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RAINFED LOWLAND RICE:

SELECTED PAPERS FROM THE 1978 INTERNATIONAL RICE RESEARCH CONFERENCE

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Foreword

Only about one-fourth of the world's rice lands are irrigated. The remainder depend entirely on rainfall for water. Unfortunately, these rainfed areas have been bypassed by modern rice production technology and have received little research attention. As a consequence, the available technology is inadequate or inappropriate for the vast rainfed areas, such as those in South and Southeast Asia, which depend on unpredictable monsoon rains and suffer from either insufficient or excess water during the crop growing season.

There are three general rainfed systems: upland (unbunded), rainfed lowland (generally bunded and with water depth less than a meter), and deepwater. The two extreme rainfed situations of upland and deepwater have been the subjects of international discussion and cooperation in recent years as reflected by recent IRRI publications on the topics. The 1978 International Rice Research Conference focused on the intermediate category, namely, rainfed lowland rice, and organized the Institute's first international discussion on this important subject. It is estimated that such rainfed lowland rice occupies about one-third of the world's rice area.

Scientists from 28 countries participated in the discussions on various aspects of rainfed lowland rice -- varietal improvement, crop management, cropping patterns, and socioeconomic aspects. This publication presents selected papers from the conference and reflects the dedication, enthusiasm, and growing interest of national programs in research to improve rainfed lowland rice production technology.

The keynote address of Dr. Ch. Krishnamoorthy, project director, All-India Coordinated Dryland Improvement Project, served well to elucidate the problems and potentials associated with the rainfed system. Drs. R. Barker and R. W. Herdt present a concise summary of why the rainfed rice areas failed to get early attention, and follow that summary with an extremely valuable identification of rainfed areas and an analysis of their potentials for world rice production. For the first time we have pulled together country-by-country reports on the problems and potentials for rainfed lowland rice production and carefully examined the means available to focus attention on the research needs.

The other papers are addressed to the major constraints on rice production in rainfed areas. The current knowledge base as well as suggestions for future research is presented by authors with experience in rainfed areas.

The research strategies committee report at the end of this document presents effectively the multidisciplinary teamwork, international cooperation, and collaboration needed if science is to help improve the lot of the rainfed lowland rice farmer. One immediate result was the creation in 1978 of the first International Rainfed Lowland Rice Observational Nursery (IRLRON).

The work of those who prepared country reports and background papers for the conference is gratefully acknowledged. Dr. D. V. Seshu served as chairman of the organizing committee and coordinated the technical editing of these proceedings, and Walter G. Rockwood, assisted by Gloria Argosino and Emerita Cervantes, edited the proceedings.

This publication should serve as a useful reference volume for scientists and administrators; we hope that it will stimulate further research on this important rice production system.

N. C. Brady
Director General

General

Rainfed lowland rice as a research priority — an economist's view

R. BARKER and R. W. HERDT

Modern rice technology has largely bypassed the rainfed areas of Asia as illustrated by the yield trends in Figure 1. Yields have risen significantly over the past decade in northern India and neighboring Pakistan, and in southern India and neighboring Sri Lanka. In those regions from 50 to more than 80% of the rice area is irrigated. In the largely rainfed rice-growing regions of eastern India and Bangladesh there has been no upward trend. Sharp year-to-year variation in both areas was caused by weather. Several reasons account for the little progress in raising yields of rainfed rice, but an important factor is that it has received little research. Why, some 17 years after IRRI's founding, is attention only now being focused on rainfed rice?

- First, it was not at all clear 17 years ago whether it would be possible to develop a superior rice production technology even for the irrigated areas. Once the new varieties were released, there was a major effort to improve their quality and build in resistance to diseases and insects.

- For a period of time many scientists argued that the modern varieties were superior to other varieties in almost all environments. Among our own scientists, the data to support such arguments came largely from experiments at IRRI and in nearby farmers' fields. Those were, unfortunately, favorable environments for rainfed rice production but not representative of most rainfed areas.

- Some observers argued that the new technology would be suitable largely in the irrigated areas (Hsieh and Ruttan 1965), and by the late 1960s it became obvious that the modern varieties were spreading only in areas with good water control.

The Conference on Rice Research and Training in the 1970s, held at IRRI in October 1969, marked a turning point (IRRI 1969) For the first time attention was focused on the rainfed rice area. During the next several years, scientists accumulated knowledge about the performance of the rice plant in unfavorable soil-water conditions. Work was initiated to develop varieties with flood and drought *tolerance*. This work was hampered by inadequate definition and description of the rice-growing

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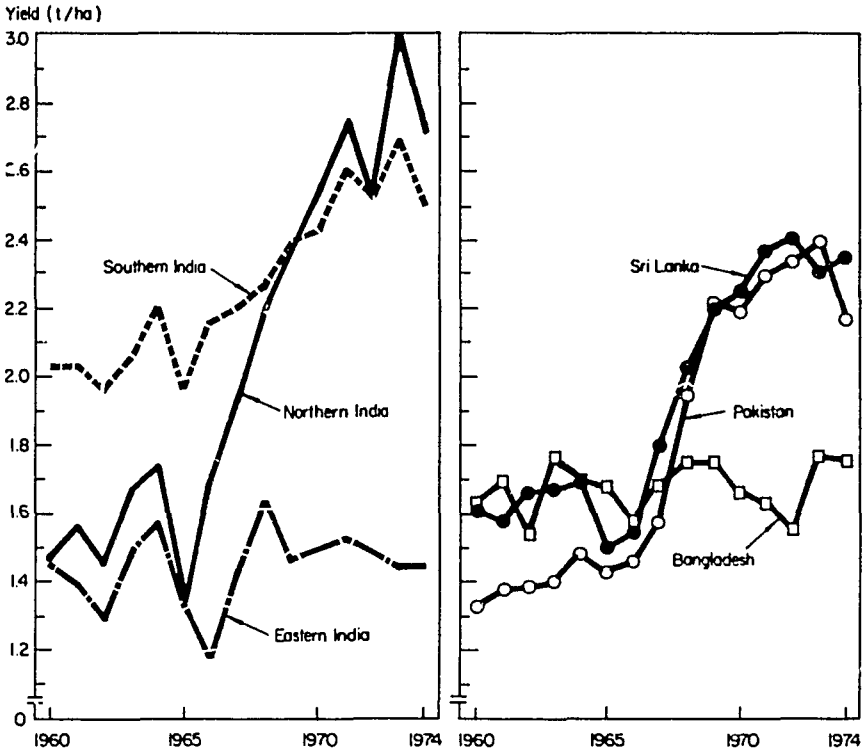


1. Rice yield trends in Bangladesh, Pakistan, Sri Lanka, and three regions of India, 1960–75.

environment. Even phrases such as *rainfed lowland rice* have different meanings to different people.

The purpose of this paper is to:

- define and describe the rainfed lowland rice environment,
- analyze the benefits and potential benefits from research, and
- discuss the barriers to effective research.

DESCRIPTION OF THE RAINFED RICE AREAS

The rainfed lowland rice setting includes all rice-growing areas except those that are irrigated, those where water exceeds 1 m in depth, and upland area fields where water normally is not impounded. We refer to this setting as the rainfed area.

Using the best data we could assemble, we estimate that about one-third of the world's rice land is rainfed (Tables 1 and 2). Most of the rainfed rice is grown in South and Southeast Asia. The rainfed rice area exceeds a million hectares in 8

Table 1. World's rice area (million ha) by type of culture, 1973-75.

Region	Rice area (million ha)							
	Total	Irrigated	Shallow rainfed	Medium deep rainfed	Deep-water	Upland	Arid high temp	Long days, low temp
India	38.4	12.6	12.6	6.1	2.4	2.4	2.0	0.3
Other S & SE Asia	45.1	10.5	15.1	6.8	4.6	5.9	1.6	0.6
China	34.1	30.7	2.7	0	0	0.7	n.a.	n.a.
Other developing countries[a]	10.3	1.2	0.4	1	0	4.8	0.5	2.4
USA, Japan, USSR	4.2	4.1	0	0	0	0.1	n.a.	n.a.
Others	5.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Total world	137.3							

[a] Rep. of Korea, North Korea, Iran, Afghanistan, all Africa, all Latin America.
n.a. = data not available.

Table 2. Proportion (%) of rice area of various regions by type of culture.

Region	Rice area (%)							
	Total[a]	Irrigated	Shallow rainfed	Medium deep rainfed	Deep-water	Upland	Arid, high temp	Long days, low temp
India	28	33	33	16	6	6	5	1
Other S & SE Asia	33	23	34	15	10	13	4	1
China	25	90	8	0	0	2	n.a.	n.a.
Other developing countries	8	13	4	10	0	46	4	23
USA, Japan, USSR	3	98	0	0	0	2	n.a.	n.a.
Total classified[b]	96	42	24	10	5	10	3	3

[a] Refers to percent of world's total, percent in other columns refer to percent of region in specified culture. [b] Refers to 96% of total world area classified in first table.

n.a. = not available.

countries (Table 3) and accounts for 65% or more of the total rice area in Burma, Vietnam, and Thailand. Information on rice area by country is in Appendix Table 1.

A detailed classification of the environmental factors influencing rice production is in Appendix Table 2. We use climate, soil, water, and topography to describe various facets of the rainfed rice-growing environment, with emphasis on water and topography. Definitions of the water environment are in Appendix B. The rainfed rice area is divided into shallow rainfed (5-15 cm water depth) and medium-deep rainfed (16-100 cm). The medium-deep area is further subdivided into intermediate-deep rainfed (15-50 cm) and semideep rainfed (51-100 cm). These water depths relate to rice plant type. Roughly speaking, modern semidwarf varieties can withstand water as deep as 15 cm, although they may not perform well in stagnant water. A few modern varieties of medium height (e.g. Pankaj and Mahsuri) may

Table 3. Countries with 1 million ha or more of rainfed rice by rank, 1973-75.[a]

Country	Area in rainfed rice (million ha)	(%)
India	18.1	49
Eastern [a]	9.9	51
Others	8.2	46
Bangladesh	4.6	48
Burma	4.3	84
Vietnam	3.7	71
Thailand	3.6	65
Indonesia	3.4	39
China	2.7	8
Philippines	1.6	46
Other S & SE Asia	1.0	29

[a] Eastern Uttar Pradesh, Bihar, W. Bengal, Assam, and Orissa.
Source: Appendix Tables 1 and 3.

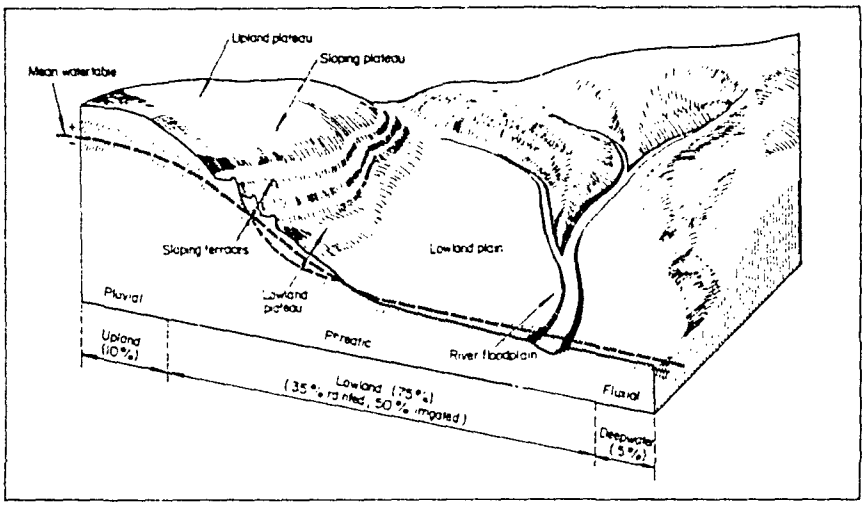
withstand water as deep as 50 cm. Traditional tall varieties survive 1 m of water and floating rices are grown where water depth exceeds 1 meter.

It is presumptuous to assume that we can accurately determine the amount of rice grown in each water depth. Nevertheless, rough indications are useful and the definition by water depth helps avoid any confusion in terms. It appears that about two-thirds of the rainfed rice in Asia is shallow rainfed (Table 1). Modern varieties can grow in those areas, but only a small portion currently grows modern varieties.

A visualization of the topographic sequence of rice production is in Figure 2. This figure helps to relate physiographical and hydrological features. The definitions are further elaborated in the classification system by the Cropping Systems Program (IRRI 1976). The topographic sequence shows large distances covering entire river valley systems as well as microrelief within the area of, say, one village.

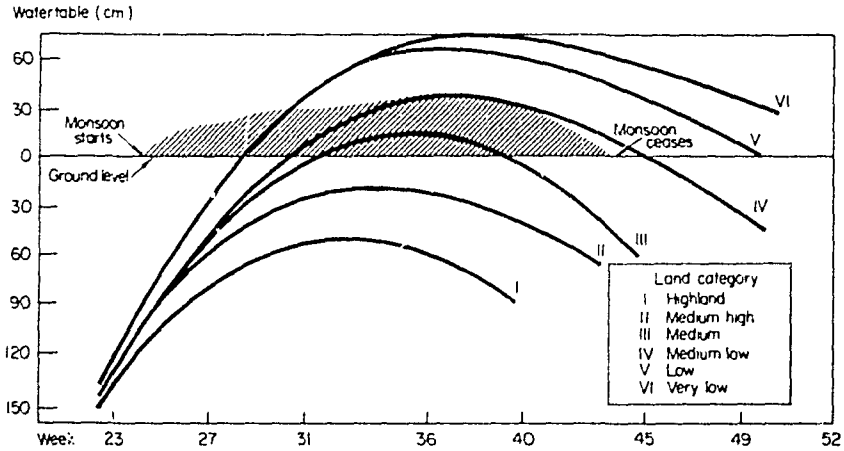
With a macroclassification one can make some rough estimates of rice land allocation. The lowland plains and river floodplains probably account for half to two-thirds of the total rainfed rice area. In those areas, flooding and stagnant water are the most serious problems. On the other hand, drought is the major problem on the terraced slopes. The plateaus may experience either drought or waterlogging.

D. Lenka (Orissa College of Agriculture, personal communication, 1977) shows how a categorization similar to the above is



2. An overview of the world's physiographically and hydrologicall, diverse rice cultural systems. The diverse systems are classified by the predominant hydrological feature of the crop environment: pluvial, phreatic, and fluxial (terminology from Moormann and van Breemen 1978). Source O'Toole and Chang (1978). Percent area in upland, lowland and deepwater rice adjusted to conform with Table 1.

used to define rice culture in Orissa State, eastern India (Fig. 3, Table 4). After the monsoon starts, the land in categories he calls medium and medium high flood to different depths, and the duration of flooding determine the suitability of varieties in terms of growth duration. On upland terraces



3. Variation of water table in rice field of Orissa (Lenka 1977).

Table 4. Land category and rice culture in Orissa (Lenha 1977).

Land category (topographic)	Rice area (%)	Duration (days)	Sowing	Panicle initiation	Flowering	Ripening
Highland	15	85-105	10 June to 25 June	15 July to 25 July	10 August to 25 August	10 September to 30 September
Medium high	20	105-120	10 June to 25 June	25 July to 10 August	25 August to 10 September	22 September to 10 October
Medium	27	120-135	8 June to 20 June	10 August to 25 August	10 September to 25 September	10 October to 25 October
Low medium	23	135-150	6 June to 14 June	10 September to 25 September	20 October to 5 November	10 November to 20 November
Low (Gahir-Pat)	12	150-165	4 June to 14 June	20 September to 5 October	20 October to 5 November	20 November to 5 December
Very low (Pat)	3	> 165	4 June to 12 June	30 September to 15 October	30 October to 15 November	30 November to 20 December

and plateaus the land never floods and short-duration varieties are planted to escape drought.

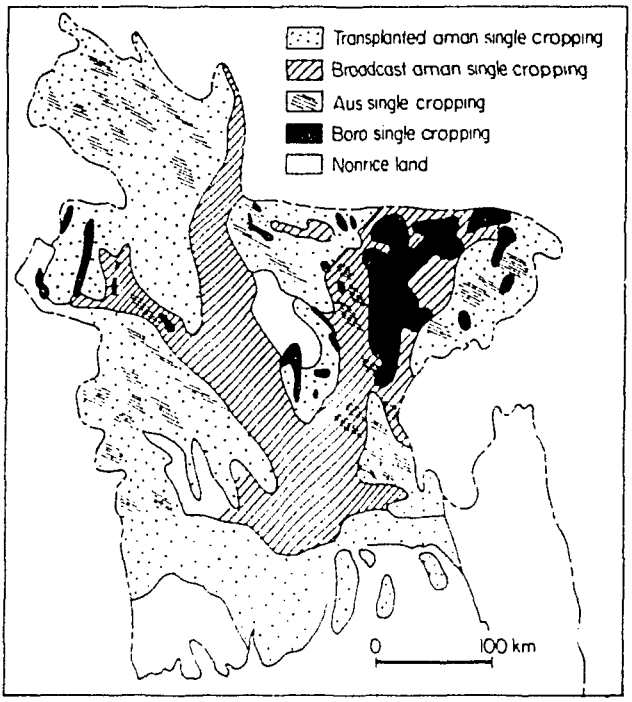
It is useful to distinguish between the rainfed rice grown in the lowland plains and that grown on the terraces and plateaus. The farming practices and research requirements for the two broad areas appear to be extremely different. Much of the rice land in the medium-deep category is found in the major river deltas.

The river deltas

Four major river deltas in South and Southeast Asia are planted largely to rainfed rice -- the Mekong in Vietnam, the Chao Phraya in Thailand, the Irrawaddy in Burma, and the Ganges-Brahmaputra in Bangladesh and eastern India. Probably more than one-third of the 35 million ha of rainfed rice in the region is found on those deltas.

With a few exceptions (such as Java), Southeast Asia historically has been less densely populated than India, China, and East Asia. It is puzzling that in the mid-19th century, the three fertile river deltas of Southeast Asia were less densely populated than the other areas of population concentration in Southeast Asia (Siamwalla 1972). One implication relates to farm size. Most farms in Bangladesh and eastern India are less than 1 ha, but those on the Southeast Asian deltas typically range from 3 to 6 ha.

The presence of the sparsely settled deltas in Southeast Asia set the stage for the first *green revolution* in rice nearly a century ago. The opening of export markets provided price incentives. No modern inputs were needed. Traditional

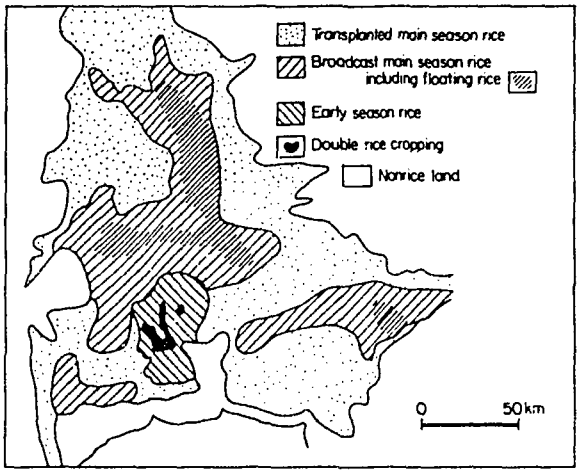


4. Rice cropping patterns in the Ganges Brahmaputra delta, Bangladesh (Takaya 1975)

cultural practices were followed. The main limitations to output were a shortage of labor and capital.

