludhiana, Pantnagar, Masodha, Nandyal, Rudrur, Junagadh, Karjat, and Parbhani helps in meeting that deficiency through increased energy output per unit area of land. A rice - wheat - pulse sequence appears to be ideal in the wheat-growing areas. In the south, rice - rice - groundnut or ragi - rice - groundnut as reported at Thanjavur, rice - rice - pulse at Mangalore, green gram/cotton - sunflower at Siruguppa, and rice - rice - rice at Bhavanisagar appear quite profitable. Inclusion of a tuber crop like potato, as in Masodha, boosts the food value of the crop with very significant improvement in the net returns per unit area.

The number of idle days under such high intensity cropping is invariably less than 70 d/yr, providing better employment opportunities throughout the year.

The limited information available on the influence of various cropping systems in changing soil fertility under Indian conditions suggests that growing grain legumes in rotation with cereals would make only a marginal impact on the grain yield of the succeeding crop but may possibly reduce drainage losses of N. Depletion of soil K appeared to be very high under rice - ragi - jowar as well as in rice - rice - rice sequences at Bhavanisagar.

The general indication is that, because of inadequate application of K at some locations, soil K was being depleted at an alarming rate under high intensity cropping. Thus, in multiple cropping, there is a commonly felt need to use higher levels of plant nutrients so as to sustain crop productivity as well as soil fertility.

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ASSOCIATED CROPS IN RICE-BASED CROPPING SYSTEMS

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Various upland crops grown before or after the rice crop in lowland rainfed areas of Asia are described. Examples of upland crop management for soybean, sorghum, and peanut are discussed. Major problems are crop establishment, drought, flooding and waterlogging, lack of suitable varieties, and fertilizer management. Promising varieties of mungbean, cowpea, soybean, peanut, sorghum, maize, sweet potato, and pigeonpea for cropping before and after rice are described.

Where rainfed rice is grown in shallow favorable, shallow drought-prone, shallow drought- and submergence- prone, deep water submergence-prone, medium deep water, and very deep water environments, associated crops are usually grown beforehand or afterwards toward the drier season or at the start of the rainy season. Traditional cropping systems are generally based on one rice crop. In many areas a second, upland crop is grown on residual moisture; however, crop management is often very poor, yield levels low, and the risk high. With the development of high yielding, early-maturing, photoperiod-insensitive rice varieties, the potential to increase the production of upland crops in rice areas has become tremendous. Improved varieties such as IR36 that mature within 90-140 d with high yields are now available. They can fit into different rainfed conditions with varying rainfall distribution. Hence, upland crops can now be grown after early- or medium-maturing rice varieties. Cropping intensity can be increased from one rice crop to two and even three crops (rice - rice - upland crop, upland crop - rice - upland crop, or rice - upland crop - upland crop).

However, many problems are associated with growing upland crops in rainfed rice fields. The major ones are crop establishment, drought, waterlogging, lack of suitable varieties, and fertilizer management.

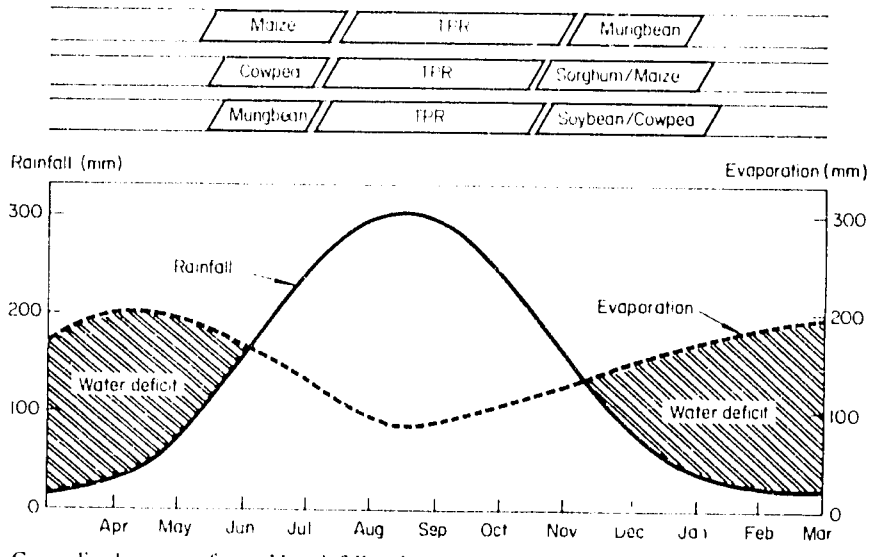
UPLAND CROPS

The most common upland crops grown before rice are early-maturing (about 70-90 d) maize (both green and for grain), mungbean, cowpea, and potato. The crops grown after rice are wheat, mustard, mungbean, cowpea, soybean, maize, chickpea, sweet potato, lentil, and blackgram. In general, farmers grow

upland crops under zero or minimum tillage, low management levels, and without fertilizer. Thus, yields are low. A very small percentage of the rainfed rice area is grown to a second crop. Cropping systems research at IRRI and the Asian Rice Farming Systems Network (ARFSN) has concentrated on increasing the cropping intensity of rainfed rice areas with the use of early-maturing, photoperiod-insensitive, and high yielding varieties. The cropping systems research teams in different countries are testing two- and three-crop systems using various upland crops.

Temperature plays an important role in determining the crops to be grown after rice. In areas where the temperature is significantly lower during winter (Nepal, northern India, Pakistan, Bangladesh, northern Thailand), the most common crops are wheat, barley, chickpea, mustard, lentil, finger millet, and soybean. In the tropics, where the temperature is only slightly lower during winter, the most common crops are peanut, mungbean, soybean, cowpea, sorghum, sweet potato, maize, blackgram, rice bean, and sesamum.

In areas with good rainfall, including gradual onset and termination, there is the potential to grow mungbean, sesamum, and cowpea before rice, and soybean, cowpea, and sorghum after rice (Fig. 1). In northeast Thailand, annual rainfall is only 900-1,200 mm, distributed bimodally (2 wet mo and 6 dry mo). Rainfall starts in April, gradually increasing to June and decreasing in July; it increases again in August, peaks in September, and sharply ends in October. Traditionally, one rice crop is transplanted in July-August and harvested in December-January. The research team there is studying the use of mungbean, peanut, and cowpea, which are planted in April and harvested in late June or early July before rice is transplanted.



1. Generalized pattern of monthly rainfall and evaporation and cropping pattern in rainfed lowland rice growing areas. TPR = transplanted rice.

In limited areas with lighter soils and high water table, upland crops are grown after rice. In areas with higher rainfall (6 wet mo and 4 dry mo) and good drainage, such as in Pumdi Bhumdi, Nepal, the cropping pattern is maize - rice - wheat in high-potential production areas. Maize is grown in spring, rice during the monsoon season, and wheat in winter. In low-potential production areas, rice - wheat is grown. In areas with gradual termination of rainfall (4-5 wet mo and 2-4 dry mo), upland crops are grown after rice, for example: wheat and chickpea in Suchaina, Nepal; a third crop of mungbean or cowpea in rice - rice - upland crops in Iloilo, Philippines; rice - rice - mungbean in Carmen, Philippines; rice - peanut in Yezin, Burma; and barley with chickpea in Alimganj, Bangladesh.

ESTABLISHMENT OF UPLAND CROPS

Upland crop establishment in previously puddled soil is one of the major problems that constrain crop intensification in rainfed lowland rice areas. Puddling breaks down soil aggregates into particles and increases bulk density, making the soil compact and hard upon drying. After heavy rainfall, the crops are subject to flooding. The problem is serious in heavy clay and less in lighter soils.

Farmers use low management in growing upland crops on residual moisture. Zero or low tillage is practiced, and seeds are broadcast before or after harvesting the rice crop. In areas where there is enough rainfall during drier periods, farmers prepare the land and broadcast or drill the crop. When there is plenty of water before and during the upland crop growing period, farmers generally make canals to drain excess water. Many experiments have been conducted to identify better techniques in upland crop establishment that will give better crop stand and reduce the turnaround time between crops. We present studies on crop establishment in soybean, sorghum, and peanut.

Soybean

Farmers broadcast soybean just before harvesting rice in Java, Indonesia. The method is simple and inexpensive, but yield levels are generally low because of poor stand and low management. In northern Thailand, soybean is also grown after rice; however, farmers prepare the land, make beds, and irrigate the soybean crop. Another technique practiced in Taiwan is zero tillage and dibbling the seed at the base of the rice stubble.

Experiments at IRRI compared the effects of several cultural practices on rainfed soybean establishment (3). Puddled rice fields were drained 21, 11, and 1 d before rice harvest. After harvest, soybean seeds were dibbled into five different tillage treatments: no tillage, furrow tillage, bed tillage, one rototilling, and three rototillings. Grain yield with one rototilling was highest (Table 1). The mean yield of zero tillage was only 8% less. Yields were highest for soybean grown in fields drained 1 d before rice harvest, and lowest in fields drained 21 d before rice harvest.

Table 1. Grain yield of soybean as influenced by tilage and drainage 21, 11, and 1 d before harvest of rice (A. Syarifuddin and H. G. Zandstra, unpublished data).

Tillage for soybean	Grain yield[a] (t/ha)			
	21 d	11 d (control)	1 d	Mean
No tillage (control)	1.00 ab	1.16 a	1.25 b	1.14 b
Furrow tillage	0.46 c	0.47 c	0.56 d	0.50 e
Bed tillage	0.53 c	0.61 c	0.63 d	0.59 d
One rototilling	1.10 a	1.20 a	1.40 a	1.23 a
Three rototillings	0.90 b	0.89 b	1.08 c	1.96 c
Mean[b]	0.80 ns	0.86	0.98*	

[a]Separation of means in a column by DMRT at the 5% level. [b]* = significant at the 5% level by LSD, ns = not significant.

Table 2. Grain yield of soybean as influenced by planting method and mulching (A. Syarifuddin and H. G. Zandstra, unpublished data).

Planting method and mulching	Grain yield[a] (t/ha)
Drill-relay planting	
No mulch	0.52 d
Mulch	1.09 c
Zero tillage, sequential planting	
No mulch	1.37 b
Mulch	1.90 a
Furrow tillage sequential planting	
No mulch	0.38 e
Mulch	0.27 e
One rototilling, sequential planting	
No mulch	1.64 ab
Mulch	1.97 a

[a]Separation of means by DMRT at the 5% level.

In another experiment, drill-relay planting, zero tillage, furrow tillage, and one rototilling were evaluated together with mulching (3). One rototilling and zero tillage showed higher soybean grain yield than the two other planting methods. Mulching increased the yield of soybean in drill-relay, zero tillage, and one rototilling (Table 2).

Increasing the seeding rate and drilling soybean seeds can improve the stand and yield of soybean grown after rice. The stand was slightly increased when soybean was drilled between rice rows instead of broadcast (3). Soaking the seeds before planting and increasing the seeding rate increased the stand (Table 3). Grain yield was higher when soybean was drilled, but drilling is not practical. A combination of broadcasting, soaking, and increased seeding rate would be more acceptable to farmers.

Sorghum

Sorghum is one of the most promising crops after rice because of its drought and waterlogging tolerance. In most of our yield trials after rice, yield levels

with zero tillage were the same or better than with tillage. Studies on sorghum establishment showed that zero tillage and furrow tillage with seeds dibbled beside the furrow gave higher yields than high tillage and furrow tillage with seeds drilled in the furrow (Table 4). Seedling emergence percentage was higher with zero tillage than with high tillage. Yield with high tillage was lower because the crop was planted later and was thus affected by drought. In another experiment, the rolling injection planter (RIP), broadcast, and conventional tillage practices were compared in establishing sorghum after rice. Higher yield and emergence percentage were obtained with conventional tillage (with alternate plowing and harrowing).

If moisture is available during the growing period, conventional tillage is better. However, if there is more moisture at the early vegetative stage and much less at the heading stage, zero tillage is better.

Peanut

Another crop that is relatively tolerant of drought is peanut. It is grown after rice in light- to medium-textured soils. In cropping systems studies in

Table 3. Effect of seeding method, seed soaking, and seeding rate on stand at 10 d after seeding (DAS) and 2 d before harvest (DBH) and yield of soybean relay-planted into puddled flooded rice. IRRI 1978 dry season[a] (A. Syarifuddin and H. G. Zandstra, unpublished data).

Seeding methods and seeding rates	Stand (plants/m²)		Expected stand (plants/m²)	Mean yield (t/ha)
	10 DAS	2 DBH		
Broadcast, unsoaked				
60 kg/ha	43 g	42 g	60	1.31 f
120 kg/ha	51 cd	61 cd	120	2.12 bc
Broadcast, soaked				
60 kg/ha	48 f	47 f	60	1.55 e
120 kg/ha	65 bc	64 bc	120	2.22 b
Drilled, unsoaked				
60 kg/ha	53 e	53 e	60	1.77 d
120 kg/ha	68 b	67 d	120	2.24 b
Drilled, soaked				
60 kg/ha	58 d	58 d	60	2.02 c
120 kg/ha	88 a	88 a	120	2.61 a

[a]Separation of means in a column at the 5% level.

Table 4. Seedling emergence and grain yield of sorghum as affected by variety and tillage treatment (1).

Tillage	Seedling emergence (%)		Yield (t/ha)	
	PH 8417	UPL SG #5	PH 8417	UPL SG #5
Zero	67.1	67.9	2.70	2.13
Furrow + seeds drilled in furrow	42.7	45.9	1.97	2.24
Furrow + seeds dibbled beside furrow	52.8	51.8	2.76	2.16
High	64.1	55.8	1.59	1.14

northeast Thailand, peanut was found very promising before rice. However, it matured later and affected the transplanting of rice. In our varietal testing at IRRI, we conducted peanut trials with zero tillage. Yield levels were high, but harvesting was difficult. Comparison of two tillage practices in peanut showed that dry pod yield did not significantly differ between zero (a single pass of a plow) and conventional tillage; however, shelled seed yield was significantly higher with conventional tillage. The pulling force in harvesting and the number of pods left in the soil were not significantly different. It seems that zero tillage is acceptable, especially if the soil is not very hard during harvest time.

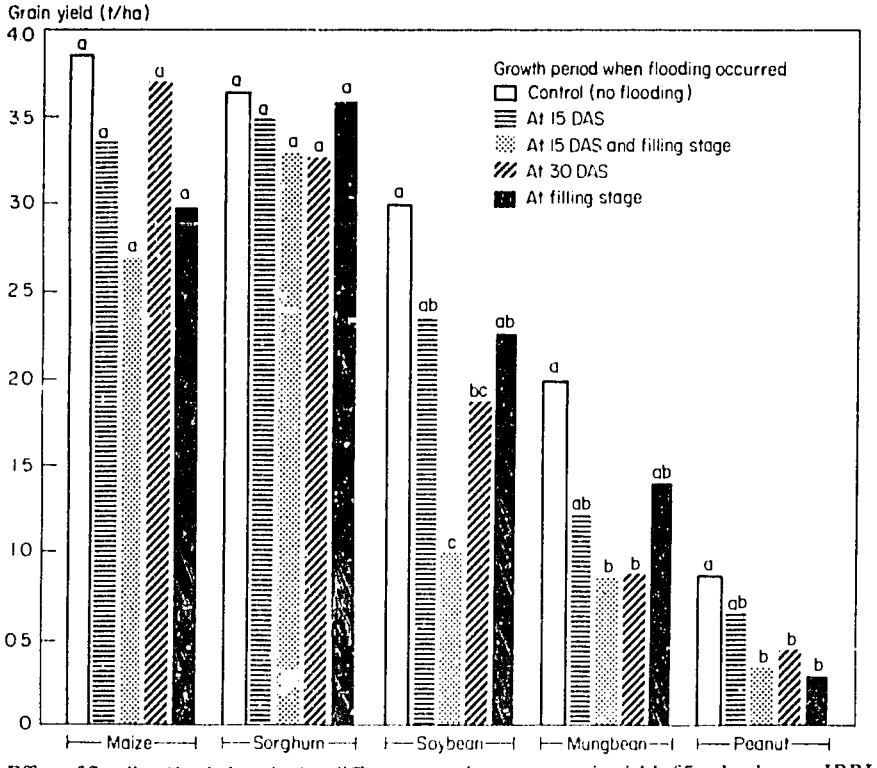
EFFECTS OF WATERLOGGING ON UPLAND CROPS

Upland crops grown after lowland rice generally have problems with excessive moisture at the early growth stages. With early-maturing rice varieties, we now can plant upland crops earlier in rainfed lowland rice areas. However, the flooding hazard for the upland crops is greater because of unpredictable weather conditions. Two experiments were conducted at IRRI to evaluate the response of maize, sorghum, soybean, mungbean, and peanut to excessive moisture (1). In the first experiment, the crops were subjected to flooding (complete soil saturation for 7 d) at different growth stages with 5 flooding treatments. Grain yield of soybean was reduced by 37%, peanut by 56%, and mungbean by 49% when flooding occurred at 30 d after seeding (DAS) (Fig. 2). Reduction was also severe with flooding at 15 DAS and at the pod filling stage. Flooding at the filling stage reduced the yield of soybean by 25%, mungbean by 27%, and peanut 66%. Maize and sorghum were unaffected by flooding. All the crops were stunted when flooded at the vegetative stage.

In the second experiment, maize and soybean treatments were imposed on 2 growth stages and different flooding durations (4, 9, 12 d). Flooding had a more depressive effect on plant characters at 15 DAS than at the grain-filling stage. Continuous flooding for 12 d reduced maize grain yield by 58% at 15 DAS and by 11% at the grain-filling stage; for soybean, the reduction was 27% at 15 DAS and 28% at the grain-filling stage.

RESPONSE TO WATER STRESS

Food legumes generally suffer from drought during the vegetative stage when grown before rice and during the reproductive stage when grown after rice. An experiment compared the response of mungbean, cowpea, peanut, and soybean to water stress using a line source sprinkler irrigation system (2). Grain yield of all four crops decreased as stress increased (Table 5). At the highest stress level, mungbean was reduced by 83%; yield reduction was 66% in soybean and 65% in cowpea; peanut showed greater drought tolerance, with only 46% yield reduction. Among the yield components, pods/m^2 was the most sensitive. Seeds/pod and 100-seed weight were less affected by water stress. Peanut and cowpea had higher rooting density at 40-80 cm. Peanut had



2. Effect of flooding (1-wk duration) at different growth stages on grain yield of 5 upland crops. IRRI, 1977 (3). For each crop, bars with a common letter are not significantly different at the 5% level by DMRT. DAS = days after seeding.

the highest water use, followed by cowpea, soybean, and mungbean, in both the wet and dry regimes. The deep root systems in peanut and cowpea are their major adaptive mechanisms for drought avoidance.

Ten mungbean and cowpea varieties were evaluated along a moisture gradient using a line source sprinkler system. Irrigation was provided at planting time, and line source irrigation treatments were started 15 d after planting. Across the moisture gradient, EG MG 174-3 and M350 produced higher grain yields than the other mungbean varieties. M350 yielded more at the wet end of the gradient and EG MG 174-3 yielded more at the dry end. CES 1D-21, a commonly grown variety, yielded poorly at the dry end but responded favorably to irrigation. Among the cowpea varieties, Vita 4 gave the highest yield at the dry and wet ends of the moisture gradient. CP 2-3-1 and TVx 66-2H also showed better performance at the dry and wet ends of the moisture gradient.

PROMISING VARIETIES OF UPLAND CROPS IN RAINFED LOWLAND RICE AREAS

Lack of suitable upland crop varieties is the most important problem in a rice-based cropping system, especially in rainfed areas. The existing varieties

Table 5. Effect of moisture regime on seed yield and yield components of 4 food legumes (R. K. Pandey, W. T. Herrera, A. N. Villegas, and J. W. Pendleton, unpublished data).

Crop	Moisture regime[a]					V/I[b]
	1	2	3	4	5	(%)
			Seed yield (t/ha)			
Mungbean	0.9	0.8	0.6	0.3	0.1	17
Cowpea	1.4	1.3	1.2	0.8	0.5	35
Soybean	1.4	1.4	1.2	0.8	0.5	34
Peanut	1.2	1.1	1.1	0.8	0.6	54
			Pods/m²			
Mungbean	286	253	223	152	105	37
Cowpea	156	147	141	110	85	54
Soybean	367	320	303	225	178	48
Peanut	317	286	265	218	150	47
			Seeds/pod			
Mungbean	6.93	6.30	5.70	5.10	4.60	66
Cowpea	8.97	8.70	7.70	7.20	6.70	75
Soybean	3.10	3.10	2.80	2.80	2.40	77
Peanut	1.90	1.80	1.73	1.43	1.40	74
			100-seed wt (g)			
Mungbean	4.58	4.34	4.30	4.20	4.39	96
Cowpea	14.02	13.48	12.32	12.70	12.60	90
Soybean	13.34	11.60	10.87	11.22	10.67	80
Peanut	32.36	30.30	28.80	30.57	24.63	84

[a] 1 = wet; 2, 3, 4 = intermediate; 5 = dry.

[b] $\frac{V}{I} = \frac{\text{value of rating 5}}{\text{value of rating 1}}$ = reduction in performance due to water stress.

were developed and evaluated under upland conditions. With the interest in cropping systems research, breeding of upland crop varieties that fit rice-based cropping systems was initiated. Since IRRI has no mandate to develop upland crop varieties, it is collaborating with other international centers (IITA, ICRISAT, AVRDC, and CIMMYT), the Institute of Plant Breeding (IPB) of the University of the Philippines at Los Baños, and other national programs to develop varieties that fit rice-based cropping systems. One of the collaborative research projects in the ARFSN is varietal testing of upland crops before and after rice. Entries come from national programs, IPB, and the international centers. In 1982-83, 53 trials before rice and 159 after rice were distributed. The number of entries in the trial ranged from 8 to 12. The most promising varieties that were superior to the local check are presented in Tables 6 and 7.

Before rice

In the Philippines, the highest yielding mungbean line was IPB M79-13-60, with a seed yield of 0.83 t/ha, followed closely by IPB M79-9-82 and M350. CES N-6Y was the highest yielder at 1.03 t/ha in Burma, while in Indonesia, MB-4 (1.40 t/ha) and CES 3N-1 (1.04 t/ha) were the best. Higher mungbean yields were obtained in Thailand. CES 1D-21 or Pag-asa 1 was the highest

Table 6. Promising varieties of upland crops grown before rainfed lowland rice in South and Southeast Asian countries, 1983 cropping season.

Crop	Philippines (IRRI)	Burma	Vietnam	Thailand	Indonesia
Mungbean	IPB M79-13-60 IPB M79-9-82 M350	CES N-6Y		M350 CES 55 Pag-asa 1	CES 3N-1 MB-4
Cowpea					
Green pod	TVx 4262-014D TVx 3236-01G			All season	
Grain	TVx 3236-01G	CP 2-3-1 Vita 4			
Vegetable cowpea	BS_1 (6-14 R × AS) BS_3 (6-14 R × AS)	BS_1 (6-14 R × AS)			
Soybean	UPL SY-2	30290-11-11	7207-1 Clark 63		B 3034 B 3035
Peanut		CES 101 M10 F334-33	F334-33	Acc 12	CES 2-25
Sorghum			CS 182		CS 268 CS 110 CS 226
Maize	Glutinous Syn. #41 (green) Los Baños Lagkitan (green) Phil. Supersweet #9 (green)	Early DMR Comp. 2	KUC #2		Phil. DMR Comp. #2 IPB Var 1 Early DMR Comp. 1

Table 7. Promising varieties of upland crops grown after rainfed lowland rice in South and Southeast Asian countries, 1983 cropping season.

Crop	Philippines (IRRI)	Sri Lanka	Vietnam	Thailand	Indonesia	Nepal	Malaysia	Bangladesh
Mungbean	IPB M79-13-60 CES 3N-1 Pag-asa 2 M350	Pag-asa 1 CES 3N-1 CES 1T-2	CES 2F-1	CES 3N-1 MG 50-10A(Y)				
Cowpea								
Green pods	All season TVx 289-4G TVx 7-5H			TVx 1850-01E TVx 289-4G				
Grain		TVx 1836-19E		TVx 7-5H TVx 1850-01E TVx 2949-01D	TVx 289-4G	All season		TVx 7-5H
Vegetable cowpea	BS_1 (6-14 R × AS) BS_3 (6-14 R × AS)	BS_1 (6-14 R × AS) BS_3 (6-14 R × AS)						
Soybean	UPL SY-2 7207-1 30290-11-11							
Peanut	CES 101 UPL-PN-2 Acc 12 CES 2-25			PI 118200 CES 101 Kidang			M-10	UPL PN-2 M-10
Sorghum	CS 226 CS 110 CS 292			CS 110				
Maize	Early DMR Comp.2 Poza Rica 7931 Pirsabak 7930			KUC #2	Thai Comp. 1 Early DMR(S)C_4			
Sweet potato	Tinipay Minesuya Kinabakab							

yielding variety at 1.60 t/ha. Varieties M350 and CES 55, however, performed equally well with their local check variety U Thong 1, with yields of 1.40 t/ha.

For cowpea, the highest yield was obtained in Thailand at 8.0 t/ha of green pods for variety All Season. In the Philippines, TVx 4262-014D yielded 4.20 t of green pods/ha and TVx 3236-01G yielded 3.60 t/ha. The highest cowpea grain yields were obtained in Burma from Vita 4 (1.38 t/ha) and CP 2-3-1 (1.30 t/ha). TVx 3236-01G, the highest grain yielding variety in the Philippines, yielded only 0.75 t/ha.

Vegetable cowpea variety BS_1 (6-14 R × AS) was the highest yielding variety for the Philippines (12.20 t/ha) and Burma (6.97 t/ha). Another sister line of this variety, BS_3 (6-14 R × AS), was the second highest yielder (8.12 t/ha) in the Philippines.

Although testing of soybean before rice was dropped in crop year 1984-85, results from the 1983 testing were satisfactory, especially in Vietnam and Indonesia. A yield of 1.15 t/ha was obtained from variety 7207-1 in Vietnam and 1.50 t/ha for varieties B3034 and B3035 in Indonesia. Similarly, UPL SY-2 yielded 1.53 t/ha in the Philippines. Among the different sites, Burma recorded the lowest yield — 0.94 t/ha from variety 30290-11-11.

For peanut, variety F334-33 yielded 4.30 t/ha in Vietnam. It was followed by CES 2-25 at 1.50 t/ha in Indonesia, and CES 101, M10, and F334-33 at 1.0 t/ha in Burma. The lowest yield was from Acc 12 — 0.60 t/ha in Thailand.

Although sorghum production poses many problems for planting before rice, yields were high in Vietnam and Indonesia. Variety CS 268 was found promising in Indonesia, having a yield of 5.10 t/ha, and CS 182 showed a yield of 1.34 t/ha in Vietnam.

The highest yield of maize recorded was from variety KUC #2 — 6.98 t marketable ears/ha — in Vietnam, followed by Early DMR Comp. 2 with 5.20 t/ha in Burma. In Indonesia, IPB Var 1 yielded highest with 3.31 t/ha, followed by Phil. DMR Comp. #2 and Early DMR Comp. 1. For green maize, Glut. Syn. #41 and Los Baños Lagkitan exhibited the same yield (3.65 t/ha), followed by Bxj Comp. #1 (Supersweet) at 3.57 t/ha in the Philippines.

After rice

Mungbean variety CES 3N-1 performed consistently well in three countries; it yielded 1.66 t/ha in Thailand, 1.48 t/ha in the Philippines, and 0.93 t/ha in Sri Lanka. Another outstanding variety in the Philippines, which also yielded highest before rice, was IPB M79-13-60 (1.61 t/ha). In Vietnam, CES 2F-1 was best (2.34 t/ha).

In cowpea, TVx 289-4G was superior in the Philippines (5.62 t green pods/ha) and Thailand (4.1 t/ha). However, All Season (6.10 t/ha) was better than TVx 289-4G in the Philippines. TVx 1836-19E recorded the highest grain yield (1.92 t/ha) in Sri Lanka, followed by TVx 7-5H (1.62 t/ha) in Bangladesh, All Season (1.52 t/ha) in Nepal, and TVx 289-4G (1.42 t/ha) in Indonesia. Lower yields were observed in Thailand: 0.85 t/ha from TVx 7-5H, 0.66 t/ha from TVx 2949-01D, and 0.64 t/ha from TVx 1850-01E.

Table 8. Yield and other agronomic characters of the top 5 pigeonpea varieties evaluated with zero tillage after rice at IRRI, 1983-84 dry season.

Variety	Main crop yield (t/ha)		Days to mature	Plant height (cm)	Ratoon yield (t/ha)	
	Grain	Fodder			Grain	Fodder
QPL-72	2.70	5.17	96	78	0.17	20.14
FC(FC)J-1	2.00	4.06	96	90	0.07	16.53
ICPL-142	1.94	3.11	108	94	0.16	16.81
ICPL-81	1.78	3.94	108	95	0.22	9.17
QPL 70-2	1.52	8.72	96	74	0.21	18.20

Two sister lines of vegetable cowpea ranked highest in two countries. BS_1 (6-14 R × AS) yielded 9.75 t/ha while BS_3 (6-14 R × AS) yielded 7.96 t/ha in the Philippines; in Sri Lanka, BS_1 yielded 5.32 t/ha and BS_3, 5.80 t/ha.

Only the Philippines reported yields for soybean after rice. The highest yield was observed on UPL SY-2 (1.48 t/ha) followed by 7207-1 (1.45 t/ha) and 30290-11-11 (0.92 t/ha).

Bangladesh reported the highest peanut yields of 3.30 t/ha for varieties UPL PN-2 and M-10. This was followed by Philippine yields of 2.00 t/ha (CES 101), 1.98 t/ha (UPL PN-2), 1.80 t/ha (CES 2-25), and 1.62 t/ha (Acc 12). Yields from Thailand were lower; the most promising varieties there were PI 118200 (1.64 t/ha), CES 101 (1.61 t/ha), and Kidang (1.58 t/ha).

Sorghum yields of 4.71 t/ha (CS 226), 4.54 t/ha (CS 110) and 3.18 t/ha (CS 292) were reported in the Philippines. In Thailand, CS 100 yielded 4.36 t/ha.

Maize variety KUC #2 yielded the highest at 7.81 t/ha in Thailand, followed by Thai Comp. 1 Early DMR(S)C_4 (3.02 t/ha) in Indonesia. In the Philippines, the most promising were Early DMR Comp. 2 (2.00 t/ha), Poza Rica 7931 (1.99 t/ha), and Pirsabak 7930 (1.94 t/ha).

Sweet potato trials were conducted only in the Philippines. Marketable tuber yields were 15.8 t/ha (Minesuya), 14.5 t/ha (Tinipay), and 13.0 t/ha (Kinabakab).

Pigeonpea is a drought-tolerant crop that is promising for grain and fodder. Yield trials of 10 promising early-maturing varieties from ICRISAT and Australia were evaluated at IRRI for use after rice (1983-84 dry season). Yields of the main crop ranged from 0.97 to 2.70 t/ha; those of the ratoon were 0.07 to 0.23 t/ha. The highest grain yielder was QPL-72 (2.70 t/ha), but its fodder yield was relatively low (5.17 t/ha). QPL 70-2 was a high fodder yielder (8.72 t/ha) but had a low grain yield (1.52 t/ha). Both varieties were among those that matured earliest (96 d) and were short. Generally, all the varieties produced poor grain yields when ratooned, but their ratooned fodder yields (9.86-26.12 t/ha) were much higher than the main crop fodder yield. Table 8 shows the data for the top 5 entries of the 10 tested.