It is somewhat ironic that these delta areas, which became a major source of Asia's exportable surplus in the 19th century, are not well suited to the use of the modern technology of the 1970s. The potential of the new varieties is realized in areas of good water control and high solar energy, precisely what the delta environment lacks. Modern varieties are planted in a negligible portion of the rainfed areas in the deltas. The exception is the Mekong, where high yielding varieties grew in 27% of the delta in 1973 (Xuan 1975).

An excellent set of maps describing the physiography and cropping pattern of delta areas has been prepared by Takaya (1975) for the Mekong, Chao Phraya, and Brahmaputra deltas (Fig. 4-6). Figure 7 shows the rainfed rice-growing areas in lower Burma (Richter 1977). Rice is broadcast seeded on dry growth in areas of uncontrolled water that lie at the center of the floodplains of these systems -- about one-third of the total delta area. The areas fall into the category of semideep and deepwater, and traditional tall and floating rice varieties are grown. Because of poor stand establishment and poor weed control,



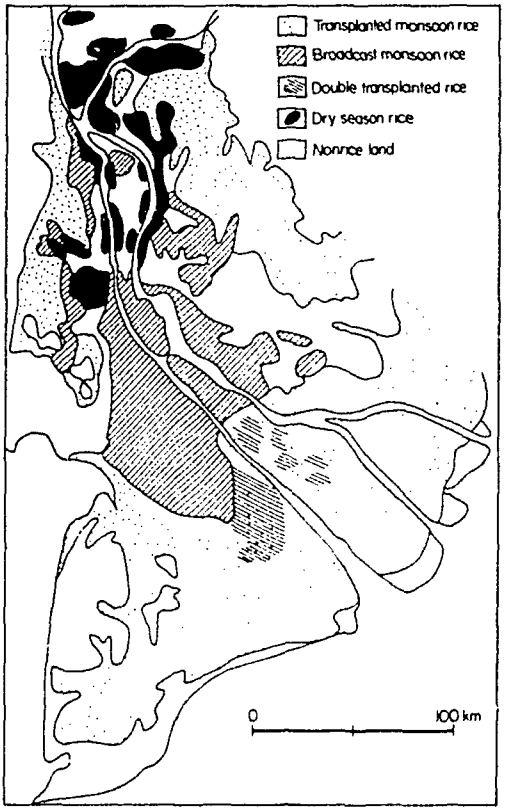
5. Rice cropping patterns in the Chao Phraya delta, Thailand (Takaya 1975).

yields frequently are lower than those for transplanted rice. Much of the transplanted area is subject to flooding, but the margins of the delta contain a fan-terrace complex of foothills where water deficiency can be a critical crop growth factor.

Most of the rice grown in the rainfed delta areas is photoperiod sensitive, i.e. flowering is triggered and hence harvest date determined by day length. If we define the period having monthly rainfall of more than 200 mm as the monsoonal season, the earlier onset of the monsoon in Bangladesh and eastern India permits a photoperiod-insensitive *aus* crop to be grown. There are more than 2 million ha of *aus* in Bangladesh. In some of the deeper flooded areas of the Ganges-Brahmaputra, Irrawaddy, and Mekong deltas, a single crop of photoperiod-insensitive rice is planted as the floodwaters recede (Takaya 1975).

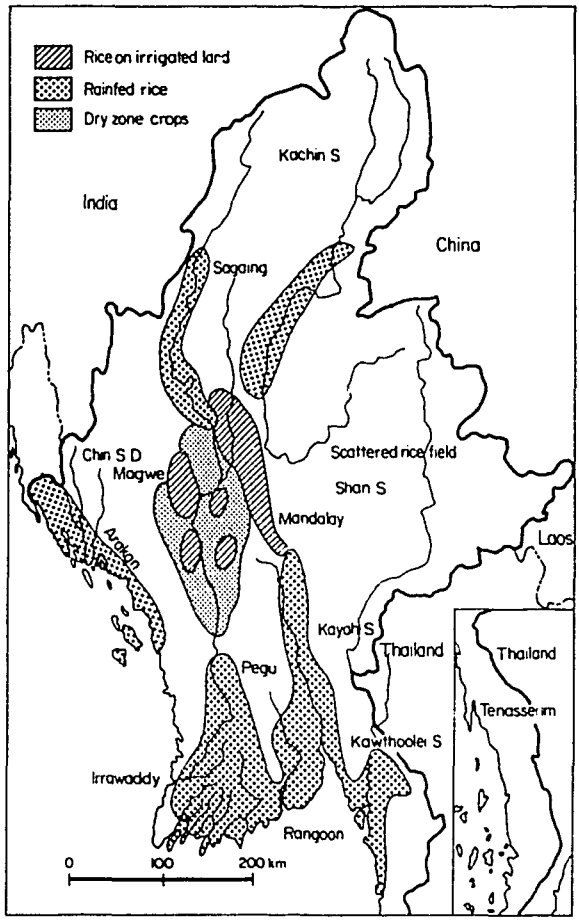
Major soil problems exist in the delta areas. About 700,000 ha of acid sulfate soils in South and Southeast Asia are found in the deltas. Some of these soils can be utilized for rice production if tolerant varieties can be developed (IRRI 1977). Salinity is also a problem on more than 4 million ha in the Ganges-Brahmaputra and Irrawaddy deltas (Ponnamperuma 1977).

Cropping patterns in the deltas are also closely related to soils. The heavy clay soils severely limit the potential for



6. Rice cropping patterns in the Mekong delta of Vietnam, based on the Netherlands delta development team report, 1974 (Takaya 1975).

growing a second crop in combination with rice. However, second cropping is common in the sandier soils and shallow water table area of the Ganges-Brahmaputra delta, and is practical on from one-third to one-half of the area. The detailed description of the Chao Phraya River Basin by Fukui (1973) illustrates the relationship between physiography, water conditions, soil fertility, planting practice, farm size, and paddy production (Table 5). Generally speaking, farm size was larger in the broadcast seeded than in the transplanted area, but yields are higher in the latter. The notable exception was the water-deficient foothills where production was highly variable. In all other regions, the paddy production per farm family was uniformly



7. *Irrigated and rainfed rice-growing areas of Burma (Richter 1977).*

high, with a sizable marketable surplus. (A typical family requires about 1.5 to 2 t of paddy rice per year for home consumption).

Rainfed terraces and plateaus

Much rainfed rice is grown on gentle to steeply sloping terraces in areas that are difficult to irrigate. The position of the paddy on the terrace affects the soil and water conditions and,

therefore, the cultural practices and cropping patterns. Farmers are highly conscious of these differences. Many areas have local systems for classification of paddy position that depict, in microcosm, the system described in Figure 2. For example, in the terraced areas of the Chotanagpur hilly region of eastern India (covering parts of Bihar, Orissa, and West Bengal) the rainfed terraces are in four categories: upland (coarse-textured, light, badly eroded soils), medium upland, medium lowland, and lowland (with intermittent flooding and drainage). Gora paddy is grown on the uplands and can be harvested in about 85 days, but yields are typically less than 1 t/ha. It generally is argued that crops other than rice would perform better in these areas. Soils are more fertile and yields higher in the medium lowlands and lowlands and sparse plantings of high yielding varieties are found in the more fertile areas.

There is a general tendency for yields to be lower in the higher elevation bunded terraces. A series of experiments in farmers' fields at two rainfed sites in Central Luzon, Philippines, showed a yield decline of more than 700 kg/ha for every 1 m increase in elevation (IRRI 1973).

Rainfed farms with poor soil and water resources are sometimes larger than farms with better land quality or in irrigated areas (Table 5). However, this is not always the case. Many hill areas were settled by farmers migrating from the lowlands and in areas of intense population pressure, as in eastern India, farms on less fertile upland terraces may be smaller than farms in the neighboring lowlands.

The single largest plateau area extensively planted to rice is the Korat Plateau in northeastern Thailand. More than 3 million ha in this plateau grow rice -- about 40% of Thailand's total rice area. Only about 100,000 ha are irrigated. The Korat Plateau soils are infertile and average rice yield is about 1.5 t/ha, compared with more than 2 t/ha for the rest of Thailand.

Rainfed vs. irrigated rice farms

Socioeconomic studies of farming in the rainfed rice-growing areas are relatively few. The major research interest over the past decade centered on the modern varieties and on the irrigated areas where the major changes in rice production were taking place. The introduction of the new rice technology widened the yield gap between the rainfed and irrigated areas. With the exception of the Philippines, where 70% of the rainfed area is

Table 5. Regional division of rice land in the lower Chao Phraya River Basin, Thailand (from Fukui 1973).

Rice cultural regions	Physiography	Water conditions	Soil fertility	Planting system	Paddy yield (t/ha)	Rice area (ha) cultivated per farm family	Paddy production (t) per farm family	Approximate rice area (thousand ha)
Water-deficient foothills	Fan-terrace complex area	Effective	Low	Transplanted	1.0 - 2.5	3 - 4	2 - 7	600
		Ineffective						
Barrage irrigation area	Old delta	Controlled	Medium	Transplanted	1.8 - 2.2	3 - 4	5 - 7	80
		Uncontrolled	High	Broadcast	1.8 - 2.2	3 - 5	6 - 8	310
Canalled lowland	Delta flat	Uncontrolled	Low	Broadcast	1.0 - 1.5	5 - 7	6 - 10	750
Less flooded delta	Deltaic high	Controlled	High	Transplanted	1.8 - 2.5	3 - 4	7 - 12	280

planted to modern varieties, the rainfed areas are planted almost exclusively to traditional varieties.

Input use and returns above variable cost are compared for a sample of rainfed and irrigated farms in three Philippine studies: Nueva Ecija (Table 6), Camarines Sur (Table 7), and Iloilo (Table 8). Similar data are shown for Suphan Buri, Thailand, which is on the western edge of the Chao Phrava delta (Table 9). In each case, the rainfed and irrigated areas represented neighboring farms or villages. In all cases, yields, input levels, and returns per hectare on the rainfed farms were substantially lower.

Table 6. Comparison of farm size, input use, yields, and returns on three samples of rainfed and irrigated rice farms in Nueva Ecija, Philippines, 1975-77 wet seasons.[a]

Water control	Farms (no.)	Farm size (ha)	Hired weeding labor (days)	Chemical fertilizer (kg nutrients/ha)	Other chemicals (US$/ha)	Yield (t/ha)	Return above variable cost (US$/ha)
Rainfed	62	2.3	3	47	9	1.9	216
Irrigated	128	2.6	5	76	20	2.6	288

[a] Samples of 70 farms in 1975, 50 in 1976, and 70 in 1977.

Table 7. Comparison of farm size, input use, yields, and returns on three samples of rainfed and irrigated rice farms in Camarines Sur, Philippines, 1975-77 wet seasons.[a]

Water control	Farms (no.)	Farm size (ha)	Hired weeding labor (days)	Chemical fertilizer (kg nutrients/ha)	Other chemicals (US$/ha)	Yield (t/ha)	Return above variable cost (US$/ha)
Rainfed	41	1.7	8	32	10	2.2	262
Irrigated	116	1.9	14	73	18	3.2	366

[a] Samples of 40 farms in 1975, 51 in 1976, and 66 in 1977.

Table 8. Comparison of yields, cost and returns for 2 crops of rice under rainfed and irrigated conditions, 98 plots, Barrio Oton and Tigbauan, Iloilo, Philippines, 1976-77 (Roxas et al 1977).

Water control	Plots (no.)	Yield (t/ha)		Labor (days/ha)	Material cost (US$/ha)	Return above variable cost (US$/ha)
		1st crop	2d crop			
Rainfed	25	2.3	1.7	140	85	250
Irrigated	48	3.2	3.3	113	130	570

Table 9. Comparison of yields, input use, and returns on 91 rainfed and irrigated farms in Sakrachon village (rainfed), Rairot village (irrigated), Don Chedi, Suphan Buri, Thailand, 1971 wet season (Sriswasdilek 1973).

Water control	Farms (no.)	Farm size (ha)	Modern varieties (%)	Yield (t/ha)	Labor (days/ha)	Chemical fertilizer (kg/ha)	Return above variable cost (US$/ha)
Rainfed	44	5.4	4	1.1	44	0	36
Irrigated	47	5.3	41	2.7	100	54	80

Table 10. Fertilizer, drought, flood, and yield comparisons for sample rainfed and irrigated rice farms, Philippines, 1975-77 wet seasons.

	Camarines Sur					Nueva Ecija				
	Farms (no.)	Fertilizer[a] (kg/ha)	Drought[b]	Flood[b]	Yield (t/ha)	Farms (no.)	Fertilizer (kg/ha)	Drought[b]	Flood[b]	Yield (t/ha)
					1975					
Rainfed	12	11	25.3	1.5	1.8	18	53	27.9	2.9	1.6
Irrigated	28	42	17.4	0.1	2.6	52	61	29.6	1.4	2.5
					1976					
Rainfed	2	27	2.5	0.5	1.4	19	27	2.5	3.5	1.2
Irrigated	49	66	0.7	0.2	3.2	31	73	1.1	0.4	1.4
					1977					
Rainfed	27	41	13.4	0.4	2.4	25	59	6.9	2.1	2.4
Irrigated	39	105	0.5	0.3	3.6	45	95	1.4	1.4	3.2

[a] $N + P_2O_5 + K_2O$.

[b] In 1975 and 1977 the figures are the number of days of flood or drought in the season. In 1976, they are the reported frequency of flood or drought in the previous 5 wet seasons.

Are rainfed farmers relatively more *conservative* or *averse to risk* than irrigated farmers? The hypothesis was tested using data from research at Camarines Sur and Nueva Ecija for the 1975-77 wet seasons. Table 10 summarizes the fertilizer, water control, and yield data. It is obvious that the better water control and higher inputs on irrigated farms rasulted in higher yields. However, it is not clear whether this was due to a more favorable yield response on the irrigated farms or to the greater aversion to risk of the rainfed farmers. This may be judged by determining the profit maximizing level of fertilizer for both groups of farmers and comparing the profit maximizing level with the actual level that farmers use. The group that is more averse to risk would be expected to use less fertilizer relative to the maximum profit level.

Table 11 shows, for the two groups, the actual and optimal levels of fertilizer calculated from a fertilizer production function derived from previous research in farmers' fields.

Table 11. Optimal nitrogen,[a] actual nitrogen and ratio of marginal value of product (MVP) to effective fertilizer price for irrigated and rainfed rice farms, with average and high number of drought days (SD), Philippines, 1975-77.

Sample	Actual N (kg/ha)	Optimal nitrogen		Marginal value of product of actual N[c]		Marginal value of product: effective fert. price[d]	
		Av SD[b]	High SD[b]	Av SD	High SD	Av SD	High SD
Camarines Sur rainfed	24	73	50	8.32	5.95	2.0	1.4
Camarines Sur irrigated	49	89	76	7.41	6.06	1.8	1.5
Nueva Ecija rainfed	33	80	54	7.75	5.16	2.1	1.4
Nueva Ecija irrigated	48	86	67	6.87	4.95	1.9	1.4

[a]Calculated from the function Y = 1853 + 16.38 N - 0.06 N^2 - 50.42 SD - 0.39 N x SD, where N is nitrogen and SD is stress days. Palay price = 1.04 in Camarines Sur and 1.00 in Nueva Ecija.

[b]See footnote[d] for fertilizer price.

[b]Av SD equals 10 stress days for rainfed, 5 for irrigated farms in Camarines Sur and equals 8 and 6 stress days for rainfed and irrigated farms in Nueva Ecija. High SD equals 17 and 9 for rainfed and irrigated farms in Camarines Sur, and equals 16 and 12 for rainfed and irrigated farms in Nueva Ecija.

[c]Calculated MVP was reduced by 1%, which is the share given to harvesters.

[d]Effective fertilizer price in Nueva Ecija equals P 3.67/kg. In Camarines Sur 31% of the farmers are share-tenants, 3% of whom pay all fertilizer costs and share output with the landlord in 25-75 ratio; i.e. 23% of the sample have inequitable tenure. Effective fertilizer price for them is therefore P 3.87 (actual) ÷ (1.04 x .75) = P 4.96. The 77% have effective price equal to actual price of P 3.87. Weighted average is P 4.12.

The production function excludes flood effects, but includes drought effects. The latter interacts with nitrogen fertilizer, so optimal levels for different moisture conditions are different for the four cases considered. *Average* and *high* levels of plant moisture stress are derived from the survey data. Because 23% of the farmers in Camarines Sur were share-tenants who paid all the cost of fertilizer, the effective fertilizer price was adjusted to reflect the 25-75 landlord-tenant sharing arrangement.

The last two columns of the table show that farmers use fertilizer to achieve a return 1.5 to 2.0 times as great as cost. Rainfed rice farmers are slightly more conservative in fertilizer use but it is impossible to claim there is any large difference in the degree of risk-aversion between the two groups. Both groups apply fertilizer so that, even in a year of relatively high moisture stress, they will have a marginal return to fertilizer 1.5 times its cost.

THE POTENTIAL IMPACT OF SHORT SEASON VARIETIES

In much of the world's rice-growing area, yields tend to decline as the harvest extends into November and December. The patterns for this are not uniform from year to year or site to site, but it is clear that in many areas there may be advantages from advancing planting and thus date of harvest. This is particularly

true in rainfed areas where an advanced harvest may allow the crop to escape drought. Consider, for example, the upland rainfed areas in much of eastern India. The monsoon tapers off rapidly in late September or early October and the sandy red soils (Ultisols) dry quickly and the rice plants suffer from drought within a few days. At the same time, because of delayed planting of the rainfed crop, much of it is in flower. A similar situation exists in some areas of the Philippines where data now are becoming available to document the impact of early maturing varieties. The Rainfed Upland Rice Project (RURP) was initiated in Central Luzon in 1971 in Bulacan and Nueva Ecija. To evaluate the impact of the project on rice production, 12 rainfed villages were surveyed in 1971, 1974, and 1977. More than 200 farmers were interviewed each year to obtain information on cultural practices, input use, and yields.

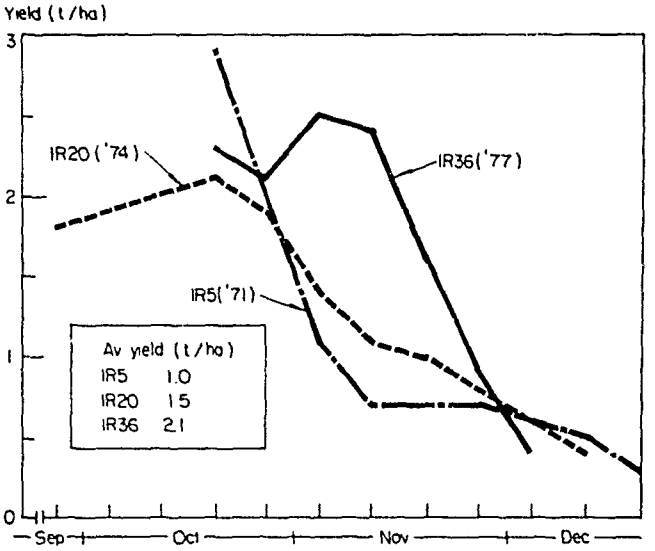
Two-thirds of the RURP area was planted to modern varieties at the start of the project. In 1971, IR5 was the most widely planted variety. After a severe outbreak of tungro virus, IR5 nearly disappeared and by 1974, IR20 was the most widely planted variety. After 1974 other early maturing varieties became important and by 1977, IR36 was the most popular variety.

For the sample of farms yields were somewhat higher in 1974 than in 1971, and were sharply higher in 1977 (Table 12). To identify the reason for the increase, we examined the data for 72 farmers planting only IR5 in 1971, for 32 farmers planting only IR20 in 1974, and for 28 farmers planting only IR36 in 1977.

Trend in yield by date of harvest is shown in Figure 8 for each of the varieties. The yields of IR5 dropped sharply because the late planted crop was severely affected by tungro virus (IRRI 1973). IR20 yields were reduced by typhoons in 1974. It appeared initially that 1977 also would be a bad year because rains started late and farmers were delayed in planting by about 2 weeks (Fig. 9). Despite this, IR36 plantings were harvested at least a week earlier than those of IR5 and IR20.

Table 12. Average rainfed rice yield and nitrogen use in 12 rainfed villages in Bulacan and Nueva Ecija, Philippines, 1971, 1974, and 1977.

Year	Yield (t/ha)	Nitrogen used (kg/ha)
1971	1.4	35
1974	1.5	39
1977	2.2	43

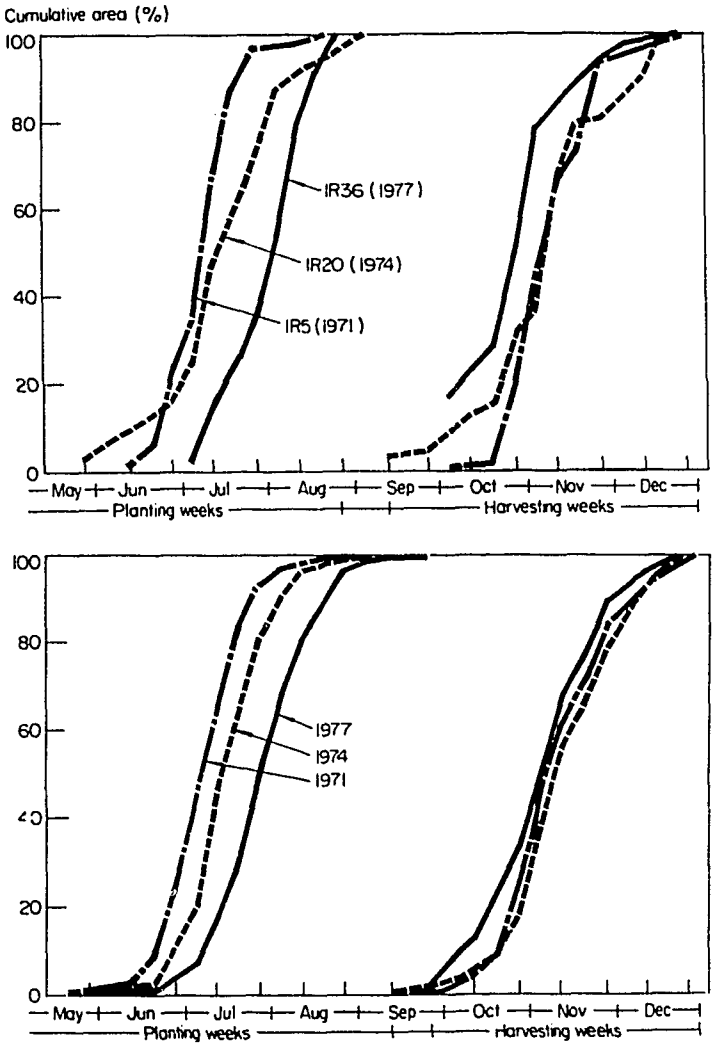


8. *Three-week moving average of yield of three varieties in 3 years in Bulacan and Nueva Ecija, Philippines.*

By the first week of November, about 80% of the harvest on the IR36 farms was complete. Yields tapered off for the farms harvested after the first week of November. However, the yield decline was delayed by several weeks compared with that for IR5 and IR20 (Fig. 8).

In 1977, early maturing modern varieties, including IR36, yielded 2.2 t/ha, medium maturing modern varieties 2.2 t/ha, and medium-late maturing varieties 3.2 t/ha. All three varietal types performed well. The principal medium-late variety C4-63 was grown primarily in the 2 southernmost of the 12 barrios surveyed where soil and moisture were more favorable. Under ideal conditions the medium-late maturing varieties, such as C4-63 or IR5, gave higher yields than IR36. It is recognized that a decrease in yield may occur as the maturity date is shortened, but there is no precise information on the probable magnitude of decline.

Information on the relationship between age of seedlings, length of maturity, and yield are also inadequate. For modern varieties, the *recommended* practice has been to transplant seedlings at 21 days of age. It was argued that yields decline as seedling age extends beyond 30 days. Farmers in the survey area typically transplant 35- to 40-day-old seedlings, which may help explain the short growth duration of 80-85 days for IR36 (Fig. 9).



9. a) Cumulative frequency of area planted and harvested weekly in 3 years for three varieties, Bulacan and Nueva Ecija, Philippines.
b) Cumulative frequency of area planted and harvested weekly in 3 years in Bulacan and Nueva Ecija, Philippines.

There is evidence that the sharp increase in yields in the survey areas between 1974 and 1977 was due to both favorable weather and early maturing varieties. The use of early maturing varieties was particularly beneficial in 1977 because of the delay in transplanting due to lack of rain. But even for this small area, early maturing varieties are not the complete

Table 13. Use of early maturing rice varieties and double-cropping in Oton and Tigbauan, Iloilo, Philippines, crop years 1974-75 to 1977-78.

Crop year	Cultivated area (%) on which the first rice crop was an early maturing variety	Cultivated area (%) double-cropped in rice
1974-75	2	5
1975-76	19	20
1976-77	40	37
1977-78	55	47

answer. In the future, farmers may discover that the proper choice of variety will depend on when the monsoon starts. For example, if the rains are early, later maturing varieties planted before 1 July may give a higher yield than early maturing varieties such as IR36. Farmers will have to weigh the potential for added yield against the added risk of delaying the harvest date, or the potential for growing a second crop following rice.

The experience in Central Luzon was repeated elsewhere in the Philippines. In Iloilo, for example, the introduction of early maturing varieties resulted in an expansion in the area double-cropped (Tinsley et al 1977). From 2% in 1974, 55% of the area was planted to early maturing varieties by 1977 and the double-cropped area rose from 5 to 47% of the total (Table 13). In Iloilo early maturing varieties are normally sown on land prepared before the first of July. The wet-seeded method (broadcast seeding on puddled soils) is used, which facilitates the growing of two crops. There seems to be little difference in yield between wet-seeded and transplanted rice. On land prepared after the first of July, late maturing varieties are planted and only a single crop is harvested.

We emphasize here that the early maturing photoperiod-insensitive varieties are appropriate only for specific rainfed situations. An important body of research is devoted to the improvement of photoperiod-sensitive varieties that are generally, but not always, late maturing. These varieties are designed for areas of deeper water so that ripening and harvest can be timed to occur as the floods recede.

POTENTIAL BENEFITS FROM RESEARCH

In this section, we examine the benefits to be derived from research on irrigated, rainfed, upland, and deepwater rice. Our objective is to assess the potential contribution of

research on rainfed rice to increased production of rice and other crops in the rice-based cropping systems.

The distinct differences in the rainfed and irrigated rice-growing environments lead to differences in technology and, therefore, research requirements. Theoretically, to maximize the productivity of research resources, expenditures should be allocated so that the increase in productivity and the additional amount of funds spent on research for each rice environment are equated. A refinement of this approach would be to identify research inputs by research problem area or project (e.g. drought resistance). The analysis should take into account the extent of the area with an environment in which the new technology is suitable, the expected productivity gain, the direct costs involved in using the new technology or the reductions in costs achieved, the probability of success, and the time period until the productivity gain is achieved. A model that includes all these factors is shown in Appendix C.

Data for the analysis described above cannot be readily obtained. However, a simplification was implemented by the IRRI Long Range Planning Committee, and is presented here. A group of IRRI scientists estimated the anticipated increase in rice yield and cropping intensity that would be possible from *reasonable* research inputs directed at each environment.[1] It was assumed that these yields could be realized over a 20-year period. The probability of success, the direct cost of technology for each area, and the time required to achieve success were assumed to be identical for all environments. Thus, the objective of the exercise was to estimate the value of the potential increase in production in each area.

Increase in total production was assumed to be due to the gain in production from yield, cropping intensity, and new irrigation development. Gains in yield and cropping intensity are shown in Table 14. The first two columns of Table 15 show the land area in specific categories and the changes that will occur if the irrigated area grows at 1.5%/year. The gross area in rice increased by 3 million ha because of the increase in the area double-cropped, but the area in rainfed rice declined by 6 million ha as rainfed rice was converted to irrigated rice.

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[1]These estimates include a good deal of judgment, but an increasing amount of information is becoming available on which to base a reasonable potential. For example, Jackson (1977) reports experimental yields in Thailand of 3.8 t/ha in shallow water, 2.8 t/ha in 60 cm water depth, and 2.4 t/ha in 100 cm water depth.

Table 14. Estimated changes in yield and cropping intensity for specified environmental complexes in South and Southeast Asia, 1970s to 1990s.

Environmental complex	Yield (t/ha)			Rice cropping intensity			Upland cropping intensity		
	1970s (1)	1990s (2)	Change (3)	1970s (4)	1990s (5)	Change (6)	1970s (7)	1990s (8)	Change (9)
Irrigated	3.0	4.1	1.1	1.2	1.6	0.4	0.3	0.5	0.2
Shallow rainfed	1.8	2.6	0.8	0.7	1.0	0.3	0.4	0.5	0.1
Medium-deep rainfed	1.0	1.8	0.8	0.8	0.9	0.1	0.3	0.5	0.2
Deepwater	1.0	1.5	0.5	0.9	1.0	0.1	0.3	0.4	0.1
Upland	1.0	1.5	0.5	0.8	0.8	0	0.5	0.8	0.3

Table 15. Estimate of contribution of research and extension to the increase in rice production due to yield increase in specified environmental complexes, South and Southeast Asia, 1970s to 1990s.[a]

Environmental complex	Gross area[b] (million ha)		Yield increase[c] (t/ha)	Undiscounted benefits from irrigation[d] (million t)	Undiscounted benefits from research and extension due to yield[e]		
	1970s (1)	1990s (2)	(3)	(4)	million t (5)	Billion US$ (6)	% (7)
Irrigated	27	36	1.1	27.0	39.6	3.96	52
Shallow rainfed	29	25	0.8	-7.2	20.0	2.00	26
Medium-deep rainfed	13	11	0.8	-2.0	8.8	0.88	12
Deepwater	7	7	0.5	0	3.5	0.35	5
Upland	8	8	0.5	0	4.0	0.40	5
Total	84	87		17.8	75.9	7.59	100

[a]Based on estimates of the IRRI Long Range Planning Committee.

[b]Irrigated area is assumed to increase at 1.5%/annum and gross land area at 0.2%/annum.

[c]From column 3 of Table 14.

[d]Col. 4 equals col. 2 x - col. 1 of Table 11. Benefits are for the 20th year.

[e]Col. 5 equals col. 3 x col. 2.

The increase in rice production in the 1990s from expansion of irrigated land, assuming no change in the 1970s yield level, is projected as 17.8 million t. If the value of rice is assumed to be US$100/t, the undiscounted benefit in the 20th year will be US$1.78 billion. The benefits from research and extension are estimated by multiplying the yield increase (col. 3) by the 1990s area (col. 2). The results shown in paddy rice (col. 5) are equivalent to $7.59 billion (col. 6). Rainfed rice accounts for 38% of the total research-extension benefits that result in an increase in yield (col. 7).

Table 16. Estimated contribution of research and extension to increase in rice and upland crop (UC) production through cropping intensity in specified environmental complexes, South and Southeast Asia, 1970s to 1990s.[a]

Environmental complex	Net area[b] (million ha)		Anticipated intensity effect				Undiscounted benefits from research-extension due to intensity			
			Ratio[c]		Area[d]		Billion US$[e]		% [f]	
	1970s (1)	1990s (2)	Rice (3)	UC (4)	Rice (5)	UC (6)	Rice (7)	UC (8)	Rice (9)	UC (10)
Irrigated	23	30	0.4	0.2	12.0	6.0	4.92	1.85	61	54
Shallow rainfed	41	36	0.3	0.1	10.8	3.6	2.81	6.70	35	21
Medium-deep rainfed	16	14	0.1	0.2	1.4	2.8	0.25	0.38	3	11
Deepwater	8	8	0.1	0.1	0.8	0.8	0.12	0.09	1	3
Upland	10	10	0	0.3	0	3.0	0	0.38	0	11
Total	98.0	98.0					8.10	3.40	100	100

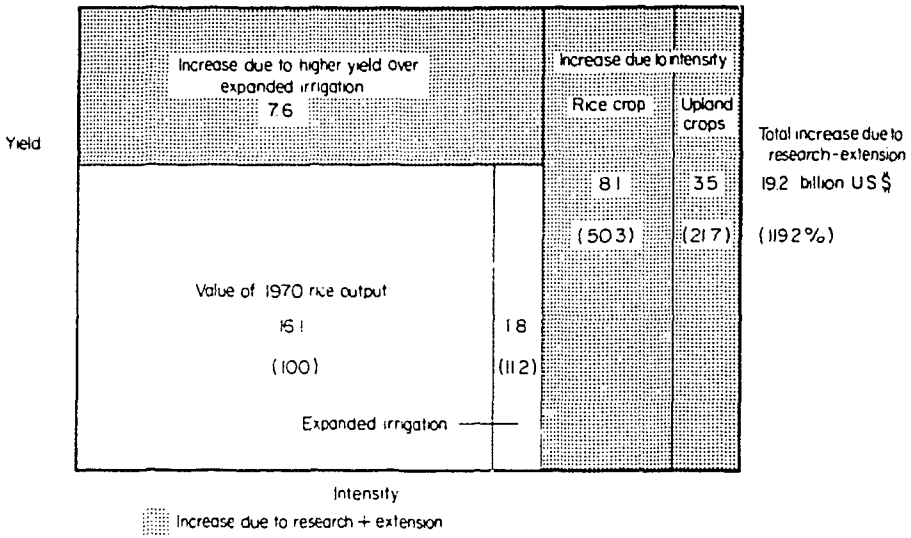
[a]Based on estimates of the IRRI Long Range Planning Committee.
[b]Net area computed by adjusting gross area in Table 12 by cropping intensity shown in col. 6 of Table 11.
[c]From col. 6 and 9, Table 14.
[d]Col. 5 equals col. 3 x col. 2. Col. 6 equals col. 4 x col. 2.
[e]Col.7 equals col. 5 x col. 3 of Table 14 converted to dollars where one t paddy rice equals $100. Col. 8 equals col. 6 x col. 9 of Table 14 converted to dollars where one t upland crop equals $75. Benefits are for the 20th year.
[f]Col.9 is col. 7 expressed as a percentage. Col. 10 is col. 8 expressed as a percentage. Benefits are for the 20th year.

Table 17. Summary of discounted added benefits from research and extension due to yield increase and cropping intensity for specified environmental complexes in South and Southeast Asia, 1970s to 1990s.

Environmental complex	Benefits (billion US$) due to			Total benefits	
	Yield increase	Rice cropping intensity	Upland cropping intensity	Billion US$	%
Irrigation	7.89	9.80	3.69	21.38	56
Shallow rainfed	3.98	5.58	1.39	11.00	29
Medium-deep rainfed	1.75	0.48	0.76	2.99	8
Deepwater	0.72	0.24	0.18	1.14	3
Upland	0.80	0	0.76	1.55	4
Total	15.14	16.10	6.78	38.06	100

The impact of crop intensification is shown in Table 16. Undiscounted benefits in the 20th year are US$8.10 billion from rice, and US$3.40 billion from upland crops, where upland crops have a net value (gross value less cash costs) of US$75/t (col. 7, 8).

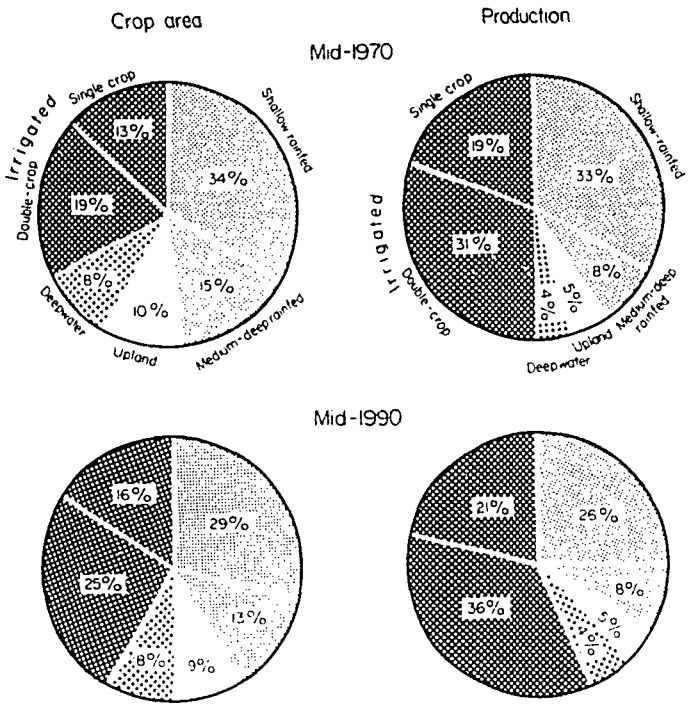
The discounted benefits from rice research are summarized in Table 17. Figure 10 depicts graphically the contribution



10. Value of crop production increase from the 1970s to the 1990s (billion US$) arising from research and extension investment. Values in parentheses show percentage of increase for specified categories of yield and cropping intensity.

of yield and cropping intensity to total benefits. Rainfed rice accounts for 37% of the total increase in benefits. The largest share of benefits is in the irrigated area both because the area is expanding (Fig. 11) and because the absolute yield gain is larger for irrigated than for rainfed rice (Table 10). The potential for increasing yields on shallow and medium-deep rainfed areas was assumed to be equal (0.8 t/ha), but that of the shallow rainfed area is considerably greater than the medium rainfed. Upland and deepwater rice account for only 3 and 4%, respectively, of the total benefits, both because their areas are small and the potentials for increase in yield are low.

While the above figures give some indication of the potential payoff to research in rainfed rice for South and Southeast Asia as a whole, for individual countries the results are different. We sent questionnaires to groups of rice scientists from different countries asking them for information on the present area in irrigated, upland, deepwater, and rainfed rice (shallow, intermediate, and semideep) and for the present and potential yields in each of those categories. These unofficial data from each country were used to compute the potential benefits from research-extension in each country following the procedure shown in Table 15. (Benefits due to cropping intensity were not considered). The results for each country are shown in Appendix Tables 3-10. The percentage shares of the benefits



11. Estimate of the percentage of rice crop area and production by specified environmental complex in South and Southeast Asia, mid-1970s and mid-1990s.

attributable to each rice crop environment are summarized in Table 18.

The results indicate that the countries in Asia fall in two categories: those with high potential benefits from investment in rainfed rice research, and those with high potential benefits from investment in irrigated rice research. Bangladesh, Burma, Thailand, and Nepal are in the first category; Indonesia, the Philippines, and Sri Lanka in the second. India shows a distribution of benefits intermediate between the two groups. But if India, which accounts for almost half of the total rice area, was divided into regions we probably would observe the same bimodal distribution.

Among the rainfed-oriented countries, four are traditional exporters: Burma, Thailand, Vietnam, and Nepal. The first three have large delta-based rice industries. It is useful to compare the research expenditures of the rainfed and more export-oriented countries with those of the irrigated and more import-oriented countries. Table 19 shows the total and

Table 18. Estimated contribution (%) of research-extension to growth in rice production by specified environmental complexes for selected countries in South and Southeast Asia, 1970s to 1990s.