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337

PEST MANAGEMENT

DISEASES AND DISEASE MANAGEMENT OF RAINFED LOWLAND RICE

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The occurrence of diseases in rainfed lowland rice differs not only among countries but also in different seasons within a country. Excess or inadequate rain associated with rainfed lowland environments is conducive to disease at different crop growth stages. Sheath blight, bacterial blight, tungro, ragged stunt, sheath rot, brown spot, and blast appear to be the most important diseases in the five largest rainfed areas in Asia. Tungro, however, has not been reported in Burma and Vietnam. No information is available on how much yield loss and damage are caused by single or combined diseases in the region. Some cultural practices that farmers exercise may also have beneficial effects on reducing pathogen populations. Any recommendation for disease management should be validated at several sites under different environmental conditions.

Much of the rainfed rice in the lowland plains and river floodplains of South and Southeast Asia is located in four major river deltas: the Mekong, Chao Phraya, Irrawaddy, and Ganges-Brahmaputra (3). This paper reviews and describes the current and potential disease problems in these areas and suggests possible management practices for them.

OCCURRENCE OF DISEASES

Disease management is not the primary goal in crop production. However, it should be viewed as a functional component of the production system. Diseases are important when they reduce the productivity of the system by an amount greater than the cost of implementing a management strategy.

Diseases often interact among themselves and with other components of the system. It is therefore important to have accurate information about the pathogens and the diseases they cause under specific climatic conditions. Logical disease management should be based on knowledge of the diseases in the agroecosystems.

It is not easy to assemble information on the occurrence of diseases in the major rainfed rice areas. We attempted to do so using several sources. One was the International Rice Research Newsletter (IRRN) from 1976 to 1983, on the theory that if a disease was important it would have been discussed there.

There has been little effort by Asian agricultural scientists to study crop diseases just for the sake of research. Their main interest is solving production problems. Table 1 shows the 10 diseases that appeared most often in IRRN. The top six are also major diseases in IRRI's varietal improvement program. Among the 213 reports, 91% were on diseases of lowland rice, 7% on deep water rice (ufra, root nematode, ragged stunt), and only 2% on upland rice (root-knot nematode, root lesion, cyst nematode). The main deep water rice disease discussed in IRRN is ufra caused by the stem nematode, the information coming primarily from Vietnam and Bangladesh. Little information is available on diseases in Burma.

The ranking of diseases varies in different countries and seasons (Table 2). In India, sheath blight (ShB) is the top ranking disease, followed by brown spot, bacterial blight (BB), tungro (RTV), sheath rot, and blast (Bl); in Thailand, it is ragged stunt (RSV), followed by orange leaf; and in Vietnam, Bl, ShB, and BB are the predominant diseases. In Bangladesh, the top ranking diseases are different in boro, aus, and aman rices. In boro rice, BB, ShB, sheath rot, Bl, and brown spot were listed as most important; in aus rice, they were RTV, BB, ShB, sheath rot, and Bl; in aman rice, RTV, BB, sheath rot, and brown spot were important. While no information is available on how much damage and yield loss are caused by diseases, either alone or combined, it is reasonable to assume that they are significant.

RAINFED LOWLAND ENVIRONMENT AND RICE DISEASE EPIDEMICS

Disease is a function of three interacting factors: the host, the pathogen, and the environment. With a susceptible host population, virulent pathogen, and conducive environment, an epidemic may develop. Epidemics lead to crop loss or failure, the magnitude depending largely on the hectarage planted to the susceptible host variety, the rate of pathogen population increase after the disease has started, and the duration of an environment favorable to disease increase. The farmer's roles in an epidemic are deciding which varieties to

Table 1. The 10 most published diseases in rice culture.

Disease	Rank	Articles (no.)						Total no.	%[a]
		1976–78	1979	1980	1981	1982	1983		
Sheath blight	1	3	10	7	1	3	2	26	12.2
Rice tungro	2	1	6	7	5	5	1	25	11.7
Bacterial blight	3	8	3	1	3	3	0	18	8.4
Brown spot	4	4	4	3	2	4	0	17	8.0
Sheath rot	5	0	0	8	4	2	2	16	7.5
Blast	6	3	3	1	6	1	1	15	7.0
Ufra	7	3	1	5	3	0	0	12	5.6
Ragged stunt	7	4	5	1	1	0	1	12	5.6
Grain discoloration	8	0	3	3	1	2	0	9	4.2
Leaf scald	9	1	2	1	3	1	0	8	3.7
Root-knot nematode	10	3	1	1	1	0	1	7	3.3

[a]Based on total number of articles on rice diseases (213); 48 articles (22.5%) dealt with other diseases.

Table 2. Disease rank in the major rainfed lowland rice growing countries.

Bangladesh (1979-81)			India (1976-83)	Thailand (1979-80)	Vietnam (1978-80)
Boro	Aus	Aman			
Bacterial blight	Tungro	Tungro	Sheath blight	Rice ragged stunt	Blast
Sheath blight	Bacterial blight	Bacterial blight	Brown spot	Yellow orange leaf	Sheath blight
Sheath rot	Sheath blight	Sheath blight	Bacterial blight	Bacterial blight	Bacterial blight
Blast	Sheath rot	Sheath rot	Tungro	Sheath rot	Ufra
Brown spot	Blast	Brown spot	Sheath rot	Sheath blight	Rice ragged stunt
Leaf scald	Brown spot	Leaf scald	Blast	Cercospora leaf spot	Brown spot
Grain discoloration	Stem rot	Stem rot	Leaf scald	Grain discoloration	Kernel smut
Bakanae	Grain discoloration	Grain discoloration	Root knot		
Root rot	Cercospora leaf spot	Ufra	Udbatta		
Tungro	Root knot	Cercospora leaf spot	Ragged stunt		
Ufra	Bakanae	Blast			

plant, how and when to plant them, and what crop management practices to use, such as the amounts of fertilizer and pesticide. All the farmer's activities in managing the crop directly or indirectly affect the epidemic.

Too often, the farmer is left little choice in his farming activities. In the rainfed lowlands, he has no control over the amount of rainfall available for cultivation and planting, or over its onset. Although climatic factors such as temperature, sunlight, and rainfall directly influence the physiological process of rice growth and development, they also indirectly affect the incidence of diseases; diseases, in turn, influence the crop. Rice plant establishment, physiological status, and the growth stages are important factors in the onset of a disease. In rainfed lowlands, Krishnamoorty (10) listed four subsystems of aberrant rainfall patterns based on the amount and reliability of rainfall received during the vegetative and reproductive stages of rainfed lowland rice:

System 1. Rainfall during the vegetative and reproductive stages is adequate and assured.

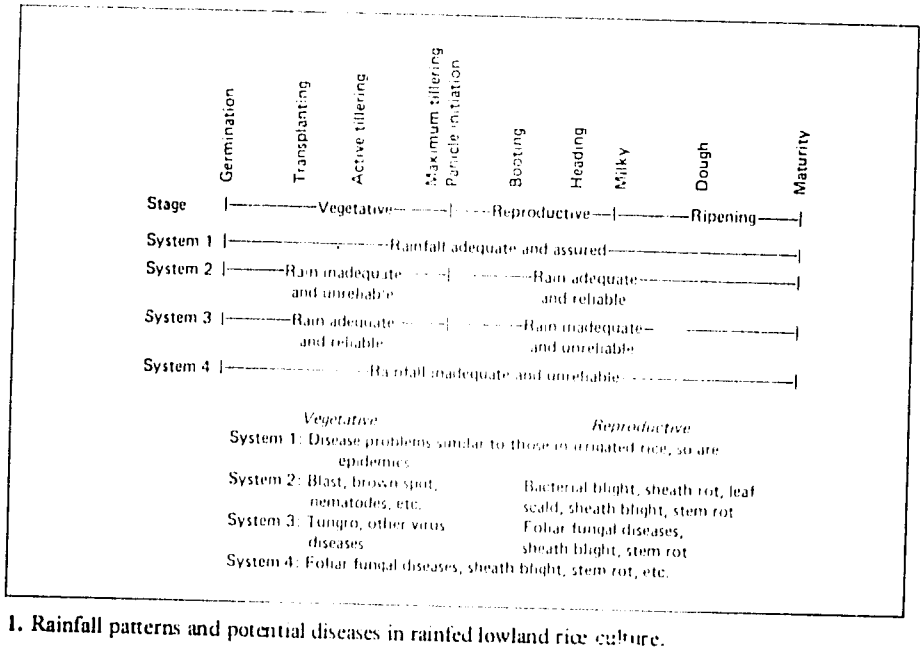
System 2. Rains during the vegetative stage are inadequate and unreliable.

System 3. Rains are adequate and reliable during the vegetative stage but inadequate and uncertain in the reproductive stage.

System 4. Rainfall is inadequate and uncertain during both the vegetative and reproductive stages.

The disease problems and potential epidemics within these subsystems are difficult to assess, as no accurate information is available. Figure 1 presents some speculations.

In system 1, the condition is like that for irrigated rice, and the diseases perhaps do not differ. Diseases that will occur and become epidemic depend



1. Rainfall patterns and potential diseases in rainfed lowland rice culture.

on the country and the district as well as on climatic factors such as temperature and sunlight, in addition to the water status of ricefields and frequency of rains. The rice variety and agronomic practices adopted by farmers are directly related to the outbreak of an epidemic.

In system 2, if rice is direct seeded, either wet or dry, it is likely that fungal diseases will be troublesome. Bl and brown spot, for instance, are often reported in systems of this nature. Nematode disease like root knot may also occur. Once the rain comes and the field has standing water, the damage caused by Bl and nematodes may be reduced. As the plants have been under stress, other diseases such as sheath rot, leaf scald, and BB may prevail. However, no accurate information is available with which to make a reasonable assessment of the relative importance of these diseases.

In system 3, the prevalence of disease may again be associated with the geography and variety. RTV and other virus diseases may be more dominant than others if the variety is susceptible and inoculum sources from previous crops are present. Other fungal diseases may become problems, as the plants are under stress.

The disease problems of system 4 may be more of fungal or nematode origin than viral or bacterial.

Since the introduction of semidwarf rice varieties, grain discoloration has been observed more frequently than when traditional varieties were planted in rainfed areas. Whether this is due to photoperiod insensitivity of the rice, which matures during the rainy season, or to greater susceptibility of the new varieties to grain discoloration is not clear. Research on this aspect is needed in the varietal improvement program.

DISEASE MANAGEMENT AND CONTROL

There are no standard procedures for disease control and management in rainfed lowland rice culture. The culture systems per se are so diverse that no single procedure is likely to apply to all. An accurate knowledge of the pathogens and the diseases they cause under the prevailing climatic conditions is essential.

We have relied on the information published in IRRN to determine what research has been undertaken and whether or not some of the available information may lead to disease management tactics in rainfed conditions. About 29% of the papers dealt with disease reporting, 21% with chemical control, and 10% with etiology of diseases (Table 3). Thirty-six percent of the reports related to disease management other than chemical control. It appears that in many rice research programs, little effort is devoted to research on disease management.

Host resistance

As rice producers in tropical Asia are mostly small landholders, the use of resistant varieties is still the most economical and feasible method of disease control. There are resistance sources for most of the rice diseases, and many

Table 3. Rank order of research areas (7).

Research item	Rank	Reports (no.)						Total (no.)	%
		1976-78	1979	1980	1981	1982	1983		
Disease occurrence[a]	1	12	16	13	11	5	5	62	29.1
Chemical control	2	10	13	6	5	7	1	45	21.1
Etiology[b]	3	0	5	5	8	3	1	22	10.3
Epidemiology[c]	4	3	1	5	4	4	2	19	8.9
Ecology	5	1	5	7	3	2	0	18	8.4
Cultural control[d]	6	4	3	2	1	2	1	13	6.1
Nitrogen and diseases	7	5	1	2	0	2	1	11	5.2
Disease survey	8	3	1	1	1	1	0	7	3.3
Crop damage or loss	9	2	0	2	1	0	0	5	2.3
Physiology, biochemistry	10	1	2	0	0	1	0	4	1.9
Biocontrol	11	1	1	0	0	1	0	3	1.4
Botanical fungicide	12	0	0	0	1	0	1	2	0.9

[a]Reports on diseases that appear in a certain area, region, or country. [b]Reports on host range, weed host, strains, and new diseases. [c]Reports on disease outbreak, spreading of diseases, and influence of physical environments on disease development. [d]Reports on planting time, density, soil amendments, and cultural practice.

advanced breeding lines bred at IRRI and in national rice improvement programs (5, 6) are resistant to several diseases. A few resistant varieties should be grown over wide areas and monitored for the presence of new diseases or new races of pathogens. This would constitute a sound disease warning system.

Management of pathogen vectors

All reported rice virus diseases in tropical Asia are transmitted by insect vectors and are often suppressed more efficiently when management efforts are directed at the vectors rather than at the pathogens. RTV, for instance, is transmitted only by leafhoppers (10, 11). It is endemic in South and Southeast Asia and is the most important virus disease in the region. In the five major rainfed lowland river deltas, particularly in eastern India and Bangladesh, RTV is also one of the most important rice diseases. It has not, however, been reported in Burma and has not been considered important in Vietnam. Epidemics are closely associated with the availability of inoculum source, the vector population, and the dispersal of the vector. Dispersal is affected by variety and plant size (or density) (11). Field monitoring has indicated that in Central Luzon, Philippines, RTV incidence from June to October in the wet season rice crop was correlated with the number of vectors and the proportion that transmitted RTV from May to July. The May-July period is either immediately before seedbeds are prepared or when rice seedlings are at very early stages of growth, either in the seedbeds or soon after transplanting. RTV incidence may be controlled by suppressing the vector population in seedbeds with insecticides or adjustment in planting date.

Management of alternate hosts and pathogen antagonists

The occurrence and spread of many diseases depend on other organisms in addition to pathogens, hosts, and people. Other components of the biotic

environment, such as alternate hosts (Table 4), enhance diseases, while others, such as pathogen antagonists, limit disease development.

ShB caused by an aerial form of *Rhizoctonia solani* is an important disease of rainfed lowland rice. This fungal pathogen has a very wide host range, attacking other crops planted after or before rice, such as legumes, maize, and sorghum. Although sclerotia serve as the primary inoculum in the tropics, many weeds in ricefields are also hosts of the pathogen. Proper field sanitation may serve to decrease the initial inoculum, thus reducing the ShB foci for secondary infection (6).

Table 4. Weed hosts of rice disease pathogens.

Weed	Pathogen	Reference no.
Echinochloa crus-galli	*Rhynchosporium oryzae*	18
Brachiaria mutica	*Pyricularia oryzae*	15
E. colona		
Echinochloa sp.		
Digitaria sp.		
Leptochloa chinensis		
Leersia hexandra		
Paspalum conjugatum		
Polytrias amaura		
Sacciolepsis sp.		
E. colona	*Sarocladium oryzae*	16
Eleusine indica		
Monochoria vaginalis		1
Echinochloa crus-galli		
Cyperus iria		
Cyperus teneriffae		
E. colona	*Rhizoctonia solani*	9
Cynodon dactylon	*Rhizoctonia solani*	15
Cyperus pilosus		
C. haspan		
Eichornia crassipes		
E. colonum		
Echinochloa crus-galli		
E. crus-pavonis		
Eleusine indica		
Fragrea colhinchinensis		
Fimbristylis miliacea		
Haydystis brynii		
Leptochloa chinensis		
Leersia hexandra		
Lindernia peduculanta		
Monochoria hastata		
Paspalum conjugatum		
Sacciolepsis interrupta		
Scirpus grossus		
S. articulatus		
Neyrandia reynandiana		
Alternathera repens		
Brachiaria mutica		
B. distachya		
Echinochloa colona	Tungro virus	20
Cyperus rotundus		
Cynodon dactylon		
Paspalum notavum		

Many bacteria in the ricefield show antagonistic activity to the fungal pathogen (13). Soaking seeds in bacterial suspension may reduce ShB (12). Although managing antagonistic bacteria in field conditions or in farmers' fields has not been realized, the information has provided clues to their potential field application.

Suppressing infection with cultural practices

Many pathogens survive in rice straw. In rainfed lowland rice, straw or stubble is either used as animal feed or left in the field under fallow until the next crop season. If rice straw and stubble are not removed or burned, sclerotia of ShB or the stem rot pathogen will invade the following rice crop. Burning straw and stubble is widely practiced by farmers in tropical Asia as a means of reducing these pathogens, the validity of which has been confirmed for stem rot by research (4). Rice residue disposal influences the level of overwintering or oversummering inoculum and stem rot severity. Rice residue decomposition also has the benefit of lowering the initial inoculum level (13).

Shukla and Anjaneyulu (17) found that RTV incidence generally increased with increase in plant spacing. The difference in disease incidence among the spacings was more pronounced in the tolerant than in the susceptible variety.

Increasing N application in general favors disease development. Split application of N, however, was found to reduce BB incidence. Brown spot appeared to be more severe in unfertilized fields than in fertilized ones (8). High N rate at a spacing of 25 × 15 cm minimized the incidence and severity of ShB and BB (2).

Chemical control

Although a high percentage of papers published in IRRN describe chemical control of rice diseases, such control is not yet popular in rainfed lowland rice, perhaps because of the lack of accurate knowledge of the diseases and the damage or yield loss they cause, the unavailability of the chemicals to farmers, and their cost.

FUTURE RESEARCH

Little information is available, and no systematic research has been done either in farmers' fields or experiment stations from which to formulate strategies for disease management in rainfed lowland rice. Burning or removal of rice straw and stubble reduces the population of certain pathogens. Plowing the field while it still has standing water may accelerate plant residue decomposition and either encourage the increase of antagonistic bacteria or suffocate the pathogens, as most of them are aerobic. Strategies and available methods should be tested not only at research stations but also in farmers' fields. Some need validation at several sites in different environments before recommendations can be made.

The technology available to most farmers is limited to disease-resistant rice varieties. It is unlikely that a variety will be bred that is resistant to all diseases.

An integrated disease management approach, making use of resistant varieties together with other technology such as chemical control, deserves careful study. In such a combination, the use of chemicals may be minimized, but their efficiency would increase.

With the introduction of improved varieties and with a change in crop management, the application of N fertilizer may increase. The influence of N fertilizer, methods of planting, and plant density on diseases should be well documented. In virus diseases, cooperation between plant pathologists and entomologists in vector management is vital. That weeds are hosts of other pathogens should encourage plant pathologists to cooperate with weed scientists on pest management.

Finally, plant pathologists should take up the task of answering critical questions on disease development in rainfed lowland rice, i.e., how much damage and crop loss is caused by diseases, at which crop stage, and under what cultural practices?

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-349-

MANAGEMENT OF INSECT PESTS IN RAINFED LOWLAND RICE

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The most serious insect pests of rainfed lowland rice in Bangladesh, India, the Philippines, and Thailand are the yellow stem borer, armyworms, cutworms, caseworm, leaffolder, green leafhopper, brown planthopper, and whitebacked planthopper. Although rice varieties with resistance to a few insects and diseases are available in some countries, additional research is needed to increase varietal resistance.

Fifty-two percent of the total rice area in the world is rainfed lowland (11). Shallow and intermediate rainfed lowland comprises 69% of the rice area in Bangladesh, 44% in India, 45% in the Philippines, and 71% in Thailand. Only minor effort has been exerted to raise yields of rainfed rice compared with efforts in irrigated rice (2). Because of the diversity of rainfed rice environments and the fact that most lowland rice research is conducted under irrigated conditions, research on rainfed lowland rice entomology has been limited (10). However, the same insect pests occur on both irrigated and rainfed lowland rice. The technology that has been developed to manage insect pests in irrigated areas is for the most part transferable to rainfed conditions. We discuss the relative importance of the various insect pests attacking rainfed lowland rice in Bangladesh, India, the Philippines, and Thailand and the status of technology developed to manage them.

STATUS OF INSECT PESTS

Numerous pests attack rainfed lowland rice. The most common are listed in Table 1. Thrips, rice mealy bugs, rice gall midge (GM), and hispa are problems in Bangladesh and Thailand, but not in the Philippines. The yellow stem borer (YSB), armyworms, cutworms, caseworm (CW), leaffolder (LF), green leafhopper (GLH), brown planthopper (BPH), and whitebacked planthopper (WBPH) are pests in the four countries. The root weevil is a minor pest only in India and Thailand.

Although a pest in rainfed lowland rice, BPH is more important in irrigated areas. Leovinsohn et al (9) reported that the BPH population as based on

Table 1. Insect pests and their importance in rainfed lowland rice in Bangladesh, India, Philippines, and Thailand.

Insect	Degree of importance[a]					
	Bangladesh[b]	India	Philippines			Thailand
			Iloilo	Samar	Nueva Ecija	
Thrips	**	*	*	—	*	* (6)
Mealy bug	* (10)	*	—	—	—	* (8)
Whorl maggot	*	* (7)	* (6)	* (6)	* (7)	*
Hispa	** (1)	** (6)	—	—	—	*
Yellow stem borer	** (2)	** (1)	*	** (2)	* (1)	** (2)
White stem borer	*	*	** (5)	—	—	—
Striped stem borer	*	*	*	* (8)	*	*
Armyworms	** (5)	*	*	** (3)	* (2)	** (4)
Cutworms	* (7)	** (3)	*	** (3)	* (2)	*
Caseworm	* (8)	** (4)	** (1)	* (7)	* (5)	*
Leaffolder	** (6)	** (5)	** (2)	** (5)	* (4)	* (3)
Gall midge	*	*	—	—	—	** (1)
Green leafhopper	** (4)	** (2)	** (3)	* (9)	*	*
Brown planthopper	** (3)	*	** (4)	* (10)	* (6)	*
Whitebacked planthopper	*	*	*	* (11)	*	*
Rice bug	* (9)	*	*	** (1)	*	* (7)
Grasshoppers	*	*	*	*	*	* (5)
Root weevil	—	*	—	—	—	*

[a] — = not present, * = minor pest (occasionally or never causes yield losses), ** = major pest (regularly causes yield losses). Numbers in parentheses indicate the numerical ranking of importance, with 1 as the most important. [b] Source (8).

light-trap catches was lowest in dryland, intermediate in rainfed lowland, and highest in irrigated areas. The extent of the dry season affects insect populations and is a severe stress on pests of rainfed lowland rice. As irrigation expands, some minor pests become serious, e.g., BPH.

In Bangladesh in 1981, 4% of the crop area was damaged by hispa and 0.3% by YSB. In Samar, Philippines, the complex of rice bug (RB), YSB, armyworms, cutworms, and LF damages about 15% of the area. In Iloilo, Philippines, the complex attacking rice at the vegetative stage includes the whorl maggot (RWM), LF, YSB, caseworm, and GLH (as a virus vector); damage is up to 30% of the area.

MANAGEMENT OF INSECTS

Provisional economic thresholds have been established for most of the major pests of rainfed lowland rice. About 25% damaged leaves is considered the threshold at the vegetative stage (Table 2). The threshold of GLH as a tungro virus (RTV) vector is 1/sweep in Bangladesh and 0.5/sweep in the Philippines, where this level has resulted in 10-15% RTV infection (E. A. Heinrichs, unpubl. data). The SB threshold for Bangladesh is based on the number of moths or egg masses/m^2. The RB threshold varies widely.

Resistant varieties

Growing of genetically resistant varieties is an important tactic in the management of rainfed lowland rice insects. Bangladesh has included

Table 2. Economic thresholds for rainfed lowland rice insects.

Insect	Bangladesh[a]	Philippines[b]	Thailand	India[c]
Defoliation	25% severely damaged leaves	Seedbed = 50% defoliation Vegetative = 25% defoliation Reproductive = 15% defoliation	20% folded leaves (for leaffolder)	—
Green leafhopper	1 sweep and presence of damaged plants (as a virus vector)	20/hill (for direct damage) 5/10 sweeps (as virus vector)	—	ET = more than 5-10 insects/hill MT = 20 insects/hill PI to booting = 2 insects/hill (virus vector), 20 insects/hill or more (for direct damage)
Brown planthopper	2-4 gravid females or 10 nymphs/hill in 50% of plants	1/tiller	10/hill (for direct damage) 2-3/hill (as virus vector)	ET = 5-10/hill MT = 5-10/hill PI = 5-10/hill
Stem borer[d]	3 female moths or egg masses/m^2 Midtillering = 10% DH Late vegetative = 5% DH	1-10 DT = 8 DH/25 hills 11-20 DT = 16 DH/25 hills 21-30 DT = 24 DH/25 hills 31-40 DT = 32 DH/25 hills	5-10% DH	ET = 5% or more DH or 1 egg mass/m^2 MT = 5% or more DH PI = visible adults
Rice bug	2-3/hill	16/25 hills	4/m^2	—
Gall midge	5% silvershoots	—	3-5% silvershoots	ET = 1 gall/m^2 or more
Hispa	4 adults/hill 15 grubs/leaf 35% damaged leaves	—	—	ET = 1 insect or damaged leaf per hill
Ear-cutting caterpillar	2-5 larvae/10 m^2	—	—	—

[a]DH = deadhearts, DT = days after transplanting. Source: (1) [b]Guimba, Nueva Ecija, pest management project. [c]ET = early transplanting, MT = midtillering, PI = panicle initiation.

resistance to BPH, GLH, and thrips as an objective of its breeding program. For shallow rainfed situations, India has developed the multiple-resistance variety CR190-103 (Table 3), which is very popular in Orissa. Another variety that has been widely accepted is Shakti, which was released in 1973.

Popular tall, photoperiod-sensitive indica varieties grown by farmers in waterlogged areas were screened against YSB under artificial infestation to identify YSB tolerance. The least susceptible varieties identified were Madhukar, Kalam Banki, and Dhusasa.

The germplasm comprising 12 NCS and 193 AC varieties collected from waterlogged areas was tested for YSB resistance at the boot leaf stage under field conditions. NCS2505 and 19 AC varieties — 1864, 1871, 1885, 1890, 1916, 1922, 1999, 2051, 2246, 2298, 2300. 2309, 2375, 2521, 2546, 2557, 2577, 2985, and 2805 — were free from whiteheads, whereas AC4669 recorded the maximum incidence of 28.6% whiteheads. The above donors have been utilized in the breeding program.

Thirty-one salt-tolerant varieties collected from waterlogged saline areas of coastal districts of Orissa and West Bengal were also screened for YSB under artificial infestation. Six — Patnai, Nonasal, Bantulsi, Damodar, Chettu Pokkali, and Kailash Pati — were least susceptible.

In Thailand the breeding program includes resistance to BPH, GLH, GM, SB, and LF. Varieties RD4, RD9, and MN62M with GM resistance have been released.

In the IRRI breeding program, resistance for thrips, RWM, GLH, BPH, zigzag leafhopper (ZLH), WBPH, SB, RB, CW, and LF has been incorporated (Table 4). No commercial varieties with resistance to ZLH, LF, and RCW have been released, and only a few varieties have moderate resistance to WBPH, YSB, RWM, or thrips. Breeding lines with high resistance to WBPH and moderate resistance to LF are available, and resistant varieties will likely be released in the future. IR 36, the most widely grown IR variety covering 13 million ha, has multiple resistance to several insects and diseases and tolerance for several adverse soil conditions.

In Bangladesh, the commercial variety BR14 has field resistance to rice hispa; BR1 to YSB; BR12, BR14, and BR15 to thrips; and BR12 and BR14 to RWM. Five lines with BPH resistance are being tested in farmers' fields.

Table 3. Multiple insect and disease resistance of two rice varieties suitable for shallow rainfed lowland conditions in Orissa, India.

Variety	Cross	Days to flowering	Response to insects and diseases	Yield (t/ha)
CR190-103	IR8/Lacrosse Zenith//Ptb 21/TN1	93	Resistant to BPH, GLH, GM, and blast; Moderately resistant to YSB, WBPH, and RTV	4.5-5.5
Shakti	Ptb 18/Ptb 21//IR8	105	Resistant to GLH, WBPH, GM, and RTV	3.5-4.0

Table 4. Resistance of IR varieties to insect pests (6).[a]

Variety	Maturity[b] (DS)	BPH biotypes			GLH		WBPH	ZLH	YSB	SSB	LF	CW	RWM	Thrips
		1	2	3	*N. virescens*	*N. nigropictus*								
IR5	130	S	S	S	MR	MR	S	S	S	S	S	S	S	S
IR8	125	S	S	S	MR	MR	S	S	S	S	S	S	S	S
IR20	121	S	S	S	MR[c]	MR	S	S	MR	R	S	S	S	S
IR22	119	S	S	S	S	MR	S	S	S	S	S	S	S	S
IR24	118	S	S	S	MR	MR	S	S	S	S	S	S	S	S
IR26	121	R	S	R	MR	R	S	S	S	MR	S	S	S	MR
IR28	104	R	S	R	R	R	S	S	S	S	S	S	S	S
IR29	112	R	S	R	R	R	S	S	S	S	S	S	S	MR
IR30	105	R	S	R	R	R	S	S	S	MR	S	S	S	S
IR32	130	R	S	MR[d]	MR	MR	S	S	S	MR	S	S	S	S
IR34	122	R	S	R	R	MR	S	S	S	MR	S	S	S	S
IR36	110	R	R	MR[d]	MR	R	S	S	MR	R	S	S	S	S
IR38	123	R	R	MR[d]	MR	MR	S	S	S	MR	S	S	S	S
IR40	130	R	MR	S	MR	MR	S	S	MR	R	S	S	MR	S
IR42	132	R	R	S	MR	MR	S	S	S	MR	S	S	S	S
IR43	120	S	S	S	MR	R	S	S	S	MR	S	S	S	S
IR44	123	R	R	MR[d]	MR	R	S	S	S	R	S	S	S	S
IR45	120	R	S	R	MR	MR	S	S	S	S	S	S	S	S
IR46	112	R	S[e]	R	MR[c]	MR	S	S	S	S	S	S	S	S
IR48	127	R	S	S	MR	MR	MR	S	S	S	S	S	S	S
IR50	107	R	MR	R[d]	R	MR	S	S	MR	R	S	S	S	S
IR52	117	R	R	MR[d]	R	MR	MR	S	S	MR	S	S	S	S
IR54	120	R	R	S	R	MR	S	S	MR	MR	S	S	S	S
IR56	106	R	R	R	R	R	S	R	S	—	S	S	S	S
IR58	108	R	R	R	R	R	S	MR	S	—	S	S	S	S
IR60	110	R	R	R	R	R	MR	S	S	—	S	S	S	—
IR62	110	R	R	R	R	—	MR	MR	S	—	S	S	S	—

[a]Based on replicated experiments. Hopper resistance based on greenhouse evaluation of seedlings; YSB and SSB resistance based on a screenhouse evaluation of 40- to 70-d-old plants; LF and CW resistance based on the reaction of 30- and 11-d-old-plants in the greenhouse; RWM resistance based on field observations at 30 d after transplanting. Varieties Standard evaluation system for rice of 1-3 are considered resistant (R), 5-7 moderately resistant (MR), and 9 susceptible (S). [b]DS = days after sowing. [c]Occasional susceptible reactions. Least resistant of the IR varieties except for IR22, which is highly susceptible. [d]Reaction to biotype 3 varies, occasionally being susceptible and often resistant. [e]IR46 has field resistance to biotype 2. [f]Tests still to be conducted.