Environmental complex	Share (%) of benefits from research-extension a								
	South and South-east Asia	Nepal	Thai-land	Bangla-desh	Burma	India	Philip-pines	Indo-nesia	Sri Lanka
Irrigated	52	20	22	23	25	45	75	76	79
Shallow rainfed	26	67	49	41)	53	10	11	10	8
Intermediate rainfed	12	-	20	17)		19	1	-	5
Semideep rainfed		-	4	5)		7	0.5	-	4
Deepwater	5	-	4	4)	19	4	0.5	6	-
Upland	5	13	1	10	3	15	12	8	4
Total	100	100	100	100	100	100	100	100	100
Implied annual growth in rice production	2.4	3.0	4.1	1.9	3.2	3.6	2.9	4.2	2.4

a Benefits are due to yield increase only.
Source: Appendix Tables 3-10.

Table 19. Rice research expenditures for selected countries in East, South, and Southeast Asia, 1974 (from Evenson and Flores 1978).

Country	Total research expenditures (1971 thousand US$)	Expenditures per 100,000 ha (1971 US$)
Rainfed oriented, S & SE Asia		
Bangladesh	120	1.20
Burma	40	0.80
Nepal	100	8.10
Thailand	300	3.50
Vietnam	160	3.00
Irrigation oriented, S & SE Asia		
Indonesia	550	6.40
W. Malaysia	1,460	252.00
Pakistan	210	17.00
Philippines	500	14.00
Philippines (including IRRI)	2,900	80.60
Others		
India	3,900	10.30
Japan	46,000	1,688.70
Taiwan	1,700	218.50
Korea South	250	35.70

per-1000 ha research investment for selected countries. Both in absolute level and by unit of cultivated rice area, the research investment generally was lower in those countries with a high proportion of rainfed area. IRRI research to date has been of greater benefit to countries with a high proportion of irrigated area. Only in the Philippines is a significant portion of the rainfed area planted to modern varieties.

This analysis assumed that the probability of success, the direct cost of technology for each area, and the time required to achieve success were the same for all environments. This may not be a reasonable assumption. In fact, it seems more reasonable to expect that developing technology for an expanding irrigation base has a greater probability of success, but a higher cost.

In Table 20, we budgeted the annual returns and costs for expansion of production in the irrigated and in the rainfed

Table 20. Annual returns and costs of increase in producing rice in the irrigated and shallow rainfed environmental complexes, South and Southeast Asia, 1990s.

Item	Annual increase	Unit cost (US$)		Annual capital investment (million US$)	Annual additional	
		Capital investment	Current costs		Costs (million US$)	Returns (million US$)
		Irrigated				
Irrigation[a]	450,000 ha	1500/ha	10/t	675	11	-
Fertilizer[b]	574,000 t	290 million/ plant	150/t	157	129[c]	-
Research-extension[d]	-	100 million	-	100	-	-
Labor[e]	266 million man-days	-	1/day	-	266	-
Paddy[f]	8.87 million t	-	150/t	-	-	1330
Total				943	406	1330
		Rainfed				
Fertilizer[b]	172,000 t	290 million/ plant	150/t	50	39[f]	-
Research-extension[d]	-	100 million	-	100	-	-
Labor[e]	123 million man-days	-	1/day	-	123	-
Paddy[f]	4.12 million t	-	150/t	-	-	618
Total				150	162	618

[a]Irrigation grows at 1.5%/annum; 0.015 x 30 million ha = 450,000 ha.
[b]Fertilizer use will grow at 6%/annum on irrigated land, or from 1.35 million to 4.32 million t nutrients, an assumed increase of 2.59 million t nutrients. Converted to urea and TSP, assuming 3/4 of fertilizer as urea and 1/4 TSP, the tonnage is 574,000. The rainfed area is assumed to require about 30% as much total fertilizer as the irrigated area: 172,000 t vs. 574,000 t. For the fertilizer produced domestically one plant is assumed to cost $270 million and produce 495,000 t urea/year. The annual investment requirement is computed assuming that 50% of the fertilizer will be produced domestically. Domestic fertilizers will be produced at $100/t and imported fertilizer will cost $200/t.
[c]Fertilizer cost multiplied by 1.5 to account for cost of other cash inputs excluding labor.
[d]$100,000 is allocated annually to research-extension for irrigated and rainfed areas.
[e]It is assumed that producing an additional ton of paddy requires 30 man-days or $30.
[f]Increased paddy production per annum in the 1990s is based on the implicit rate of growth from Tables 14-16. Irrigated output will increase from 81 million t in the 1970s to 197 million t in the 1990s or 4.5%/annum (197 x 0.045 = 8.87 million t). Rainfed output will increase from 65 million t in the 1970s to 125 million t in the 1990s or 3.3% (125 x 0.33 = 4.12 million t).

environment. The annual change in yield, production, and land area is based on Tables 14-16. Some of the assumptions about investment costs and current expenses are based on Herdt et al (1978). For this set of calculations we assume that by the mid-1990s, US$100 million will be spent on research and extension in irrigated rice and another US$100 million on research in rainfed rice. The expenditure in 1974 was US$50 million (Evenson and Flores 1978) and in these calculations it is, therefore, estimated to grow at 8% during the next 20 years, close to the rate of growth in fertilizer use.

These data show the investment requirement not only for research and extension but also for fertilizer and irrigation. While the returns from the irrigated area are almost double, the capital investment to create 1 irrigated hectare is more than 6 times as great. Therefore, the return on investment is much larger for the rainfed than for the irrigated area.

In summary, Asian governments, particularly among the rice-importing countries, are likely to emphasize irrigation as a fairly sure but costly means of increasing rice production and achieving price and political stability. However, if the estimates of the potential for yield increase in rainfed rice are correct, the total benefits for the Asian economies may be greater if more emphasis is given to research on rainfed rice problems.

Unlike wheat technology, the new rice technology has not lowered the cost of rice production to any significant degree. As a result, world rice prices continue to remain at twice the level of world wheat prices. Part of the reason lies in the fact that the technology has been suitable for only about one-fourth of the rice area with better water control. Raising yields in the rainfed areas that have been largely bypassed by the new technology will have important social as well as economic benefits.

BARRIERS TO EFFECTIVE RESEARCH

The potential benefits for research in rainfed rice were discussed in the previous section. Whether or not these benefits are realized in the next two decades will depend upon the ability to:

- develop a suitable technology for the rainfed areas
- put the technology into the hands of farmers, and
- provide the proper incentives to encourage farmers to utilize the technology.

On all counts, the task is more formidable for the rainfed areas than it has been for the irrigated areas.

Developing a suitable technology

Developing technology suitable for the rainfed areas probably will take more time and money than for the irrigated areas because lack of water control results in a more heterogeneous environment. The present research effort directed toward the rainfed rice area is exceedingly small (Table 19). Furthermore, many of the major experiment stations are not located in typical rainfed environments. IRRI is a classic example. Our scientists are forced to use deepwater tanks and greenhouses to simulate the flood and drought conditions of the major rainfed areas. Nevertheless, during the 1970s there has been a considerable increase in our understanding of rice production under flood and drought conditions throughout Asia. There are already signs that even the current modest research investment will pay large dividends.

The technology for the rainfed areas should be yield stabilizing and cost reducing. For such areas, it would be more appropriate to refer to high stability varieties (HSV) rather than to the conventional but misleading term high yielding varieties (HYV). Farmers should be given the choice of raising varieties that produce a minimum level of yield every year (HSV) or varieties that produce higher yields under ideal conditions, but lower yields under unfavorable conditions. The international rainfed rice trials may help to identify varieties with these different traits.

Cultural practices, as well as varieties, will differ for the rainfed areas. For example, the wide variability in cropping patterns from one location to another, and even within a given area, reflects the extreme heterogeneity of conditions and the attempt of farmers to stabilize production by providing contingencies for variable weather conditions. Cropping patterns generally vary according to topography, but are adjusted also to annual variation in weather. The implications of these types of adjustments are important for technology development. Researchers can provide technology components, such as short season varieties, that can be used to adjust cropping patterns and increase production. But because of the extreme heterogeneity of the environmental conditions and the limited capacity of the research-extension network, it normally must be left to farmers to work out the most appropriate cropping patterns.

Getting technology into the hands of farmers

The input delivery system for rainfed areas is, in general, not as well developed as for the irrigated areas. Seed multiplication and delivery are a major weakness in many areas. For example, we were told recently in eastern India that it takes about 10 years from the time of the first cross to the release of a new variety of rice (Barker 1977). Even when the variety is released, there is no assurance that it will be made available to farmers. In contrast, varieties become available to farmers in the Philippines within 5 years of the first cross. The only modern varieties currently grown on a wide scale in eastern India are Jaya, IR8, Pankaj, and Mahsuri, all of which were released more than a decade ago. These varieties are grown almost exclusively in the irrigated areas: Jaya and IR8 in the dry season, and Pankaj and Mahsuri in the wet season.

Hargrove's research (1977) suggests that the problem begins with the breeding objectives. Breeders, at least until recently, have not emphasized the genetic characteristics required for the drought and flood conditions common to eastern India. The problem, however, is not only with research. We saw varieties in eastern India that seemed to be more suitable than what farmers are using now. But the mechanism for testing promising new rice and assuring their rapid and wide dissemination is not adequate.

Other inputs must accompany the seed. The distribution system in the rainfed areas is often such that farmers have to travel several kilometers to purchase inputs or obtain institutional credit. Only the 2 most progressive of the 12 rainfed villages surveyed in the RURP in Central Luzon received a significant amount of Masagana 99 credit and extension support in 1974. The government surmised, perhaps correctly, that given the potential of existing technology in the rainfed area at that time, the irrigated areas would provide a higher return on investment.

Providing incentives

Many observers associate farmer incentives with prices: low rice prices and high input cost will discourage production. However, the disincentives for rainfed rice producers extend well beyond the pricing mechanism. Land fragmentation, small size of farms, lack of credit, inappropriate technology, and lack of knowledge on how to use inputs are often noted. A

strong research-extension program and an efficient input delivery system are among the most important incentives to farm production.

The expansion of heavily subsidized irrigation provides another important incentive to production. As an alternative to irrigation expansion, we suggest that strengthening the research-extension system in the rainfed areas may give a higher economic benefit and will result in a more equitable distribution of benefits from rice technology. No country can afford to ignore either alternative. It is a matter of finding the proper balance. The weight has been in favor of the irrigated areas too long.

Ultimately, the strengthening of farmer incentives requires the strengthening of community leadership and organization. This is perhaps the greatest challenge for social science research.

SUMMARY AND CONCLUSIONS

Rainfed rice, as we have defined it, occupies about one-third of the world's rice-growing area in South and Southeast Asia. The bulk of the rainfed rice area is shallow rainfed where the water depth seldom exceeds 15 cm.

Topographically, the rainfed areas can be divided into lowland plains and river floodplains, terraces, and plateaus. 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. The soil and water problems in the deltas differ markedly from those of the terraces and plateaus. The former area is subject to flooding, while drought is the more common problem in the latter.

Modern rice technology has to a large degree bypassed the rainfed areas with two notable exceptions. Almost 30% of the Mekong Delta had been planted to modern varieties by 1973, and in the Philippines modern varieties were on 70% of the rainfed area in 1977. The Philippine situation demonstrates the potential of short season varieties in rainfed areas.

Analysis of the potential benefits from research-extension over the next two decades indicates that for South and Southeast Asia as a whole, about 37% of the benefits can be realized through increases in rainfed rice production. But countries tend to fall into two very distinct groups. In Bangladesh,

Burma, Nepal, Thailand, central and eastern India, and Vietnam, 70% of the benefits from research-extension are likely to come from production increases in the rainfed rice area. For Indonesia, Malaysia, Philippines, Sri Lanka, northern and southern India, the benefits will come largely from the irrigated rice areas.

Over the past decade, there has been a substantially heavier investment in rice research and development of new technology for the irrigated areas. However, if we include the cost of irrigation development, the economic benefits of expanding output through investment in rainfed rice may have a benefit-cost ratio greater than for irrigated rice.

Investment in rice research is increasing in most of the major rainfed rice-growing countries and regions -- Bangladesh, Burma, Nepal, Thailand, and eastern India -- supported by national funds, by the World Bank, the United Nations Development Program, and a number of other international donor agencies.[2]

The barriers to the effective development and dissemination of rainfed rice technology are numerous. Yet there are already signs that the modest investment in rainfed rice research to date is paying high dividends.

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[2] See for example the report by the Rice Division of the Department of Agriculture of Thailand, "Rainfed Rice Improvement Pioneer Project: Review of Annual Action Program for 1976"; or Government of India – International Rice Research Institute "Production Oriented Survey on Rice in Problem Areas of Bihar, Orissa and West Bengal," 1977 (mimeo.). In October 1977, the Bangladesh Rice Research Institute sponsored a workshop devoted to the problems of rainfed rice production (BRRI 1978).

Appendix Table 1. Allocation of gross rice area in major producing countries of five types of rice culture, 1973-75 average (million ha).[a]

Country	Gross rice area (million ha)						
	Total rice	Upland	Deepwater	Shallow rainfed	Medium deep rainfed	Total irrigated	Dry season irrigated
South and SE Asia							
India	38.4	2.4	2.4	12.6	6.1	14.9	1.7
Bangladesh	9.5	2.2	1.9	2.2	2.2	1.0	1.0
Indonesia	8.5	1.4	0.4	1.7	1.7	3.3	1.3
Thailand	8.2	0.8	1.7	2.0	1.7	2.0	0.5
Burma	5.1	neg.	neg.	4.1	0.2	0.8	0.1
Philippines	3.5	0.5	0	1.6	0	1.4	0.4
Vietnam	5.3	0.4	0.5	3.0	0.7	0.7	0.1
Pakistan	1.6	0	0	0	0	1.6	1.6
Nepal	1.2	0.1	neg.	0.9	0	0.2	n.a.
Sri Lanka	0.6	0.1	0	0.2	neg.	0.3	0.2
Laos	0.7	0.2	0	0.2	0.2	0.1	n.a.
Malaysia (Peninsular))							
Sarawak	)0.8	0.1	0	0.2	0	0.5	0.2
Sabah	)						
Total	83.4	8.2	6.9	28.7	12.8	26.8	6.6
Other Asian countries							
China	34.1	0.7	0	2.7	0	30.7	n.a.
Japan	2.7	0.1	0	0	0	2.6	0
Korea, Rep. of	1.2	neg.	0	0.1	0	1.1	0
Korea North	0.7	neg.	0	0.1	0	0.6	0
Iran	0.3	0	0	0	0	0.3	0
Afghanistan	0.2	0	0	0	0	0.2	0
Total	39.2	0.8	0	2.9	0	35.5	n.a.
Other regions							
Brazil	4.8	3.7	0	0	0.6	0.6	n.a.
Malagasy Rep.	1.1	0.2	0	0.3	0.3	0.3	n.a.
USA	1.0	0	0	0	0	1.0	1.0
USSR	0.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Egypt	0.5	0	0	0	0	0.5	0.5
Guinea	0.4	0.25	0	.06	.06	.06	0.4
Ivory Coast	0.3	0.3	0	neg.	0	neg.	n.a.
Colombia	0.3	0.1	0	0	0	0.2	n.a.
Sierra Leone	0.4	0.22	0	.05	.05	.05	n.a.
Others	5.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Total	14.5	4.77	0	0.41	1.01	2.71	1.9

[a] Data sources listed in Appendix D. See definitions Appendix B, neg. = negligible, n.a. = data not available.

Appendix Table 2. Classification of the variability of environmental factors influencing rice production.

Factor	Subfactor	Variability: Across locations	Across seasons	Across years
Soils	Physical properties	x		
	Chemical properties	x		
	Biotic properties	x	x	
	Origin	x		
Geographic	Topography	x		
	Position	x		
	Photoperiod	x	x	
Water	Depth	x	x	x
	Rate of increase, decrease	x	x	x
	Temperature	x	x	
Climatic	Solar radiation	x	x	x
	Precipitation	x	x	x
	Air temperature	x	x	x
	Wind	x	x	x
Biotic	Competitive plants	x	x	x
	Dependent plants	x	x	x
	Insect predators	x	x	x
	Microbes	x	x	x
Socioeconomic	Farmer knowledge	x		x
	Input and product prices	x	x	x
	Personal characteristics	x		
	Farm size	x		

Appendix Table 3. Estimate of contribution of research-extension to the increase in rice production in specified environmental complexes, Bangladesh, 1970s to 1990s.[a]

Environmental complex	Gross area[b] (million ha)		Yield (t/ha)		Production[c] (million t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	tons (8)	% (9)
Irrigation, 1st crop	0.1	0.1	2.5	4.0	0.25	0.25	0.40	0.15	2.1
Irrigation, 2d crop	1.0	1.5	3.5	4.5	3.50	5.25	6.75	1.50	20.5
Shallow rainfed	3.0	3.0	2.0	3.0	6.00	6.00	9.00	3.00	41.1
Intermediate rainfed	2.4	2.4	2.0	2.5	4.80	4.80	6.00	1.20	16.4
Semideep rainfed	1.5	1.5	1.5	1.75	2.25	2.25	2.63	0.38	5.2
Deepwater	1.3	1.3	1.25	1.5	1.63	1.63	1.95	0.32	4.4
Upland	1.0	1.0	1.0	1.75	1.00	1.00	1.75	0.75	10.3
Total	10.3	10.8			19.43	21.18	28.48	7.3	100.0

[a]Based on questionnaire completed by M. S. Ahmad, head of the Division of Rice Breeding and M. S. Nasiruddin, principal scientific officer (Breeding), BRRI, Dacca, Bangladesh (1978).
[b]Irrigated area assumed to grow at 2%/annum and gross land area at 0.3%/annum.
[c]Col. 6 is 1990s gross area (2) multiplied by 1970s yield (3). Col. 7 is 1990s gross area (2) multiplied by 1990s yield (4).
[d]Col. 8 is col. 7 minus col. 6. Col. 9 is col. 8 expressed in percentage.

Appendix Table 4. Estimate of contribution of research-extension to the increase in rice production in specified environmental complexes, Burma, 1970s to 1990s.[a]

Environmental complex	Gross area[b] (million ha)		Yield (t/ha)		Production[c] (million t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	million t (8)	% (9)
Irrigation, 1st crop	0.8	0.9	3.0	5.0	2.40	2.70	4.50	1.80	19.4
Irrigation, 2d crop	0.1	0.2	3.5	6.0	0.35	0.70	1.20	0.50	5.4
Shallow rainfed) Intermediate rainfed)	3.5	3.5	2.3	3.7	8.05	8.05	12.95	4.90	52.7
Semideep rainfed) Deepwater)	0.5	0.5	0.9	2.5	0.45	0.45	2.25	1.80	19.3
Upland	0.2	0.2	1.0	2.5	0.20	0.20	0.50	6.30	3.2
Total	5.1	5.3			11.45	12.10	21.40	9.3	100.0

a Based on questionnaire completed by Ohn Kyaw and P. B. Escuro, deputy general manager and FAO rice improvement specialist, respectively, Rice Division, Agricultural Research Institute, Yezin, Pyinmana, Burma (1978).
b Irrigated area assumed to grow at 1.0%/annum and total land area at 0.2%/annum.
c Col. 6 is 1990s gross area (2) and 1970s yield (3). Col. 7 is 1990s gross area (2) and 1990s yield (4).
d Col. 8 is col. 7 minus col. 6. Col. 9 is col. 8 expressed in percentage.