A survey conducted in Nueva Ecija, Philippines (B. Duff, unpubl. data), indicated that farmers in rainfed and irrigated areas planted the same varieties (Table 5). IR36 is by far the most popular variety, occupying 85% of the rainfed and 81% of the irrigated area. The survey indicated that most farmers knew which varieties were resistant to insects.

Pesticide management

The percentage of farmers in Nueva Ecija using insecticides in rainfed lowland rice has increased significantly since 1971. By 1978, 70% of the farmers were using insecticides, compared with less than 16% ten years earlier and 4% in 1960 (Fig. 1).

Monocrotophos is commonly used for control of the major pests in Bangladesh and the Philippines. Carbofuran granules are used for control of several insect species in Thailand, but application rates are much lower than recommended. In Bangladesh, diazinon is commonly used to control rice hispa, SB, BPH, and GLH.

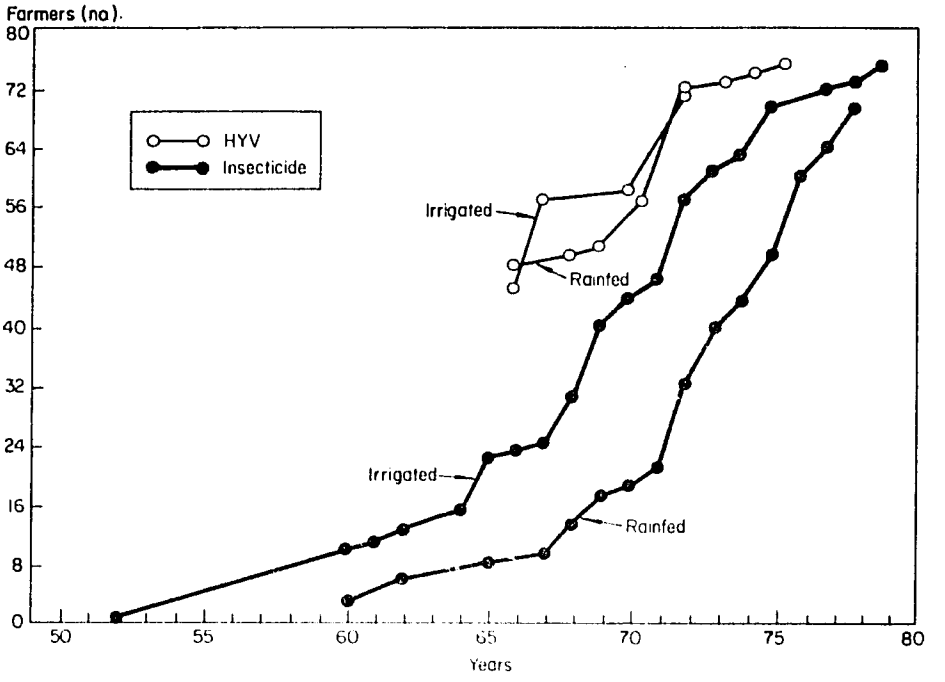
Foliar sprays are the most common method of insecticide application in both irrigated and rainfed lowland rice in Nueva Ecija (Duff, unpubl. data). Almost all the farmers spray, rather than broadcast granules, in rainfed lowland rice, whereas 70% spray in irrigated rice.

In India, soil incorporation (transplanted) and subsoil application (direct seeded) of carbofuran or phorate at 1.0 kg ai/ha controls SB at the vegetative stage. At the heading stage, foliar application of insecticides such as phosphamidon, chlorpyrifos, or quinalphos at 0.5 kg ai/ha has proven more effective. Foliar sprays with phosphamidon, monocrotophos, and carbaryl at 0.5 kg ai/ha have been found effective against GLH. Chlorpyrifos, quinalphos, methyl parathion, and endosulfan at 0.4 kg ai/ha at the dough stage are effective against the climbing cutworm; quinalphos, endosulfan, and chlorpyrifos at 0.5 kg ai/ha are effective against RWM, CW, hoppers, and LF (12).

Because of the interest in dry seeded rice in Thailand, tests are being conducted to identify insecticides that are effective as a seed treatment for the control of ants, termites, and the white grub. In a field test, carbofuran and

Table 5. Rice varieties planted on irrigated and rainfed farms in Nueva Ecija, Philippines, 1979.

Variety	Irrigated		Rainfed	
	No.	%	No.	%
IR36	64	85.3	61	81.3
Maligaya	3	4.0	4	5.3
IR42	2	2.7	2	2.7
IR46	2	2.7	—	—
IR44	2	2.7	—	—
IR34	1	1.3	1	1.3
IR22	1	1.3	—	—
Unknown	—	—	5	6.7
IR28	—	—	2	2.7



I. Adoption of high yielding varieties and insect control technology by rainfed lowland farmers in Nueva Ecija Province, Philippines (unpubl. data).

carbosulfan seed treatments controlled ants and thus doubled the grain yield over that of the check.

The average number of insecticide applications per rice crop varies considerably with location. Farmers spray once in Bangladesh; 1-2 times in Thailand; 0-2 times in Cagayan, Iloilo, and Pangasinan, Philippines; and 5 times in Samar, Philippines. In a survey by Duff (unpubl. data) in Nueva Ecija, Philippines, 1-8 applications were made in rainfed lowland rice; most farmers made 3-4 applications. The number of applications was generally similar to that in irrigated rice. Duff also found that most field applications in rainfed lowland and irrigated rice in Nueva Ecija were made during the vegetative stage. In studies conducted by Litsinger (personal communication), yield losses due to insects were highest during this growth stage.

Resistance of insects to insecticide fortunately does not appear to be a problem in rainfed lowland rice. Responses to our survey in India, Thailand, Bangladesh, and three regions in the Philippines indicated no evidence of insecticide resistance problems, which is to be expected as the number of applications/crop is not excessive and usually only one crop/yr is grown.

Biocontrol

Knowledge of the identity and importance of parasites, predators, and pathogens as population-regulating agents of rice insect pests is limited.

Litsinger et al (10) listed 44 parasites attacking rice insects and 34 predators occurring in rainfed lowland rice in Iloilo and Pangasinan, Philippines. Parasitism was highest (60%) on YSB egg masses. Both predators and parasites appear to be more abundant in rainfed lowland rice than in irrigated rice. However, the species density of spiders was highest in irrigated areas, followed by rainfed lowland and dryland environments (3) because of multiple cropping and the lack of a rice-free dry season.

The incidence of insect pathogens is high in rainfed lowland rice and low in irrigated conditions (4, 5). However, knowledge of pathogens is limited.

CULTURAL CONTROL METHODS

The planting of early-maturing varieties is an effective means of managing insect pests that require several generations to build up dense populations that cause economic damage. Very early-maturing varieties are used in Bangladesh to avoid BPH damage in fields where intermediate-maturing varieties are hopperburned. In Ubol Ratchatani, Thailand, planting of early-maturing varieties is the most common cultural control method used in the management of GM. The early-maturing local photoperiod-sensitive varieties Leaung Boonma and Dawh-Ang are transplanted as soon as the rain comes in June-July. The plants reach the panicle initiation stage in late August before the peak incidence of GM.

In Cheingrai, Thailand, rice planted early in the season is severely attacked by GM. Farmers have developed the double transplanting technique to reduce damage by GM and crabs, and to cope with the water shortage problem. Early in the season, rice seedlings are transplanted at very close spacing in a small area where sufficient irrigation water can be provided up to 50 d. Then the seedlings are pulled and transplanted at normal spacing in fields where water is sufficient. Although GM incidence in double- and single-transplanted crops is similar (Table 6), the incidence is higher in early than in late transplanted rice (7). The number of panicles per hill and yield were higher in double-transplanted rice.

Draining of ricefields is used to control CW, CWM, and BPH in the Philippines and Bangladesh. CW is highly sensitive to draining, as the larva is aquatic. RWM lays few eggs in a field that has no standing water (Viajante and Heinrichs, unpubl. data). Flooding is used to control the mole cricket in the Philippines and the swarming caterpillar in Thailand.

Burning of rice stubble is an insect control measure in Bangladesh, India, the Philippines, and Thailand. In Bangladesh it is used to control SB, swarming caterpillar, and ear-cutting caterpillar. In Thailand, burning of rice stubble is considered the most effective method of SB control. In many areas, it is normal practice in preparing the land for plowing. In Chiengmai, the SB population is believed to be low. At harvesting the rice stems are cut very near the soil surface to obtain rice straw for mulch in growing onions, tomato, garlic, and cabbage. Few pupae survive in the cut stems.

Table 6. Silvershoots, panicles, and grain yield of RD6 rice from single and double transplanting at 2 planting dates.[a] Ban Parauk, Cheingrai, Thailand, 1980.

Transplanting method	Planting date	% silvershoot		Panicles (no. hill)	Grain yield (t/ha)
		5 Sep	23 Sep		
Double	15 Jul	50.6 b	58.4 b	5.8 a	2.38 a
Single	15 Jul	33.6 b	67.4 b	4.0 b	1.36 c
Double	15 Aug	5.3 a	28.1 a	7.1 a	2.38 a
Single	15 Aug	0.3 a	16.6 a	6.5 a	1.83 b
CV (%)		36.8	27.5	7.4	5.9

[a]Averaged from 4 replications. Plot size was 4 × 5 m. Means followed by a common letter are not significantly different at 5% level.

IPM PROGRAMS IN RAINFED LOWLAND RICE

In 1982, the Plant Protection Division of the Department of Agricultural Extension in Bangladesh began pest control programs by developing "Integrated Pest Control" (IPC) blocks where integrated pest management (IPM) tactics are demonstrated. There are currently 40-ha IPC blocks in each of the 23 districts and 4-ha blocks in each of the 420 subdistricts.

Most IPM projects in the Philippines have been established for irrigated rice, but sites were established in Samar and Nueva Ecija for rainfed pest control, and a program has started in Iloilo in coordination with the Kabsaka rice production program.

Pest surveillance and forecasting in Thailand have been conducted in the central region by the Thai-German project since 1982. The Plant Protection Division of the Department of Agricultural Extension conducts IPC field demonstration plots of 80 ha each at all Plant Clinic Centers throughout the country.

IMPROVEMENT OF CONTROL TACTICS

Throughout Asia, the development of pest-resistant varieties is considered the most important tactic to improve existing insect management programs for rainfed lowland rice. The varieties, however, should have multiple resistance to insects and diseases, drought tolerance, and desirable agronomic characters. Currently, rainfed lowland rice in most countries consists primarily of traditional varieties that, in most cases, have low levels of insect resistance but numerous desirable characters. The challenge is to develop varieties that have the various desirable characteristics of traditional rices together with high yield and pest resistance. Where high yielding insect-resistant varieties are now available, resistance to additional pests such as the RWM, SB, and LF is still needed.

There is a need to develop insecticides with high toxicity to the pests but low toxicity to man and natural enemies. Some insect pests of rainfed lowland rice

are difficult to control with insecticides; more effective chemicals and methods of application are needed in the control of RWM, GM, and SB.

There is a need to better understand the importance of the various natural control agents and to develop methods of conserving and augmenting their populations. There may be places where importation of certain natural enemies is advisable. The application of insect pathogens as a foliar spray should receive high priority.

Rapid, accurate and easy-to-teach sampling methods must be developed and taught to farmers in a way that will encourage them to monitor their own fields. Practical, action thresholds are yet to be developed for many of the species. Because species usually appear in a complex, multiple species thresholds must be developed and put in a form that is easy to use.

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WEED CONTROL IN RAINFED LOWLAND RICE

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Yield losses due to weeds are greater in rainfed than in irrigated lowland rice. In rainfed lowland areas, moist aerobic conditions or shallow water lasting for extended periods during early crop growth, followed by prolonged periods of flooding to variable depths, favor the growth of a more diverse weed flora and more competitive weed species. C_4 species are more important under rainfed conditions. Weed weights are also higher under these conditions. Poor water control leads to reduced efficiency with all weed control methods, particularly with herbicides. Few weed management options are available to the farmer. Also, more time is spent weeding when water control is poor. Herbicides that give excellent weed control, provided there is sufficient water in the field when they are applied, have been identified in trials conducted at the International Rice Research Institute and in India. Herbicides that are recommended as alternatives to manual or mechanical weeding in India, considering labor availability and critical wage rate, are given. To minimize dependence on purchased inputs, herbicides should be used in combination with other weed control practices. In farmers' fields in the Philippines, herbicides alone, in combination, or combined with hand weeding have been used successfully for weed control, the level depending on the severity of infestation.

Most rice in Asia is grown under rainfed conditions; the amount and distribution of rainfall are uncertain, and fields may not be flooded from planting to maturity. In India, rainfed lowland rice is grown on 16.5 million ha or 42% of the total area planted to rice. West Bengal, Bihar, and Orissa account for 43% of the rainfed lowland rice area (9). The water environment of rainfed ricefields is governed by the seasonal distribution of monsoon rainfall (31). Most ricefields change from upland conditions to submerged conditions during the monsoon rains.

Ricefields can be colonized by terrestrial, semiaquatic, or aquatic plants depending on the type of rice culture and also on the season (27). In rainfed lowland ricefields, all three communities occupy the same physical location at different times of the year. Weeds compete severely with the crop, reducing grain yield by 10-50% depending on such factors as the weed species and their population (4). Yield losses due to unchecked weed growth in 144 field experiments coordinated by the All India Coordinated Rice Improvement

Project (AICRIP) over a 13-yr period (1969-1981) ranged from 13 to 40%, with a mean value of 25% (22). However, yield losses due to uncontrolled weed growth in trials at IRRI from 1971 to 1980 were greater, averaging 62% for irrigated lowland rice and 75% for rainfed lowland rice (30). In India, a number of field experiments dealing with crop-weed competition have shown that a weed-free period of 30 d after transplanting (DT) is necessary to prevent yield losses caused by weeds. However, submerged aquatic weed species such as *Eriocaulon quinquangulare* L. and *E. sexangulare* L. (syn. *E. sieboldianum* Sieb. and Zucc.) occur as a thick carpet during the late tillering and flowering stages of the crop and compete with it for nutrients applied as a topdressing.

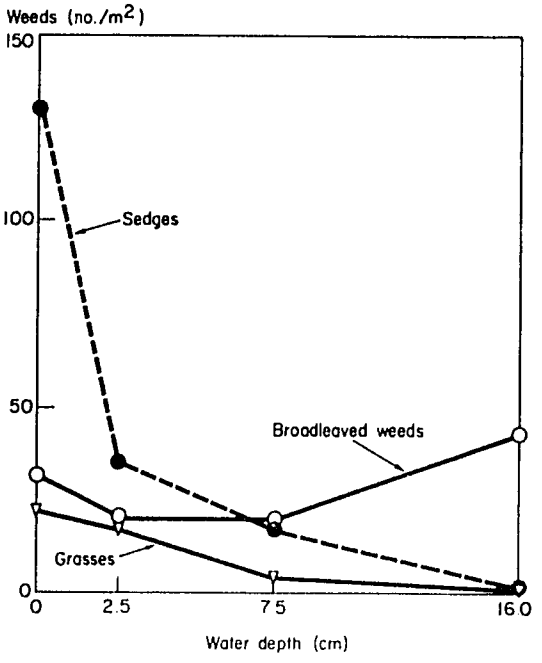
Transplanting is the most important system for establishing lowland rainfed rice in tropical Asia. But, because of the decreasing availability and increasing cost of labor, the importance of wet seeded rice (sowing pre-germinated seed on puddled soil) has increased in recent years. In India, wet seeding is recommended in the traditional rice-growing belt in rabi (dry season) (2?). Wet seeded rice is more susceptible to weed competition than transplanted rice. Bhan (4) reported that weed density and weed weight were markedly higher in wet seeded rice than in transplanted rice. In wet seeded rice, where weed weights were greater than crop dry matter for up to 60 d after sowing, weed competition was severe. In transplanted rice, weed weight was less than crop dry matter throughout crop growth. Even though weed competition continued up to 60 DT, it was less severe than in wet seeded rice. The average yield loss due to uncontrolled weed growth in 56 field experiments conducted from 1970 to 1981 ranged from 18 to 51%, with a mean value of 32% (22).

EFFECTS OF FLOODING

One reason for flooding ricefields is to decrease the total amount of weeds (23). Good water management is a major factor in weed control in rice. Keeping the field flooded after planting will kill some weeds and slow the growth of others. Greater weed growth will occur when the soil is saturated than when it is continuously flooded or alternately flooded and drained. Weed populations decrease as water depth increases. The total dry weight of weeds per unit area is significantly reduced by submergence (31).

Many weed seeds will not germinate under flooded conditions (25), but usually they cannot be killed by flooding. They will germinate when conditions become favorable. Moist, aerobic conditions that favor germination and growth of many weeds may occur for extended periods in rainfed rice fields. Flooding has a major suppressive effect on weed establishment, growth, and development when it is applied during the early stages of weed growth (8). Once weeds become established, flooding has less effect on them. Deeper flooding is needed to affect weed growth when flooding is delayed.

Mabbayad (19) found that shallow continuous flooding to a depth of 2.5 cm decreased weed weight markedly compared with saturated conditions. Very few weeds grew when the field was continuously flooded to a depth of 17.5 cm.



1. Effect of water depth on weed population in a field of IR8 at 28 DT. IRRI, 1968 wet season.

Others (4, 6, 7, 10, 11, 13, 14, 17, 20, 29) also reported that good water management significantly reduced weed growth (Fig. 1).

In most ricefields even in irrigated areas, continuous flooding to a depth of 5-10 cm is seldom attained. There is a problem of not only regulating water depth but also providing drainage. Moomaw et al (28) found that exposure of the soil surface at any time during the first 3 wk after transplanting encouraged weed germination and increased the labor required for weeding. Other researchers (17, 24) reported that more time was spent weeding when water control was poor than when water was controlled.

Various authors (16, 17, 20, 32) have shown that yields of transplanted rice are not significantly reduced by weeds when water management is good, but yield losses increase with poorer water management (Table 1). With good land preparation and good water management, further weed control may not be necessary or may be reduced to the minimum in transplanted rice.

Table 1. Effect of moisture regime on yield loss due to weeds (17).[a]

Moisture regime	Yield (t/ha)		Yield loss (t/ha)	Yield loss (%)
	Hand weeded 15 and 35 DT	Unweeded check		
Continuous flooding	5.3	4.5	0.8	15.1
Intermittent flooding	4.9	3.1	1.8	36.7
Saturated	4.9	2.4	2.5	51.0
Unirrigated until 28 DT, then saturated	5.3	2.2	3.1	58.5

[a]DT = days after transplanting.

Ricefields support a varied flora whose diversity decreases with increase in the potential for flooding and puddling (27). Mabbayad et al (20) reported more weed species and higher weed weights in puddled rainfed conditions than in puddled irrigated conditions (Table 2).

Another reason for flooding is the selective depression of C_4 weeds (23). Submergence may have a large influence on rice photosynthesis through the control of C_4 weeds, which compete strongly with rice, a C_3 species (31). The high photosynthetic capacity of C_4 weeds under high temperatures and high light intensities makes them very efficient competitors. Under these conditions, the photosynthetic rate of rice is usually lower than that of C_4 species. Therefore, C_4 weeds may be serious competitors with rice, especially during periods of water shortage brought about by irregular rainfall distribution. In irrigated fields, competition for water is not important, but in rainfed cultivation, where the water supply is limited, the additional transpiration of water by weeds may lead to a precarious situation. Efficient use of water is another distinguishing characteristic of C_4 species.

Arai et al (3) reported that distribution of weed species and their growth vary with soil moisture conditions. Tanaka (31) rearranged the results of Arai et al (3) and found that under saturated (80-90% of maximum moisture capacity) and upland (40-60% of maximum moisture capacity) conditions, C_4 species accounted for more than 90% of the total dry weight compared with only 10% under submerged (6 cm standing water) conditions (Table 3). In the Philippines, Mabbayad (19) reported that at water depths greater than 2.5 cm most of the weeds growing were *Monochoria vaginalis* (Burm.f.) Presl, a C_3 species; at soil saturation, grasses such as *Echinochloa* sp. and sedges such as *Fimbristylis miliacea* (L.) Vahl, both C_4 species, predominated. Mukho-

Table 2. Number of weed species and weed weight at rice maturity in unweeded plots as affected by land preparation method and water management (20).

Field condition	Weed species (no.)				Weed weight (g/m^2)
	Broadleaf weeds	Grasses	Sedges	Total	
Puddled irrigated	3	1	2	6	10.4
Puddled rainfed	5	3	5	13	34.6
Unpuddled irrigated	6	4	4	14	108.4
Unpuddled rainfed	9	6	4	19	162.9

Table 3. Effect of soil moisture on distribution of weeds with different photosynthetic pathways (31).

Photosynthetic pathway	Total weed weight (g/m^2)		
	Flooded	Saturated	Upland
C_3	10.7	21.6	4.8
C_4	1.3	35.9	66.7
Total ($C_3 + C_4$)	12.0	38.0	71.5

padhyay (personal communication, cited in 26) observed that there were more broadleaf weeds and fewer grasses when there was standing water in rainfed transplanted rice fields. These results indicate that submerged conditions play an important role in protecting rice plants from severe weed competition.

Carbonell and Moody (5) found differences in the weed species that farmers regarded as important in irrigated and rainfed transplanted rice in Nueva Ecija, Philippines. In the irrigated area, the most important weeds, in decreasing order of importance, were *E. crus-galli* (L.) Beauv., *Paspalum distichum* L., and *M. vaginalis*. In the rainfed area, the most important weeds were *Ischaemum rugosum* Salisb., *F. miliacea*, *E. crus-galli*, and *M. vaginalis*.

In India, irrespective of agroclimatic region, the floristic composition of weeds in transplanted rice differs least between shallow (5-19 cm water depth) rainfed and irrigated conditions. Sedges such as *Cyperus difformis* L., *C. iria* L., *F. miliacea*, and *Scirpus* sp. are predominant. Grasses such as *E. colona* (L.) Link, *E. crus-galli*, and *E. glabrescens* Munro ex Hook.f. and broadleaf weeds such as *Sphenoclea zeylanica* Gaertn., *Ludwigia perennis* L. (syn. *L. parviflora* Roxb.), and *Hydrolea zeylanica* (L.) Vahl are less important.

Weeds that are increasing in importance in transplanted and wet-seeded rice in the intermediate (20-49 cm water depth) rainfed lowlands are *Chara zeylanica* Willd., *Nitella* sp., and *Eichhornia crassipes* (Mart.) Solms in eastern India, *Salvinia molesta* D.S. Mitchell in southern India, *Potamogeton distinctus* A. Benn. in the Kashmir Valley, and wild rice (*Oryza* sp.) throughout the traditional rice-growing belt.

HERBICIDE EFFICIENCY

Poor water control leads to reduced efficiency with all methods of weed control, particularly with herbicides. De Datta et al (11) reported that weed control was less efficient and grain yields were lower when herbicides were applied to plots kept saturated for the first 20 DT than when they were kept flooded to a depth of 5 cm for the same period. Others (1,14,16,17,29) have also reported increased herbicidal efficiency with continuous flooding. Thus, with poorer water control the number of weed management options available to the farmer would be expected to decrease.

If the water depth in the field within 1 wk after herbicide application exceeds 10 cm, the herbicide rate must be increased 1.5-2.0 times the recommended rate when water control is good, to achieve equivalent control.

WEED CONTROL IN FARMERS' FIELDS

In transplanted rice in Haryana, India, poor field management that resulted in low standing water, combined with inefficient mechanical weed control measures, has been largely responsible for an increase in weed population and weed growth (21). In northwest India, annual weeds in transplanted rice have been controlled with butachlor, fluchloralin, nitrofen, thiobencarb, and oxadiazon (18). Effects of herbicides in farmers' fields are given in Table 4.

Table 4. Effect of herbicides on grain yield of transplanted rice in farmers' fields at 4 sites (11).[a]

Treatment	Formulation[b]	Active ingredient (kg/ha)	Yield[c] (t/ha)			
			Kurukshetra	Karnal	Ambala	Hissar
Oxadiazon	EC	0.60	—	—	—	6.4
Butachlor	EC	1.50	2.8	—	—	7.7
Pendimethalin	EC	1.50	—	2.3	3.5	8.5
Butachlor	G	1.50	—	2.5	3.4	8.1
Thiobencarb	G	2.00	—	2.3	—	6.7
Pendimethalin	G	1.50	—	2.2	3.5	7.8
Thiobencarb	EC	2.00	2.9	2.3	3.6	7.3
Fluchloralin	G	0.75	2.7	2.0	3.3	7.7
Oxadiazon	12 L	0.60	2.4	2.2	3.5	5.8
Farmers' weed control method			3.0	1.7	3.0	5.5
Oxyfluorfen	G	0.20	3.0	—	3.4	—

[a]Jaya cultivar was grown at Hissar, and local scented cultivars at other sites. [b]EC = emulsifiable concentrate, G = granule, 12 L = shaker bottle application. [c]— = no data.

In Nueva Ecija, Philippines, most farmers who grew irrigated transplanted rice used herbicide alone or combined with hand weeding; only 3% did no weeding (5). Herbicide adoption has been slower in rainfed transplanted rice. Only 20% of farmers in rainfed areas used herbicide alone or combined with hand weeding, 64% hand weeded, and 16% did no weeding. Thus, under poorer water conditions where herbicide performance was likely to be reduced and yield levels might be lower, the tendency to use herbicides was less. The farmers appear to have adjusted their weed control intensity to the production potential of the crop under a given set of environmental conditions (5).

In the irrigated area, most farmers applied liquid butachlor; in the rainfed area, most of those who applied herbicide used liquid 2,4-D. The economic and physical conditions under which the farmers operated probably influenced their choice of herbicide.

Hand weeding is and will remain an effective method of weed control in rice. In India, control of semiaquatic weeds in transplanted rice by traditional methods does not require much labor or expense provided that it is done at the early stages of crop growth. Where labor for hand weeding is in short supply or where it is expensive, the use of herbicides for weed control has proved effective and economical.

The control of submerged aquatic weeds is difficult, time-consuming, and costly in wet seeded or transplanted rice when manual methods are used. AICRIP (2) found that chemical weed control resulted in a saving of 45% on cost of control and an increased income ranging from 3 to 27% compared with hand weeding. Oxadiazon will control aquatic weeds such as *S. zeylanica* and *Nitella* sp. (15).

In recent years, the identification and availability of low-cost herbicides such as 2,4-D and butachlor have changed the weed control practices of many lowland rice farmers, including those in rainfed areas, from total dependence

on hand weeding to the use of herbicides as complete substitutes for or as supplements to hand weeding. Butachlor is marketed in 22 countries for use in both irrigated and rainfed rice. In yield constraint studies conducted by IRRI during the 1982 and 1983 wet seasons in Camarines Sur, Philippines, the yields of rainfed transplanted and wet seeded rice using the farmers' method of weed control did not differ from those obtained with the researchers' method (Table 5).

In 1982, 18 of the 21 farmers growing transplanted rice controlled weeds with butachlor, butachlor or 2,4-D followed by hand weeding, or with a combination of these methods. Yields of about 5 t/ha were obtained (Table 6). A single application of butachlor provided adequate weed control and gave yields comparable to those obtained with the combinations. For wet seeded rice, all the farmers used sequential applications of butachlor, 2,4-D, and hand weeding.

In 1983, almost all farmers used combinations of two or three control methods in both rice cultures (Table 7). Yields ranged from 4.0 to 6.5 t/ha. However, three farmers who applied 2,4-D alone obtained grain yields comparable to those obtained by farmers who used weed control combinations.

Table 5. Effect of weed control level on yield of rainfed transplanted and wet seeded lowland rice in Camarines Sur, Philippines, 1982 and 1983 wet seasons.

Weed control level	Grain yield[a] (t/ha)			
	Transplanted rice		Wet seeded rice	
	1982 (21)	1983 (11)	1982 (3)	1983 (7)
Researchers'	5.1	4.8	4.3	4.9
Farmers'	5.0	5.0	4.1	5.2

[a]Numbers in parentheses indicate the number of farms.

Table 6. Weed control practices of farmers and yield of rainfed transplanted and wet seeded rice in Camarines Sur, Philippines, 1982 wet season.

Weed control level[a]	Time of application[b] (DT/DAS)	Farmers (no.)	Av yield (t/ha)
	Transplanted rice		
No weed control	—	1	3.2
One hand weeding	30-35	2	5.2
Butachlor	4	2	5.4
2,4-D fb hand weeding	36 fb 40	1	5.6
Butachlor fb hand weeding	2-7 fb 16-34	5	4.8
Butachlor fb 2,4-D	2-6 fb 25-36	5	5.1
Butachlor fb 2,4-D fb hand weeding	2-6 fb 21-47 fb 30-50	5	5.1
	Wet seeded rice		
Butachlor fb 2,4-D fb hand weeding	8 fb 25 fb 29	3	4.1

[a]fb = followed by. [b]DT = days after transplanting, DAS = days after seeding.

Table 7. Farmers' weed control level and yield of rainfed transplanted and wet seeded rice in Camarines Sur, Philippines, 1983 wet season.

Weed control level[a]	Time application[b] (DT/DAS)	Farmers (no.)	Av yield (t/ha)
	Transplanted rice		
No weed control	—	1	4.9
2,4-D	19, 39	2	5.4
Hand weeding fb hand weeding	35 fb 37	1	3.6
Hand weeding fb 2,4-D	20 fb 45	1	5.1
2,4-D fb hand weeding	20-30 fb 28-30	3	4.9
Butachlor fb hand weeding	6 fb 45	1	5.9
Butachlor fb 2,4-D	3 fb 30	1	4.0
Butachlor fb 2,4-D fb hand weeding	3 fb 23 fb 47	1	6.5
	Wet seeded rice		
2,4-D	20	1	5.9
Hand weeding fb 2,4-D	20 fb 25-30	2	4.6
2,4-D fb hand weeding	20-31 fb 42-60	3	4.9
Butachlor fb 2,4-D fb hand weeding	4 fb 20 fb 26	1	6.2

[a]fb = followed by. [b]DT = days after transplanting, DAS = days after seeding.

These results indicate the diversity of the weed situation in rainfed lowland ricefields. For example, in a farm where the weed infestation was minor, the farmer did not weed and still obtained a grain yield of 4.9 t/ha (Table 7). But in many farms where the weed flora were varied and infestation was severe, the farmers had to resort to herbicide combinations or herbicide combined with hand weeding to obtain the desired yields. In other areas, a single application of butachlor or 2,4-D provided adequate weed control, indicating that herbicides may be used in rainfed lowland ricefields depending on the kind of weeds present.

HERBICIDE SCREENING TRIALS

From 1974 to 1983, 102 herbicides were tested in transplanted rice and 78 in wet seeded rice at IRRI at varying rates and times of application (Table 8). Among these, 32 looked promising for weed control in transplanted rice and 27 for wet seeded rice. The outstanding chemicals in each year's screening trial gave yield increases over the untreated checks of up to 4 t/ha in both rice cultures (Tables 9 and 10). Bensulfuron-methyl, naproanilide , and pendimethalin are included in current advance herbicide screening trials in irrigated transplanted and wet seeded rice at IRRI.