Appendix Table 5. Estimate of contribution of research-extension to the increase in rice production in specified environmental complexes, India, 1970s to 1990s.[a]

Environmental complex	Gross area[b] (million ha)		Yield[c] (t/ha)		Production[d] (million t)			Benefits from research-extension[e]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	(million t) (8)	(%) (9)
Irrigation, 1st crop	11.5	14.5	2.5	3.5	28.75	36.25	50.75	14.50	27.6
Irrigation, 2d crop	2.5	4.5	3.5	5.5	8.75	15.75	24.75	9.00	17.1
Shallow rainfed	4.5	4.0	1.5	2.8	6.75	6.00	11.2	5.20	9.9
Intermediate rainfed	7.3	6.8	1.0	2.5	7.30	6.80	17.05	10.20	19.4
Semideep rainfed	2.8	2.8	1.0	2.3	2.80	2.80	6.44	3.64	7.0
Deepwater	2.3	2.3	1.05	1.8	2.30	2.3	4.14	1.84	3.5
Upland	8.1	8.1	1.0	2.0	8.10	8.10	16.20	8.1	15.5
Total	39.0	43.0			64.75	78.00	130.48	52.48	100.0

a Based on questionnaires completed by S. Biswas, Chinsurah Rice Research Station, West Bengal, and M. V. Rao and J. B. K. Rao, CRRI, Cuttack (1978).
b Irrigated areas assumed to grow at 1.5%/annum and gross land at 0.5%/annum.
c Adjusted upward to reflect India's current level of production.
d Col. 6 is 1990s gross area (2) multiplied by 1970s yield (3). Col. 7 is 1990s gross area (2) multiplied by 1990s yield (4).
e Col. 8 is col. 7 minus col. 6. Col. 9 is col. 8 expressed in percentage.

Appendix Table 6. Estimate of contribution of research-extension to the increase in rice production in specified environmental complexes, Indonesia, 1970s to 1990s.[a]

Environmental complex	Gross area[b] (million ha)		Yield (t/ha)		Production[c] (million t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	Tons (8)	% (9)
Irrigated, 1st crop	3.9	5.2	3.1	5.0	7.00	16.12	26.00	9.88	49.1
Irrigated, 2d crop	2.7	3.6	3.5	5.0	9.45	12.60	18.00	5.40	26.9
Shallow rainfed	1.8	1.3	2.5	4.0	4.50	3.25	5.20	1.95	9.7
Deepwater	0.8	0.8	2.0	3.5	1.60	1.60	2.8	1.2	6.0
Upland	1.2	1.2	1.6	3.0	1.92	1.92	3.60	1.68	8.3
Total	10.4	12.1			24.47	35.49	55.60	20. .	100

a Based on questionnaire completed by agronomy staff, Central Research Institute for Agriculture, Bogor, Indonesia (1978).
b Irrigation increases at 1.5%/annum and gross land area at 0.8%/annum.
c Col. 6 is 1990s gross area (2) multiplied by 1970s yield (3). Col. 7 is 1990s gross area (2) multiplied by 1990s yield (4).
d Col. 8 is col. 7 minus col. 6. Col. 9 is col. 8 expressed in percentage.

Appendix Table 7. Estimate of contribution of research-extension to the increase in rice yield in specified environmental complexes, Nepal, 1970s and 1990s.[a]

Environmental complex	Gross area[b] (million ha)		Yield (t/ha)		Production[c] (million t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	Tons (8)	% (9)
Irrigated, 1st crop	170	235	2.8	4.0	475	660	1940	280	16.3
Irrigated, 2d crop	20	45	3.0	4.5	60	135	200	65	3.8
Shallow rainfed	925	965	1.8	3.0	1665	1735	2895	1160	67.4
Upland	165	165	1.2	2.5	200	200	415	215	12.5
Total	1280	1410			2400	2730	4450	1720	100

a Based on questionnaire completed by B. B. Shahi, national rice coordinator, Parwanipur, Nepal (1978).
b Irrigation increases at 2%/annum and gross land area at 0.5%/annum.
c Col. 6 is 1990s gross area (2) multiplied by 1970s yield (3). Col. 7 is 1990s gross area (2) multiplied by 1990s yield (4).
d Col. 8 is col. 7 minus col. 6. Col. 9 is col. 8 expressed as a percentage.

Appendix Table 8. Estimate of contribution of research-extension to increase in rice production in specified environmental complexes, Philippines, 1970s to 1990s.[a]

Environmental complex	Gross area [b] (million ha)		Yield (t/ha)		Production [c] (million t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	tons (8)	% (9)
Irrigated, 1st crop	0.98	1.20	2.2	4.0	2.16	2.64	4.80	2.16	50.6
Irrigated, 2d crop	0.43	0.70	3.5	5.0	1.51	2.45	3.50	1.05	24.6
Shallow rainfed	1.50	1.15	1.3	1.7	1.95	1.50	1.96	0.46	10.7
Intermediate rainfed	0.08	0.08	1.0	1.5	0.08	0.08	0.12	0.04	0.9
Semideep rainfed	0.05	0.05	0.8	1.5	0.04	0.04	0.06	0.02	0.5
Deepwater	0.07	0.07	0.5	1.5	0.04	0.04	0.06	0.02	0.5
Upland	0.39	0.39	0.9	2.5	0.35	0.35	0.87	0.52	12.2
Total	3.50	3.64			6.13	7.10	11.37	4.27	100.0

[a]Based on questionnaire completed by T. S. Eugenio, rice research training director, Maligaya Rice Research and Training Center, BPI, Muñoz, Nueva Ecija, Philippines (1978).
[b]Irrigation increases at 2%/annum and gross land area at 0.4%/annum.
[c]Col. 6 is 1990s gross area (2) multiplied by 1970s yield (3). Col. 7 is 1990s gross area (2) multiplied by 1990s yield (4).
[d]Col. 8 is col. 7 minus col. 6. Col. 9 is col. 8 expressed as percentage.

Appendix Table 9. Estimate of contribution of research-extension to the increase in rice production in specified environmental complexes, Sri Lanka, 1970s to 1990s.[a]

Environmental complex	Gross area [b] (thousand ha)		Yield (t/ha)		Production [c] (thousand t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	Million t (8)	% (9)
Irrigated, 1st crop	255	295	3.3	4.5	842	974	1328	354	52.1
Irrigated, 2d crop	100	120	2.5	4.0	250	300	480	180	26.5
Shallow rainfed	110	110	1.7	2.2	187	187	242	55	8.1
Intermediate rainfed	50	50	1.5	2.2	75	75	110	35	5.2
Semideep rainfed	50	50	1.2	1.8	60	60	90	30	4.4
Deepwater	0	0	-	-	-	-	-	-	-
Upland	50	50	1.0	1.5	50	50	75	25	3.7
Total	615	685			1464	1646	2325	679	100

[a]Based on questionnaire completed by M. D. Davis, team leader and crop protection specialist, IRRI Sri Lanka (1978).
[b]Irrigation assumed to grow at 1%/annum and gross land area at 0.5%/annum.
[c]Col. 6 is 1990s gross area (2) multiplied by 1970s yield (3). Col. 7 is 1990s gross area (2) multiplied by 1990s yield (4).
[d]Col. 8 is col. 7 minus col. 6. Col. 9 is col. 8 expressed as a percentage.

Appendix Table 10. Estimate of contribution of research-extension to the increase in rice production in specified environmental complexes, Thailand, 1970s to 1990s.[a]

Environmental complex	Gross area[b] (million ha)		Yield (t/ha)		Production[c] (million t)			Benefits from research-extension[d]	
	1970s (1)	1990s (2)	1970s (3)	1990s (4)	1970s (5)	1990s (6)	1990s (7)	million t (8)	% (9)
Irrigation, 1st crop	1.5	1.7	2.5	4.0	3.75	4.25	6.80	2.55	14.9
Irrigation, 2d crop	0.4	0.6	3.5	5.5	1.40	2.10	3.30	1.20	7.0
Shallow rainfed	3.6	4.0	1.4	3.5	5.04	5.60	14.0	8.40	49.0
Intermediate rainfed	1.7	1.7	1.8	3.8	3.06	3.06	6.46	3.40	19.8
Semideep rainfed	0.5	0.5	2.0	3.5	1.00	1.00	1.75	0.75	4.4
Deepwater	0.5	0.5	2.0	3.5	1.0	1.0	1.75	0.75	4.4
Upland	0.1	0.1	1.0	2.0	0.1	0.1	0.20	0.10	0.5
Total	8.3	9.1			15.35	17.11	34.26	17.15	100.0

[a]Based on questionnaire completed for the International Rice Research Conference, April 1978 by B. R. Jackson, Sermsak Awakul, and Boriboun Somrith.
[b]Irrigated area assumed to grow at 1%/annum and gross land at 0.5%/annum.
[c]Col. 6 is 1970s gross area (2) multiplied by 1970s yield (3). Col. 7 is 1990s gross area (2) multiplied by 1990s yield (4).
[d]Col. 8 is col. 7 minus col. 6. Col. 9 is col. 8 expressed in percentage.

Appendix B

DEFINITION OF RICE-GROWING ENVIRONMENTAL COMPLEXES

The following definitions were used in completing the questionnaire that formed the basis for area estimates in Appendix A Tables 3-11.

Irrigated - water is added to the field from canals, river diversions, pumps, etc.

Upland, unbunded - rice is grown on flat land or terraces and slopes, without an attempt to impound standing water in the field. These areas are drought-prone.

Deepwater - mostly broadcast-seeded fields, usually unbunded with maximum water depth from tillering to flowering exceeding 100 cm. This is the present area of the floating rice.

Shallow rainfed - this area has a maximum water depth of 5-15 cm. Some parts are drought-prone, but in general the area is potentially suitable for photoperiod-insensitive semidwarf varieties. This includes normal as well as terraced paddy.

Medium-deep rainfed - includes the two subcategories below.

Intermediate rainfed - this area has a maximum water depth of from 15 to 50 cm. The area is potentially suitable for high yielding varieties of intermediate stature, and photoperiod sensitivity may be desirable in some areas. Semidwarfs could be grown in some areas of relatively low water level.

Semideep rainfed- this area has a maximum water depth of from 50 to 100 cm. It is suitable for traditional tall varieties and photoperiod sensitivity may be desirable for most of the area.

APPENDIX C

CRITERIA FOR RESOURCE ALLOCATION

Factors constraining rice production can be identified and overcome through the application of research, and IRRI has a critical role to play in the process, both through its own research and through the stimulation and development of national rice research capabilities. The allocation of resources among research and other functions and among various research areas has in the past been made on the basis of informal judgment. In the process of considering the long-range plans for the Institute, several efforts were made to develop a systematic technique for allocating resources among research problems. No attempt was made to apply such techniques to the other functions. Two related systematic approaches were used, a scoring approach and a productivity approach.

The scoring technique

A series of criteria were developed against which each actual or potential research problem area was to be scored on a scale of 1 to 10. The criteria were:

- The extent to which the research is expected to increase yields of rice or related crops, increase area planted per unit time, increase the nutritional quality of rice, increase rice farm incomes, or reduce consumers' real cost of rice;
- The extent to which similar research of adequate quality on this problem is not being conducted elsewhere;
- The extent to which substantial success is expected on the problem within 5 years (or alternatively within 20 years for basic problems) if research is continued at a specified level;
- The extent to which information is needed for the solution of an urgent threat or problem; and
- The extent to which the research would create new knowledge.

The IRRI senior staff were asked to score all research problem areas and to indicate the most appropriate weighting

system to be used to aggregate the scores. It proved impossible to achieve a consensus on either the interpretation of the criteria or on the scores to be assigned to each problem area. It also proved difficult to get scientists to score research problems with which they were not directly associated.

The productivity approach

An alternative approach based on productivity concepts was used to develop an appropriate resource allocation rule. Theoretically, in order to maximize the productivity of research resources, expenditures should be allocated so the *increase in productivity* from an additional amount of funds spent on research for each problem is equated. This rule requires the definition of research problems, the estimation of research productivity and related time lags, and the measurement of the extent of the area affected by a technology. To facilitate discussion a one-to-one correspondence between a *research project* and a new *rice farm technology* (RFT) is assumed. Success in a research project implies the development of a new RFT. A model taking account of time required to solve the problem, expected benefits, probability of success, area affected, direct costs of using the technology, and intensity changes was formulated.

Consider initially only research activities aimed at increasing rice yield per hectare. Suppose there is a probability of P_1 that successful completion of a project will result in Y_1 yield increase, a P_2 chance that the yield increase will be Y_2 and so forth over n yields. The expected yield increase then is:

$$E(\Delta Y) = \sum_{k=1}^{n} P_k Y_k \qquad (1)$$

If the project has a life of t years and the social rate of time discount is r, the present value of such an increase is:

$$PV(Y_j) = (1 + r)^{-t} (E \Delta Y) \qquad (2)$$

Generalizing by letting the j subscript represent projects and ΔY_{jk} the yield increase expected with probability P_k, the present value of the yield increase per hectare is:

$$PV(Y_j) = (1 + r)^{-t} \sum_k (\Delta Y_{jk} \cdot P_k) \qquad (3)$$

Recognizing that certain RFT are more productive in one season (wet, dry) than in another, this present value must be calculated on a per-hectare per-year basis.

Projects that can be confidently expected to give a stated yield increase but which will succeed in an uncertain number of years can be evaluated by letting the probability term represent the probability of success in a given number of years. Then

$$PV(Y_{ij}) = \sum_{k} (1 + r)^{-t_k} (\Delta y_{ij} \cdot P_k) \qquad (4)$$

If both yield and years for success are uncertain, the two can be combined. For simplicity, the first formulation is subsequently used.

A RFT applicable in an environment which has a very large hectarage of rice will have a bigger impact than a technology applicable to a small area. This is reflected by multiplying the present value of the yield effect of the technology by the area affected to get the present value of the technology for, say, the area i

$$PV(T_{ij}) = (1 + r)^{-t} \sum_{k} (\Delta Y_{ijk} \cdot P_k) A_i$$

Some research is directed at expanding the area on which crops are grown during a year. Cropping systems research, and work to find cultivars suited to adverse conditions fall in this category. In this case, the appropriate formulation would be:

$$PV(T_{ij}) = (1 + r)^{-t} \Big[\sum_{k} (\Delta Y_{ijk} P_k A_i) + \sum_{m} (\Delta A_{ijm} P_m Y_i) \Big] \qquad (5)$$

This formulation is suitable for evaluating yield and area increasing technologies that are costless to use, but many new technologies entail some additional direct costs to the users, for example, fertilizer-responsive varieties require the purchase of fertilizer. The benefit of such new RFT must be calculated net of the direct costs involved in their use. Once the possibility of costs is recognized, the benefits of the new RFT must be measured in monetary terms -- a simple transformation of yield. Then, the net present value of technology j for area i is:

$$NPV(T_{ij}) = (1 + r)^{-t} \left[\sum_k (\Delta Q_{jk} P_k A_i - C_j) + \sum_m (\Delta A_{jm} P_m Q_i - C_j) \right] \quad (6)$$

where ΔQ_{jk} equals ΔY_{jk} times price, Q_i equals Y_i times price, and C_j equals the additional per-hectare cost involved in attaining the increased productivity of the jth technology in the ith environment.

With this formulation, the relative value of RFT that do not raise rice yields can be evaluated. For example, a RFT that reduces costs reduces the C_j term and can be directly evaluated using equation (6). The net present value, being measured per hectare per year, will reflect the productivity increase.

APPENDIX D

Notes on Sources of basic data for Appendix A, Table 1

Proceedings refers to *Proceedings of the International Seminar on Deepwater Rice*, August 1974, BRRI; *Upland* to *Major Research in Upland Rice*, IRRI, 1975.

India: See Appendix A Table 3 for sources and assumption, dry season area equals "summer rice."

Bangladesh: 20% in Deepwater, *Proceedings*, p. 7, Irrigated area equal to irrigated aus + boro (11%) as given in *Bangladesh Economic Survey* 1973-74, Minist. of Finance. *Upland* p. 3, cites 23% as upland, but description on p. 4 shows much of it is dry seeded lowland -- that % implies 2176 upland. Allocation made in table assumes difference between total rice and deepwater plus irrigated is equally allocated to three other categories. Dry season area is equal to *boro* area reported in *Bangladesh Economic Survey*.

Laos: 20% in upland, according to 1973 estimate by USAID. Yield estimates of some source are: upland 2.8t/ha, lowland 2.8t/ha, with provision that upland rice yields were well above long-term average and the normal. Balance of total-upland divided equally to irrigated, SRF and MDRF. Source: TOAID A-569, February 13, 1974, USAID.

Malaysia: Source: *Review of Current Status of Rice Production, Imports, Consumption in Malaysia*, MARDI Review Paper, August 1977. Assumed WS irrigated area is 125% of dry season rice area, so total irrigated = 2.25 x dry season area; balance assumed shallow rainfed. For Sarawak same source gives upland area; balance assumed shallow lowland. Sabah assumed same as Sarawak.

China: Allocation indicated by recent visitors to China, "90% irrigated." *Upland* reports 2% in UL in 1961, assumed constant %.

Korea: *Yearbook of Agriculture and Forestry Statistics*, Minist. of Agric. & Fisheries, Repub. of Korea, 1973. DPR assumed same.

Indonesia: Allocation to upland, deepwater, dry season estimated by R. A. Morris (personal communication, 2/15/75), based on data assembled by World Bank. Difference between total and above three types allocated half to irrigated and 25% each to SRF, MDRF.

Sri Lanka: Informed scientific opinion assembled by J. Wimberly (personal communication, May 1974). Data from published

statistics of Department of Agriculture are not as complete, but very similar. Dry season area from official statistics (Yala).

Japan: "Rice Statistics in Japan," by Hayami and Kikuchi, from offered statistics.

Burma: Deepwater area reported in 1965 in Irrawaddy Division = 84,536 acres, the "main deepwater area of Burma;" other areas total 10,000 acres, according to *Trip Report SKD*, Aug.-Sept. 1977. 94,536 acres = 38,256 ha. Total, irrigated and dry ("winter") acreage from *Agricultural Statistics*, 1973-74, 1974-75 and 1975-76, Burma, Minist. of National Planning, refer to 1972/73 and 1973/74 average.

Burma: Upland area derived from M. Y. Nuttonson, *The Physical Environment and Agriculture of Burma* by HEK, 1/21/75. Balance allocated to SRF and MDRF in the same proportion as irrigated and deepwater.

Thailand: Y. Gaesuwan, A. Siamwalla, and D. Welsch, *Thai Rice Production and Consumption Data 1947-1970*. Kasetsart University, Department of Agric. Econ., Staff Paper 13, June 1974 gives broadcast and transplanted areas. All broadcast assumed in "Central" region and assumed to be deepwater. Balance of "Central" assumed MDRF. South assumed MDRF, North and Northeast Thailand assumed SRF. Regional data from Div. Agric. Econ., Minist. of Agric. quoted in *Constraints, Interim Report* - Irrigated area of all crops from same source. Seventy five percent of irrigated area attributed to rice, 25% of irrigated rice area assumed to carry dry season crop, giving 6% of total rice as dry season, which agrees with conventional "estimates." Upland estimated at 10% total. MDRF and SRF allocated to remaining area in same proportion as DW and IRRIG.

Philippines: BAEcon data provide irrigated, nonirrigated, and upland area. Rainfed = nonirrigated + upland. Dry season is taken as second crop lowland area, which is given in BAEcon data. Source is *Data Series on Rice Statistics, Philippines*.

Vietnam: Allocation among types based on reply of T. P. Nien to questionnaire on basis of his informed scientific opinion about S. Vietnam. North given same allocation, though likely overstates deepwater, understates irrigated area.