In India, many herbicides including 2,4-D, MCPA, butachlor, thiobencarb, nitrofen, propanil, oxadiazon, pendimethalin, piperophos, oxyfluorfen, anilofos, and dinitramine have proved as effective as hand weeding in transplanted rice. However, many of them are not used by the farmer because they are not commercially available or they are too expensive.

Table 8. Herbicides screened in rainfed lowland rice at IRRI, 1974-83.

Year	Transplanted rice (no.)		Wet seeded rice (no.)	
	Tested	Promising	Tested	Promising
1974	18	4	6	3
1975	17	4	15	4
1976	14	3	14	3
1977	7	3	7	[a]
1978	8	3	7	3
1979	6	3	4	3
1980	13	3	6	4
1981	6	5	6	3
1982	5	2	5	2
1983	8	2	8	2
Total	102	32	78	27

[a]Crop failed because of drought.

Table 9. Most promising herbicides for rainfed transplanted rice, IRRI 1974-83.

Year	Herbicide	Grain yield (t/ha)		
		Treated with herbicide	Untreated check	Difference
1974	Terbuchlor	4.7	2.7	2.0
1975	WL 29226	3.0	0.5	2.5
1976	Methiocarb - 2,4-D	4.0	0	4.0
1977	Fluorochloridone	2.4	0.5	1.9
1978	EF 5004	4.6	0.6	4.0
1979	Pendimethalin	2.7	0.9	1.8
1980	Perfluidone - molinate	5.8	3.5	2.3
1981	Lactofen	4.1	3.5	0.6
1982	M-8140	4.4	3.8	0.6
1983	MY 93E	3.4	1.5	1.9
Average		3.9	1.7	2.2

Table 10. Most promising herbicides for rainfed wet seeded rice, IRRI, 1974-83.

Year	Herbicide	Grain yield (t/ha)		
		Treated with herbicide	Untreated check	Difference
1974	Terbuchlor	3.4	0	3.4
1975	Naproanilide - thiobencarb	4.2	0.7	3.5
1976	Chlomethoxynil - 2,4-D	4.1	0	4.1
1977[a]	—	—	—	—
1978	EF 5004	2.7	0	2.7
1979	X-150	2.8	0.8	2.0
1980	Tiocarbazil - 2,4-D	4.0	1.6	2.4
1981	Molinate - 2,4-D	3.7	1.4	2.3
1982	DPX 5384	4.7	1.2	3.5
1983	MY 71	3.2	1.8	1.4
Average		3.6	0.8	2.8

[a]Crop failed because of drought.

Table 11. Critical wage rate for adoption of chemical weed control in transplanted rice in shallow rainfed lowlands (22).

Herbicide	Formulation[a]	Application rate (kg ai/ha)	Time of application (DT)[b]	Cost ($/ha)	Critical wage rate[c] ($/d)
Butachlor	5% G	1.0	5-6	22.30	0.75
Butachlor	50% EC	1.0	5-6	15.90	0.53
Thiobencarb	10% G	1.0	6-8	19.30	0.64
Thiobencarb	50% EC	1.0	6-8	15.00	0.50
2,4-D	4% G	0.5	5-6	15.00	0.50
2,4-D	80% WP	0.5	18-20	3.40	0.11

[a]G = granule, EC = emulsifiable concentrate, WP = wettable powder. [b]DT = days after transplanting. [c]With 30 d/ha required for manual weeding, the critical wage rate was determined as follows:

$$\text{Critical wage rate} = \frac{\text{cost of chemical weed control}}{\text{days required for manual weeding}}$$

Table 12. Critical wage rate for adoption of chemical weed control in wet seeded rice in shallow rainfed lowlands (22).

Herbicide	Formulation[a]	Application rate (kg ai/ha)	Time of application (DAS)[b]	Cost ($/ha)	Critical wage rate[c] ($/d)
Butachlor	5% G	1.0	6-7	22.30	0.56
Thiobencarb	10% G	1.0	6-7	19.30	0.48
Propanil	34% EC	1.7	15	33.70	0.84
Butachlor	50% EC	1.0	6-7	15.90	0.40
Thiobencarb	50% EC	1.0	6-7	15.00	0.38

[a]G = granule, EC = emulsifiable concentrate, WP = wettable powder. [b]DAS = days after seeding. [c]With 40 d/ha required for manual weeding, the critical wage rate was determined as follows:

$$\text{Critical wage rate} = \frac{\text{cost of chemical weed control}}{\text{days required for manual weeding}}$$

The herbicides listed in Table 11 are recommended as alternatives to manual or mechanical weeding only when labor resources are inadequate and the prevailing labor rate is well above the critical wage rate indicated for each herbicide (22). The herbicide 2,4-D, when applied 18-20 DT, is an inexpensive treatment that will control sedges and broadleaf weeds but not grasses. However, when applied shortly after transplanting it will control grasses as well as sedges and broadleaf weeds (12). Herbicides that are recommended for use in wet seeded rice and their critical wage rates are given in Table 12 (22).

The results indicate that weeds in rainfed lowland ricefields can be adequately controlled with herbicides. For herbicides to be effective, there must be sufficient water in the field at application time to dissolve them and, if a granular formulation is applied, to activate them. Naturally, it is better to combine herbicides with other weed control practices to minimize total dependence on purchased inputs.

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RAT CONTROL IN RICE

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Rats damage the rice crop at all stages of its growth, during postharvest processing, and during storage. Observations on major rat species in India are given. Quantitative estimates are provided of preharvest damage to the crop and of grain hoarding in burrows. Rat population density is correlated with cropping pattern. The strategic aspects of management of field populations of rats described include environmental management, land/crop management, field proofing barriers, vulnerable seasons, and rodenticides.

Rats ravage the rice crop at all stages from seeding to maturity and during postharvest processing and storage. Freshly sown seeds are dug out and eaten. Typically, seedlings and early tillers are cut 5-15 cm above ground within about 40 d of sowing. The tillers cut by rats are replaced by new tillers in due course, but by the time these attain the panicle stage the crop is harvested (27). In later stages of the crop, the attack commences with the earliest development of grains. Smaller rats climb up the plants to eat maturing grains, while larger rats cut down the tillers basally. Milky ears and ripe panicles are nibbled and carried to the burrows; the grains shattered in the field are eaten there. At rice maturity, when the field is dry, the plants bend, bringing the ears near the ground. The bandicoot rats, standing almost erect on their hind limbs, cut the ears and carry them to their burrows (4). Rats also reach the ears by pulling down the tillers or seeking out lodged stems instead of cutting them at the base (14). Comprehensive descriptions of the biology and control of rodents in rice are given in the PANS Manual (12). Some interesting contributions on the ecology, biology, and control of rats in ricefields have also been made (4,10,14,27,29). Some species of rats reported infesting the rice crop are given below.

India *Bandicota bengalensis* (Gray), lesser bandicoot or mole rat
Bandicota indica (Bechstein), large bandicoot rat
Rattus rattus brunneusculus (Hodgson), field rat
Rattus rattus (Linnaeus), the house rat
Rattus rattus rufescens (Gray)
Rattus rattus nitidus (Hodgson)
Rattus bowersi mackenziei (Thomas)
Rattus norvegicus (Berkenhout), Norway or brown rat
Mus booduga (Gray), Indian field mouse

	Tatera indica (Hardwicke), Indian gerbil
	Millardia meltada (Gray), soft-furred field rat
Pakistan	*Bandicota bengalensis*
	Millardia meltada
	Nesokia indica (Gray)
	Rattus rattus
	Tatera indica
Sri Lanka	*Gunomys kok gracilis*, field mole rat
Thailand	*Rattus exulans*, little Burmese rat
	Rattus rattus argentiventer, rice field rat
	Rattus rattus jalorensis, Malaysian wood rat
Indonesia	*Rattus rattus brevicaudatus*, sawah rat (said to be indistinguishable from *R. rattus argentiventer*)
Philippines	*Rattus rattus argentiventer*, rice field rat (called *R. rattus umbriventer* by some authors)
	Rattus exulans
	Rattus rattus mindanensis Philippine house rat
Europe	*Rattus norvegicus*
North America	*Rattus rattus*
	Myocaster coypus, *coypu* or *nutria*
	Ondatra zibethica, muskrat
Africa	*Thryonomys swinderianus*, cutting grass or cane rat
	Rattus (Mastomys) natalensis, multimammate rat

SEASONAL INCIDENCE AND POPULATION INTENSITY

The incidence, intensity, and seasonal breeding cycle of most of the species of field rats correlate with the cropping pattern of the region. Some salient features related to these aspects of the major pest species infesting rice crops in India are described below.

Bandicota bengalensis is the most destructive and abundant species inhabiting ricefields throughout India except in the mountainous and arid zones; it prefers wet soils (1). The males and females live in separate burrows (2); they multiply and concentrate heavily in bunds and hutments from June to October, and as soon as the harvest starts they begin to dig in the fields (4). In Andhra Pradesh they breed twice a year, during October-December and April-May, coinciding with the maturity period of the first and second rice crops (27). In Karnataka, the peak infestation is during December and January, but it declines thereafter; subsequent peak damage takes place during July. Severe damage correlates with the maturity of panicles and the harvest period of the crop during December-January. The lowest population of the pest is found in May (9). In the eastern region of India, in West Bengal, during the postharvest period in November-December, an average of 38 live burrow systems provided shelter to 456 rats (4). In Orissa, it is a predominant species and attacks rice even when there is 5-10 cm of water in the fields (R.C. Dani, personal communication).

Some estimates of the rice hoarded by *B. bengalensis* in field burrows have been made in different regions. In West Bengal, 3.2 kg of rice on the average were found to have been stored in each burrow system during December and January. Since there were 38 burrow systems (containing stored grains) per ha, the total loss of rice from hoarding was about 121 kg. Evidently, this loss in crop produce was exclusive of damaged rice plants (4). In Karnataka, the maximum quantity of rice excavated was 2.5 kg from a single rat chamber in the field (9). In Andhra Pradesh, the hoarding capacity was estimated to be a maximum of 2 kg/burrow (25). There are further reports that this species is capable of hoarding about 450 kg grain/ha of land (21). In Pakistan, the loss from hoarding was estimated as 27.8 kg in rat chambers per ha of rice crop (14).

Rattus rattus brunneusculus is the most dominant species of rat damaging rice in the Northeastern Hill Region (Mizoram). It constitutes 92.6% of the murid species in the region. An unusual increase in population intensity of this rat is said to be associated with the periodic mass flowering and seeding of 'Rawthing' bamboo (*Bambusa tulda*), resulting in extensive damage to the rice and creating almost famine-like conditions. Rats damage the crop by cutting tillers; they either eat the grains or hoard them inside their burrows.

This rat infests abandoned as well as fresh ricefields. In the abandoned fields, the population intensity peaks in January, declines abruptly in the following two months, and then gradually continues to decline until December. In fresh fields, the population remains low during the growth period of the rice crop (June-July) but subsequently picks up to peak during the harvest period in November-December. An oscillating trend of rat populations is found in the two habitats: when the population density in the abandoned fields decreased, it increased in fresh fields. Such a shift in population may perhaps be attributed to the stage of the crop, reproductive cycle, intra- and interspecific competition, related predator populations, and short-range migrations for food and shelter (7).

A female-dominated sex ratio has been recorded for the adult population. The male is a seasonal breeder and shows sexual activity from April to October. The female shows breeding characteristics from March to October; peak fecundity occurs during June-August; the nonbreeding phase is confined to January-February (7).

Millardia meltada is the common field rat of Punjab. It breeds from March to November, with a peak period from July to October (15). After harvest, rice grains arranged systematically are found in food chambers of this species (8). It also infests ricefields in Pakistan (14).

Tatera indica is the predominant species occurring with *B. bengalensis* in ricefields in Orissa. It attacks the crop at all growth stages, but the damage is most severe at the time of maturity, when ripe panicles are destroyed in large numbers (J.P. Kulshreshtha and R.C. Dani, personal communication). It also attacks ripening rice plants in Pakistan (14).

Mus booduga is the predominant species occurring with *B. bengalensis* in most of the irrigated lands in southern India. It is a serious nocturnal pest of

rice. The field mouse is very small and light (6 g); it normally climbs the plants and damages the panicles without cutting them (26).

Rattus norvegicus is a predominant species infesting rice crops in Orissa from sowing until harvest and may attack even where there is 5-10 cm of water in the field. It destroys a larger number of panicles than the amount actually consumed (R.C. Dani, personal communication).

Rattus rattus attacks the rice plants in Andhra Pradesh. It also attacks rice plants in Pakistan (14).

Bandicota indica subsists mainly on tubers and damages the rice crop during the dry and winter seasons. It is unable to compete with the dominant species, *B. bengalensis* (5).

Rattus rattus nitidus lives in cultivated fields and damages rice crops in Mizoram (S.K. Gangwar and Y.P. Singh, personal communication).

Rattus rattus rufescens damages ricefields in Andhra Pradesh (27).

Rattus bowersi mackenziei feeds mainly on tender shoots in ricefields in Mizoram (S.K. Gangwar and Y.P. Singh, personal communication).

The duration of maximum population intensity of various rat species in the ricefields of some regions is shown in Table 1.

PREHARVEST DAMAGE

There appears to be a higher intensity of rat infestation in fallow fields and wastelands than in cultivated areas according to a study of burrows in Gujarat. Maximum numbers of rat burrows per ha of fallow land were 434 for all burrows and 281 for occupied or live burrows. In wastelands, the numbers were 261 and 100, and in cultivated land, 167 and 116 (6). The yield of rice is consequently reduced by up to 60% and the yield of straw by up to 46% (17). In Andhra Pradesh, *B. bengalensis, M. meltada,* and *R. rattus rufescens* damaged 10-61% of the tillers of rice plants during the monsoon crop and 0.5-31% in the subsequent crop.

In Pakistan the rice crop is damaged mostly by *B. bengalensis, Nesokia indica,* and *M. meltada*. Damage to the tillers in most fields is more than 10%. Most estimates are between 15 and 25% (14).

MANAGEMENT

The basic consideration in rat control is cost effectiveness of the package of management practices. The cheapest and most effective methods have to be adopted. Evaluation of postoperational residual populations of the pests is an essential follow-up step. Further, the decisive factor in success of the control operation is people's involvement over a wide area.

Environmental management

Killing rats should be resorted to only as an interim measure for reasons of "biotic resurgence" and the high cost of supporting antirat campaigns. Strategic manipulation of environmental features that provide shelter for rats

Table 1. Peak damage periods of rat species in India.

Region	Species	Duration of peak damage		
		1	2	3
Tamil Nadu	*Bandicota bengalensis*	Feb-Mar	Jun-Jul	Oct-Nov
Karnataka	*Bandicota bengalensis*	—	Jun-Jul	Nov-Jan
West Bengal	*Bandicota bengalensis*	—	—	Oct-Mar
Orissa	*Bandicota bengalensis* *Rattus norvegicus*	—	Apr-Jun	Sep-Dec
Mizoram	*Rattus brunneusculus*	—	Nov-Dec	—

in the fields appears feasible. The distribution pattern and habitats of murids are influenced by ecological interactions of soil characteristics, vegetation, and crop. The fallow fields and wastelands adjoining ricefields harbor large numbers of *B. bengalensis* and *M. meltada* and must be managed regularly.

Land/crop management

A series of measures needs serious consideration. Thickness of bunds around ricefields should be kept to a minimum to discourage burrows. Synchronized planting schedules and the monoculture system in rice growing areas are likely to reduce destruction and alternative food sources. Weed control within the crop and along the bunds is an effective practice to contain the rat population; this practice could remove 90% of field rodents (18). Prompt disposal of crop residues from threshing floors prevents off-season infestation.

Indigenous rice varieties seem to have suffered more damage than the harder-straw IRRI varieties (14). Varieties of grains difficult to husk may also be spared to a certain extent. The late maturing variety HR35 was relatively less damaged (31). Variety IET5472 had no rat damage. Jaya variety, which is susceptible to many insect pests, averaged the highest rat damage (35.4%) (3).

Field proofing barriers

In the Philippines, rats have been successfully excluded from experimental plots of rice with an electrified fence (24). Two wires supported on insulators are placed beside a wire-netting fence (30 cm high) around the field. The wires are charged with a current of 125-230 volts transformed from a 6-12 volt battery (12). In India, farmers in Tamil Nadu have successfully prevented damage by electrocuting rats (31,32). The practice is dangerous but ingenious. Perhaps the provision of sublethal electrical barriers has potential to reduce crop losses.

Augmentation of predators

Some common and effective biotic agents such as predatory reptiles, hawks and owls, foxes, and the mongoose (*Herpestes* sp.) play an important role as regulators of rat populations in fields. Interestingly, the mongoose was introduced into Jamaica from India in 1872 (11) and was subsequently shipped to Cuba, Puerto Rico, and Hawaii in large numbers. These natural enemies of rats need augmentation, particularly in rat endemic areas.

Vulnerable season

The choice of season for antirat operations depends on the habitat and the species. Control operations must be initiated when the rat population is lowest; the main effort should be to track down the reservoir populations. In dry areas of tropical countries, minimum population density occurs in summer, when vegetation and water are scarce. In such circumstances, the bait is likely to be accepted more readily by the resident rats. Furthermore, their fertility is lowest during summer, when the farmers have spare time and labor to participate as a community in the antirat campaigns.

RODENTICIDES IN POPULATION MANAGEMENT

Antirat field campaigns should be organized systematically on a regional basis during lean periods of pest intensity after extending proper training and motivation to the community. Technically, the following sequence of field operations is necessary:

1. Quantitative surveys of rice growing areas to assess the number of live burrows; fallow fields and wastelands should also be included under the operational program.
2. Fumigation of live burrows to manage a large resident field population of rats in a short time.
3. Prebaiting for 3 d with locally available bait (rice in the present case) with about 4% vegetable (groundnut) oil.
4. Poison baiting with an acute (single-dose) poison like 2% zinc phosphide for 1 d.
5. Poisoning with chronic (multidose) poison like fumarin and warfarin anticoagulants for 6 or more d. In houses adjoining threshing areas and haystacks, anticoagulant baits need to be applied continuously for at least 1-2 wk.

In special situations, such as in Mizoram, all operations should also be done around the bamboo clumps adjoining the fields to prevent the migration of rats to the rice crop.

Fumigation

The burrow fumigation method is warranted when a large resident field population of rats is to be managed in a short time. The use of calcium cyanide powder pumped into the burrows with a cyanogas pump has been replaced with use of aluminum phosphide pellets, which release phosphine gas, but only in humid air. Against *B. bengalensis*, a dose of 1.5 g of aluminum phosphide in each live burrow was found most effective and economic, with 91% mortality (16).

Poison baiting

Prebaiting is practiced for 3 d. The choice of a bait base depends on the species and the common food of the area; rice constitutes the best base in rice-growing tracts. Texture of the bait also influences acceptability. There is a marked

preference for wet rather than dry baits. Vegetable oils are added (4% by weight of the cereal base), but should be avoided if the bait is likely to become moldy or rancid under humid conditions. The use of groundnut oil rather than mustard oil improves the acceptability of the bait material (28). Each bait station should have 50-80 g of bait material located at places frequented by rats.

Zinc phosphide is probably the most widely used acute poison for rats. It is effective against most species. In dry environments it remains effective for about 3 wk in baits but deteriorates rapidly in humid conditions because phosphine gas is released; the latter is not repellent to rats. The quality of the rodenticide is very important because impurities may be the basic cause of avoidance of the bait that has occurred with scilliroside extracted from red squill (*Urginea maritima*), zinc phosphide, warfarin, etc.

The use of zinc phosphide induces aversion to feeding or "bait shyness," which lasts for weeks after the first operation (20). Evidently it is not effective against the rat population left over after the first operation. In fact, it is the residual population that is a serious problem because of its high breeding potential. Bait shyness in *B. bengalensis* and *T. indica* is overcome when both poison and bait material are changed (30). With acute poisons, about 70% of the population may be eliminated.

Pyriminyl (coded as RH-787) is said to be a target-specific acute poison (23). Bait shyness for pyriminyl lasts for 7-15 d, whereas for zinc phosphide shyness lasts 15-22 days (13). Other workers have not observed any pyriminyl shyness (23).

There are several other products in use such as norbormide (Raticate) and scilliroside (from red squill) (22).

To deal with residual populations after the use of acute poisons, protracted baiting with chronic poisons is essential. Rodafarin and pival proved better at 0.025% concentration than ratafin, coumatetralyl, pindone, and chlorophacinone (19). The coumafuryl (ratafin)- and warfarin (rodafarin)-based anticoagulants have the ability to counteract the action of vitamin K; bait shyness is not developed.

Precautions are required in handling poisonous substances. To avoid secondary poisoning of scavenger birds, dogs, or other carnivores, poisoned dead rats must be disposed of carefully. Using traps of local design may help to eliminate residual rat populations after poisoning campaigns.

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TECHNOLOGY TRANSFER

383

OPERATIONAL RESEARCH PROJECTS ON RICE IN INDIA

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This paper describes 1) the basic problems and potential of rice production, especially of rainfed lowland rice; 2) the genesis and conceptual framework of operational research projects (ORPs); 3) ORPs as an integral part of the first line extension system of the Indian Council of Agricultural Research; 4) the aims and objectives of ORPs; 5) the achievements of ORPs; 6) the constraints to change; and 7) the future extension strategy. The limited number of ORPs on rainfed lowland rice is indicative of the need for starting more ORPs and extension efforts to accelerate rice production, particularly in the eastern states of Bihar, West Bengal, and Orissa and the eastern parts of Uttar Pradesh and Madhya Pradesh. Recent efforts in this direction and those being planned for the Seventh Five-Year Plan are discussed.

Rice is the most important cereal crop and staple food in India. Of about 40 million ha of land devoted to rice farming, 30% is irrigated and the remaining 70% rainfed lowland. Rice production in India is beset with two major problems: drought stress in upland rice, and water management of ill-drained soils in the rainfed lowlands. The States of Bihar, West Bengal, and Orissa have about 10 million ha of lowlands affected by flash floods and waterlogging.

In the recent past, there have been considerable developments in technology for both upland and rainfed lowland rice farming. Rice production increased from 21.3 million t in 1951-52 to 59.3 million t in 1983-84, and rice provides 40% of the total food grain production (including pulses). Average national rice production is now over 1.9 t/ha, and imports stopped in 1976. The main share of increased production has come from the northern and southern states, while production in the eastern states has remained more or less stable. Rice yield patterns have varied widely: 3-4 t/ha in northern India, 2.4-3.0 t/ha in the south, and 1.0-2.0 t/ha in the eastern region.

Rainfed lowland rice requires at least 30 cm of rainfall/mo, consecutively for 3 mo, which is satisfied only in two areas: the northeast, which constitutes 9% of the total rice area, and the west coast, which constitutes 5%. The northeast suffers from chronic, devastating floods. The ideal condition for rice farming is nearly met in Bihar, Orissa, West Bengal, eastern Uttar Pradesh, and eastern Madhya Pradesh, which receive more than 30 cm of rainfall but in two consecutive periods: July-August, and September. This region con-

tributes 45% of the rice area of the country; however, weather aberrations and frequent drought or flood upset rice production.

The rice crop does not have wide adaptability like wheat. Modern rice varieties have in their parentage Taichung Native 1 and IR8, and are derivatives of one genotype — the Chinese dwarf Dee-Geo-Woo-Gen (DGWG) — with enormous uniformity. This is why attacks of pests and diseases in rice occur in endemic forms. Heavy irrigation and fertilization further aggravate the problem. The modern varieties are not very suitable for stress conditions such as upland or ill-drained soils. Widely varying agro-climatic conditions have posed serious problems to rice scientists as well as to extension professionals.

OPERATIONAL RESEARCH PROJECTS

For utilization of resources according to needs, relative priority to a particular area, and proper division of labor among scientists, research has been categorized into 1) basic/fundamental (creating knowledge), 2) applied/mission-oriented (problem solving), and 3) adaptive (field trials or verification). The Indian Council of Agricultural Research (ICAR) extended this concept a step further by introducing operational research projects (ORPs), which aim at field testing research results, disseminating technical knowledge, and identifying constraints to change.

The first-line extension work in agriculture and allied areas in India is undertaken by research and educational institutions under the umbrella of the ICAR Extension System. This lead function is intended to demonstrate research results promptly to farmers as well as to extension functionaries, especially around institutions and their stations and substations. The firsthand feedback to scientists on the field performance of their technologies is another important objective of the ICAR Extension System. ICAR has launched six transfer-of-technology projects that include ORPs.

The first-line extension role of institutions or scientists needs proper recognition and strengthening in all developing countries as a foundation to the main extension system in the Ministry or Department of Agriculture. Such efforts in India, even though on a limited scale, have had a salutary effect on the extension agencies as well as the farmers, and are a direct approach to achieving integrated functioning of research, education, and extension.

Experience with national demonstrations (one of the extension projects of ICAR) led to the belief that demonstration of a particular technology or a combination of technologies in a whole village, a cluster of villages, or a watershed would be more effective in convincing farmers and would provide greater scope for field testing and constraints analysis. This is why the ORP concept was introduced in 1975. The basic approach has been to identify and attack a common problem on a community basis — for instance, ORPs on improving the Diara farming system, popularizing composite fish culture, or integrated management of rice pests. Some ORPs are also devoted to all-round development of an area — the transformation of the rural economy through

technological changes. Forty-six recent watershed management ORPs aim at total resource development in the operational areas. The collaborative efforts of ICAR, the Ministry of Agriculture, and the Ministry of Rural Development in the watershed management ORPs are a good example of effective linkage, marrying scientific expertise and capital and extension resources. Presently there are 39 ORPs with 124 centers. Two of the 39 (with 9 centers) are devoted to rice farming: integrated management of rice pests (6) and the rice production system (3). In addition, rice farming also figures in other ORPs wherever agroclimatic conditions permit.

OBJECTIVES AND PROGRAMS

The rice production ORP is being implemented in Khammam District (shifted from Nalgonda) in Andhra Pradesh, Burdwan in West Bengal, and Basudevpur of Balasore District in Orissa. The centers at Khammam and Basudevpur are in rainfed lowland areas. The ORP on integrated management of rice pests aims at 1) comparing traditional chemical methods with integrated management, 2) determining the economic threshold of the pests and evaluating minimal and regulated plant protection schedules, 3) minimizing environmental pollution by avoidance of excessive use of chemicals, 4) working out the cost-benefit ratios between the two methods, 5) assessing the increase in crop yields, and 6) finding out the impact of the project on the socioeconomic condition of rice farmers in the operational areas.

The programs in five villages near Khammam in 1983-84 included prekharif green gram (Pusa Baisakhi) or green gram for green manuring followed by varietal demonstrations in kharif with brown planthopper (BPH)-resistant IET7575 vs Surekha; IET8130 with resistance to rice tungro virus (RTV) vs Surekha; IET5912 possessing fine grain quality vs Mahsuri; and rice gall midge (GM)-resistant IET7970 and short-duration IET7880 vs Tella Hamsa. Fertilizer-saving techniques such as use of neem cake-coated urea, coal tar-coated urea, urea supergranules, and management of N were tested and demonstrated. Other extension activities were organization of short training programs for rice farmers, organization of pest control campaigns, and field days.

The rice ORP in Basudevpur continued for the third successive year in waterlogged and flood- and salt-affected areas (normally an ORP continues at a location for 5 yr). The program for 1983-84 included intensification of cultivation of modern varieties (MVs) for lowlands (CR1018, CR1009, CR1030, and CR1011) with recommended packages of practices. Demonstrations were conducted at different levels of submergence (0-20 cm, 15-20 cm, and 30 cm). The management of saline areas ORP introduced salt-tolerant varieties and studied the relative performance of Getu, Damodar, Getu mutant, and other Central Rice Research Institute (CRRI) cultures. Adoption of green manuring practices, monitoring of salt hazards, use and efficiency of fertilizers, and use of azolla were encouraged through demonstrations and training programs.

The ORP on integrated management of rice pests was implemented in five states in six locations where major pests are endemic: stem borer (SB) and BPH in Bapatla and GM in Warangal, Andhra Pradesh; BPH in Moncompu, Kerala; GM in Raipur, Madhya Pradesh; SB and GM in Cuttack, Orissa; BPH and GM in Pandooah, West Bengal; and SB in Thana and Kolaba, Maharashtra. Integrated pest control was practiced in a compact area of 1,000-3,000 ha, and an adjacent village was taken as a control. Pest surveillance, use of insecticides based on economic threshold of the pests, use of pest resistant or tolerant varieties, cultural control, and exploitation of natural enemies or parasites were main components of the program. Table 1 presents the economic threshold adopted for the major pests.

ACHIEVEMENTS

Rice farming systems

In the ORP on rice farming systems in Khammam District involving multiple cropping demonstrations of prekharif green gram followed by kharif rice, green gram (Pusa Baisakhi) and rice variety Phalguna gave the best results. Yields were 0.67 t/ha for green gram and 5.42 t/ha for rice. The BPH-resistant variety IET7575 (5.45 t/ha), RTV-resistant IET8130 (6.20 t/ha), and fine-grain IET7918 (4.53 t/ha) performed much better than the local varieties.

Demonstrations on efficient fertilizer use for rice supported the superiority of neem cake-coated urea and urea supergranules. Split application of N — 25% basal, 50% in the first split, and 25% in the second — gave the best results. Most farmers have shifted to the varieties and practices demonstrated on their farms.

There were 105 demonstrations in Basudevpur. Increases in rice yields were spectacular because of the adoption of MVs and associated technology. In the villages of Jaipur and Narainpur, variety CR1009 gave mean yields of 6.43 t/ha in areas of shallow submergence (15-25 cm) and 5.40 t/ha in areas of intermediate submergence (25-35 cm). In Nanpur and Makhalpur, yields averaged 6.2 t/ha under submergence levels of 25-35 cm. The highest yields of 8.2 and 8.5 t/ha were recorded for CR1009 in two locations. The yield levels

Table 1. Economic threshold of major pests adopted in ORP on integrated management of rice pests.

Pest	Stage of crop	Damage to population
Stem borer	vegetative	10% deadheart
	heading	2 moths or 1 egg mass/m²
Brown planthopper	vegetative	4-5 nymphs or adults/hill
	flowering	20-25 nymphs or adults/hill
Green leafhopper	vegetative	4-5 nymphs or adults/hill
Leaffolder	vegetative and flowering	5% leaves damaged
Rice hispa	vegetative and flowering	5% leaves damaged
Rice gundhi bug	flowering	2 nymphs or adults/m²

were reduced to the range of 3.8-4.5 t/ha where there was a slight deficiency of water in the late reproductive phase. In CR1030, which had been grown under slightly deeper water, average yields were 5.2 t/ha in the village cluster of Jaipur-Narsinghpur and 5.9 t/ha in Banpur-Nakhalpur under intermediate submergence levels (25-35 cm). Under deeper submergence levels ranging from 40 to 45 cm, mean yields were 5.3 t/ha in Jaipur-Narsinghpur and 5.8 t/ha in Bonpur-Nakhalpur. The highest yields for these varieties were always higher than 7 t/ha. The local varieties yielded less than 3 t/ha in the project area.

Integrated pest management

The integrated pest control ORP on the rice crop in Andhra Pradesh, Orissa, Kerala, Madhya Pradesh, Maharashtra, and West Bengal has made considerable impact on rice farming.