Pakistan: All assumed to be irrigated, equivalent to dry season culture in SE Asia.

Nepal: Breakdown based on GSK's field trip report Oct. 9-13, 1973. All rainfed area assumed to be shallow rainfed, 128,000 ha in hills with temperate climate, rest in Tarai.

Brazil: *Upland* shows 77% in upland rice, balance assumed equally distributed to irrigated and MDRF.

Colombia: Grant Scobie, *Costs and Returns to Rice Research*, Consequences Discussion Paper No. 11 1976 shows yield and production data that result in this allocation.

USA: Assumed.

Egypt: Assumed.

Sierra Leone: *Upland* shows 60% upland, balance equally allocated to irrigated SRF, MDRF.

Guinea, Ivory Coast: Same as for Sierra Leone.

Malagasy: Upland area given in *World Rice Statistics* for 1961 balance allocated equally to other types.

Iran and Afghanistan: Judgment of WRC.

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Tropical climate and rice

S. YOSHIDA

Climatic factors such as temperature, sunlight, and rainfall influence the growth and yield of rice in two ways. Directly, they affect physiological processes involved in grain production, such as vegetative growth, development of spikelets, and grain filling. Indirectly, they affect grain yield through incidence of diseases and insects.

TAILORING RICE VARIETIES ADAPTED TO CLIMATIC CONDITIONS

From a crop physiologist's point of view, three important aspects of rice cultivation are crop period, productivity, and yield stability. Climatic factors affect each in different ways.

To a limited extent, the rice environment can be modified, as in the case of theplastic-covered nursery bed in temperate regions. The construction of irrigation and drainage facilities is man's most important effort to modify the rice environment, and maximize and stabilize rice yields. With the current situation in the tropics, however, it is unlikely that the provision of irrigation and drainage facilities for rice cultivation will expand greatly within a foreseeable period of time. More importantly, temperature in the field and solar radiation cannot be changed. At best plant breeders can modify rice varieties and better adapt them to existing environments. Or cultural practices can be adjusted to avoid some hazards.

A sustained effort in rice-growing countries and at IRRI has been the tailoring of rice varieties better adapted to climatic conditions. The desirable characteristics aimed at include sensitivity to day length, resistance to drought, tolerance for deepwater and flood, and tolerance for low and high temperatures. These topics have been discussed elsewhere (Parthasarathy and Rajan 1972).

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In the following sections I discuss two problems of varietal alterations:

- Plant height. A defect of high yielding dwarf varieties is short stature, which makes them unadapted to areas without dependable water control.

- Early maturity. Use of early maturing varieties is one way of making maximum use of the tropical climate. In the tropics, where temperature remains favorable for plant growth throughout the year, the ultimate concern is with total yield per year; in the temperate regions the concern is mostly with yield per crop.

IRRI varieties

An examination of IRRI varieties that is focused on growth duration and plant height gives some ideas of the limitations of IRRI varieties in different environments and what can be done to improve them.

There are 15 IRRI varieties known in the Philippines. They range from IR5 to IR42. Some of their characteristics follow (Fig. 1):

- They are either photoperiod insensitive or weakly photoperiod sensitive.

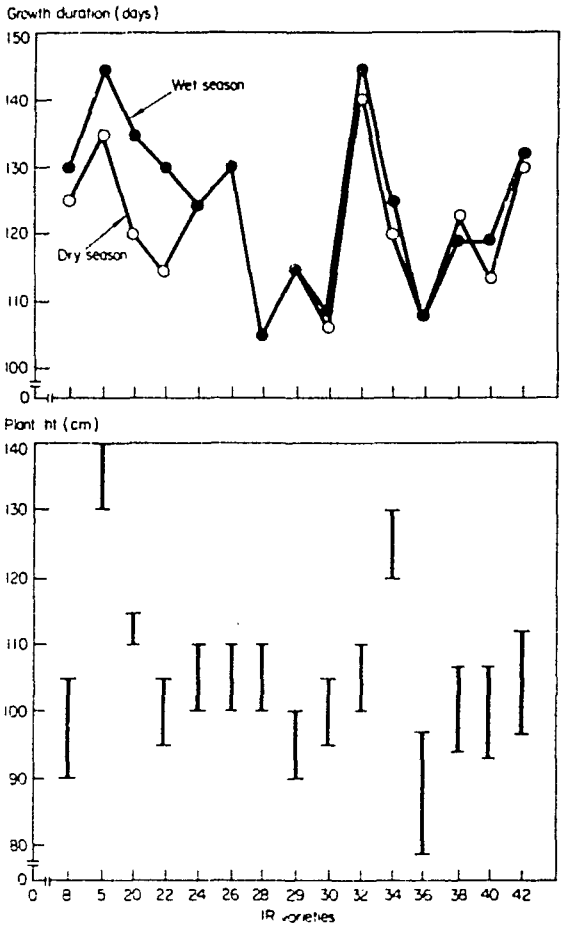
- Most have a growth duration of 105 to less than 130 days; only 4 (IR5, IR26, IR32, and IR42) have a growth duration longer than 130 days; 3 (IR28, IR30, and IR36) are early maturing.

- Only two (IR5 and IR34) are taller than 120 cm; the rest are mostly 100 to 110 cm tall. IR36 is extremely short.

Plant height

The traditional, tall, droopy-leaved rice cultivars in the tropics are popular because it is believed that they efficiently suppress weeds (Jennings 1966). There is evidence to support this notion (Table 1). Tall varieties are also more adapted to areas with less dependable water control.

Because the traditional varieties are generally tall, and the modern varieties generally short, a compromise would be varieties of intermediate plant height. The grain yield of a rice crop decreases as water depth increases (Table 2). The yield-decreasing effect of partial submergence could be attributed to impaired



1. Growth duration and plant height of IRRI varieties.

tillering and decreased photosynthetic leaf surface. The increase in plant height should counteract the effect of partial submergence. In one experiment with IR8 (Peta) and Bahagia (a sister line of IR5), Bahagia, which has intermediate plant height, suffered much less from moderate water depth than Ria (Sugimoto 1971). A similar experiment appeared to confirm that increased plant height is beneficial under partial submergence (Table 3). In this example, however, one semidwarf selection /T(N)1 x T.65/ performed well under partial submergence. The reason is not clear, but the data for panicle number suggest that vigorous tillering under partial submergence could be important.

Table 1. Yield reduction due to weeds, and plant heights 10 weeks after transplanting of various rice cultivars grown under different weeding regimes.[a]

Cultivar	Yield (t/ha) Weed free	Yield (t/ha) Unweeded	Yield reduction (t/ha) due to weeds	Av plant ht (cm)
IR1561-228-3-3	5.7	2.8	2.9	79.7
IR26	5.4	2.6	2.8	77.2
IR28	5.2	2.5	2.7	83.5
IR34	6.1	3.7	2.4	95.1
IR36	4.7	2.4	2.3	79.9
BG90-2	6.2	4.1	2.1	84.3
IR4816-70-1	6.3	3.5	1.8	91.8
IR1632-93-2-2	5.0	3.7	1.3	92.4
Binato	4.7	3.5	1.2	143.1
Peta	2.9	1.8	1.1	113.9

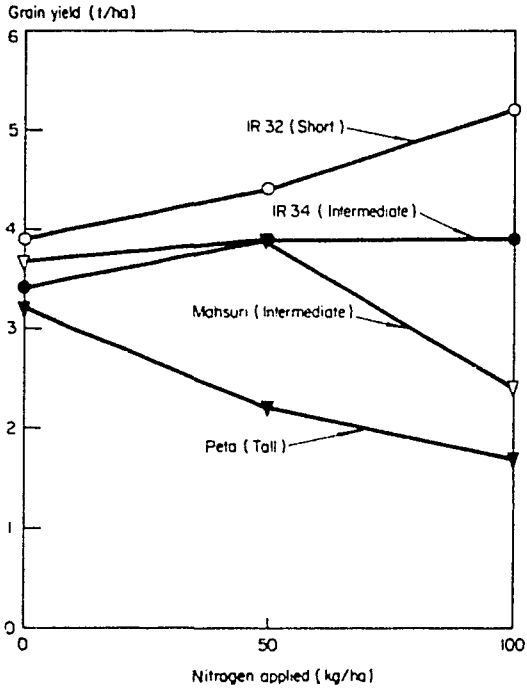
[a] Moody 1977.

Table 2. Yield of variety Jaya under three levels of submergence (25, 50, 75% of crop height) at each of the 3 growth phases during aman (July-Nov.) and boro (Jan.-April 1973-74).[a]

Plant growth stage	Ht of plant submerged	Relative grain yield (%) 1973 (aman)	Relative grain yield (%) 1974 (boro)
Control (continuous submergence 5 ± 2 cm)		100	100
Seedling establishment to maximum tillering	25%	82	75
	50%	75	62
	75%	68	58
Maximum tillering to flowering	25%	81	74
	50%	71	64
	75%	72	56
Flowering to maturity	25%	79	71
	50%	76	66
	75%	70	50

[a] Adapted from Pande 1976.

Increase in plant height, however, makes the crop more susceptible to lodging and decreases nitrogen response (Fig. 2). Mahsuri produced reasonably good yields at 0 and 50 kg N/ha, but it lodged at 100 kg N/ha. IR34, an improved intermediate-height variety, performed better than Mahsuri at 100 kg N/ha but its grain yield did not increase when nitrogen was increased from 50 to 100 kg/ha.



2. Response of four varieties to nitrogen application, 1976 wet season, IRRI.

Table 3. Effect of partial submergence on yield and yield components of 5 varieties.[a]

Variety	Treatment	Plant ht (cm)	Panicles (no./pot)	Grains (no./ panicle)	Relative yield (%)
Padura	Control	87	62	101	100
	Submergence[b]	91	59	89	84
T(N)1 x T.65	Control	92	57	82	100
	Submergence	99	61	85	107
IR8	Control	92	43	138	100
	Submergence	103	38	119	87
Jaya	Control	92	47	109	100
	Submergence	105	41	114	95
MTU 15	Control	154	46	93	100
	Submergence	156	45	102	100

[a] *Adapted from Vinaya Rai and Murty (1976).*

[b] Water depth was kept at 30 cm throughout the growth stage.

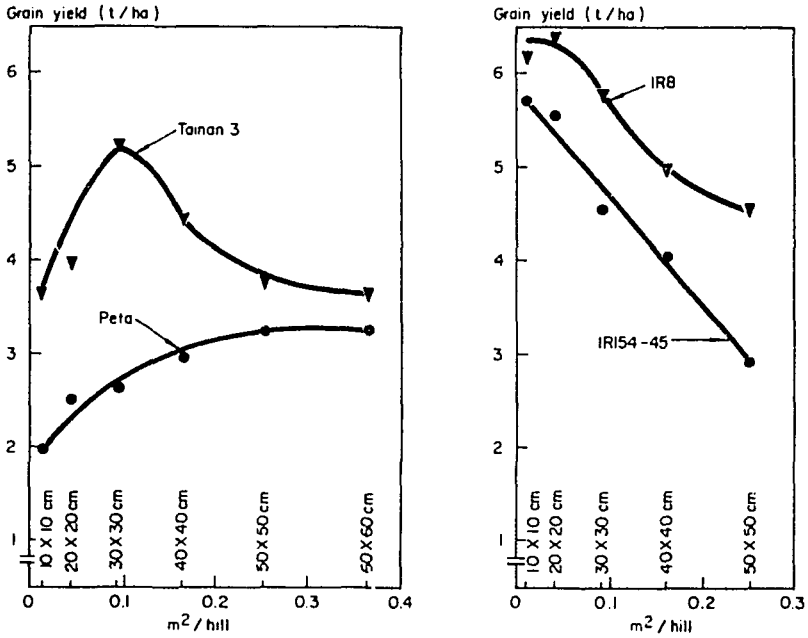
Plant height may cause spacing problems, too. Varieties of intermediate or tall plant stature tend to lodge at close spacings; short and lodging-resistant varieties give the highest yield at close spacings (Fig. 3, Tanaka et al 1964, Yoshida and Parao 1972). At close spacings and in partial submergence, culms of the rice plant tend to elongate more, and the crop may suffer more frequent lodging.

Intermediate plant height has recognized advantages where there is undependable water control, but those benefits may not be realized unless the varieties are made resistant to lodging.

Early maturity

There is increasing interest in early maturing varieties presumably because they allow increased cropping intensity. But at conventional spacings, varieties with short growth duration usually give lower yields (Table 4) because insufficient vegetative growth prevents them from achieving maximum yields.

Close spacing is essential for early maturing varieties to achieve high yields. The grain yield of IR747B2-6 at 5- x 5-cm



3. Yield of Tainan-3 and Peta at 6 spacings (left), 1962 wet season, and of IR8 and IR154-45 at 5 spacings (right), 1967 wet season.

Table 4. Effect of spacing on grain yield and daily production of 3 varieties. IRRI, 1970.[a]

Selection	Spacing (cm)	Growth duration (days)	Grain yield (t/ha)	Daily grain production in main field (kg/ha)
		Wet season		
IR747B2-6	5 x 5	95	5.62	75
	10 x 10	95	4.70	63
	20 x 20	95	4.15	55
IR22	5 x 5	114	4.92	52
	10 x 10	114	5.01	53
	20 x 20	114	4.57	41
IR8	5 x 5	124	5.32	51
	10 x 10	124	5.31	51
	20 x 20	124	5.14	49
		Dry season		
IR747B2-6	10 x 10	98	7.92	102
	20 x 20	98	7.23	93
IR154-18-2-1	10 x 10	110	7.23	80
	20 x 20	110	6.98	78
IR8	20 x 20	132	8.61	77

[a] IRRI 1971.

spacing was as high as that of IR8 in the wet season. In the dry season, IR747B2-6 produced about 8 t/ha at 10- x 10-cm spacing, and IR8 gave 8.6 t/ha at 20- x 20-cm spacing. At close spacings, therefore, the yield potential of IR747B2-6 can be nearly as high as that of IR8.

One clear benefit of early maturing varieties is high daily grain production. In both the wet and dry seasons, IR747B2-6 is about 30% more efficient than IR8 in daily grain production.

Another advantage of an early maturing variety is high water-use efficiency. Evapotranspiration of a paddy field is proportional to incident solar radiation and to the number of days the crop is in the field. Hence, a higher daily production gives a higher water-use efficiency.

As mentioned earlier, a disadvantage of an early maturing variety is that it requires close spacings to achieve high yield. In addition, it requires a high level of management because each day in the field contributes to maximum yield.

One question on early maturing varieties is how far growth duration can be shortened without sacrificing yield potential. For rice, the duration of panicle development before heading is fairly fixed at about 30 days. The duration of ripening is about 30 days in the tropics. Thus, about 60 days is necessary for reproductive growth and ripening. How many days are necessary for vegetative growth? Allocating 30 days for vegetative growth, the total growth duration of early maturing varieties is about 90 days. Using a 90-day variety and allowing 20 days in the seedbed leaves only 10 days for vegetative growth after transplanting. Obviously that is not sufficient.

Direct seeding appears essential for a 90-day variety to have sufficient vegetative growth before panicle initiation. For transplanted rice, about 100 days would be the shortest duration for achieving reasonably high yields. In the comparison above, the number of field days is shorter for a 100-day variety of transplanted rice than for a 90-day variety of direct-seeded rice. Among the materials available, IR747B2-6 is one of the best early maturing lines; it matures in 95-98 days (Table 4). IR28 matures in 105 days. Thus, attempts to shorten growth duration are approaching the limit for the shortest growth duration possible with high yielding potential.

Benefits and disadvantages of contrasting plant characteristics

Good environment and good management are assumed for the good plant type or the ideotype. Under those conditions, IR8 and similar semidwarf varieties are ideal. On the other hand, when diverse environments and different levels of management under which rice is grown are considered, the problem becomes specific to a given location and management level.

No single variety can meet all the requirements set by the different environments and management levels. Thus, it is important for plant breeders to recognize the benefits and disadvantages of contrasting plant characteristics (Table 5).

Apparently, gains in one aspect are accompanied by losses in another. Therefore, the choice of individual characteristics or their combination is bound to vary with location, conditions of culture, and level of use of inputs.

Table 5. Benefits and disadvantages of contrasting plant characteristics.

Plant characteristic	Benefits and disadvantages
Plant height	
Short	Increases resistance to lodging.
Tall	Suppresses weeds. Adapted to areas of less dependable water control.
Leaf inclination	
Erect	Uses solar energy efficiently when leaf area index is large.
Droopy	Uses solar energy efficiently when leaf area index is small. Suppresses weeds.
Tillering	
High	Adapted to a wide range of spacing; capable of compensating for missing hills; permits faster leaf area development (transplanted rice).
Low	Adapted to direct seeding.
Root	
Shallow, and low root-to-shoot ratio	Uses high proportion of assimilates for shoot.
Deep, and high root-to-shoot ratio	Increases resistance to drought. Uses soil nitrogen and recovers applied nitrogen efficiently.
Grain size	
Small	Related to fast grain filling, adapted to areas having drought at later stages of ripening.
Large	Has potential for high yields; requires longer ripening period.
Growth duration	
Early maturing	Increases grain production per day. Increases water-use efficiency. Requires close spacings to achieve yield potential.
Late maturing	Adapted to low fertility.
Photoperiod sensitivity	
Sensitive	Adapted to areas of a long monsoon season.
Insensitive	Can be grown any time of the year, fitted to multiple cropping systems.
Early growth	
Fast	Suppresses weeds. Essential to early maturing varieties.
Slow	Prevents excessive growth at later stages under good management.

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Rainfed lowland rice — problems and opportunities

CH. KRISHNAMOORTY

I use two key terms in this paper: *rainfed* and *lowland* rice. Rainfed rice is the crop grown either directly or indirectly with local rainfall. It includes the crop grown with supplemental irrigation, provided the water is not imported from another catchment; or with water from tanks and wells that depend entirely upon local rainfall. In other words, the term rainfed includes situations where the catchment and the command area are the same or have comparable climates, particularly rainfall. One characteristic of rainfed agriculture is the lack of control over amount and timing of water. Hence, moisture insufficiency as well as excess is encountered.

The term lowland is defined in the various publications of the International Rice Research Institute as bunded area that allows standing water to a depth of about 100 cm. It excludes uplands, which are unbunded, and the deepwater rice areas, where inundation may be 3 m or more.

A typical catena consists of upland, lowland, and deepwater rices grown in the different elements of topography. It is obviously a continuum and any attempt to rigidly define lowland rice is met with difficulty. However, because of variations in soil texture as one moves from the ridge to the slope and to the valley, the demarcation between upland and lowland is generally discernible. The lowlands are characterized by heavy soil texture. In short, drainage within the catchment differentiates the uplands from lowlands, and the drainage from the catchment decides the further subdivision of the lowlands.

In the uplands, moisture moves vertically and laterally in the subsoil. The lowlands are characterized by a better moisture regime because water exhibits a slow movement and seepage from the uplands contributes moisture over and above rainfall, a fact that greatly facilitates cultivation of lowland rice in areas where the rainfall is otherwise inadequate.

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The distinction between lowland rice and deepwater rice remains arbitrary. A 1974 workshop in Bangladesh subdivided deepwater rices into shallow, semideep, and floating rices. The subdivision shallow is common to the lowland and deepwater rices. It is hoped that this conference will arrive at an agreed description of lowland rice.

APPROACHES TO UNDERSTANDING THE RAINFED SYSTEMS

Rainfed lowland rice can be considered an extension of the irrigated lowland rice system with certain modifications, or one may proceed from the rainfed systems to gain an understanding of the specific requirements of lowland rice. Hitherto most of the studies and concepts concerning rainfed lowland rice have been developed starting from the irrigated lowland rice system. Because irrigated lowland rice has a rather stable and assured microenvironment, particularly with reference to moisture, the treatment of rainfed lowland rice as an extension of irrigated lowland rice has resulted in heavy concentration of effort on varietal improvement.

I believe this approach has not helped much in understanding the rainfed lowland rice system. One may, therefore, start with the rainfed systems and project into rainfed lowland rice. Thus, the primary dependence on rainfall and its vagaries, management of the land and water, and the specific cultural practices come to the forefront.

Crop improvement projects have, by and large, confined themselves to breeding of new varieties suitable for assured water supply, and have initially emphasized yield and, more recently, pest and disease resistance. Difficulties are faced immediately when those varieties are extended to *marginal* environments, that is, rainfed conditions. The preoccupation with elite varieties and high yield also resulted in varieties that did not fit into the growing season and the farmers' cropping systems. I do not intend to say that the breeders should stop looking *beyond the horizon*; they should also pay attention to the realities of the farmers' world.

Because plant expression and crop performance are the result of a genotype-environment interaction, improvement of the environment itself can give visible yield increases from the existing genotypes (local varieties) and, equally important, can make the specifications less stringent for the genotypes the breeder must evolve. This is an area in which the breeder and the agronomist should closely cooperate. The breeder should

attempt to overcome specific and predictable stresses through new varieties, and the agronomist should overcome nonspecific unpredictable stresses through appropriate management practices.

SOIL AND CLIMATE REQUIREMENTS

The most important soil requirement for rice is low seepage rate. This requirement is readily fulfilled in medium to heavy textured soils. Seepage is dependent on the exchangeable sodium percentage (ESP) of the soil. Recent studies indicate that in the case of montmorillonitic clays (black soils) seepage losses are drastically reduced if the ESP is of the order 5-8%. Even in loam soils seepage losses are considerably reduced if the ESP reaches a value of 20%. It is fortunate that rice is not sensitive to exchangeable sodium and the yields are not reduced significantly if the ESP is less than 30%.

Rainfed rice can best be grown in areas receiving not less than 200 mm of rainfall/month for a minimum of 3 months. The 200 mm/month is based on 6-7 mm of daily evaporation. Besides direct rainfall there is the contribution of water through seepage and runoff from uplands into lowland rice paddies. Another important requirement is that days between two rainfalls should not exceed 7-10.

SYSTEMS FOR RAINFED LOWLAND RICE

Two well-defined systems of rainfed lowland rice exist. The first and the most obvious is the one in which the system is wet throughout the life cycle of the crop, i.e. puddled and inundated during the entire life cycle. Obviously such a system is practiced only in areas of high rainfall or in areas that receive supplemental irrigation.

Alternatively, in the relatively low-rainfall areas, it is possible to develop a system of rainfed lowland rice starting with dry and ending up with a wet paddy. In this system, rice is dry drilled in the early part of the monsoon; when the heavy rains arrive, the system is converted to wet by impounding water.

The system that is wet throughout is more productive, but the risks are higher. In case of insufficient rainfall, the wet paddies are more susceptible to drought injury.

ABERRANT WEATHER

There are four types of contingencies (aberrant weather) based on the amount and reliability of rainfall received during the vegetative and reproductive phases of the rainfed lowland rice.

- *Rainfall during the vegetative and reproductive phases is adequate and assured.* This is the ideal. No special problems are encountered. The choice of variety is based on the length of the growing season.

- *Rains during the vegetative phase are inadequate and unreliable, but rains during the reproductive phase are adequate and reliable.* In this case two alternatives are possible. First, instead of waiting for heavy rains and losing the growing season, dry drilling of rice followed by conversion to wet later in the season is recommended. For the practice of dry drilling, it is necessary to adopt year-round tillage to prepare a weed-free field so that rice can be drilled at the earliest opportunity. Because tillering is less under these conditions, it is necessary to use a high initial population (seed rate of about 100 kg/ha) to reduce dependence on tillering. The other alternative is to use photoperiod-sensitive varieties and to transplant them when rains are sufficient for puddling and transplanting.

- *Rains are adequate and reliable during the vegetative phase but inadequate and uncertain in the reproductive phase.* Again two alternatives are available. The first is to provide supplemental irrigation by storing the runoff from the early rains. The other is to select shorter duration varieties that would ripen with limited moisture.

- *Rainfall is inadequate and uncertain during both the vegetative and reproductive phases.* Under this condition rainfed lowland rice and rice in general would be extremely risky. Crops other than rice should be preferred. Maize, sorghum, and finger millet are recommended.

CASE STUDIES

India

India grows 38 million ha of rice, of which only 38% is irrigated. Thus, nearly 60% of the rice land is rainfed and accounts for 40% of production. The rainfed area is subject to vagaries of the weather and shows high fluctuation of yield.

Table 1. Net area irrigated by various sources of irrigation in India, 1972-73.

Region[a]	Net irrigated area (million ha) by source[b]					Total
	Canals	Tanks	Wells		Others	
			Tube	Others		
Central	4.07	1.58	2.68	3.53	0.46	11.32
East	2.84	0.61	0.52	1.32	1.18	5.47
North	2.61	0.006	1.95	0.38	0.11	5.05
South	3.04	2.20	0.12	1.66	0.37	7.39
West	0.51	0.23	0.11	1.76	0.13	2.74
All India	13.07	3.62	5.38	7.65	2.25	31.97

[a] Central - states of Madhya Pradesh, Rajasthan, and Uttar Pradesh
Eastern - mostly states of Assam, Bihar, Orissa, and West Bengal.
Northern - states of Haryana, Himachal Pradesh, Jammu and Kashmir, and Punjab.
Southern - states of Andhra Pradesh, Karnataka, Kerala and Tamil Nadu.
Western - states of Gujarat and Maharashtra.

[b] Data from Directorate of Economics & Statistics, Ministry of Agriculture and Irrigation, Government of India.

The net area irrigated by various sources, as of 1973, is given in Table 1. It is clear that of the 32 million ha of various crops irrigated, only 18.4 million ha are fed by canal systems or tube wells and have assured irrigation. The remaining 13.6 million ha are irrigated from tanks, open wells, or other sources. In southern and western India, tanks and open wells are the major sources of irrigation.

Table 2 gives the area and production of rice in the various states as of 1974-75. It is particularly noteworthy that Bihar, Uttar Pradesh, Orissa, Madhya Pradesh, and Gujarat have 19 million ha in rice, which are almost entirely rainfed and produce below average yields.

On the Chotanagpur plateau of Bihar and in the districts of Purulia and Bankura of West Bengal, farmers wait for the heavy rains before puddling and transplanting lowland rice. The practice often results in a shortened growing season, and the transplanted crops run out of moisture during the reproductive phase. To overcome this problem year-round tillage is recommended to prepare a weed-free field and allow early dry seeding. The dry rice is converted to wet when the heavy rains arrive in late July or early August.

In Madhya Pradesh, a *biasi* system of cultivation is followed. In adjoining parts of Orissa a *bushening* system of rainfed lowland rice cultivation is practiced. The land is prepared as for dry crops and rice is broadcast. When the heavy

Table 2. Area, production, and yield of rice in various states of India, 1974-75.

State	Area (million ha)	Production (million t)	Yield (kg/ha)
	Above average yield		
Pondicherry	0.027	0.08	2993
Punjab	0.570	1.18	2072
Jammu & Kashmir	0.238	0.46	1916
Tamil Nadu	2.250	4.17	1855
Karnataka	1.230	2.08	1687
Andhra Pradesh	3.550	5.70	1604
Kerala	0.880	1.33	1513
Haryana	0.275	0.39	1425
West Bengal	5.420	6.54	1207
	14.440	21.93	1519
	Average yield		
Tripura	0.299	0.33	1091
Meghalaya	0.100	0.107	1066
Maharashtra	1.324	1.41	1063
Himachal Pradesh	0.092	0.097	1051
Assam	2.058	1.98	963
	3.873	3.924	1013
	Below average yield		
Bihar	5.228	4.559	872
Uttar Pradesh	4.488	3.489	777
Orissa	4.432	3.166	714
Madhya Pradesh	4.526	2.409	532
Gujarat	0.367	0.178	484
	19.041	13.801	725

rains arrive, the field is wet plowed crisscross with a local plow, the object being to remove the weeds and reduce crowding of the seedlings. At the same time, gaps are filled with seedlings from crowded parts of the field. The productivity of rainfed lowland rice in such areas could be improved by line sowing. However, the practice of line sowing requires a weed-free field, and a heavy seed rate is essential to make up for low tillering.

In Andhra Pradesh, tank-irrigated rice is particularly important in the districts of Srikakulam, Visakhapatnam, Ongole and Nellore of the coastal region, in all districts of Rayalaseema except Kurnool, and in all the districts of the Telangana region, except Nalgonda and, to some extent, Nizamabad districts. Canal systems cover 50% of the 3.573 million ha in the State, and the

remaining 50% is irrigated from either tanks or open wells and comes under the category of rainfed.

Almost the entire rice area of Chittoor district is rainfed lowland provided with water from tanks and wells.
the uncertainty of rains in the early part of the monsoon, the usual practice in the eastern parts is to dry seed and convert to wet paddies when the monsoon is active in October-November. In the western parts of the Chittoor district, which enjoy both southwest and northeast monsoons, rice is transplanted and photoperiod-insensitive varieties, particularly the high yielding varieties, have become popular. Some of the highest yields in the State are obtained in this district with water from wells. Because of the extremely coarse-textured soils in the Telangana region, almost all the lowland rice is treated wet throughout, i.e. the land is puddled and the seedlings are transplanted. In some parts of the region, the practice is to grow a catch crop of mung bean (*Phaseolus aureus*) in the early part of the monsoon and to transplant rice in the first week of September.

Thailand

Thailand grows about 8 million ha to rice. Except for a small irrigated area in the central region, the rest is all rainfed lowland. The north and northeast are particularly important for improving rice production in Thailand. In the northeast the rainfall is somewhat lower and less dependable. On the basis of existing information, the recommendations for the northeast are:

- Dry seeding of rice as early as possible in the weed-free seedbed. An alternative is transplanting photoperiod-sensitive varieties, which flower in the second week of October (± 5 days).

- Fertilizing the crop only when it is in the panicle initiation stage, because the rainfall is much more dependable after this stage.

CROPPING SYSTEMS

Most of the lowland rice areas in India, Bangladesh, Thailand, Malaysia, Indonesia, and the Philippines are potentially two-crop areas. It is, therefore, necessary to make adjustments in rice growing so that the system as a whole becomes more productive.

In North India lathyrus, lentil, linseed, safflower, mustard, gram, barley, and wheat follow lowland rainfed rice. Lathyrus, lentil, and linseed are sown broadcast in the standing rice crop just before harvest. The other crops are grown after tillage and field preparation after rice harvest. In the south where the temperatures are warm, a rice-rice sequence is common in rainfed lowland rice. Recently, wheat after rice has become popular where there are wells. There is a growing interest in the use of residual moisture for raising groundnut and hardy crops such as safflower after rice.

In Malaysia a number of upland crops such as maize and soybean follow rainfed lowland rice.

In the Philippines, a rice-rice sequence has been successfully developed in some areas where only a single crop of rainfed lowland rice was being grown.

ACTION PROGRAMS FOR RESEARCH AND DEVELOPMENT

The more important action programs for research and development are given here. The list is by no means exhaustive.

Criteria for lowland and deepwater rice culture

In contrast to the sharp distinction between upland and lowland rice, the transition from lowland to deepwater rice is less abrupt. The criterion for differentiating lowland and deepwater areas is the depth of standing water. Although this criterion is still valid, it could be revised on the basis of an understanding of the effect of depth of standing water on the physiological processes governing the growth of the rice plant. For instance, the water depth where tiller initiation is not appreciably delayed may be considered as the upper limit for lowland rice.

There is some information that rice yield is not drastically reduced if three to four leaves emerge and function above the water surface. Hence, the definition of lowland rice is based not only on water depth but also on the plant type and its phenotypic expression.

What is perhaps most immediately needed is the categorization of lowland rice (including deepwater) and an estimate of the area growing each category. Knowledge of the extent to which each environment could be modified would help in the development of suitable approaches and assignment of priorities for research and development.

Climatic analysis for drought and flood characterization

An analysis of the long-term data on climate, particularly rainfall, would give an estimate of the growing season and hence identify the varietal diversification within a given maturity zone. In addition, methods that are capable of identifying the period and duration of drought and moisture excess should be developed. The latter should include the anticipated runoff and its time of occurrence, and cumulative runoff that would be available during the season. Such an analysis would allow us to decide which to prefer -- a dry-wet lowland rice system or a wet system throughout. It will also help in devising crop-saving practices.

Runoff recycling

The term runoff recycling includes moisture conservation in situ as well as utilization of the inevitable runoff. Obviously this area of research and development is more important in the dry-wet system where the object is to minimize moisture deficiency in the dry-seeded crop and to convert the crop into wet later in the season.

Runoff recycling is also important in the development of cropping systems, particularly when winter crops follow rice.

Common contingencies and alternatives

An analysis of long-time records is generally useful for planning at the macro level, but the weather for rainfed rice growing is uncertain. It is necessary to characterize the common deviations from the normal and to develop alternatives to overcome such contingencies.

Crop life-saving research

Ratooning of sorghum and pearl millet has developed as a *crop life-saving operation* in rainfed areas. An open question is whether it is possible to develop a similar system for rice. It is well known that ratooning of rice has not proved satisfactory, but little information is available on the ratooning ability of rice. Is it possible to develop a system of ratooning a moisture-stressed rice crop to take advantage of certain rains later in the season?

A related problem is the late planting of photoperiod-sensitive varieties. With GEB24, which normally flowers in the third week of October, the Indian experience is no drastically reduced yields if there is an interval of about 7-8 weeks

between planting and flowering, i.e. GEB24 can be planted as late as the first week of September. Some farmers use the early part of the monsoon for raising a green-manure crop, which is plowed under, and the lodging problems of late-planted GEB24 are far less severe. The question to be resolved is, how long can the transplanting of photoperiod-sensitive rice varieties be delayed?

Low-cost inputs and their management

The two major constraints in rainfed agriculture, irrespective of the crop, are stand establishment and pest (weed, insect, and disease) management. Some of the ideas developed on primary tillage and its timing, and weed management during the off-season are summarized in the paper on tillage (De Datta, Morris and Parker, this volume). The advantage of year-round tillage is a firm weed-free field, which facilitates early sowing and good stand establishment.

Poor stand establishment may be caused by low seed rate, failure of seedlings to emerge, and early seedling mortality. The remedy for low seed rate is farmer education. With minor modifications on native implements, it is possible to develop seeding practices that give satisfactory crop stand. Instead of sowing behind a country plow, a seed tube may be used to ensure that the seed is placed in firm contact with the moist soil. Once the crop is sown in lines it is possible to directly use native implements or modify them for interculture and weeding.

Considerable work has been done on pest management through the evolution of resistant varieties. Because it is difficult to incorporate resistance to all the major pests and diseases, it is still necessary to adopt cultural practices and minimum use of pesticides. There is considerable evidence that irrespective of the crop, early sowing gives a distinct advantage. The general advantage is seedling vigor, which enables the crop to overcome nonspecific and nonlethal pests and diseases. In addition, there is the advantage of minimizing specific pest and disease problems, e.g. gallfly.

All the preceding points have been recognized in India as vital to kharif rice, which is mostly rainfed.

Fertilization

Fertilization of rainfed crops should be designed to optimize input use and minimize risks. Split application of nitrogen is a recognized way of overcoming risks. The levels of nitrogen

and their timing should be worked out specifically for each situation.

SUMMARY AND CONCLUSIONS

Nearly 50% of the world's rice area is rainfed lowland. The risks and hazards associated with lowland rice are due largely to weather and associated pest problems. Control over the system is least when it is directly rainfed. In such cases risks are mitigated to some extent by the choice of the climatic zones in which lowland rice is grown. Best control is achieved through supplemental irrigation from tanks and wells.

When there is good control over the system, as in the case of irrigation from wells, the objective should be high yields. For conditions of less control, approaches should be developed to minimize risks; stability of productivity and production then become particularly important. The need is to develop systems of lowland rice culture capable of capitalizing on years of favorable weather. It is understood that in years of bad weather such systems may not prove superior to those traditionally practiced by the farmers.

Rainfed Lowland Rice in Selected Countries

Rainfed lowland rice in Bangladesh

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The total rice area of Bangladesh is about 10.3 million ha. Only 1.1 million ha are irrigated, and the rest are rainfed. The rainfed area includes drought-prone upland areas and areas where rice is grown in water 4.5 m deep. The area with water depths of 5-100 cm, which is designated as rainfed lowland for this paper, comprises about 66.8% of the total rice area. Therefore, rainfed lowland rice in Bangladesh occupies an important place in the economy. Although favored by rainwater, the rainfed lowlands have many problems arising from the four rice seasons with their different ecological conditions. The concept of semidwarf or short-statured, photoperiod-insensitive varieties has been found inadequate to solve the problems.

TYPES OF RICE CULTURE

Bangladesh has four different, but overlapping, rice crop seasons. They are aus (March to September), broadcast aman or deepwater rice (March to December), transplant aman (June to December), and boro (November to May).

Table 1 shows 5.2 million ha are transplanted and 5.1 million ha are direct- or broadcast-seeded. From another viewpoint, photoperiod-sensitive varieties grow in 5.6 million ha, and photoperiod-insensitive varieties are in 4.7 million ha The classification in Table 1 has 15 subgroups, 10 of which belong to the different ecological conditions of rainfed lowland. Rainfed lowland rice occupies 66.8% of the total rice area and the 10 ecological groups demand appropriate emphasis for the improvement of the crop for the area.

VARIETAL GROUPS AND CHARACTERISTICS OF RAINFED LOWLAND RICE

Table 2 presents the comparative importance of different varietal groups growing as rainfed lowland. Transplant aman occupies the

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Table 1. Area, types of culture, and rice varietal groups in Bangladesh, 1978.

	Area (million ha)				
	Transplant		Broadcast		
	Photoperiod sensitive	Photoperiod-insensitive	Photoperiod sensitive	Photoperiod-insensitive	Total (million ha)
Upland, unbunded				1.00	1.00
Irrigated					
1st crop (monsoon)		0.10			0.10
2d crop (dry boro)		1.00 (boro)			1.00
Shallow rainfed lowland (5-15 cm)	1.80	0.20		1.00	3.00
Intermediate rainfed lowland (16-49 cm)	1.30		0.10	0.98	2.38
Semideep rainfed lowland (50-100 cm)	0.70	0.10 (local boro)	0.50	0.20	1.50
Deepwater (100 cm +)			1.20	0.12	1.32
Total	3.80	1.40	1.80	3.30	10.30

Table 2. Rice varietal groups in three water regimes of rainfed lowland in Bangladesh, 1978.

Varietal group	Area (million ha) occupied by varietal groups			
	Shallow rainfed lowland	Intermediate rainfed lowland	Semideep rainfed lowland	Total
Aus	1.20	0.98	0.20	2.38
Transplant aman	1.80	1.30	0.70	3.80
Broadcast aman	-	0.10	0.50	0.60
Boro	-	-	0.10	0.10
Total	3.00	2.38	1.50	6.88

largest area. All four groups have the common characteristics of height (about 150 cm), plant type, and yield potential. Short-plant-type varieties do not have much access to the rainfed lowland area and, as such, the impact of the modern high yielding varieties on total rice production has not been significant.