The work on integrated control of BPH in Bapatla district is being carried out by the Andhra Pradesh Agricultural University. As a result of improved practices, BPH and other pests exceeded the economic threshold level in only 40 ha compared with 175 ha in the uncontrolled village. Application of neem cake at 125 kg/ha at the panicle initiation stage was effective in reducing susceptibility to BPH. With the integrated control measures, average rice yields in the operational area ranged from 4.5 to 5.8 t/ha.

In Warangal District, seedling root dip, introduction of insect-tolerant varieties, and the suggestion to spray on the attainment of economic threshold levels of pests have proven successful. Destruction of stubble soon after harvest in order to destroy SB larvae, and the introduction of pulse crops between kharif and rabi rice have benefited farmers. Early planting in kharif has also been adopted to escape GM incidence. The formulation of alleyways has minimized BPH incidence.

At Mahabubabad Center, continuous monitoring of BPH allowed prediction of its occurrence. The yield of Tella Hamsa increased from 0.6 t/ha in 1980-81 to 3.9 t/ha in 1982-83 due to BPH management measures. There was progressive reduction of insecticidal sprays from 0.06 to 0.01 (rice) and 8.89 to 4.41 (chilies). The GM-resistant variety Surekha became popular in the area. The cost of plant protection measures adopted declined from Rs 5.87 to Rs 3.60 for rice and Rs 14.96 to Rs 11.76 for chilies. Application of the entire dose of N within 45 d after transplanting reduced BPH incidence.

Integrated pest control measures have been successfully introduced in the Kerala project area through replacement of susceptible paddy varieties like Jaya and IR8 by pest-tolerant varieties such as Jyoti, Bharathi, and Trivani; cultural methods such as flood fallowing of rice fields; and early direct seeding or transplanting before September to avoid the peak incidence of pests such as BPH during February-March. Rice culture M11-57-5-1 was identified through adaptive minikit trials, and the concept of economic threshold of pest incidence was taken up as the control measure. The latter was accepted by the farmers in the region, with the result that the number of sprayings was brought down from 6-7 to 1-2.

In Raipur District the Jawaharlal Nehru Krishi Vishwa Vidyalaya (NKVV) in Jabalpur implemented an ORP on control of rice pests in four selected villages. GM-resistant varieties Surekha, Balguna, BP94, R35-2750, and R35-2752 were introduced in addition to some of the early-maturing varieties. To control SB, over 200,000 *Trichogramma* sp., an egg parasite, were obtained from the Central Biological Control Station at Gorakhpur and distributed in the project area. The attack subsided and no SB damage occurred during kharif the following year.

In Hooghly District (West Bengal), pest-tolerant rice varieties Shakti and Vikram helped check GM incidence; about 50% of the operational area is at present planted to those varieties. The use of light traps has been accepted by farmers, and they have improvised torches or earthen plates with oil-pierced bamboo stroves. Dipping rice seedlings in insecticides before transplanting, and leaving alleyways for BPH control were widely adopted. The coverage of recommended high yielding, pest-tolerant varieties increased from 9.2% in 1975-76 to 43.2% in 1980-81.

Rice/fish culture

In rainfed lowlands with rice, fish culture has been successfully introduced. The culture of fish along with deep water rice provides increased production and income. Fish production has been as high as 3.8 t/ha, along with rice production of 2 t/ha. In several cases, vegetable and fruit cultivation on the sides of the bunds of the fish/rice fields has also been encouraged, especially in West Bengal and Orissa.

CONSTRAINTS

Rice production in rainfed lowlands is beset with problems and constraints. The following were observed in the ORP areas:

1. MVs are not suitable for stress conditions such as poorly drained soil. Good deep water rice has yet to be developed. Some promising varieties (IET series) are still under initial evaluation.
2. MVs almost uniformly have their parentage in Taichung Native 1 and IR8, and are derivatives of DGWG. Thus, pests and diseases have been endemic. Varieties resistant to diseases and pests should receive the priority attention of rice scientists.
3. MVs of rice are not as widely adapted as those of wheat and sugarcane.
4. Effective techniques of N management in submerged rice have been difficult, ineffective, and expensive. Studies should evolve efficient methods and techniques of fertilizer application and management.
5. Zn deficiency in soils has been noted in some of the ORP areas. Besides NPK, attention to minor elements is needed to maintain soil fertility level and thus productivity.
6. A labor shortage occurs during peak agricultural operations in rice farming. Labor-saving devices — especially agricultural implements for

transplanting, weeding, and harvesting — are extremely important but are not available.

7. Farms in India are not only small-scale, but are also fragmented and scattered, and the trend is toward further fragmentation. Holdings should be consolidated, and further fragmentation due to land distribution among sons and daughters should be arrested by government policy and law.
8. Agricultural inputs — improved seed, fertilizers, pesticides, and credit — are not readily available to the rice growers. Village cooperatives must play an important role in this respect.
9. Rice technologies have become very complex and sophisticated such that extension workers are not able to cope with them. Rice agronomists have to be provided in transfer-of-technology projects, especially in West Bengal, Bihar, Orissa, eastern Uttar Pradesh, and eastern Madhya Pradesh, where the scope for rice production is great.
10. The training institutions for the farmers such as Farmers Training Centers, Krishi Vigyan Kendras (Farm Science Centers), and the Directorates of Extension of the agricultural universities must organize short-term as well as long-term courses for rice farmers. The extension workers of the rice-farming areas must also be continuously updated.
11. There are not many ORPs in rainfed lowland rice areas, and the existing ones need to be strengthened. The ORPs have to be more educational and motivational.

FUTURE THRUST

The potential areas for rice production are known — Bihar, Orissa, West Bengal, eastern Uttar Pradesh, and eastern Madhya Pradesh — but they are problem areas. Rice scientists should give priority to evolving technologies suited to these areas. The regional research capabilities being developed through the National Agricultural Research Projects (NARPs) of ICAR should concentrate more in these areas to evolve location-specific technologies. NARP projects have already been approved by ICAR in Bihar, Orissa, eastern Uttar Pradesh, and eastern Madhya Pradesh, but not in West Bengal.

Transfer-of-technology programs must be focused and location- and problem-specific. The Ministry of Agriculture has realized this issue, and the Government is now poised to attack the problem with concentration and strength. Consequently, 50 community development blocks in the states in question have been selected to boost rice production with more inputs of both men and material. In the Seventh Five-Year Plan, some 500 such blocks are to be adopted in those states to accelerate rice production, and training support for both farmers and field extension functionaries will be strengthened.

TRANSFER OF TECHNOLOGY FOR INCREASING YIELDS OF RAINFED RICE IN EASTERN INDIA

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The social, economic, and business aspects of lowland rainfed rice development in the smallholder environment in eastern India are reviewed. Three socioeconomic factors restrain development: the land tenure system, population pressure, and lack of financial capacity of rice smallholders. Three medium-term measures can effect the needed transfer of technology: adoption of low-cost technology, improvements in the extension system, and cooperative arrangements for the supply of inputs and credit services.

Nearly two-thirds of the agricultural area of eastern India is used to cultivate rice, and three-quarters of the crop is rainfed. It is estimated that about one-third of all rice is grown in low topography areas where problems of drainage depress yields. Considerable advances have been made in eastern India in lowland rice technology, including improved varieties (e.g., CN540, CNM539, Jaladhi 1, Jaladhi 2, and NC1281), plant nutrition, and plant protection strategies.

The accumulated stock of technology for lowland rainfed rice is perhaps able to increase yields by 30-40%. The present conference will surely add further to the thrust for higher yields. The rice farmer of eastern India has given ample evidence of his response to profitable technology. In West Bengal, for example, 100% of the area is planted to modern varieties of summer (boro) rice and 40% to modern varieties of winter rice. The average yield exceeded 2.5 t/ha in 1983-84.

Most boro farmers are relatively large landholders with ample resources for investment, but only about 10% of the land is irrigated. Smallholders cannot muster adequate resources for investment in boro crops and hence are barred from using a profitable technology.

THREE SOCIOECONOMIC CONSTRAINTS

The agricultural economy of eastern India is characterized by three socioeconomic factors that have delayed progress. First, eastern India suffered historically from a pernicious kind of land tenure system, called Zamindari, under which the actual tiller of the soil had little incentive to invest in modern technology. Even though the Zamindari system was abolished by law, the considerable imbalance in the demand for and supply of land led to tenurial

conditions that did not improve the condition of the actual tiller of the soil. Second, the pressure of population has led to extreme fragmentation of landholdings. In West Bengal, for example, the average holding of about 1 ha typically consists of 8-10 pieces of land kilometers apart from each other. Third, there are many small and marginal landholders who have little or no financial capacity to invest in land and crops. About 90% of all families hold 2 ha or less; some 60% have 1 ha or less. They have very little economic capability to experiment with new agronomic practices and to undertake risks. The uneconomic size of the holdings makes individual investment in irrigation and drainage very difficult.

The need is to develop the most effective transfer of available technology to rice farmers, while continuously upgrading that technology. Unlike the industrial sector, where the time interval between the arrival of a new technology and its application is brief, the interval in the farm sector can be quite long in view of socioeconomic constraints. Each constraint may take a long time to overcome. The process of land reform is delayed, thanks to well known constraints prevailing in a democratic system. Equally time-consuming will be consolidation of holdings, without which investment in irrigation and drainage on individual initiative is unprofitable. Public investment in such activities is constrained by budgetary resources.

THREE MEDIUM-TERM MEASURES

Under the circumstances, one has to stress medium- and short-term measures for effective transfer of technology, while continuing to tackle the more stubborn and long-term constraints. Such medium- and short-term measures could consist of 1) resorting to low-cost and no-cost elements in technology, 2) improvements in the extension system, and 3) improvements in input and credit delivery.

Low-cost technology

Constraints analysis has shown that an important cause of low yields is the unduly large spacing in the crop stand. Research has determined the optimal spacing between rows and plants, yielding handsome dividends on the relatively small additional investment for extra seedlings and labor. Similar is the situation regarding seed and nursery treatment, good preparatory tilling, timely sowing, prompt gap-filling, timely weeding, topdressing, and harvesting. Use of inexpensive biological fertilizers like blue-green algae could also add to cost effectivity. The Department of Agriculture in West Bengal has undertaken trials in all adaptive trial stations to identify the most profitable method and time of application of a threshold dose of 20 kg N/ha, which, costing about Rs 100/ha, is what most marginal holders can afford. It is estimated that these low-cost inputs could add 30% to yields. Having tasted success and additional income, smallholders would naturally graduate to a higher level of investment to increase yields further.

Extension system

While the recent emphasis on professionalization of the extension services is bearing fruit, it involves heavy costs. In eastern India, considerable additional resources are needed to strengthen four essential linkages. First, the applied and adaptive research support to the extension system needs to be strengthened so that location-specific recommendations can be provided and solutions to local problems found. Second, there should be stronger relationships between extension and other agricultural development agencies, spelling out feasible targets for crops, areas, yields, input supplies, and market support. Third, the input delivery system should work in full coordination with the extension agency such that demand generated for inputs is met in full and on time. Fourth, it is necessary to have a creative personnel management policy for managing a nation-building corps such as the extension service, which is expected to work with missionary zeal and secure changes in the habits of 1,000 families per worker. It is a sad fact that most village extension workers get their first promotion (yielding an increase of less than Rs 50/mo) after 20-25 yr of service. It is impossible to expect them to continue working with enthusiasm in difficult environs under such conditions. The situation for graduate extension officers at the block and district levels is no better. A personnel system with heart is needed.

Delivery of inputs and credit services

Modern farm technology involves cash outlays for the use of improved seed, fertilizers, pesticides, and machines, which most smallholders cannot afford without assistance from state-aided agencies such as cooperative societies. In all dynamic smallholdings in India and abroad, the development of agriculture and that of cooperative institutions have gone hand in hand. One has only to consider the success of farming in Japan, Taiwan, South Korea, and Israel. A district by district analysis in eastern India shows close correlation between high yields and cooperative support.

Under ideal conditions, a farm cooperative society should, with state aid, be able to extend credit, input and marketing services to all farmers, particularly smallholders. But reality is unfortunately at variance with the ideal. Many of the cooperative societies suffer from lack of unity and democratic spirit, cliquish rule, and financial and managerial efficiency. The exceptional, efficient ones stand out as beacons for others through their successes in helping their member-farmers to achieve higher yields.

In eastern India, the private sector is the predominant sector at present in the distribution of improved seed, fertilizers, pesticides, and farm implements. It is essential to train sales people to render to farmers reasonably well-informed services. Nationalized commercial banks have also begun to provide credit support to farmers. The critical element here is supervised credit to ensure that it is used for productive purposes and that credit recovery is assured through linkage with marketing of produce. The efficient cooperative society, being able to combine input, credit, and marketing services, has a

natural superiority in this sphere; a strong cooperative service is of critical importance to the successful transfer of technology.

It is also essential to recognize the risky nature of credit and input supply services, and the sophisticated management necessary to avoid the huge losses that characterize many cooperatives in eastern India. In an agriculture dependent on rainfall in 75% of the area, advance stocking of seed, fertilizers, and pesticides in inaccessible areas has a risk quotient higher than any in the industrial sector. A beginning has been made with crop insurance, which should gradually increase farmers' inclination to invest in inputs, with much of the risk duly covered by insurance.

Finally, agriculture in smallholder situations requires considerable community action, particularly in sharing irrigation and drainage services; bullocks, plows, and power tillers; and farmers' own labor through planting compatible crops and taking plant protection measures.

In this context, we should also highlight the need for incentives to medium-scale farmers holding between 2 and 4 ha, who are presently left out of many government support schemes. It is these farmers who produce marketable surpluses to feed the urban areas and who are victims of inflation. The benefits designed for small farmers with holdings up to 2 ha should be extended to medium-scale farmers so that the estimated 25% of the landholdings under the control of the latter can also receive larger investments and achieve higher yields.

CONCLUSIONS

This paper has reviewed the social, economic, and business aspects of lowland rainfed rice development in the smallholder environment. The extension worker must be as much a motivator and mobilizer as a technologist. Public policy and social action are factors as critical as increasingly profitable farm technology. The degree of social cohesion and solidarity in eastern India will dictate the pace of technology transfer in lowland rainfed rice production.

PROSPECTS FOR RAINFED LOWLAND RICE PRODUCTION IN INDIA BY THE YEAR 2000

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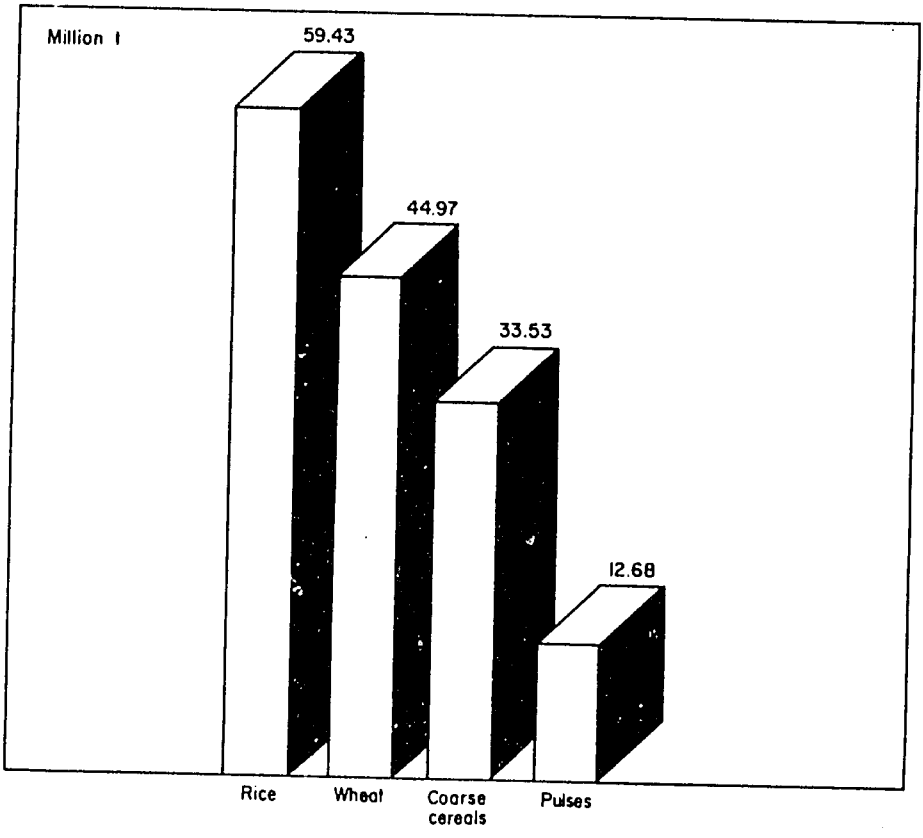
The major problem in increasing the productivity of rainfed lowland rice in India is the lack of suitable varieties to withstand submergence and insect pests. Some recent advances in the production and management of rainfed lowland rice are discussed, and the importance of postharvest technology is noted. Farmers in these areas need better access to improved varieties and an efficient input delivery system.

Rice occupies 39.5 million ha or 32% of the total area of food grain crops in India. Rice yields have reached about 60 million t, contributing 40% of the total food grain supply (Fig. 1). A conservative estimate puts the country's grain need at 225 million t by the turn of the century (14), so an additional 44 million t of rice must be produced by then (Table 1). Accepting that this has to come from existing areas under rice, the yields of the three categories of land — irrigated land, rainfed upland, and rainfed lowland — will have to be increased. A good part of the increase is expected to come from existing irrigated rice areas through improved water use efficiency in existing irrigation systems, and also from areas to be brought under irrigation. At present over 42% (16.8 million ha) of riceland is irrigated.

Water being the key input in rice production systems, controlled water would ensure higher productivity and yield stability. However, rainfed rice is often grown under uncertain water supply and usually suffers from either drought or flooding and waterlogging. In some irrigation systems, rice yields are affected adversely when the crop has an inadequate supply of irrigation water at critical growth stages. Climatic and management factors also affect yield considerably (Fig. 2). The average yield of rice in the southern and northern regions, which have larger irrigated areas, is appreciably higher than in the eastern and central regions. With irrigation, rice yields of 4-5 t/ha have been obtained. If farmers in the irrigated areas can realize an average of 3.0 t/ha, that would provide an additional yield of 23.0 million t. But even this increase would still leave a gap of about 20 million t to be bridged by increasing the productivity of rainfed ricelands.

Upland rice is grown on 6.15 million ha, which are mainly rainfed, and crop performance eventually depends on the adequacy and distribution of rainfall during the crop growth period. Upland rice areas are categorized into three



1. Food grain production in India, Jul 1983-Jun 1984 (1).

types based on total annual rainfall: low (less than 700 mm), medium (700-1,100 mm), and high (more than 1,100 mm). Only the last category can potentially support successful cultivation of rainfed upland rice provided rainfall is favorably distributed. Normally, rainwater does not stagnate in upland ricefields, but during heavy rains water may accumulate for certain periods, saturating the root zone and rendering the soil environment more favorable for rice. Presently upland rice contributes 3.7 million t/yr, having an average yield of 0.6 t/ha. A yield of 1.2 t/ha is possible when available improved technology is implemented; uplands would then contribute another 3.5 million t.

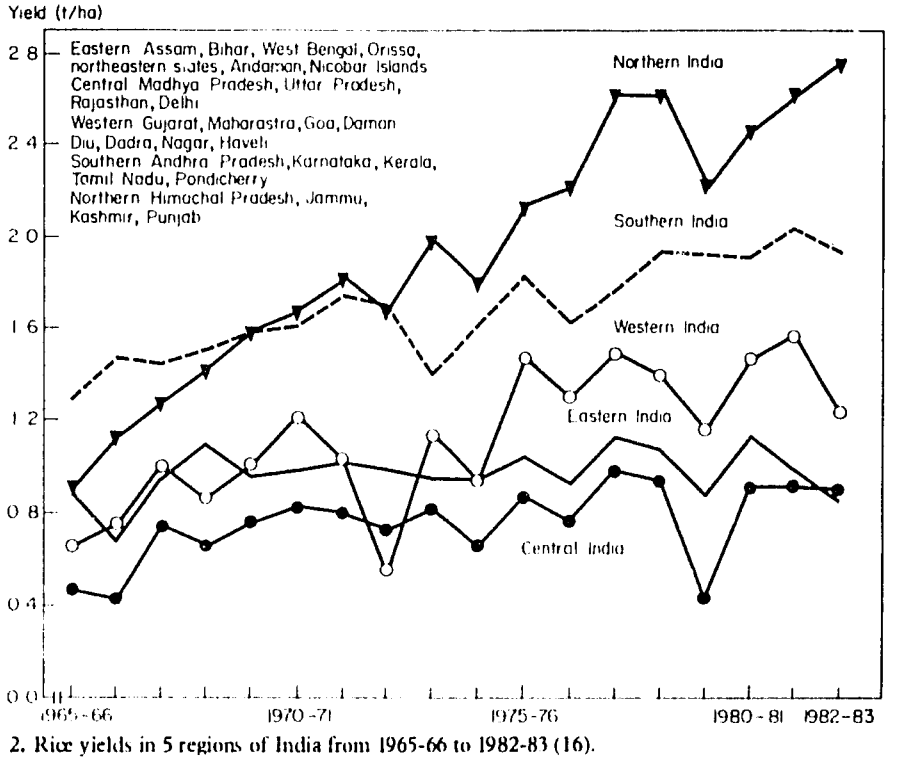
Despite the increases, a sizable deficit of 17.5 million t would still remain and would have to be met by the rainfed lowlands. Substantial increase in their productivity, presently ranging from 0.86 to 1.24 t/ha, is needed.

RAINFED LOWLAND RICE AREAS

The rainfed lowlands include all areas where water stagnates to a depth of 15-100 cm but exclude manageable irrigated lowlands. The deep water rice

Table 1. Production and productivity of rice under rainfed and irrigated conditions, 1980-81, and projections for the year 2000 (8, 14, 15).

Item	Unit	1980-81	Proposed or estimated increase by 2000
Food grain production	million t	130	225
Rice production	million t	53	97
Area under rainfed lowland	million ha	16.5	16.5
Rice production from rainfed lowland	million t	21.1	38.7
Productivity of rainfed lowland	t/ha	1.28	2.34
Area under rainfed upland	million ha	6.15	6.15
Rice production from rainfed upland	million t	3.69	7.38
Productivity of rainfed upland	t/ha	0.60	1.20
Rice production from irrigated area	million t	28.17	50.90
Productivity of irrigated area	t/ha	1.67	3.01
Fertilizer (N+P+K) consumption	million t	5.5	16.0
Fertilizer application	kg/ha	32	80



2. Rice yields in 5 regions of India from 1965-66 to 1982-83 (16).

Table 2. Category and area by state, present rice productivity and production (autumn + winter), and projections of the augmented productivity and estimated total production in the year 2000 in high rainfall regions of India (7).

Category and yield range in t/ha	State	Districts	Gross cropped area (million ha)	1980-81		2000[a]	
				Yield (t/ha)	Total production (million t)	Yield (t/ha)	Total production (million t)
I — Up to 15 cm water							
Less than 1.0	Assam	Goalpara, Kamrup, Darang, Nowgang	1.377	0.86	1.190		
	Bihar	Gopalganj, Sitamari, Siwan, Saran, Muzaffarpur, Vaishali, Madhubani, Darbhanga, Begusarai, Saharsha, Purnea, Katihar, Mongyr	1.856	0.73	1.552		
	Orissa	Puri, Mayurbhanj	0.698	0.97	0.678		
	Uttar Pradesh	Baraich, Faizabad, Hardoi, Sitapur, Unnao, Basti, Gorakhpur, Allahabad, Mirzapur, Balia, Gazipur, Azamgarh	2.068	0.83	1.723		
	Nagaland	Nagaland	0.109	0.84	0.091		
	Subtotal or average	32	6.068	0.87	5.24	1.92	11.65
II — 15-50 cm water							
1.0 to 1.5	Assam	Sibsagar, Lakhimpur, Dibrugarh, Cachar	0.796	1.44	1.091		
	Manipur	Manipur	0.189	1.45	0.273		
	Meghalaya	Meghalaya	0.098	1.33	0.130		
	Bihar	West Champaran, East Champaran, Samastipur, Patna, Bhagalpur	0.771	1.17	0.904		
	Orissa	Balasore, Cuttack, Ganjam	1.249	1.13	1.413		

	Kerala	Alleppy, Ernakulam, Trivandrum, Trichur, Quilon	0.304	1.33	0.403		
	Uttar Pradesh	Barabanki, Kheri, Deoria, Moradabad, Bareilly, Agra, Mathura, Aligarh, Bulandshar, Meerut, Muzaffarnagar, Jaunpur, Varanasi	1.106	1.22	1.350		
	West Bengal	Malda, West Dinajpur, Mushidabad, Midnapur (East), Midnapur (West), 24 Paraganas (North)	2.136	1.24	2.653		
	Subtotal or average	38	6.638	1.24	8.24	2.30	15.27
III-50-100 cm water 1.5-2.0							
	Andhra Pradesh	Nellore	0.057	1.84	0.105		
	Tamil Nadu	Chingelput, South Arcot	0.456	1.77	0.806		
	Uttar Pradesh	Pilibhit, Sahranpur	0.233	1.83	0.424		
	West Bengal	Hooghly, Burdwan, Howrah, 24 Parganas (N), Birbhum	1.305	1.68	2.188		
	Subtotal or average	10	2.052	1.71	3.51	2.77	5.68
IV-100 cm water and above 2.0-2.5							
	Andhra Pradesh	East Godavari, West Godavari, Khrisna, Guntur, Prakasham	1.245	2.22	2.764		
	Tamil Nadu	Thanjavur	0.593	2.32	1.373		
	Subtotal or average	6	1.837	2.25	4.14	3.31	6.08
	Total	86	16.5	1.28	21.14	2.34	38.7

*Estimated.

areas, where water depth is more than 1 m, are not included in the lowland rice category. Sometimes the irrigated lowlands in high-rainfall zones receive no special advantage from irrigation because they are prone to waterlogging.

The rainfed lowland areas can be broadly classified into shallow (up to 15 cm), intermediate (15-50 cm), semideep (50-100 cm), and deep water (100 cm and above) lowlands. Practices specific to each situation need to be developed, with viable technology that may include adapted varieties and input management.

The rainfed lowland rice areas prone to waterlogging are located in eastern Uttar Pradesh, Bihar, West Bengal, Orissa, Assam, and some areas in the northeastern states; the coastal districts of Andhra Pradesh, Tamil Nadu, and Kerala; and some areas in coastal Karnataka and Maharashtra. These problem areas are spread over 11 states (Table 2). Eighty-six rice-growing districts of the country have waterlogging in their rice areas (12, 22, 23, 25), which lie in the zone of high rainfall (>110 cm). The districts in the 11 states are grouped into 4 priority areas based on existing productivity and efforts needed for the desired level of improvement.

Thirty-two districts (Table 2) are in priority I, 38 in priority II, 10 in priority III, and 6 in priority IV. Most areas in priority I are located in Bihar, Uttar Pradesh, and Assam. The average yield is 0.9 t/ha, and annual total production amounts to 5.3 million t. With available technology in shallow to intermediate waterlogged situations, rice yields of about 1.6-2.0 t/ha are not uncommon. These areas could yield an average of 1.9 t/ha, which would raise total production of the area to about 12 million t. In priority II, the yield could be improved from 1.2 to 2.3 t/ha and production from 8.2 to 15.3 million t. The major areas in this category are in Uttar Pradesh, Bihar, West Bengal, Orissa, and Assam.

In priority III, which cov[illegible] 2.05 million ha, rice yields are better, and production may be raised from 1.7 to 2.8 t/ha or 3.5 to 5.7 million t.

Five coastal districts of Andhra Pradesh and the Tanjavur District of Tamil Nadu (an area of 1.84 million ha) come under priority IV, which has both irrigated and rainfed ricelands with a total production of 4.1 million t. The yield of 2.3 t/ha is higher than the national average. Those areas suffer from excess water. By improving drainage, using suitable varieties tolerant of waterlogging, and providing adequate plant nutrients, it would not be difficult to raise the present rice yield to 3.3 t/ha and production from 4.1 to 6.1 million t.

Rainfall patterns in high rainfall regions are shown in Table 3 and Figure 3.

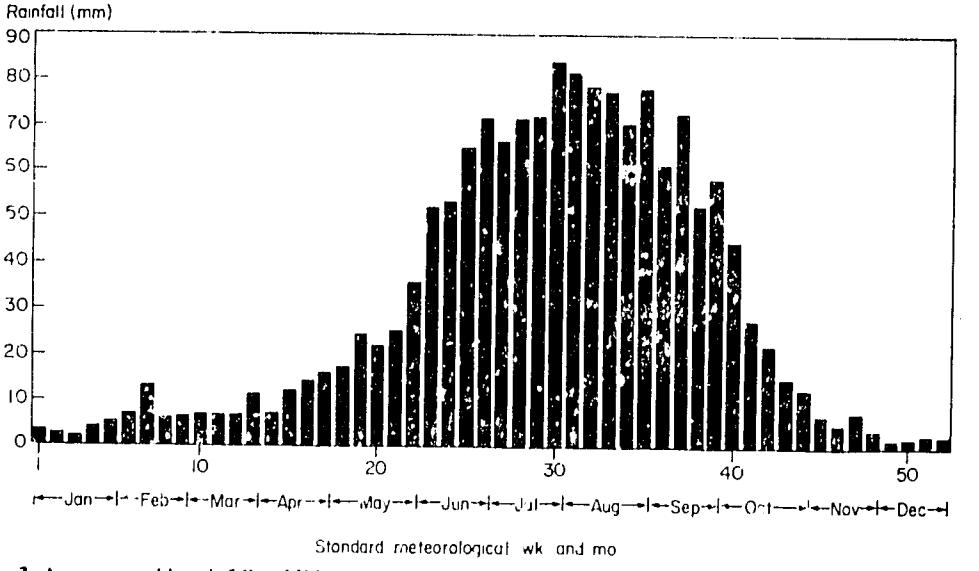
CHARACTERISTICS OF RAINFED LOWLAND RICE AREAS

Rainfed lowland with limited water at seeding and excess water at later growth stages

In rainfed lowland areas, the rice crop is direct seeded in dry soil in April-May before the onset of the monsoon (June-September), and seeds germinate with the showers received after sowing. Drought at the seedling stage kills seedlings

Table 3. Average 50-yr rainfall (1901-50) in the high rainfall regions of India (10).

Subdivision	Annual rainfall (mm)	Percentage of rainfall received during			
		Jan-Feb	Mar-May	Jun-Sep	Oct-Dec
Assam (including Manipur and Tripura)	2,516.4	2.3	25.1	65 3	7.3
Sub-Himalayan West Bengal	3,126.2	1.0	15.4	78.0	5.6
Gangetic West Bengal	1,425.3	2.7	12.4	75.6	9.3
Orissa	1,482.2	2.7	8.6	76.7	12.0
Bihar plateau	1,372.0	3.9	6.5	82.0	7.6
Bihar plains	1,202.9	2.9	6.1	85.0	6.0
Uttar Pradesh, east	1,007.7	3.4	3.0	88.2	5.6
Madhya Pradesh, east	1,401.7	3.1	3.5	87.7	5.7
Coastal Andhra Pradesh	1,008.3	2 3	8.8	56 6	32.3
Tamil Nadu	1,008.1	5.3	14.6	33.0	47.1
Kerala	2,996.1	1.2	13.5	66.9	18.3
Konkan	2,872.0	0.1	1.2	93.9	4.8



3. Average weekly rainfall at Midnapur observatory, West Bengal, India, 1900 to 1978 (21).

and leads to poor stand. Furthermore, heavy rains in the catchment areas of river basins result in waterlogging or flooding of ricefields at late growth stages. The deeper water hinders tillering and results in lower panicle number — generally less than 200/m^2 as against 350 panicles/m^2 of high yielding varieties.

Rainfed lowland with limited/excess water at transplanting and excess water at later stages

When the onset of the monsoon is delayed, transplanting is delayed because the farmer has to wait for adequate rains for land preparation. Monsoonal rain

submerges the transplanted crop, resulting in poor stand. In some areas, the land gets inundated before transplanting and farmers generally transplant aged and tall seedlings to keep the plant parts above water. Plant survival in deeper water depends on the rise in water level and on the elongation ability and submergence tolerance of the plant. Varieties that elongate fast develop weak culms and may lodge when the water level recedes. In this situation tillering is poor and panicles per unit area are few.

Assured irrigated areas with excess water during crop growth due to poorly drained conditions

Rice grown in river deltaic areas of the Krishna, Godavari, Cauveri, and Indo-Gangetic Rivers suffers from water stagnation even though some areas have irrigation facilities. Heavy rains in the catchment cause flooding and stagnation in the ricefields because of congested drainage or lack of drainage caused by topographically saucer-shaped land. This condition develops during the peak monsoon period (July-September). The late planted crops, being at an early stage of growth, suffer from the water stagnating in the fields. In these areas, transplanting early in the season is necessary for the plants to grow enough to escape submergence.

Rainfed areas with excess water throughout crop growth

Some lowland areas get inundated with the first few monsoon showers before seeding or transplanting operations take place. Such areas fall into two categories: those in which water depth does not exceed 1 m and those in which that depth is exceeded. In the former category, seedlings about 75 cm tall are normally used for transplanting. In the latter category, deep water rice varieties are grown and the crop is seeded well in advance of the rains.

Rainfed lowlands with flash floods

Even in the lowlands where water depth varies from 0 to 15 cm during most of crop growth, transplanted rice may be submerged for a few days to 2 wk due to flash floods caused by overflow from rivers. Some varieties can tolerate floods to a certain extent and recover if floodwaters recede within 2 wk.

Rainfed coastal saline areas with excess water at later growth stages

Large tracts of Orissa, West Bengal, Karnataka, Tamil Nadu, Goa, and Maharashtra suffer from tidal inundation. The coastal saline areas have varied characteristics, the most common being low-lying topography, inadequate drainage, fairly high water table of poor quality water (5-8 mmho/cm), and moderate to heavy soil texture. About 2 million ha of ricelands in India are saline and waterlogged (30-70 cm water), and in those areas rice yields are 0.5-1.0 t/ha.

During May-June, cyclonic storms bring seawater to coastal areas through rivers and estuaries. Even when the land is not inundated, it does not support crops because of the high salt content. The salt rises to the surface through capillaries and accumulates there.

Rainfed acid sulfate and tidal marsh areas

Most acid sulfate soils are in Kerala and West Bengal. Crop failures due to salinity and acidification during droughts, intrusion of saltwater, and deep flooding are common. Observed problems include low pH; toxicity from Al, Fe, and H_2S; partial pressure of CO_2; salt injury; toxicity of organic acids; deficiency of P and micronutrients; and low nutrient status (4, 17).

The potential acid sulfate soils in tidal swamps will not acidify as long as the tidal effects are strong enough to prevent prolonged aeration. In most such areas, soils are strongly alkaline, and rice can be grown only along river banks, where the tides back up freshwater every day during the wet season. However, the soil remains productive only if wet conditions are maintained (26).

MANAGEMENT PROBLEMS

Low spread of high yielding varieties

Only small proportions (25-35%) of rice areas in the states of Assam, Bihar, Orissa, West Bengal, and eastern Uttar Pradesh are under high yielding varieties (HYVs) (Table 4). The absence of long-duration modern varieties suited to varying degrees of waterlogging is the reason for their low spread in these regions. On the other hand, in Andhra Pradesh and Tamil Nadu, where depth of submergence generally does not exceed 30 cm, more than 75% of the rice area is under HYVs of medium to long duration.

The suitability of existing varieties varies with the land situation and hydrological conditions related to the height of the variety, flowering time, and tolerance for deep water. The traditional varieties grown in waterlogged and flood-prone conditions are photoperiod-sensitive, medium to tall, and

Table 4. Area under modern rice varieties (MVs) during wet season, plant nutrient consumption, and irrigated rice area in high rainfall areas of eastern and southern states of India (9).

State	1980-81			1982-83 consumption of NPK (kg/ha)	1978-79 irrigated area (%)
	Total area (million ha)	Area under MVs			
		million ha	%		
Andhra Pradesh	3.61	2.79	77	53	94.3
Assam	2.28	0.58	25	4	33.8
Bihar	3.57	1.40	25	19	34.8
Kerala	0.785	0.36	46	37	31.9
Manipur	0.19	0.051	25	20	46.9
Meghalaya	0.10	—	27	12	45.3.
Nagaland	0.10	0.01	11	2	71.0
Orissa	4.20	1.10	26	11	26.6
Tamil Nadu	2.85[a]	2.32	81	51	92.7
Tripura	0.25[a]	0.15	58	8	6.0
Uttar Pradesh	5.18	2.20	42	61	21.7
West Bengal	5.18	1.80	35	33	28.7
All India	39.5	18.49		37	41.6

[a]1979-80.

nonresponsive to fertilizer. Depending on the rise in water level, these varieties elongate faster, with early nodal differentiation. Although they are adapted to the environment, their yield is low.

Response to fertilizer

Lowlands are generally more fertile than medium lands or uplands. Having lower nutrient requirements and growing on the natural fertility of the soil, traditional varieties in rainfed lowlands exhibit good growth without any sign of nutrient deficiency. Of course yields are low. With high yielding varieties being developed for rainfed lowlands, it becomes imperative to develop suitable fertilizer management schedules describing the source, level, method, and time of application.

Pests

The major insect pests of lowland rice areas are the stem borer, green leafhopper, rice hispa, and caseworm; the major diseases include bacterial leaf blight, leaf streak, sheath blight, and stem rot. The problem weeds for lowland rice in the early stages of growth are *Ipomoea aquatica* and *Eichhornia crassipes*; at later stages when water accumulates, algae, chara, and submerged and floating weeds cause serious damage to the crop. Wild rice (*Oryza sativa* var. Balunga) poses a major problem because it cannot be identified before the flowering stage.

Harvest and postharvest problems

Efficient management of harvesting, threshing, drying, and storage help achieve optimum crop yields. Harvesting the crop at the right time (20-24% moisture) improves the milling quality. Harvesting the crop at maturity creates difficulty because of standing water in the field. Furthermore, most indigenous varieties grown in the areas lodge at maturity, and the grains on the panicles become wet. These problems necessitate special postharvest technology for rainfed lowland areas.

RECENT ADVANCES IN RAINFED LOWLAND RICE CULTURE

Varietal improvement

In the past, most varieties adopted for deep water or flash-flood areas were selected from local varieties, and their yields were marginally better than those of the local types. Recent efforts in varietal development for those problem areas at different research stations have resulted in varieties of some promise (Table 5, 6).

Under intermediate deep water situations (15-50 cm), CR1010, CR1011, CR1016, CR1018, CR1030, IET7970, Janaki, CN540, and CN539 prove better than local varieties. In lowland areas where water depth is less than 30 cm, Pankaj, Jagannath, CR1009, and Mahsuri have shown promise.

In semideep (50-100 cm) situations, medium tall varieties having strong photoperiod sensitivity, moderately stiff straw, moderate response to fertiliza-

Table 5. Promising rice varieties developed for rainfed lowland areas.

State	Shallow rainfed, water depth up to 15 cm	Intermediate deep, 15-50 cm	Semideep, 50-100 cm	Deep water, 1 m	Flood resistant	Coastal saline waterlogged areas
Andhra Pradesh	Mahsuri, Gouthami, Vashista	Pankaj, Jagannath, MTU8002, MTU8089, MTU7020, MTU7633,	PLA-2, PLA-4, AR108-1		PLA4	
Assam	Manoharsali, Jaya, Mahsuri		EB-1, EB-2, AR-1, ARC 353-148, AR614-458	HB-1, HB-2 HB-3, HB-4		
Bihar	Br 34, Mahsuri, T 141	CN540 Pankaj, Br 8	Br 14, Janaki, Jalaj, Jalmagna		Janaki, Br 13, Br 46	
Kerala	Bhadra, Sabari		PTB15	PTB16	PTB7	Pokkali Vytilla-2 Pavizham
Orissa	T141, CR1009, Mahsuri, Pankaj, Jagganath	CR1016, CR1018, CR1030, Pankaj, Jagannath	OR1104, OR1105, OR143-7, Kajurchanai			
Tamil Nadu	Mahsuri, CR1009, Pankaj		Co 14, PTB15, ADT17		Co 14, PTB7	
Eastern Uttar Pradesh	Sarjoo-52, Saket-4	Chakia-59	Chakia-59 Madhukar	Jalmagna, GMS13, DW48, Doodalachi	Madhukar, Chakia-59	
West Bengal	CR1014, CR1009, Pankaj, CR1012	Pankaj, CNM539, CNM540. CN643, CR1012	CNL 231 B/B, CNL 108, Jaladhi-1, Jaladhi-2	Jaladhi-1, Jaladhi-2, Dolaman, Laki Badal	—	Getu, Dasal, Jagannath, CSR6, SR26B, Mahsuri, Sadamota and Kalamota selection
Northeast Hilly Region		BM2010, HG60-49, CR149-501-228, CR1030	—	—	—	—

Table 6. Performance of rice varieties under intermediate deep water conditions (30-60 cm). Central Rice Research Institute, 1983 wet season.[a]

Variety	Grain yield[b] (t/ha)	Flowering date
BIET-720	2.89	2 Oct
Jaishree	2.96	30 Sep
Janaki	2.59	3 Oct
BIET-724	2.10	3 Oct
CN492	3.62	30 Oct
CR320-9	3.86	6 Oct
CR292-5258	3.16	20 Oct
Halhipanja	3.71	25 Oct
SP-83	3.30	6 Oct
CR1018	4.06	23 Oct
CR1010	4.12	23 Oct
RD-19	3.19	30 Sep
CD at 5%	0.75	

[a]Reddy and B. C. Ghosh (personal communication). [b]Sowing date: 15 Jun 1983. Fertilizer level: 40-9-17 kg NPK/ha.

tion, tall seedlings, and early elongation perform better. For these situations CN603, Jalaj, and RAU21-128-1-2 have shown great promise. In depths of 50-70 cm, CN540 (Suresh) and CN539 (Biraj) have consistently given higher grain yield. The success of these varieties relies on the slow rise of water to a depth they are able to tolerate; a sudden rise in depth submerges the plants and causes high mortality.

In deep water or floating rice areas where water depth exceeds 1 m, varieties such as Jaladhi 1, Jaladhi 2, and Jaisurya grow well. They are suitable for both semideep and deep water areas.

In some areas, flash floods flowing over the fields at a critical velocity uproot the plants. When the crop becomes fully submerged and the water stagnates for more than a week, the crop rots. A variety with submergence tolerance for 8-15 d, the normal flood period, would escape major damage (Table 7). Varieties that have attained certain growth and height before flooding have a

Table 7. Performance of rice varieties in flood-prone situations in farmers' fields. Allapur, Kantapara, Cuttack, Orissa, 1978 wet season (9).

Variety	Water depth (cm)			Panicles (no./m^2)	Grain yield (t/ha)
	During crop growth period	During flood			
		1st[a]	2d[b]		
CR1009	0-15	40	120	315	4.6
CR1016	0-15	40	120	322	6.6
Dusurakajra(local)	0-15	40	120	166	2.5
CRM10-4748-9-63	15-30	60	140	188	2.4
CR98-7270	15-30	60	140	187	1.9
CR1009	15-30	60	140	177	2.5
CR98-7223	15-30	60	140	203	1.9
CR1018	15-30	60	140	206	2.5

[a]First flood for 6 d in 3d wk of August. [b]Second flood for 8 d in 1st wk of September.

better chance of recovery. CR1009, CR1016, CR1018, and CR1030 can withstand submergence for 8-10 d, while FRG1, FRG2, FRG7, FRG8, Madhukar, Jaladhi 1, Jaladhi 2, PLA4, FR13A, FR43B, Jalamagna, and C64-117 (Janaki) can withstand 10-15 d of submergence.

Direct seeding

The low tillering ability of a variety caused by excess water stress in lowlands results in fewer panicles and low yield. The situation is mitigated by using higher seeding rates, which initially provide more seedlings per unit area. A suitable variety tolerant of submergence may tiller normally and yield as expected. Sowing early in the season is necessary for the plants to attain enough size and vigor to withstand subsequent water stress. In lowland areas of Orissa, West Bengal, and eastern Uttar Pradesh, the crop needs to be sown by the first week of June.

Seeding the crop early in the season to help the seedlings grow and establish before the water stagnates to a depth of 30 cm or more is better than transplanting the crop into a field having standing water of similar depth (Table 8). Seedling establishment is a problem in transplanted rice. In direct seeded rice the problem is heavy weed infestation. The latter is manageable with weedicides, but there appears to be no remedy for the former condition.

Transplanted rice

In waterlogged areas where direct sowing is not possible, transplanting is the only alternative. In high rainfall regions of eastern India, transplanting generally begins the first week of July with younger seedlings and continues until early September. Grain yields are usually highest with 45- to 50-d-old seedlings provided transplanting is over by mid-August. In flood-prone areas, the farmers transplant old and tall seedlings in stagnant water of at least 30 cm. In intermediate deep water situations, planting younger seedlings (35 d) earlier in less than 20 cm water is better than planting older seedlings later in the season when water is deeper.

In these problem areas, manipulation of seedling and hill densities can overcome the ill effects of poor stand and compensate for yield loss. The practice of closer hill planting (15 × 15 cm) and higher seedling number (6/hill) would compensate for mortality of seedlings and low tillering caused

Table 8. Rice grain yield as influenced by method of stand establishment and fertilizer application in intermediate deep water situations (24).[a]

Variety	Grain yield (t/ha)			
	Drilling		Transplanting	
	Fertilized[b]	Unfertilized	Fertilized[b]	Unfertilized
Janaki	3.25	2.58	2.32	1.59
Jalaj	1.91	1.58	1.62	1.04
CD at 5%		0.4		

[a]Maximum water depth = 81 cm. Range = 35-81 cm. [b]At 40-9-17 kg NPK/ha.

Table 9. Effect of planting density on grain yield of rice varieties in intermediate deep water situations (30-60 cm) (5).[a]

Planting density (seedlings/m^2)	Grain yield (t/ha)		
	CR1018	CN540	Mean
50	3.97	3.91	3.94
100	4.20	3.83	4.02
150	4.17	3.77	3.97
Mean	4.11	3.84	

[a]Fertilizer level: 40-9-17 kg NPK/ha.

by deep water during and after transplanting. In water that gradually increases to 60 cm by maximum tillering, the difference in seedling density (50-100-150/m^2) did not make any appreciable difference in grain yield (Table 9).

In some lowland areas the ricefields are inundated early in the season by heavy rains or overflow from rivers; water stagnates to depths of 40-70 cm early in the season and stays for a long period during crop growth. In such situations, younger seedlings are severely damaged when eventually totally submerged. In areas having 40-50 cm standing water, a double transplanting technique (clonal propagation) — transplanting with tillers detached from the mother plants of earlier transplanted crops (30-40 d after first transplanting) — pays dividends. Double transplanted crops yield significantly more than crops transplanted with fresh seedlings of the same age (60-70 d) from the nursery (Table 10) because tillers used as seedlings under the double transplanting method are vigorous, taller, and well acclimatized to deeper water.

Table 10. Grain yield of double transplanted variety Suseeh (CN540) in submerged ricefields in intermediate deep water situations (50-60 cm) (5).[a]

Treatment	Water depth (cm) at transplanting	Grain yield (t/ha)
A. 30-d-old seedlings transplanted and allowed to continue	5-10	2.5
B. 30-d-old seedlings transplanted, with 50% of tillers removed at 20 d after transplanting (DT)	5-10	2.2
C. Tillers removed from treatment B transplanted at hill spacing as in B	10-13	2.3
D. 50-d-old seedlings (30+20) brought from nursery and transplanted on the same day as in C	10-13	0.8
E. Transplanting as in A but 50% tillers removed at 40 DT	5-10	2.1
F. Tillers removed from E and transplanted	55	1.8
G. 70-d-old seedlings brought from nursery and transplanted on the same day as in F	55	0.1
CD at 5%		0.4

[a]Fertilizer level: 40-9-17 kg NPK/ha.

FERTILIZER MANAGEMENT

Rice production technology, including fertilizer management, is designed to suit particular locations under heterogeneous rainfed situations (soil type, water regime, variety, and climatic factors). Waterlogging or flooding varies from year to year and from one location to another, leading to loss of nutrients through leaching, denitrification, volatilization, and surface runoff. Thus, fertilizer management is one of the most challenging tasks in improving lowland rice productivity. The benefits of NPK fertilizer in flooded situations are clear (Table 11).

Rainfed lowland rice soils are alluvial soils deposited by rivers and their tributaries. Old alluvial soils are deficient in N, P, and K and respond to N and P fertilization, while new alluvial soils are rich in P and K, are moderate in organic matter, and respond to N (13).

Nitrogen management

For direct-seeded rice plants, which are subsequently subjected to intermediate deep water situations (15-50 cm), applying 40 kg N/ha at seeding through urea supergranules (USG) placed in furrows in moist soils, sulfur-coated urea (SCU) broadcast and incorporated through plowing, or prilled urea (PU) placed in furrows proved equally effective in improving yield compared to split application of PU, basal and as foliar spray (Table 12). The improved semidwarf varieties CR1011 and CR1018 responded positively even up to 60 kg N/ha, while medium-tall CR260-30 had no response (Table 13). Even under semideep water conditions, the tall varieties responded to N fertilization, showing their endurance under higher levels of water stagnation (Table 14).

Phosphorus and potassium fertilization

The response of rice grown under rainfed lowland conditions is low to medium to P and low to zero to K, considering the fertility status of these soils at different locations. Where the soil is deficient in P, as in the coastal alluvial

Table 11. Rice grain yield of variety CR1018 as affected by flooding (90 cm) for 10 d at different stages of crop growth (active tillering, maximum tillering, and booting) and under different fertilizer treatments (19).[a]

Fertilizer treatment[b]	Grain yield (t/ha)	Yield increase over control (%)
Control (no NPK)	3.4	—
N	4.1	21
P	3.9	15
K	3.6	6
NP	4.4	29
NK	4.2	24
PK	3.7	9
NPK	4.7	38

[a]0.83% organic C, 11 kg available P/ha, pH 6.2. [b]Fertilizer level: 40-17-33 kg NPK/ha.

Table 12. Effect of form, method, and time of urea application on grain yield of rice variety CR1018 in direct sown intermediate deep water (15-50 cm). Central Rice Research Institute, 1981 wet season (18).[a]

Treatment	Grain yield (t/ha)
Control (no N)	2.8
Prilled urea broadcast amd plowed	4.0
Prilled urea drilled behind V-shaped plow and seeding in same furrow	4.3
Prilled urea drilled between seed rows[b]	4.0
Prilled urea, 50% basal and 50% as foliar spray[c]	3.5
Urea supergranules placed in moist soil between seed rows	4.4
Urea supergranules placed in shallow water[d]	4.2
Urea supergranules placement behind V-shaped plow and seeding in same furrow	4.0
CD at 5%	0.4

[a]Fertilizer level: 40-9-17 kg NPK/ha. [b]Behind hand plow 2-3 cm below soil. [c]Foliar spray of 2% urea solution was done 4 times from maximum tillering to flowering. [d]At 30 d after germination.

Table 13. Effect of nitrogen level on grain yield of rice varieties of different plant types under direct sown intermediate deep water conditions. Central Rice Research Institute, 1981 (20).[a]

Variety	Grain yield (t/ha)				
	0 kg N/ha	20 kg N/ha	40 kg N/ha	60 kg N/ha	Mean
CR1011	1.8	2.3	2.5	3.0	2.4
CR1018	2.1	2.4	2.6	2.9	2.5
CR1030	1.6	2.2	2.6	2.7	2.3
CR260-30	1.8	1.9	2.1	1.9	1.9
Mean	1.8	2.2	2.4	2.6	

[a]9-17 kg PK/ha was applied uniformly.

Table 14. Effect of nitrogen level on grain yield of rice varieties under semideep water (80-120 cm). Central Rice Research Institute, 1982 wet season (5).[a]

Variety	Grain yield (t/ha)				
	0 kg N/ha	20 kg N/ha	40 kg N/ha	60 kg N/ha	Mean
FR43B	0.1	0.3	1.0	1.4	0.7
CN643	0.5	1.4	1.4	1.4	1.2
OR143-7	1.4	1.8	2.5	2.9	2.2
OR1105	1.2	1.2	1.4	1.8	1.4
Mean	0.8	1.2	1.6	1.8	—

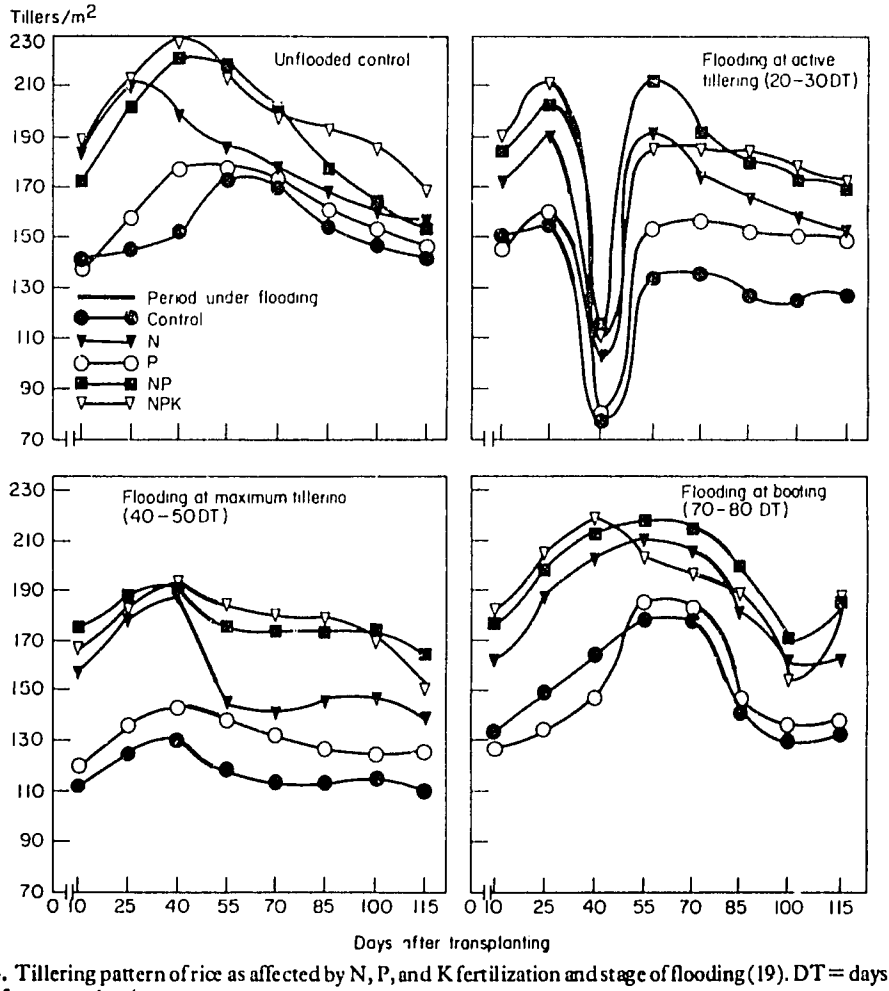
[a]9-17 kg PK/ha was applied at sowing.

region of the east coast of Orissa, rice responded to N (65 kg/ha) when 40 kg P and 40 kg K were also applied. At higher levels of N and P, rice yield was still higher (Table 15). Crops raised with basal application of N along with P showed greater tolerance for submergence (Fig. 4).

Table 15. Grain yield of rice variety CR1016 after NPK fertilization under flood-prone conditions.[a] Bhairabpur, Basudebpur, Balasore, Orissa, 1981 wet season.[b]

Treatment (kg NPK/ha)	Grain yield (t/ha)
0-0-0	1.2
25-0-0	1.6
65-0-0	1.7
65-40-40	3.8
85-0-0	2.3
85-40-0	3.6
85-60-0	4.0
85-60-40	4.2
CD at 5%	0.5

[a]Soil fertility status: 0.634% organic C, 4-8 kg available P/ha. The crop suffered complete submergence (1.5 m depth) for 7 d during panicle initiation. [b]Source: Mahapatra et al (unpublished).



4. Tillering pattern of rice as affected by N, P, and K fertilization and stage of flooding (19). DT = days after transplanting.

INSECT PESTS

Stem borer *Scirpophaga incertulas* Walk.

The stem borer is the most serious pest of lowland rice. Incidence ranges from 20 to 50% at the vegetative phase in some areas. There is no resistant variety at present; chemical control appears to be the only answer. Control at the vegetative phase through subsoil application of carbofuran granules (1 kg ai/ha) and later through foliar spray of endosulfan, and methylparathion at 0.5 kg ai/ha twice at the flag leaf stage has minimized whiteheads.

Green leafhopper *Nephotettix* spp.

The leafhopper vector and tungro virus sometimes cause serious damage. No variety that is suitable for lowland situations and resistant to green leafhopper and to tungro virus is presently available. The vector is controlled by insecticides.

Rice hispa *Dicladispa armigera* Oliv.

The rice hispa causes serious damage in parts of West Bengal. Applications of carbofuran granules at 1.5 kg ai/ha and foliar spray with quinalphos (0.04%) at 10-d intervals have proved effective. There is no variety resistant to the pest.

Caseworm *Nymphula depunctalis* Guenée

Caseworms cause serious defoliation in lowlands in standing water. Chemical control by foliar spray of malathion, diazinon, carbaryl, and endosulfan at 0.75 kg ai/ha appears effective; no rice variety is resistant to this pest.

DISEASES

In rainfed lowland rice areas, bacterial leaf blight, stem rot, bacterial leaf streak, sheath blight, and sheath rot are major diseases. Cultural and chemical control methods effective against these diseases in medium lands appear less useful in lowlands because of deeper standing water. Controlling disease in rainfed lowlands by developing resistant varieties and specific cultural and chemical methods needs attention

WEEDS

Hand weeding is still the major method of weed control in the lowlands. Nevertheless, there are now chemicals that can meet the situation effectively. Application of 2,4-D at 1-2 kg ai/ha at the 4- to 6-wk stage of rice growth controlled water hyacinth, *Ipomoea* sp., and *Scirpus* sp. A number of herbicides, including nitrofen (2,4-dichloro-4-nitrodiphenyl ether) and a zinc ethylene bidithocarbamate compound, control algae. Nitrofen also controls grass and broadleaf weeds to some extent.

COASTAL SALINE AREAS

In areas where tidal water inundation is a problem, the primary task is to construct embankments or dikes along the coast. Improvement of drainage is essential to leach out excess salts from the soil. This may be done by constructing sluices in main drains and connecting cross drains along the contours. Some rice varieties can withstand soil salinity and saltwater inundation during part of their growth period. However, rice is more sensitive to salinity at the seedling and flowering stages. The Hamilton variety has been found to be highly salt tolerant and to produce high yields. Hamilton, Getu, and Malta were found suitable for highly saline areas (10 mmho/cm), while Patnai 23, OC1393, Kumangore, and SR26B appear suitable for medium saline areas (5-8 mmho/cm).

Where the salt concentration is reduced through dilution by deep standing water, transplanting aged seedlings shows some promise. But in areas with low salt content, planting salt-tolerant varieties early in the season before the ingress of saline water would be desirable (Table 16). It has been demonstrated that N applied as USG or lac-coated urea is more effective in increasing N use efficiency (Table 17).

HARVEST AND POSTHARVEST TECHNOLOGY

Modern variety trials in controlled water conditions have revealed that the best harvesting time is at 22-24% grain moisture content, i.e., 25-45 d after

Table 16. Grain yield of rice as affected by time of transplanting in coastal saline waterlogged areas (2).

Planting date	Grain yield (t/ha)		
	Getu	Dasal	Damodar
17 Jul	3.4	3.8	3.6
31 Jul	2.5	2.2	2.2
14 Aug	1.6	1.8	1.5

Table 17. Grain yield of rice with different modes of application of slow-release urea fertilizers in coastal saline waterlogged areas[a] (15-60 cm water) (3).

Treatment	Grain yield	
	Pankaj[b]	SR26B[c]
Urea supergranules	4.3	3.4
Urea briquets	4.0	3.4
Sulfur-coated urea	5.2	4.3
Lac-coated urea	4.8	4.0
Foliar spray urea	4.0	3.4
1/2 basal + 1/2 spray urea	3.9	3.3
Urea in 3 splits	3.9	3.2
Urea mudballs	3.8	3.1
Control	3.4	3.0

[a] 1.0% organic matter, EC = 3.0-7.0 mmho/cm. [b] Fertilizer level: 72-18-33 kg NPK/ha.
[c] Fertilizer level: 36-9-17 kg NPK/ha.

flowering depending on the duration of the variety. Harvest at the right stage of maturity not only improves milling quality but also helps reduce field losses, which at times are as high as 10%. In addition, rice harvested at a grain moisture of 23% has better milling yield and head yield recovery than rice harvested at lower levels of grain moisture.

Immediate threshing and drying of grain with a mechanical dryer would keep the grain from being spoiled and prevent the fissures that are common when grains get wet at maturity.

Parboiling is a key hydrothermal treatment of rough rice prior to milling. Parboiling affects milling, storage, cooking, and ultimately consumer preference. Processing conditions of rice are as important as its production, since processing decides the final yield and its quality. Information is needed on treatment of rice that gets wet during harvesting. Should it be parboiled to avoid losses due to fissuring caused by milling raw rice? The quality of the parboiled rice would also need consideration from the consumers' point of view.

INCREASING PRODUCTIVITY OF RAINFED LOWLAND RICE

Development of suitable technology

Suitable technologies are needed for rainfed lowland areas having characteristic location, climate, toposequence, and socioeconomic conditions. A major effort has to be made to increase yields of rainfed rice having no assured water supply.

Yield stability has to be achieved through adaptable technology at a cost within the reach of the farmer. Suitable varieties, fertilizers, and plant protection inputs should be made available to the farmer. Multiplication and supply of seed of improved varieties would be the first step. Other input supply — fertilizer and insecticides — should follow.

A strong research and extension program and efficient input delivery system would form a solid base for this development effort.

Government policy: incentives to rice growers

Fair prices for the produce are important as the farmers' interest in increasing yields depends on returns for any added investment in the crop.

Input and credit availability depend on financing agencies such as cooperatives and banks, which provide loans for the purchase of seeds, fertilizers, and pesticides. Ease and timeliness of credit to farmers have a bearing on crop production management. Farmers' participation in agricultural development activities and credit utilization are low in eastern and northeastern India.

FUTURE RESEARCH STRATEGIES

Relevant technologies have been developed to meet the challenges constraining yields of lowland rice in certain situations. But they need to be tested in the problem areas to assess suitability.

RECOMMENDATIONS

Five working groups developed recommendations for future research and collaborative projects in the areas of 1) varietal improvement; 2) soil, crop, and water management; 3) pest management; 4) cropping systems; and 5) production constraints and technology transfer.

VARIETAL IMPROVEMENT

Four categories of rainfed lowland (RLL) rice should receive major attention in rice varietal improvement work:

- rainfed shallow, drought-prone,
- rainfed shallow, drought- and submergence-prone,
- rainfed shallow, submergence-prone, and
- rainfed medium deep, waterlogged.

Recommendations for future research

For the success of varietal improvement programs, it is imperative that appropriate parent materials be identified and exchanged internationally.

- Donors with adaptation to various RLL situations should be singled out for use in hybridization programs. Parents with disease and insect resistance from irrigated programs would be good donors of resistance to biotic stresses. Parents tolerant of drought, submergence, stagnant flooding, and problem soils are available and can be utilized.
- For proper evaluation of breeding materials, the observational nursery for RLL environments should be grouped into three:
  - — short duration entries with or without drought tolerance (for specific situations),
  - — medium or long duration entries with drought or submergence tolerance or both, and
  - — long duration entries tolerant of stagnant flooding with or without photoperiod sensitivity. (Cooperators in specific environments may request a particular section of this nursery.)
- For rapid progress in varietal development, it is essential that the segregating populations be exposed to appropriate stresses. Therefore hot spots for varietal screening should be identified, and segregating populations should be grown under those conditions. Hot spot locations do not

occur in all countries. Therefore the shuttle breeding approach for collaborative varietal development should be fully exploited. IRRI would be glad to develop collaborative arrangements for shuttle breeding. Crosses could be made and the F_1 population could be grown at IRRI. Collaborators could be supplied with F_2 seeds for planting under appropriate environments. Selected F_3 lines may be sent to IRRI for generation advance and for evaluation for grain quality, disease and insect resistance, and tolerance for stresses such as drought or submergence. Selected F_4 lines may be sent back to the collaborating program for planting under actual stress conditions. Shuttling may be repeated until the materials become homozygous. Because adapted local parents will be used in crosses with improved disease- and insect-resistant lines from IRRI, the breeding populations will have diverse genetic backgrounds.

- There is a considerable time lag between the identification of a variety and its spread to target environments. To expedite this process, on-farm trials should be promoted.
- Scientists interested in collaborative work are requested to submit to Dr. D.J. Mackill, associate plant breeder, IRRI, the names of the RLL categories they are interested in and a list of appropriate parents adapted to the specific categories.
- Sowing of the nursery in the proper season for the criteria considered is emphasized. Sowing has to be adjusted in view of the constraints involved and their relative importance. Early and delayed plantings or two to three sowings should be adequate. This method should lead to the identification of superior entries for the different locations.
- Normally, materials are received in time for sowing. However, when they arrive late, the cooperators can either postpone sowing wherever possible or increase the seed for sowing in the appropriate season.
- The gradual increase in the number of nurseries in the past years reflects the changing trends in the importance of problems and their relative emphasis. There could be additions or deletions. Cooperators can start appropriate nurseries for target environments.
- Data sheets contain useful items relevant to the nurseries. Proper interpretation of the information helps to eliminate or identify relevant entries for multilocation testing and on-site characterization. Cooperators are requested to suggest necessary changes in the format on the basis of their experience and the performance of entries in the nurseries.

SOIL, CROP, AND WATER MANAGEMENT

The Soil, Crop, and Water Management Working Group recommended the following technology for adoption by farmers in RLL environments.

- In shallow, puddled RLL and submergence-prone areas, within 7 d after transplanting place urea supergranules (USG) or similar materials about 10 cm deep in soil in alternate rows, equidistant from 4 rice hills.

Varieties are now available with higher yield potential for the situation where water stagnates up to 50 cm depth. Other varieties can grow in up to 60 cm of water without losing much of their yield potential, but development of a high yielding variety adapted to water depths of more than 60 cm is awaited. The existing varieties are capable of withstanding abiotic stress (water stagnation), but not biotic stress (pests and diseases). Future varieties need resistance to pests and diseases, because measures such as chemical control cannot be effective in standing water in waterlogged areas.

Most waterlogged areas are monocropped. A suitable, economically viable rice-based cropping system with detailed information on soil fertility status and crop response is required. Furthermore, slow-release N fertilizers and plant protection chemicals to be applied at sowing or transplanting need to be developed.

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- Whenever USG is not available, apply basal dose of prilled urea on mud without standing water and incorporate it before transplanting. Under shallow, favorable soil conditions, apply two-thirds as basal and one-third at panicle initiation. In shallow, submergence-prone areas, apply all the USG basally.
- Whenever feasible, excavate about one-fifth of the rice area to collect and store excess water for the current rice crop, for subsequent crops, and for fish.

Dry seeding in drought-prone rainfed lowland rice

The following collaborative trials on dry seeding in drought-prone RLL rice are recommended:

- time of seeding in relation to moisture supply available from rainfall and the water table;
- stand establishment, including seeding techniques and tillage;
- fertilizer management, including time, rate, and method of application of N, P, K, Zn, and S; and
- weed control methods with minimum use of chemicals.

The methodology will be developed by IRRI scientists and finalized through correspondence and meeting with researchers of collaborating countries.

Recommendations for future research

Recommendations for research on soil, crop, and water management for RLL rice are

- to gather more information at INSFFER trial sites about a) type of RLL environment according to IRRI terminology, and b) depth of flooding and water table throughout the testing period;
- to use in INSFFER trials for RLL the best national improved and the most widely adapted promising IRTP lines or varieties;
- to include in INSFFER trials with different levels of acidulation the application of rock phosphate for RLL (25%);
- to conduct INSFFER trials on saline RLL areas with known electrical conductivity just before transplanting, tillering, and flowering;
- to test sorjan as a water management method in RLL areas; and
- to study integrated nutrient management, including green manuring and organic matter, on RLL.

PEST MANAGEMENT

Most of the foliar diseases of rice predominate during the monsoon. Rainfed rice, foliar diseases, some insect pests, and weeds grow simultaneously in the RLL ecosystem. Some are favored and others are adversely affected by rain or standing water.

Systematic information on pest management research, specifically for the different physiographic and hydrological categories, is needed because pest

problems within these categories may vary from country to country. There are many gaps in pest management technology for RLL rice. Although RLL rice faces both drought and submergence, the pest problems are similar, in one growth stage or another, to those of irrigated rice.

Current technology

The main disease problems, in order of importance, are sheath blight (ShB), tungro, bacterial blight, brown spot (BS), sheath rot, blast, ufra, ragged stunt, grain discoloration, leaf scald, and root knot. Although the disease situation may differ in different RLL rice cultures, when there is assured and adequate rainfall it is similar to that of irrigated rice. In the case of inadequate and unreliable rain at the vegetative or reproductive stages, the disease problems are similar to those mentioned earlier, but their intensities vary. Therefore, the disease problems of RLL rice have been identified to some extent.

Disease management practices vary, however, according to agroecological conditions, cultivar, and resources available to poor RLL rice farmers. Four major points emerged from the discussion on disease management:

- National programs have identified a number of resistance materials. Ten International Rainfed Lowland Rice Yield Nursery materials have been found resistant to 1 or 2 diseases in 1 or 2 yr since 1978. Twelve entries have shown multiple disease resistance. These and other resistant materials from national programs may be collected for seed increase at a central place and the seed distributed to different RLL areas for testing.
- In some countries, the population of the tungro vector green leafhopper (GLH) has two peaks (e.g., Bangladesh) and in others only one. Therefore, measures for controlling GLH should begin at the seedling stage.
- Weed control helps minimize damage by diseases such as ShB, which has a wide host range and for which a resistance source is difficult to find.
- Some diseases such as BS and ShB may be controlled by chemical seed treatment.

The major insects of RLL rice are stem borer (SB), caseworm (CW), leaffolder (LF), mealy bug, thrips, gall midge, GLH, brown planthopper (BPH), and hispa. The technology for insect pest management includes

- use of available tolerant varieties to minimize insect pests;
- adoption of cultural practices such as stubble destruction (as in the Philippines and Bangladesh), double planting (Thailand), and early planting (India);
- chemical control; and
- weed management.

Chemical control

In areas where seedling pests consistently cause yield loss, apply carbofuran at 0.5 kg ai/ha on direct seeded rice. For transplanted rice, dip seedling roots in chlorpyrifos (0.02%) or incorporate 0.75 kg ai/ha at the last puddling.

Monitor the crop for SB, GLH, hispa, LF, BPH. etc. from mid-tillering onward. Apply suitable spray formulations such as chlorpyrifos, monocrotophos, quinalphos, or phosphamidon, basing decision on economic threshold values.

Weed management

Weed incidence is higher in RLL rice than in irrigated rice. Chemical and cultural methods of weed control for transplanted and direct seeded (dry or wet) rice are partially applicable to rainfed shallow, favorable conditions (0-20 cm water depth). For other regimes, integrated measures involving tillage, cultural practices, and chemical control are considered useful.

Recommendations for future research

Because information on the different pest associations and the extent of damage is limited, surveys and monitoring are needed. We should obtain information in different RLL rice-growing countries and monitor the pest situation in different culture types of RLL rice on a nation basis.

The Pest Management Working Group identified 13 problem areas and made the following recommendations for research:

- Develop yield loss assessment methods for pests of RLL rice.
- Determine the effect on RLL rice pests of slow-release fertilizers applied in different forms and by different methods.
- Identify better sources of resistance to SB, exchange the sources, and incorporate such resistance in RLL high yielding varieties (HYVs).
- Use known sources of resistance to major insect pests and diseases for developing HYVs for RLL.
- Develop rearing and screening techniques for hispa, mealy bug, thrips, CW, rice bug, cutworm, and root weevil, and exchange information on known procedures for other pests.
- Determine the role of natural enemies of different insect pests in the RLL ecosystem so that decisions regarding their conservation and augmentation can be made.
- Identify slow-release, persistent insecticides for RLL pests.
- Determine the efficacy of and exchange data on botanicals for pest control.
- Determine farmers' weed control practices in RLL and the potential for improving them in different categories of RLL.
- Develop an integrated weed control method for different RLL situations.
- Compare herbicide performance under different water regimes.
- Study the bacterization of rice plants for disease control.
- Study the effect of removal and burning of stubble on pests of RLL rice.

CROPPING SYSTEMS

The Cropping Systems Working Group discussed technologies recommended for transfer to farmers, and cooperative programs.

Technologies recommended for transfer to farmers

Because cropping systems are location specific, and recommended improved systems differ from country to country and are available from the individual country cropping systems programs, we did not attempt to compile recommended cropping systems for different conditions in various countries. Specific recommendations are available from the country programs and in the reports of the Asian Rice Farming Systems Working Group (ARFSWG) meeting. Recommended cropping systems technology is now undergoing multilocation testing in Bangladesh, Nepal, the Philippines, Sri Lanka, and Thailand. Pilot production programs using recommended technologies are being implemented in Bangladesh, Indonesia, Nepal, and the Philippines. Large-scale cropping systems production programs are being implemented in Nepal and the Philippines

Cooperative programs

A number of cooperative programs have resulted from the regular meetings of the ARFSWG. Six programs are discussed briefly.

Cropping pattern testing. Cropping pattern testing uses the on-farm research methodology developed and refined at the 24 rainfed lowland sites involved in the Asian Rice Farming Systems Network (ARFSN). The sites must be grouped according to the new classification of rice-growing environments used by IRRI. We recommend that India and Vietnam be invited to participate in cropping pattern testing in shallow favorable, shallow drought-prone, and medium deep RLL rice areas.

Varietal testing of upland crops. Varietal testing of maize, sorghum, soybean, peanut, mungbean, cowpea, and bush sitao (*Vigna unguiculata* ssp. *sesquipedalis*) attempts to identify varieties of upland crops that fit in rice-based cropping systems. Entries come from the Institute of Plant Breeding of the University of the Philippines at Los Baños, International Institute of Tropical Agriculture, International Maize and Wheat Improvement Center, International Crops Research Institute for the Semi-Arid Tropics, and national programs. Trials in all countries are conducted before and after rice at the time they best fit in the systems. In 1983-84, about 99 trials were distributed for testing before rice and 168 trials after rice.

Long-term cropping systems and fertilizer studies. The main objective of long-term cropping systems and fertilizer studies is to determine the effects of intensive cropping on crop performance and soil properties. Although the experiments are not uniform, the data reporting format is uniform. Bangladesh, Burma, Nepal, the Philippines, and Sri Lanka are conducting experiments in RLL areas.

Farm implements for intensive cropping. The main objective of the Farm Implements for Intensive Cropping program is to evaluate the rolling injection planter and other simple seeders in establishing direct seeded rice and upland crops after rice. The ARFSWG recommended further tests of the rolling injection planter in light to medium-textured soils in Bangladesh, Burma, Indonesia, Nepal, the Philippines, Sri Lanka, and Thailand.

Leguminous green manures. In RLL rice areas, farmers are reluctant to purchase N fertilizers because of the risks the crop faces and the high cost of fertilizer. Green manures and leguminous crops can be incorporated in the cropping sequence to provide the needed N fertilizer for rice. Scientists in ARFSN agreed to a cooperative test of selected green manures and leguminous crops with the following objectives:

- to compare alternative green manures and leguminous crops under different environments, and
- to determine the contribution of green manures and leguminous crops to the grain yield of succeeding crops.

Crop-livestock research. Crops and livestock are the two major sources of income of small farmers in South and Southeast Asia. ARFSN agreed to collaborate in crop-livestock research with the major objective of developing research methodology for other farming systems sites in Asia. Five farming systems sites are involved: one each in Indonesia, Nepal, the Philippines, Sri Lanka, and Thailand. Sites in Nepal and the Philippines are shallow, favorable; the site in Thailand is shallow, drought-prone.

Rice and upland crops

We felt that there were serious gaps in varieties of both rice and upland crops suitable for the cropping systems being developed. Close cooperation between breeders and cropping systems scientists was strongly recommended. When selecting varieties of rice and upland crops for specific regions, breeders should take into account the requirements of cropping systems. Each country should develop the means to achieve this goal. We strongly supported IRRI's attempts to organize meetings to enable breeders to discuss breeding varieties for cropping systems.

Because it is not possible to breed varieties to fit all requirements in different regions, cropping systems workers should define the required characteristics of varieties for different environments in their own countries and communicate their requirements to breeders. For rice varieties it was recommended that further classification be built around the classification of rice production environments used by the rice production group.

It was also recommended that breeders and cropping systems scientists cooperate in testing varieties at the cropping systems research sites.

Intercropping

The potential of intercropping varies from country to country in terms of suitable land type (riceland vs upland). ARFSWG should give more attention to collaborative work in intercropping. There should be appropriate exchanges of research results and methodologies through the ARFSN.

Crop establishment

Crop establishment includes tillage, seeding, and weed control. Reliable and economic crop establishment techniques remain a constraint to broader acceptance of direct seeded rice and the growing of upland crops after rice. To

improve crop establishment, the causes of poor crop establishment for different field conditions must be understood. Collaboration on the following is needed:

- characterization (texture, water content, clay mineralogy, and infiltration rates), and
- standardized emergence trials to obtain baseline data.

We recommended referring this to the ARFSWG.

PRODUCTION CONSTRAINTS AND TECHNOLOGY TRANSFER

The Production Constraints and Technology Transfer Working Group concluded that the issue of identifying constraints that can be ameliorated through research, extension, or policy changes, and the issue of technology transfer must be considered within an integrated, farm-household framework. The cropping (farming) systems research process seeks to design farmer-appropriate technology. Farmer acceptability is one focus of the research, which is conducted in a whole-farm context. We also noted that technology transfer is seen as part of the cropping-to-farming systems research process.

On that basis, and given our small number, we worked with the Cropping Systems Working Group for the remainder of the workshop.

We did, however, make the following observations on production constraints and technology transfer:

- The economic viability of a technology is conditional on a strong market existing for the crop. If the market is weak, and if the crop is a priority of the Government, the Government must be willing to adopt measures to ensure that a remunerative price prevails as supply increases; that is, cropping systems researchers must consider future market conditions when designing technology and must alert policy makers to market conditions that may hinder the adoption of priority crops.
- Eastern India has a high population density. However, as in most rainfed rice regimes, labor bottlenecks occur — particularly during final crop establishment, harvest of the first crop, and establishment of the second. The development of mechanical and other technologies to increase system productivity and employment should continue as priorities in cropping (farming) systems research.
- Farmers in rainfed regions are among the poorest rice farmers. Therefore, on efficiency and equity grounds, technology designed for them should make maximum use of labor and have a high cash payoff and a low cash input intensity. It is unrealistic to assume that material productivity increases will occur at the added cost (whether cash or opportunity costs). Therefore, to ensure that all farmers have equal access to improved technology, which is scale-neutral in concept, changes in social institutions (access to credit, inputs, markets) may be preconditions to ensure that the technology is resource-neutral as well.
- The extension message (like input supplies) must be timely and must address real problems of production constraints. Extension offices must

have training in basic principles as well as in-depth knowledge of technology so that they may

— convince farmers that the technology is worth adopting and that they are capable of using it, and

— help farmers adapt the technology to their circumstances.

We appreciated that these four points do not constitute the basis for collaborative research, and that the comments made are widely applicable. The consensus was that we did not have the breadth of expertise or the disciplinary background to make substantive recommendations for collaborative programs on production constraints and technology transfer.

426

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INDEX OF VARIETIES

This variety index is based on the most common usage. Variations between index listings and text entries are noted in two ways: 1) where spellings are similar, variations are noted in parentheses after the main listing, and 2) where variations are widely separated in the index, they are cross referenced. In the listing itself we departed from the text by modifying some entries. For the most part the modifications involve 1) deleting spaces in entries, 2) substituting capital letters for lowercase letters, and 3) changing Roman numerals to Arabic numerals.

Variety Page
2L-112 134
19MTC5/A 215
35-2752 135
62-355 126,132,14.
71-554 132,138
75-1870 132
314 235,238
498-2A(R-R-8) 127
529C-Md-10-3-6 226
813 238,239
828 238,239
8895 250

A
A200 129,141
AC1864 352
AC1871 352
AC1885 352
AC1890 352
AC1916 352
AC1922 352
AC1999 352
AC2051 352
AC2246 352
AC2298 352
AC2300 352
AC2309 352
AC2375 352
AC2521 352
AC2546 352
AC2557 352
AC2577 352
AC2805 352
AC2985 352
AC4669 352
Achra 55
Achra 108-1 211
Addey 82
ADT17 194,405
ADT21 244,245,255,256
Aijong 280
Ainantsao 132
AKP70-73 129,134,141
Alakkachari 203,204
Ambemohar 255
Ambemohar 159 258
Andrewsali 244
Ankli 128,141
Anupama 129,135
AR1 405
AR108-1 405
AR614-458 405
ARC353-148 405
ARC1250 258
ARC4236 258
ARC6650 244
ARC10399 294
ARC10550 244
ARC11353 258
ARC11554 255
ARC13349 250
ARC13804 255
ARC13904 258
ARC15570 255
Asahan 307,308
Asamchudi 141
ASD7 244,250
ASD11 244
Asgo 203,204
Asha 129,135,141,244
AT74-1 126,137

AT78-2 137
AT79-2 126,137
Aungzeya 130,226,227
Aus 8 138
Auskali 203,204
Auspanjali 203,204

B
B459 130
B589A4 254,258
B981D-SI-35-1 82
B1050-MR-44-3 183
B2388 130
B2393 130
B2709 130
Babawee 137
Badakalasura 195
Badava Mahsuri 97
Badkalamkati 65 213
Badrasail 1 204
Badrasail 2 203,204
Badshabhog 55
Bakol 127,141
Ba la 235
Balguna 388
BAM3 134,140
BAM6 128,133,141
BAM9 133
BAM10 259
Bangalami 127,141
Bang Phra (Bahng Pra) 168
Bantulsi 352
Baok 134
Bao Thai 235
Bao Thai Lun 239
Barito 124,130,141
Bashpair 210
Basmati 226
Ba thiet 125,141,235,239
Bau 237
BAU151-51 138
BAU151-56 138
Begunbichi 203,204
Berantas 307,308
Beunjing 257
BG3-5 126,132,141
BG12-1 244
BG34-6 126,132,141
BG34-8 126,141
BG38-8 126,137
BG90-2 81,96,132
BG94-1 126,132,141
BG276-5 126,141
BG380 126
BG400-1 126,141
BG407 126,132,141
BG573-7 126
BG621-1 126,137
BG621-9 138
BG671-9 126
BG745 126,132,141
BG745-4 126,138
BG750 132
Bhadoia 685 96
Bhadra 245,405
Bhandra 244
Bharati 387
Bhasakalma 215
Bhasamanik 55,127,141,203,204,210,213
Bhelki 203,204
Bhetnasia 133
Bhimsail 201,203-205
Bhonduparewa 129,141
BIET452 85,90,195
BIET720 138,406
BIET724 127,195-197,209,211,213,
214,206
BIET799 127
BIET807 196,197,209
BIET820 127
BIET821 138,196,197,209
BIET1048 195
Biraj 35,127,133,141,191,194,198,406
BJ1 245,254,255,258
BKN6322-85 136
BKN6806-46-62 137
BKN6874-40 226,230
BKN6986-3 293
BKN6986-66-2 153
BKN6986-108 183
BKN6986-147-2 152,153
BKN73004-419-2-1-1 125
BKNFR76106-16-0-1 180,183,191,198
BKNFR76109-1-2-1 180
BKNFR76109-7 183
BM2060 405
Bokra 203,204
Bongota 203,204
Boyan 213
BP94 388
BPI 3-2 124,130,141
BPI 76(NS) 124,141,156
BPT1235 135
BPT3291 84,86,90,91,154
BR1 126,131,141,242,244,352
BR3 126,131,137,141,219
BR4 77,83-86,88,89-91,93,
95,96,126,131,136,141,183,
186,219,221,254,258,260
BR5 186
BR6 219,244,254
BR7 219
BR7-J9 126
BR8 127,131,132,138,141,194,195,
219,254,405
BR9 126,131,132,141,219
BR9-HR5 126
BR10 81,88,90,92-95,126,131,141,
219,221,260
BR11 91,97,126,131,141,219

BR12 242,352
BR13 405
BR14 138,195,213,219,220,242, 352,405
BR15 244,352
BR34 127,138,195,214,255
BR34 132,141,405
BR46 405
BR51-46-5 88,90,93,95
BR51-46-51 138
BR51-49-6-HR50 137
BR51-54-2 226
BR51-74-6-J1 126,137,220
BR51-91-6 254,257,259
BR51-181-8 90,91
BR51-282-8 77,81,82,84-86,89,90,95,96, 137,219-221,260
BR51-282-8-HR9 137
BR52 235
BR52-87-1 254
BR52-90-2 221
BR109-74-2-2-1 164
BR111-140-1-1 82,221
BR118-3B-17 183,209
BR118-3B-37 183,198
BR153-2b-10-1-3 126
BR160-19-2-1 221
BR161-2B-47 164
BR166-2B-8 221
BR171-2B-8 220
BR201-193-1 126
BR203-26-2 126
BR203-70-B-2 126
BR236-10-2-2-1 220
BR308-3-2-9-A 244
BR315-12-1-4-1 137,220
BR316-15-4-4-1 126,137,220
BR593-676-4-1-2 126,137,220
BR593-676-4-1-6 220
BR593-698-5-1-8 126,137,220
BR734-1-2-2 220
BR736-20-20-3 220
BR847-76-1-1 220
BR850-9-1-1 220
BR1045-232-5-3 220
BRB11-461-1 221
BRC16-127-4-3 126,137,220
BRJ27-10-1 137
Brown gora 138
Bura Kalma 210
BW100 126,132,141
BW242 132
BW248-1 132
BW259-3 132
BW266-7 132
BW267-3 126,132
BW272-6B 126,132,141
BW288-2 126
BW293-2 126
BW297-2 126
BW298-2 126

C
C4 238
C4-63 226-229
C4-113 130
C4-117 *See* Chenab 64-117
C10 238
C15 238
C22 226,307,308
C64-117 *See* Chenab 64-117
C168 85,86,91,226,260
C242 260
C1117-2 82
C1158-8 88,90,91,93-95
Cauvery 293
CB1 213
CB2 213
CH45 259
CH63 127,133,141
Chakia 59 194,405
Chanda Aman 221
Chandina 219,242,244,254,255,258
Chatri 129,141
Chau Nang Vo 235,239
Chenab 64-117 183,195,198,214,407
Chettu Pokkali 352
Chet Xanh 235,239
Chiem 314 239
Chiem Ba La 237,239
Chiem Bau 238,239
Chiem Chanh 239
Chin 31 194
Chinese 345 136
Chinor 129,141
Chinsurah Boro 2 254
Chum ruot lua 235
Cina 135
Cipunegar 124,130,141
Cisadane 84,88,91,93,95,96,124,130,142, 154,220,221
Citarum 308
CMN539 *See* CNM539
CN492 406
CN499-160-2-1 127,139,196,209,214
CN499-160-13-1 139
CN499-160-13-6 127,196,197,209,211
CN499-160-21 197
CN505-5-3-1 211
CN505-5-32-9 127,139,195-197,209, 211-214
CN506-147-2-1 127,139,209,213,214
CN506-147-14-2 127,139,196,197, 209,211,213
CN539 *See* CNM539
CN540 55,84,86,91,133,136,144,194, 209-211,215,254,255,391, 404-408
CN603 210,211,246,406
CN643 209-211,215,405,410
CN644 210
CN691-1 209,215
CN697-3-13 215

CN704-7-3 215
CN705-18 215
CNDP217 55
CNL 31 211
CNL 108 211,405
CNL 214 210
CNL 231B-B 211,405
CNM3-2 246
CNM6 55
CNM20 55
CNM25 55
CNM31 55,226
CNM539 35,36,55,86,133,141,194, 209-211,255,259,391,404-406
CNM540 *See* CN540
CNM603 *See* CN603
CNT7246-4-2-1 245
CNT7256-4-2-3 246
CO 4 258
CO 12 164
CO 14 194,405
CO 42 244,245
CP104 195
CR12 257
CR44-35 135,245
CR44-118-1 139
CR57 245
CR94 245
CR94-13 130,140
CR98-7216 256
CR98-7223 406
CR98-7270 406
CR141-4001-2-192 132
CR141-7369 245
CR146-7003 256
CR149-501-228 405
CR149-3244-198 82
CR149-7249-CRR-29 257
CR155-5029-21 259
CR190-103 352
CR203 235
CR210-1009 134
CR210-1017-607 257
CR221-1030 213
CR256-6-436-507-96 211
CR260-30 409,410
CR280-4 259
CR292-5258 213,406
CR292-7050 209,213
CR301-3066 209
CR320-9 209,405
CR505-5-32-9 197
CR1001 246
CR1002 210
CR1006 86,90,153,210
CR1009 32,128,142,195,210,385,386, 404-407
CR1010 404,406
CR1011 385,404,409,410
CR1012 405
CR1014 128,134,142,213,405
CR1014-211 195
CR1016 404-407,411
CR1018 280,385,404-410
CR1023 82
CR1024 226
CR1030 195,209,385,387,404,405,407, 410
CRM10-4748-9-63 406
CRM13-3241 139
Cross 4 135
Cross 116 164
CSR1 293,294
CSR2 293,294
CSR3 293,294
CSR4 293
CSR6 293,405
Cut 235
Cuttack Basmati 132

D
DA29 219,221
Dabola 142
Dalkhani 36-21 215
Damodar 198,268,294,352,385
Dasal 257,294,405
Dawh-Ang 356
Dawn 258
Dee-geo-woo-gen 131,384,388
Deeptee 129
Deepti 135
Deveredderi 126,142
DGWG *See* Dee-geo-woo-gen
Dhanyalaxmi 244
Dharial 126,142
Dhullaputia 133
Dhusasa 352
Di huong 235,239
DML 70 136
Doanket 238,239
Dolaman 405
Dolangi 132
Doodalachi 405
DPAR7356 211
DR190-103s 245
Du 238,239
Dubraj 129,135,142
Dular 55,213,308
Dusurakajra 406
DV85 254
DW48 405
DW170 82
DZ192 254

E
EB1 405
EB2 405
Ekarin kewa 226
Emata 225
Engatek (Engkatek) 130,132,137
ER1 35,36
Eswarakora 244,248,250
Eyamin 130

F

FD69-1-1-1-3-2 164
FD69-1-1-3-2 164
FH60-124 128,134,142
FH355 164
FH557 164
FH559 164
FH563 164
FH567 164
FH573 164
FH622 164
Fortuna 130
FPAR7360 211
FPAR7511 211
FPAR7809 209
FR13A 55,128,133,142,177,180-184, 186,187,191,193-195,198,202, 204,209,210,407
FR43B 55,128,133,142,181,183,184, 191,193-195,198,202,204,210, 407,410
FRG1 407
FRG2 183,407
FRG7 183,195,209,407
FRG8 407
FRG10 195

G

Gaen Jan 172
Gampai 258
Garima 135,142
Gazal 204
Gazi 242
GEB24 131,194
Gerikalma 201,203-205
Getu 198,266,294,385,405,413
Getu mutant 385
Ghatakalma 203,204
GMS13 405
Gobindabhog 55
Gochi Boro 254
Goda 221
Goda Heenati 181,183
Goirol 221
Gouthami 405
Gow Ruang 142
Gow Ruang 88 125,131
GP41 137
GR2 134
GR3 128,134
GR4 128,134
Guachhari 133
Gurmatia 129,142

H

H4 126,132,137,138,142
H5 96,132
H9 134
H105 258
H501 132
Habiganj Aman 8 139,214,258
Habiganj Boro 2 126,142
Habiganj Boro 4 126,142
Habiganj Boro 6 126,142
Halhipanja 406
Hamai 201,203-205
Hamilton 55,293,413
Handifool 45
Haskikalmi 126,142,254
HB1 405
HB2 405
HB3 405
HB4 405
Hbj Boro 2 *See* Habiganj Boro 2
Hbj Boro 4 *See* Habiganj Boro 4
Hbj Boro 6 *See* Habiganj Boro 6
Hbj DW8 *See* Habiganj Aman 8
HG60-49 405
Himdhan 280
Hmawbi 1 130
Hmawbi 2 130,22[illegible]
Hmawbi 3 130
Hnanga 226
Hnanwamegauk 226,227
Hoa binh 239
Hondarawala 502 246
HR12 134
HR21 255
HR35 375
HTA7403-110-1-5 209
HTAFR77051-1 154

I

IET720 215
IET778 259
IET1444 35-37,140,293
IET1648 164
IET2703 164
IET2815 254,257
IET2895 133
IET2911 246
IET3257 210
IET3629 127
IET4106 359
IET4140 256
IET4141 254,256
IET4620 140
IET5122 257
IET5472 375
IET5656 35,36,127,142,245
IET5704 138
IET5874 138
IET5882 127,164,280
IET5912 385
IET6080 245
IET6131 245
IET6148 127
IET6155 127
IET6187 245
IET6205 164
IET6223 127
IET6261 258
IET6272 258
IET6288 245,246

IET6290 245
IET6314 127,245
IET6315 245
IET6721 245
IET6725 245
IET6729 245
IET6747 245
IET6755 259
IET6900 211
IET6905 293
IET7008 245
IET7193 258
IET7300 258
IET7301 245
IET7302 245
IET7303 245
IET7494 246
IET7562 245
IET7563 245
IET7568 245
IET7569 245
IET7575 245,385
IET7789 259
IET7880 385
IET7895 258
IET7918 245,386
IET7956 255
IET7958 255
IET7970 91,97,127,138,255,385,404
IET7976 139
IET8009 246
IET8022 246
IET8037 246
IET8130 385,386
IET8144 259
IET8252 259
IET8549 246
IET8558 255
IET8843 259
IET8862 259
IET8967 211,212
IET8970 211-213
IET8987 139
IET8989 139
IET9016 215
IET9020 215
IET9040 215
IET9055 215
IET9059 215
IET9060 215
IET9063 215
IET9065 215
IET9072 215
IET9075 215
Inmaycbaw 226
Intan 129,135,142,255
Intan 2400 250
Intan Mahsuri 129,140
IR5 130-132,227,238,244,247,266, 353
IR5-47-2 221
IR5-114 96
IR5-114-3-1 131,136,137,221,257
IR5(J) 137
IR5 mutant 130
IR5(P) 137
IR8 55,128,130-135,138,140,142, 195,214,221,226, 238,244, 245,247,250,256,352,353,384, 387,388
IR8-246 132,134
IR9-60 134
IR20 81,96,131,134,136,137,140,150, 153,154,221,244,245,247,249, 254,255,257,258,353
IR22 135,353,354
IR24 81,88,91,93,95,130,139,223, 226,227,238,244,266,353
IR26 45,139,195,214,244-249,254, 255,258,307,308,353
IR28 128,134,136,140,226,227,244, 246,353,354
IR29 244,353
IR30 139,213,214,244,246,255,353
IR32 96,136,244,246,255,259,307, 308,353
IR34 80,82,96,139,214,227,228,244, 246,266,353,354
IR36 35,36,70,119,124,127,130,131, 136,137,139,140,142,213,226, 227,241,244-247,249, 251,254,255,258,260,266,268, 307,308,323,352-354
IR38 244,353
IR40 244,266,353
IR42 96,119,124,130,131,136,142, 209,226,227,230,244,246,247, 249,260,266,353,354
IR43 124,142,244,266,353
IR44 96,226,244,266,353,354
IR45 244,353
IR46 72,77,80,81,84,85,87,88,90,91, 93,95,96,99,130,137,226,244, 260,266,353,354
IR48 226,244,266,353
IR50 127,140,220,226,244,247,254, 255,266,353
IR52 85,87-90,93,95,124,130, 142,145,153,156,209,226,244, 247,257,258,266,353
IR54 81,82,156,226,244,254,256-258, 266,354
IR56 244,247,353
IR58 244,247,266,353
IR60 244,247,266,353
IR62 244,353
IR95-31-4 133
IR127-80-1 266
IR135-40-56-3-2-1 164
IR262 131-133,137,194,246
IR272-4-1 254
IR272-4-1-2-J1 131,221

IR272-4-1-2-3-10 221
IR305 137
IR305-3-17-1-3 131,221
IR442-2-24-1-2-3 203,204
IR442-2-58 153,154
IR442-36 130
IR506-133-1 131
IR531-E-239 244
IR532-E-239 245
IR532-1-1-76 254
IR577-11-2 266
IR579 35,36,140
IR661-1-170 266
IR781-144-1 250
IR789-98 96
IR833-6-2-1-1 134
IR1366-120 96
IR1366-120-3-1 130
IR1414-753-86-2 260
IR1461-131-5 130
IR1514A-E666 139,213,214
IR1514S-E666 139
IR1529-680-3-2 238
IR1539-37 96
IR1539-37-3-1 130
IR1561-1-2 235
IR1561-149-1 134
IR1561-228 254
IR1561-288-1-2 130,140
IR1626-225-2-3 226-228
IR1737 130,134,140
IR1737-19 96
IR1814 96
IR1820-52-2 244,246
IR1833-208-1-3 138
IR1917-3 96
IR2039c-Kn-7-2-5-3-1 82
IR2053-54-1-1 136
IR2053-78-1-3-2-3 226
IR2053-375-1-1 164
IR2053-442-1-2-3 226,227
IR2055-219 96
IR2061 246
IR2061-214-3-6-20 130
IR2061-243-3-6 256
IR2061-464-2 137
IR2061-464-246 138
IR2070-2-5-6 139,214
IR2070-20-2-5-6 139
IR2070-423-2-5-6 138,215
IR2071 130
IR2071-88 130
IR2071-88-8 266
IR2071-625-1 136
IR2153-14-1-6-2 140
IR2153-26-3-5-6 136
IR2157-3 96
IR2307-217 96
IR2307-247-2-2-3 88,90-93,95,131
IR2793-10 96
IR2797-105-2 266
IR2863-38-1-2 246
IR2948 96
IR2956 96
IR2987-13-1 81
IR3018 96
IR3259-83-160-1 153
IR3259-P3-160 152
IR3511-39-3-3 259
IR3518-106-2-25-3 259
IR3646-9-1-1 226
IR3839-1 266
IR3880 308
IR3880-10 81,88,90,93,95
IR4215-301-2-2-6 81
IR4219-35-3-3 137
IR4227-24 96
IR4432-52-6 266
IR4432-52-6-4 125
IR4432-103-6-4 245
IR4568-86-1-3-2 82
IR4595-4-1-13 268
IR4630-22-2-5-1-3 268
IR4630-22-2-17 268
IR4683-54 266
IR4683-54-2 96
IR4683-54-2-2 266
IR4704-123 96
IR4744-295 96
IR4744-295-2-3 246,260
IR4819-77-3-2 77,81,82,84,85,87-91, 93-96,260
IR4829-89 91
IR4829-89-2 77,81,82,88,89,91, 93,95,96,260
IR5537-20-1-3-2 259
IR5657-33-2 266,267
IR5677-17-3-1 81
IR5793-55-1-1-1 153
IR5853-162-1-2-3 259
IR5853-198-1-2 81,153
IR5931-110-1 260
IR6023-10-1 266
IR6402-0T-7 191,198
IR6402-7-1 183
IR7732-B-A96-3 260
IR7732-RGA-B-A96-1 260
IR8073-65-6 266
IR8073-65-6-1 82,260,266
IR8192-31-2 266
IR8192-166 266
IR8192-166-2 266
IR8192-166-2-2-3 77,82,84,85,87,89-91, 95-97,101,221
IR8192-166-2-3 84,97
IR8192-200-3 266
IR8234-0T-9-2 180
IR8423-132-6-2-2 125
IR8608-82-1-3-1-3 81
IR8608-298-3 266
IR8608-298-3-1 137
IR8635 138

IR8717 138
IR9129-7-1 124,136,226
IR9129-169-2-3-5 125,131,142
IR9129-192-2 83-85,87,90,91
IR9129-192-2-3 137
IR9129-209-2 266
IR9129-209-2-2-2-1 266
IR9129-303-2 137
IR9129-456-2 266
IR9168-13-1 257
IR9209-181-2 266
IR9217-58-2 266
IR9217-58-2-2 266
IR9288-B-B-244-2 82
IR9288-B-B-B5-2 82
IR9698-16-3-3-2 81
IR9708-51-1-2 126,220
IR9729-67-3 126,220
IR9736-16-1-2 266
IR9763-11-2-3-3 99
IR9764-45-2-2 266,267
IR9782-111-2-1-2 152
IR9830-26-3-2 82
IR9852-22-3 81
IR9884-54-3 266,268
IR9884-54-54-3 266
IR9975-5-1E-P1 154
IR10110-24-1 156
IR10176-79 137
IR10179-23 137
IR10187-80 137
IR10198-66-2 82
IR10198-66-6 268
IR10198-68-2 266
IR10199-12-8-2 260
IR10751-143-2-3 260
IR10781-K18-143-1-1 260
IR10781-75-3-2 77,81,84-86,89,91,95,96, 221,260
IR10781-75-3-2-2 84,88,91,93,95,99,260
IR10781-143-2-3 82,246
IR11141-6-1-4 209
IR11185-R-0-7 209
IR11288-B-288-1 136
IR11418-19-2-3 267
IR13146-13-3-3 81
IR13146-41-3 81
IR13146-45-2 77,81,93-97,99,260
IR13146-45-2-3 81,84-86,88-91, 93-95,97,101,260
IR13149-43-2 266
IR13168-143-1 266
IR13224-26-3E-P1 154
IR13240-10-1 137,235
IR13257-46-1E-P1 81
IR13358-85-1-3 83-86,89-91,95,96, 221,260
IR13365-253-3-2 82,85,86,90,136
IR13369-86-2-2 82
IR13419-13-1 82
IR13419-35-1 260
IR13419-113-1 88,93,95
IR13423-10-2 266
IR13426-19 266
IR13427-40-2-3-3-3-3 156
IR13427-45-3-1-2-2-2 86
IR13427-69-1-2-2 226
IR13429-109-2-2-1 220
IR13429-130-2 86,90
IR13437-5-3-4E-P3 209
IR13437-20-4E-P1 136
IR13564-95-1 81,82,260
IR13610-72-2-2E-P2 209
IR13646-55-1 82
IR14497-15-2 81
IR14632-2-3 77,83-86,88,90,91,93,95,96
IR14632-21-3 266
IR14632-181-1 81
IR14718 Yn-10 228
IR14753-49-2 77,81,83-86,88-91,93, 95,96
IR14753-66-3 81
IR14753-86-2 81,82
IR14753-133-2 81
IR14875-98-5 81,88,90,93,95,260
IR15164-3 229
IR15166 Yn-16 228
IR15791-163-1-3 266
IR15853-89-7E-P3 81,82,88,90,93, 95,96,99,260
IR17643-1-5 209
IR18077-3-1 125
IR18146 Yn-1 226
IR18151 Yn-4 226
IR18152 Yn-1 226
IR18189-2-3-2 137
IR18372 Yn-13 226
IR18372 Yn-18 226
IR18599-68-1 84,88,90,93,94,95,153,209
IR18848-35 156
IR19058-107-1 156
IR19083-22-2-2 81,82,95,96,260
IR19256-88-1 81,82
IR19431-72-2 77,82,84,89-91,93-96, 209,260
IR19672-54-1-3-2-1 86
IR19728-9-3-2-3-3 125,137
IR19735-5-2-3-2-1 156
IR19743-25 137
IR19743-25-2-2 126
IR19748-9-3-2 137
IR20718 256
IR20992-7-2-2-2-2-1-1-1 154
IR21015-80-3-3-1-2 156
IR21037-2-1-2E-P1 81,82
IR21040-4-P1 153
IR21071-53-2-3-2E-P1 154
IR21141-24-2 81,95,96
IR21178-39-P1 260
IR21178-43-1-2-2-2 153,154
IR21567-16-3 81
IR21567-18-3-1 81,82

IR21717-42-1 125
IR21717-42-2 137
IR21836-90-3 81,82,86,89,90,91, 124,130,226
IR21841-91-2-3-3 130
IR21848-65-3-2-2 226
IR22277-Yn-3 226
IR24594-272-2-2 87
IR24609-32-3-2 226
IR26567-29-3-3-1-2 154
IR26702-25 183
IR26702-111 183
IR26702-155-2-3 183
IR26708-2-2-3-1-1 183
IR26721-135-2-6-1-3 183
IR28884-6-1-502-1-2 183
IR28884-26-3-505-1-1 183
IR28905-10-1-3 183
IR28930-5T 183
IR28941-164-1-5 81
IR29385-1-1 266
IR31031-43 183
IR31406-333-1 183,191,198
IR31429-14-2-3 81
IR31432-6-2-2-3 183
IR31442-1-503-1-2-1 183
IR33153-1-1-2 154
IR33153-19-1-2 154
IR33279-1-501-1 183
IR33284-4-503-1-1 183
IR38500 195
IRAT9 153,154,308
ITA119 152-154
ITA139 152
ITA186 152-154
ITA230 99,153

J
J15 258
Jabra 203,204
Jagannath 128,134,139,142,194,195,198 213,214,255,257,404,405
Jagritee 129
Jagriti 135
Jaishree 132,406
Jaisurya 406
Jajati 139
Jaladhi 1 55,391,405-407
Jaladhi 2 55,210,211,391,405-407
Jalaj 191,195,198,405-407
Jalaplaban 194,210,215
Jalmagna 405,407
Jampah Sawn 168
Janak 198
Janki(Janaki) 91,97,138,191, 195-198,209,211,214,215,255,404-407
Jaswa 142
Java 14 254
Jaya 127,128,132,135,138,142,195, 213,256,293,387,405
Jhili 128,142
Jhilli 129,142
Jhingasail 210,213
Jhona 349 266,268
JR3-756 135
JR8-26-23 135
JR16-105-3-1-1 135
Jyothi (Jyoti) 244,245,387

K
K35-3 140
Kabra 260
Kada 176-12 128,134,142
Kadaria 124,130,142
Kaharamana 183
Kailash Pati 352
Kaimsail 203,204
Kaingsaba 226
Kaiputur 203,204
Kajurchanai 405
Kakatiya 140,244,245
Kalam Banki 352
Kalambank 133
Kalamdan 127,142
Kalamkati 203-205
Kalamota 293,405
Kalarata 268
Kalaviya 142
Kalawriji 1 203,204
Kalawriji 2 204
Kalimonch (Kalimooch) 142
Kalinga 2 139
Kalma 55
Kan Bau Ngan 258
Kanchan 132
Karamana 183
Kariwai 1 203,204
Kariwai 2 204
Karjat 2-32-43-20-11 140
Karjat 14-7 134
Karjat 23 140
Karjat 24-10-25-35 140
Karjat 35-3 140
Karjat 184 134
Katakchandi mutant 215
Kataribhog 55,137,255,258
Katranqi 35
KAU2019 82
KAU2039 209
Kaukhmwe (Kauk Hmwe) 130,223,227
Kavchi 128,142
KDML 105 *See* Khao Dawk Mali 105
Kessore 132
Khadasiya 128,142
Khajuriachauer 195
Khao Dawk Mali 105 90,97,125,142,171,172,180
Khao Dawk Mali 105 mutant 131
Khao Nahng Nuey 2 133,194
Khao Pakh Maw 148 18,125,131,142
Khao Todlawng 168
Kiran 132
KJT2-32-43-20-11 128
KJT23 128

KJT24-10-25-35 128
KKN6721-5-34-1 125
KKNLR75053-PMI-40-3 125
KLG6987-143-2-P 139,214
KLG6987-191-P 136
KMJ1-17-2 133
KMJ1-19-1 133
KMP39 129
Koimurali 127,143
Kolam (Halki) [Koiam (Halki)] 128,143
Kolamba 134
Kolpi 143
KPG 136
Kranti 135
Krueng Aceh 124,130,143
Kulu 226
Kumar 245
Kumargore (Kumangore) 55,204,213,413
Kunti 244
Kurkaruppan 181,183,191,193-195,198
Kyawzeya 130,226

L
La 136
Lacrosse 254
Lacrosse Zenith 352
Laki Badal 405
Laloo-14 135
Lalrani 294
Lalu 129,143
Latisail (Latisali) 55,126,131, 133,135,143,213,219
LD66 132
LD125 132
Leb Mue Nahng 3 133,136,139,213,214,244,245
Leuang 152 244
Leuang Boonma 356
Leuang Pratew 123 125,131,143
Leuang Yai 148 125,131,143,152,153
LMN3 *See* Leb Mue Nahng 3
LT78 137
Luchai 129,143

M
M4-3-2b 130
M11-57-5-1 387
M141 129,143
MA68-1 226
Machando 130
Machhakanta 133
Madhukar 164,183,194,352,405,407
Madhuri 129,135,143
Magura 134
Mahakam 124,130,143
Mahsuri 80-85,87-97,101,119,125, 127-129,132,133,135,136, 138,143,164,194,198,209, 210,213,215,226,255,257,259, 260,280,293,385,404,405
Mala 254,258
Malabati 293
Malagkit Sungsong 254
Mala-J11 221
Maligaya 354
Malta 413
Manawhari 226
Manawthuka 226
Manoharsali 128,133,143,244, 245,258,405
MAS 250
Mas 132
Masuli 45
Mat Candu 136
Matla 55,293
Mayang Ebos 96,132
Meedon 225
Meegauk 226
Meghi 203
Meta 211
MGL-2 150,259
Millikuning 134
Mingolo 129
MN62M *See* Muey Nawng 62M
MNP36 257,258
Mockham 235,239
Moc tuyen 235,239
Mohan 293
Mohini 245
Motajata 203,204
Moyna 242
MR30 259
MR42 124
MR67 124,136
MR70 136
MRC356-172 136
MRC603-303 226
MRC801-411 136
MRC2711-2503 136
MRC4917-3146 136
MRC5731-3438 136
MRC5892-3460 136
MRC8601-4927-1 136
MRC10922-147 136
MRC10923-148 136
MRC10929-184 136
MS2 164
MS5-3-4 164
MS6 164
MS14-1-5 164
MS18-7-2 164
MS30 164
MS34-1-1 164
MS46-1-3 164
MTC6A 215
MTU3 134
MTU5 258
MTU15 254
MTU2400 149
MTU3626 134
MTU4407 135,140
MTU5249 245

MTU5995 245
MTU6024 140
MTU6861 140
MTU7020 405
MTU7029 129,135,143
MTU7633 405
MTU8002 405
MTU8089 405
Muda 124
Mudgo 244,250
Muey Nawng 62M 125,130,143,171, 244,249,352
Murungakayan 132
Mutant 14 138
Mypali 133

N
N22 132
Nagra 55,127,143,204
Nagra 41-14 213
Nahng Mon S 4 125,130,136,143,171
Nahng Prayah 132 125,131,143
Nahng Tahmi 168
Nam Dawkmai 168
Nam Sa-gui 10 81,125,254
Nam Sa-gui 19 (NSG19) 90,97, 130,131,143,156, 171,180,209,226,256
Nang Nhuan 125
Nawagam 19 134
NC437-77 211
NC487 209,213,215
NC487-77 127,139,143,210,211,214
NC488 209,210,213
NC488-78 127,143,211
NC490 139,209,211,212,215
NC491 210,211
NC492 89,127,139,195-197,209, 211-214
NC493 127,139,209,211,215
NC496 209,210,211
NC497 127,211,215
NC519 215
NC540 293
NC678 55,203,204,213,215
NC1281 55,194,203,204,213,293,391
NC1626 55
NCS2031 195
NCS2062 195
NCS2067 195
NCS2505 352
NDAU22 164
NDR91 259
NDR450 259
Neera 244
Nep 239
Nep 4 235
Nep Du 235
Nep nu u 235
Ngakwe 154
Ngakywe 124,143,225,226
Ngakywetaungbyan 226
Ngasein 225
Ngweto (Ngwetoe) 124,143
Nhang 237
Niaw Sanpah Tawng 125,130,131,137,143,171
Niaw Ubon 1 125,131,172
Nira 254
Niwari 129,143
Nizersail 126,131,143,203,2
NLR9672 129,134,143,255
NLR9674 134,244,255
NLRI 3936 140
NN1 238
NN-1A 235
NN3A 235
NN4B 235
NN5B 235
NN6A 235
NN7A 235
NN8A 235
NN22 235
NN23 235
NN27 235
NN75 235
NN75-1 235,238,239
NN75-2 235,238,239
NN75-6 235
NN75-9 235
NN75-10 235
NN750-8 235
Nogoba 280
Nona Bokra 267-269,293
Nonasail (Nonasal) 294,352
NP130 135
NSJ205 135
NSPT *See* Niaw Sanpah Tawng
Nungi 129,143

O
OB677 132
OB1280 137,138
OC1393 55,210,213,413
OC1393 mutant 133,194
OR117 209
OR117-4 128,139
OR117-8 195,209,211,214
OR117-30 211
OR117-215 213
OR142-24 211
OR142-99 128,139,209
OR142-105 128,139
OR142-193 128,139,209
OR143-7 128,139,195-197,209,211, 405,410
OR143-32 209
OR330-40-3 209
OR367-OP-11 259
OR452-36 128,139
OR455-30-2 128,139
OR1104 195,211,405

OR1105 195,211,405,410
OR(M)1103-42 215
OS4 257,258

P
Padi Hitam 136
Padmakesasi 128,143
Pak Sian 199-19-39 131
Palenthe 226
Palethwe 226
Pandunewee 152
Panidhan 2 133
Pankaj 35,36,119,127,128,132-134, 138,139,143,164,194,198,210, 213,215,255,257,258,293,404, 405
Pankhari 203 244,250,255
Parewa 129,143
Parmal 129,143
Patnai 35,352
Patnai 23 55,203,204,210,213,219,413
Pavizham 244,245,405
Pawsanbaykyar 226
Pawsanhmwe 124,143,225-228
Pawsanyin 226
Pelita I-1 80,81,96,130,227
Pendosein 226
Peshwari 203,204
Peta 131-133
Peuak Nam 43 125,131,143
Peykeo 154
Phalguna 129,135,143,241,244,249,255, 257,386
Phokawgyi 225
Pindosein 227
Pin Gaew 56 168
PLA2 405
PLA4 194,405,407
PLA1100 213
Podimi A8 137,138
Podiwee A8 132
Pokkali 126,144,198,203,204,267-269, 405
Pongsu Seribu 2 136
Poorwa (Poorva) 135,144
PP 132
PR11 126
PR14 126
PR14-1 138
PR17-1 138
Pragati 135
Prasad 254
PTB2 244,245,255-257
PTB7 405
PTB10 245
PTB15 194,405
PTB16 405
PTB18 244,245,255,352
PTB21 134,244,245,255,352
PTB33 244-246,250
Puang Ngern 168
Puang Rai 2 125,131,144
Purbachi 144
Purwa 129
Pusa 2-21 255
Pusa 33 140

R
R4 135
R9-1-6-1-3-7-7 87,90
R11 135
R16-12 254
R34-2478 135
R35-2750 135,388
R35-2752 388
R36-2468 135
R68-1 135
R114-2-1-1-1 87,91
R155-355 135
R2022 135
R2076 135
R2384 135
Radin STR 125
Raghusail 55
Rajendra 244
Rajendra Dhan 202 133,244
Ramadja 258
Ramagiri 500 128
Ramakrishna 254
Randhunipagal 55
Rasi 127,144,245,256,259
Rassi 35
Rathu Heenati (Ratu Heenati) 244,246,250
Ratna 127,128,134,144,244,245,255, 256,293
Ratnachudi 133
Ratnagiri 24 134
Ratnagiri 68 134
Ratnagiri 500 140
RAU19-313-3-2 85,90
RAU21-128-1-2 406
RAU21-168-1-2 183,211
RAU25-3-5 138
RAU73-16-1-40-1 127
RAU77-2 127
RAU79-111-49-6 127
RAU79-113-54-2 127,138
RAU83-8-4 127
RAU83-18-8 138
RAU4004-105 7,133
RAU4004-109 127,138
RAU4009-3 138
RAU4009-15 127,138
RAU4024-10 138
RAU4070-68-19 138
RAU4074-77-10 138
RAU4090-1 138
RAU PTI-30 127
Rayada 16-06 254
RD1 167,244,245
RD3 167

RD4 244-246,352
RD6 125,131,144,172,173,357
RD7 180
RD8 172,173
RD9 244-246,352
RD13 125,131,144,170,172
RD15 82,125,131,144,172,173,226
RD17 226
RD19 152,153,195,198,209,406
RD21 244,246
RD23 244,246
RD25 244,246
RD27 125,131,144,170,172
Remadja 136
RGL 1 140
RGL 172 140
RGL 1746 140
RGL 2624 140
RIA163 130
Rikku 135
RNR1466 140
RP4-14 128,144
RP5-32 257
RP6-32 257
RP79-18 132
RP125-625-939-1 257
RP348 257
RP825-71-4-11 137
RP975-109-2 81,82,84,87-91, 93,95,96,260
RP1017-76-1-3-2 257
RP1057-35-1-4 257
RP1057-184-5-3-2 257
RP1057-184-5-3-4 257
RP1057-184-5-3-6 257
RP1057-393-1 257
RP1057-394-1 257
RP1125-21-665 256
RP1125-46-3-2-1-1-2-[illegible] 256
RP1465-655-139 25[illegible]
RP1491-20 254
RP1570-11-5-1 256
RP1821-5-1-3 257
RP1821-5-5-2-2 257
RP1854-266-4-4-23 257
RP1883-873-6-1-2 257
RP2136-43-2 256
RP2151-173-1 256
RP2151-175-1 256
RP2151-192-2 256
RP2151-224-1 256
RP6510 293
RPW6-13 96,245,256,25[illegible]
RPW6-17 135,245
RPW6-516 140
R-R-8 127
RR123-2 259
RS5-32 257
RTN-24 140
Rupsail 210

S

S55C-13 308
S55C-31 308
Sabari 405
Sabarmati 135
Sadakalma 203,204
Sadamota 294,405
Sadang 124,130,144
Safri 17 129,135,144
Safri Desi 129,144
Sai duong 235,237-239
Saket 4 254,405
Sakoli 17 134
Salumpikit 153,154
Samalei 244
Samaridhi 244
Samridee 144
Samridhee 129
Samridhi 135,280
Sa quay 235
Sarjoo 52 405
Saruchinamali 133
Sasyashree (Sasyasree) 244,245
Sathi 129,144
Savithri (Savitri) 128,134,194, 195,198,255
Sayaphal 254
Shwechigyin (Schwechigin) 226,228
Seetasail 213
Segupak 130
Seintalay 130,226
Sekembang 124,130,144
Serayu 308
Seribu Gantang 136
Setanjung 124,144
Shakti 244,352,388
Shwebo Khunni 225
Shwedinga 226-228
Shwedingayin 228
Shwetasoke 124,144,225-227
Shwethwelay 226
Shwethwetun 226
Shwewartun 130,226-230
Shwewelay 226
Siam 29 134,135,244,248,250
Sigadis (Sig) 134,136,139,254,255,258
Sindewali 75 134
Sin Ekari 223,227
Sinna Sivappu 246
Sinshwethwe 226
Sintheingi 226
Sinthiri 226
Sita 127 144
Sitabhog 203,204
SKL 6-1-2-3 128
SL 016 135
Slam 164
SLM18 238
SLR51214 134
SML 40-10-4 139,195,213,214

SML Temerin 215
Sona 96,140,245,257
Soubhagya 255
SP83 406
SPR'76 Com. 3-38-3 125
SPR6118-34 137
SPR7292-151-2-1-B-B 209
SPRLR75067-62-1-1 125,136
SPRLR76130-75-1-1 125,136
SPT58-37-400 125,136
SPT6118-34 125
SPT7149-429-3 125
SPT7201-PRE-26-2 125,137
SR26B 55,128,133,144,198,201-204, 210,213,221,293,405,413
Subang Intan 124,144
Sugandha 132
Surekha 129,134,144,244,245,249,385, 387,388
Suresh 127,133,144,191,194,198,406, 408
Surjamukhi 221
Swarna 35,194,198,255
Swarnadhan 255,258
Swarnalata 137,244
Syin Ekari 130

T
T16 250
T26 164
T90 128,132-134,144
T100 164
T141 119,127,128,133,139,144,194, 195,213,214,258,259,280, 405
T141 mutant 134
T442-57 180
T1242 128,134,144
T1879 164
Tadukan 258
Taichung 65 96,132,269
Taichung Native 1 *See* TN1
Tam 4 235
Tam Ruot Lua 125,144
Tangkai Emas 136
Tangkai Rotan (Tankai or Tongkai Rotan) 131-133
Tau huong 125,144
Taungdeikpan 225
Tawng Rayah Dam 168
TC6 215
TCA4 209
TCA48 127,138,209
TCA62-31 211
TCA177 211,254
TCA183-1 260
TCA808 127,138,209
Tella Hamsa (Tellahamsa) 129,134, 140,144,385,387
Tetep 235,237-239,258
Tetnanbatngasein 226
TH2 235
Than Nong Do 125,144,235,239
Thavalu 15314 180,183
Thavalu 15325 183
Tilakkachari 55,127,144,196,197,209, 211-213,215
Tilockachari 33-754 183
Tilockkachari 219
TKM6 130,131,134,244,245,254,255
TN1 131,132,134,135,138,140,245, 256,257,352,384,388
TN73-2 254
TNAU4691 259
TNAU17005 257
Trai may cut 235
Tran chau lun 235
Trang chum 125,144,235,239
Trang lua 235
Trang lun 125,144,235
Trang tep 235,239
Triptee 129
Tripti 135
Triveni (Trivani) 137,255,387
TTB4-7 133
TTB14-1 139
TTB15-1 139
Tulsimanjari 132

U
U9 238
U14 238
U17 238
UBN6721-11-8-3 125,137
UBN6721-13-5-6 125,137
UPLRI 2 88,90,93,95
UPLRI 3 84,85,87,89,90,156,260
UPLRI 5 85,87,90,156
UPR231-28-1-2 256
Usha 129,135,244
Utrimesh 258

V
V13 235
Vashista 405
Vasista 135
Veluthachera 244-246
Vijaya 134,135,213,245
Vijaya Mahsuri 255,259
Vikram 129,135,144,244,245,388
VPAR7360 215
Vytilla 2 405

W
W1251 133
W1252 244,245
W1256 244,245
W1259 244,245
W1263 135,139,195,244,246
W12708 245
Waikoku (Waikukku) 195,213

Wase Aikoku 254
WGL 12708 135,140
WGL 22245 140
WGL 26888 140
White Lychai 112 128,144
WL 8 164
WL 112 134

X
X1 235
X70-18-38 130,226
X72-7-1 223,226,227,230
X72-7-8 226
X72-7-15 223,226,230
X72-7-107 229
X72-7-114 229
X72-7-115 229
X72-7-126 229
X72-7-137 229
X72-8-22 130,223,227,230
X72-8-39 229
X72-10-30 229
X72-10-44 229
X72-12-18 229
X72-12-20 229
X72-322 226
X73-20-19 226
Xuan 2 235

Y
Yebawlat 226
Yebawpinto 226
Yebawsein 124,130,144,223,226,227
Yebawyoesein (Yebawyoesin) 226
YN18-2 229
YN25-7 229
YN50-7 228
YN50-8 228
YN50-11 228
YN63-2 228
YN63-3 228
YN83-8 228
YN106-2 228
YN107-11 228
YN116-3 228
YN116-16 229
YN116-17 229
YN116-18 228
YN169-2 228
YN169-3 228
YN174-6 228
YN1808 229
YR13-89-11 256
YR228-33 226
YR237-13 226
YR303-D126-6-80 226
YR303-304 226
YR2097-4-8 226
YR71014-1 226
YR72078-19 226
YR72136-1 226
YR72161-6 226
YR72164-25-6 226

Z
Z31 134
Z13400 134
Zeera 225
Zenith 254,258
Zinia 63 134
Zinia 149 134