About 64% of the rainfed lowland area grows photoperiod-sensitive rice varieties, which enjoy certain advantages during the seasons over the photoperiod-insensitive varieties. Most modern varieties are photoperiod-insensitive; only a few are slightly sensitive, and have not been accepted widely. Of the photoperiod-sensitive varieties, broadcast aman occupies about 600,000 ha. These varieties can elongate with rising flood and are also considerably drought resistant.

Aus occupies 2.38 million ha. These varieties are photoperiod insensitive and drought resistant, and have short duration (85 to 120 days). Being drought susceptible and of long duration, most modern varieties are not generally suitable.

About 0.7 million ha of transplanted aman and broadcast aman in rainfed lowlands are affected by tides at the coastal belt. The local varieties are tolerant of the prevailing tidal conditions, but inland varieties of similar characteristics cannot grow.

In general, aman varieties are tolerant of cold weather at the reproductive stage and boro varieties are tolerant of cold weather at the vegetative stage.

To cover the risks of drought and flood, a considerable area is mix planted with aus and broadcast aman. The quick-growing, photoperiod-insensitive aus varieties combine satisfactorily with slow-growing, photoperiod-sensitive broadcast aman varieties. The modern short varieties are not suited for the purpose.

The characteristics of the varietal groups are adaptive mechanisms for the prevailing ecological conditions. Unless the ecological conditions change, any new varieties developed should have these characteristics in addition to the basic characters needed for high yield potential.

RICE PRODUCTION AND PRODUCTIVITY

Rice production in Bangladesh has not been as high as expected after the development of the modern rice varieties. The modern varieties (with high yield potential) have covered only 15-18% of the total rice area and provide 30-35% of total production. The impact of this increased production has significantly alleviated the chronic shortage of food due to population increase. Table 3 presents an estimated present average yield of different groups of rice varieties.

Since 1975 modern varieties like BR 4 (Brrisail), BR 5 (Dulhabhog), and BR 7 (Brribalam) have been recommended and two more varieties, BR 8 and BR 9, are being considered for recommendation. These varieties have intermediate stature and are expected to cover wider rainfed lowland areas. With the present trend in technological improvement, the expectation of higher rice production within 10 years appears reasonable. We expect improved varieties for deepwater, coastal belt, and drought-prone areas to be possible within the next 10 years.

Table 3. Rice production and productivity (t/ha) under different rice cultures and varietal groups, 1978.

Type of culture	Present average yield	Present potential yield	Foreseeable potential in 10 yr
Upland, unbunded	1.00	1.50	1.75
Irrigated, wet	2.50	3.50	4.00
Irrigated, dry (boro)	3.50	4.50	4.50
Shallow rainfed lowland (5-15 cm)	2.00	2.50	3.00
Intermediate rainfed lowland (16-49 cm)	2.00	2.25	2.50
Semideep rainfed lowland (50-100 cm)	1.50	1.50	1.75
Deepwater (100+ cm)	1.25	1.25	1.50
National average	1.80		

CULTURAL PRACTICES FOR RAINFED LOWLAND RICES

Land preparation, weed control, fertilizer management, water management, and time of seeding differ considerably for the two methods transplanting and direct-seeding. Time of planting varies considerably with water depth. The rainfed pattern and water depth also dictate whether one should direct-seed or transplant. Soil texture also affects the choice of planting method. For convenience in weed control, line seeding is considered better than broadcasting; for economy of soil moisture, dibbling is better than line sowing.

Major cropping patterns

Four main cropping patterns are recognized in the rainfed lowland areas. They can be further divided into one or more subtypes. The major patterns are linked with elevation, soil moisture and types, duration of flooding, etc.

1. *Aus-jute + transplant aman + fallow or pulse crop* is a typical pattern on moderately permeable soils, common in the Tista and Brahmaputra floodplains, parts of Madhupur tract, eastern parts of Sylhet, Comilla, Noakhali and Bhola subdivision, and Chittagong coastal plains. The pattern is also followed in the irrigation projects. Aus is usually broadcast, but it is transplanted where rainfall is higher and earlier. Jute substitutes for aus rice in the Tista-Brahmaputra floodplains. In some regions, after transplant aman the land is fallowed or winter crops such as pulses and vegetables are grown.

2. *Transplant aman (single crop)* is widespread on the Barind tract, tidal areas of Khulna division, Noakhali charland, parts of Dinajpur and Rangpur, and in scattered areas in other districts. Conversion of part of single crop of transplanted aman to double-cropped rice deserves attention.

3. *Transplant aman + boro* is common in shallow and intermediate water regimes where tube wells, low-lift pumps, or gravity irrigation have been provided in recent years. Such areas are found scattered within patterns 1 and 2.

4. *Mixed aus and broadcast aman + winter crops* is a widely practiced pattern in shallow to moderately flooded areas (semideep) on the Brahmaputra, Jamuna, and Ganges floodplains and parts of the old Meghna estuarine floodplain. In all areas jute replaces mixed aus and broadcast aman. In some areas jute is intersown with broadcast aman in place of aus. This region represents most of the triple-cropped area in Bangladesh. Some areas (Chandpur-Daudkandi) even produce four crops a year. Aus mixed with broadcast aman, grass pea, or black gram is intersown through the aman, and in January-February sesame or millets are grown. A wide range of dryland winter crops is grown: mustard, linseed, lentil, gram, wheat, barley, millets, chili, tobacco, various vegetables, and spices. This pattern is possible because of the early harvest of broadcast aman in October-November.

PRESENT STATUS OF RAINFED LOWLAND RICE RESEARCH

The breeding program for rainfed lowland rice emphasizes taller seedlings with intermediate plant height. Because the rainfed lowland area covers all rice seasons and groups, the breeding objectives are based on the requirement of each season and group. Photoperiod sensitivity is required for transplant and broadcast aman, short growth duration for transplant aman, and tolerance for cold at the reproductive stage for both aman groups. Boro varieties require cold tolerance at the vegetative stage. Aus and broadcast aman need tolerance for upland cultures. An aus variety should have seedling vigor, intermediate to tall plant height, short growth duration, and good grain quality. On the other hand, broadcast aman will need elongation ability.

For all rice groups, resistance to common diseases is also emphasized. Maximum attention is directed toward shallow to intermediate rainfed areas where aus and transplanted aman are grown.

Intermediate to tall plant types and both photoperiod-sensitive and photoperiod-insensitive varieties are needed.

The new intermediate and tall plant statures should have lodging resistance.

All those plant characters are actively sought in the research program at the Bangladesh Rice Research Institute (BRRI). A few varieties have already been released and more are expected to be released in the near future. In Bangladesh, the most important breakthrough is expected in the rainfed lowland area.

Rainfed lowland rice in Burma

OHN KYAW and P. B. ESCURO

About 9.3 million ha or about one-seventh of Burma's total land area is presently cultivated and about 5.1 million ha (55%) of that is used for rice. Rice is grown throughout the year, where sufficient water is available.

The rice areas with different environmental conditions are shown in Table 1. The figures show that lowland rice covers 87% of the total rice area. Practically all the areas in rice in the high rainfall regions of southern Burma are rainfed.

The low-lying areas, which are difficult to drain in the high rainfall regions, generally grow deepwater or floating rice. In some places these lands are left unplanted during the monsoon and then grow early lowland varieties with residual soil moisture toward the end of the rainy season.

The irrigated rice areas are generally found in the drier parts of central Burma. Most of the upland rice areas are in the hilly regions bordering the plains. In some places shifting cultivation of upland rice is still found.

PRINCIPAL RAINFED LOWLAND RICE VARIETIES AND THEIR CHARACTERISTICS

In the shallow to intermediate rainfed lowland regions, varieties grown are usually medium to medium-late maturing, photoperiod insensitive or sensitive, and medium to medium tall in stature. Locally improved varieties are generally grown in about 23% of the total rice area. Because of their large number, not one occupies a wide area. One, Ngwetoe (C53-39), however, was grown consistently on more than 40,000 ha yearly during the last few years. Ngwetoe is adapted to low-lying, high rainfall regions. It is medium tall but lodging resistant, responsive to nitrogen fertilizer, and strongly sensitive to photoperiod. Farmers plant it early in June when the water conditions in the fields are right for land preparation and transplanting. It is harvested soon after the monsoon is over in November to December.

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Table 1. Growing conditions of rice in Burma.

Growing condition	Area (thousand ha)		Percent	
Rainfed lowland		3564.0		70
Normal plains	3428.8		67	
Saline	135.2		3	
Irrigated		871.2		17
Deepwater		498.4		9
Upland		183.2		4
Total		5116.8		100

A few introduced improved lowland varieties are also grown in the rainfed lowland areas. One of them, IR5, was introduced from IRRI in 1968 and is now grown on more than 250,000 ha. It is medium maturing, nonphotoperiod sensitive, intermediate statured, fairly lodging resistant, and capable of producing high yields.

Traditional medium-late to late maturing, strongly photoperiod-sensitive, tall to very tall lodging varieties with low yielding capacity are grown in large areas of the intermediate to semideep rainfed lowland category. They are sown in June, transplanted in July-August, and harvested in December-January.

Where salinity is a problem because of intrusion of tidal seawater late in the season, salt-tolerant varieties are grown. The agronomic characteristics of such varieties do not differ much from those of the locally improved or traditional lowland varieties, except that they can tolerate usual field salinity conditions. Their grain characteristics, however, are not as good as those of the varieties that are not tolerant of salinity. Cenapu is an introduced salt-tolerant variety that is gaining popularity.

In the limited, short-rainfall rainfed areas of the central plains, very early maturing lowland varieties and upland-type varieties are grown.

RICE PRODUCTION AND PRODUCTIVITY

Statistics on production of rice by different types of rice culture in Burma presently are not available. Table 2, however, gives an indication of production and productivity. Sagaing, Mandalay, and Magwe divisions are mostly irrigated. The four

Table 2. Total production and productivity of rice in Burma by state or division, 1976-77 wet season.

State or division	Area of mature rice (thousand ha)	Production (thousand t)	Productivity (t/ha)
Mon	264	443.6	1.68
Karen	186	190.0	1.02
Kayah	22	28.7	1.30
Shan	298	424.9	1.42
Kachin	113	191.6	1.69
Chin	31	30.2	0.97
Arakan	327	548.5	1.68
Sagaing	482	854.7	1.77
Mandalay	292	515.9	1.77
Magwe	166	294.0	1.77
Pegu	895	1908.9	2.13
Irrawaddy	1311	2671.5	2.04
Rangoon	500	934.6	1.87
Tenasserim	83	121.1	1.46
Total	4970	9158.2	1.84

other divisions are essentially rainfed lowland, including deepwater and some saline-water areas. The data indicate that the rainfed lowlands, except Tenasserim division, are slightly more productive than the irrigated areas. Their yields range from roughly 1.9 to 2.1 t/ha.

The lower yields (about 1.8 t/ha) in the irrigated divisions, despite the predominance of improved varieties, can be attributed to lower native soil fertility, lack of fertilizers, and poor crop management. Last year's special rice production projects in three selected townships demonstrated that yields can be doubled, or even trebled, when suitable improved varieties are grown with adequate inputs and recommended cultural practices.

The productivity of upland rice is low, as shown by the

Table 3. Present and potential yields of different types of rice culture in Burma.

Type of culture	Present yield		Yield potential in 10 years (t/ha)
	Average (t/ha)	Potential (t/ha)	
Upland, unbunded	1.0	1.5	2.5
Irrigated, wet season	3.0	4.0	5.0
Irrigated, dry season	3.5	5.0	6.0
Shallow rainfed lowland (5-15 cm)	2.0	3.0	4.0
Intermediate rainfed lowland (16-49 cm)	1.5	2.5	3.5
Semideep rainfed lowland (50-100 cm)	1.0	2.0	3.0
Deepwater (>100 cm)	0.8	1.5	2.0

yields of Kayah, Shan, and Chin states, which have predominantly upland rice areas. The yields are low (1.0-1.4 t/ha).

The present average yield, potential yield, and potential yield 10 years hence for each rice type are shown in Table 3.

CULTURAL PRACTICES FOR RAINFED LOWLAND RICE

The cultural practices for shallow to intermediate rainfed lowlands are essentially those for the irrigated areas. Pregerminated seeds are sown in nursery beds and seedlings are transplanted later. The field is plowed and harrowed with animal-drawn implements soon after the seeds are sown in the nursery. Because of better water control, land preparation in the irrigated areas is generally more thorough than that in the rainfed areas. Because most varieties grown with irrigation are photoperiod insensitive, the seedlings are generally transplanted earlier than in the rainfed lowlands. Water control is difficult in rainfed fields; thus weeds generally grow more abundantly than in irrigated areas, and more weeding is necessary.

In the rainfall-short rainfed lowlands, the seedlings sometimes cannot be transplanted on time and become overage. Transplanting overage seedlings, particularly of early maturing varieties, results in fewer productive tillers with few grains and low yields.

In semideep rainfed lowlands, dry seeds are sometimes sown directly on fields prepared dry, or pregerminated seeds are sown directly on puddled soil at the start of the rainy season, because water rises fast when the monsoon starts and transplanting and establishment of seedlings in deep water are difficult.

MAJOR CROPPING PATTERNS FOR RAINFED LOWLAND RICE AREAS

Rainfed lowland rice is grown in an estimated 3.6 million ha. At present, the crops grown in nonrice seasons, particularly in the shallow to intermediate rainfed lowland category, are sesamum, groundnut, jute, pulses, and vegetables. The area grown to various crops other than rice totals slightly more than 400,000 ha, or about 11.2% of the total rainfed lowland rice land. The area of all nonrice crops is fast expanding and at least two more crops (corn and sunflower) are being introduced into the cropping system. The area is expected to increase to about 897,000 ha or about 25% of the rainfed lowland rice lands in the future. Table 4 shows the present and potential areas of these crops.

Table 4. Present and potential area of nonrice crops in rainfed lowlands of Burma.

Crop	Present nonrice area		Potential nonrice area	
	Ha	% of rice area	Ha	% of rice area
Sesamum[a]	50,581	1.4	97,500	2.7
Jute[a]	44,152	1.2	117,000	3.3
Groundnut[b]	102,526	2.9	195,000	5.5
Pulses[b]	142,235	4.0	195,000	5.5
Vegetables and other crops[b]	61,216	1.7	97,500	2.7
Corn[b]	-	-	78,000	2.2
Sunflower[a, b]	-	-	117,000	3.3
Total	400,710	11.2	897,000	25.2

[a]Before rice crops. [b]After rice crop.

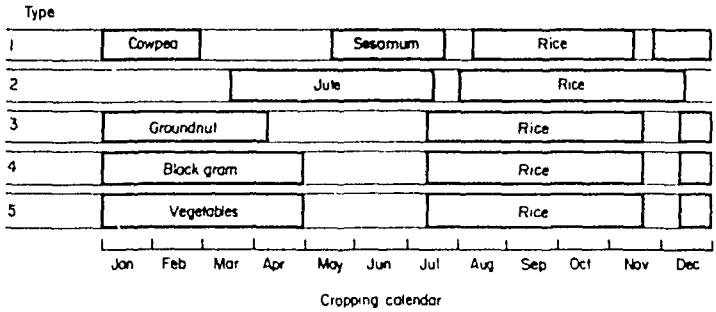
The cultivation of early sesamum, jute, groundnut, pulses, and vegetables either before or after the main rice crop has long been practiced in rainfed lowlands. Although essentially grown in nonrice lands before, corn and sorghum are gradually finding their way into the rainfed lowland rice cropping system. Sunflower, a newly introduced crop, will also be grown either before or after the main rice crop in rainfed lowland areas. Figure 1 presents the existing cropping patterns of these crops in rainfed lowland rice areas.

PRESENT STATUS OF RESEARCH ON RAINFED LOWLAND RICE

Past research on rice concentrated on problems related to irrigated rice, which occupies only 17% of Burma's total rice area. Efforts should be concentrated on solving the production problems of rainfed lowland rice, which grows in 70% of the total rice area.

The relatively low yields obtained with rainfed lowland rice are due to one or more of the following causes:

- continued use of low yielding unimproved traditional varieties,
- use of impure seed stocks,
- use of overage seedlings for transplanting,
- poor land preparation,
- use of wide transplant spacings (or low seed rates in directly seeded fields)
- inadequate and untimely fertilizer application,
- late and inadequate weeding,



1. Present cropping patterns in rainfall lowland areas of Burma.

- inadequate and late pest control, and
- late harvesting and improper handling of harvested grains on the farm.

Varietal improvement of rainfed lowland rice is being done at Yezin; eventually selections will be tested in regional stations in the rainfed lowland areas. Yield trials of locally improved rice varieties are conducted in the rainy season at three rainfed rice regional stations to determine those which are most adapted to specific areas. Basic seed of recently released improved lowland varieties are being produced at the Agricultural Research Institute (ARI), Yezin, for further multiplication in the rainfed lowlands.

Cultural management trials at three rainfed lowland rice stations use locally improved varieties to study the effects of:

- different seed rates on yield of directly seeded rice,
- seedling age at time of transplanting,
- plant spacings under different fertility levels,
- transplanting dates, and
- different fertilizer rates on broadcast fields.

To help the special production drives laid down for the major rainfed lowland areas, research programs are being drawn annually in cooperation with ARI, Yezin, for implementation at the rainfed rice regional stations.

Rainfed lowland rice in India

M. J. BALAKRISHNA RAO and S. BISWAS

In large areas in India the main rice crop is grown during June to December, the season known as *kharif*. During kharif, early duration (autumn) varieties are grown in uplands, and medium- and late-duration varieties (winter rice) are cultivated in medium-low and lowland areas where there is standing water for a longer period. The autumn crop is grown on 14.65 million ha (36.92%) of 39.68 million ha in rice, and the winter crop occupies 23.01 million ha. Where irrigation facilities exist in localities south of 24° N latitude, another rice crop, the *rabi* (dry season) crop, is grown on 2.02 million ha (5.09%) from December to May.

Most of the rice crop in India depends entirely on the June-October southwest monsoon. About 30% of the crop is reported to have assured irrigation in areas with tanks, tube wells, and shallow wells that depend indirectly on the monsoon. The average yield for 1972-76 ranged from 1.06 t/ha to 1.25 t/ha. There is no appreciable overall increase in total production or productivity for the winter and autumn rice crops. However, there is substantial increase in productivity with high yielding modern rice varieties as the autumn crop in irrigated low-rainfall regions such as Punjab, Karnataka, Andhra Pradesh, and Tamil Nadu. These regions also have the highest spread of modern rices in *kharif*. The most spectacular spread of modern varieties has been achieved in the rabi rice crop of the eastern and southern regions of India.

In the heavy rainfall zones (precipitation above 1,300 mm from June to December) of Orissa, West Bengal, Assam, Kerala, regions of Bihar plateau, the eastern part of Madhya Pradesh, and the Konkan region of Maharashtra, a large portion of rice land remains under water depths of 15-100 cm during crop growth. Even in the moderate rainfall zones of coastal Andhra Pradesh,

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Tamil Nadu, and the riverine districts of Bihar and Uttar Pradesh, the low-lying areas are subject to submergence of the rice crop to varying depths. Such areas constitute about 60% of the total kharif rice crop area.

CLASSIFICATION OF WATERLOGGED AREAS

Waterlogged areas can be broadly classified into shallow lowlands (5-15 cm water), intermediate lowlands (16-49 cm), semideep lowlands (50-100 cm), and deepwater (100 cm and above). A rough estimate of areas under each category is presented in Table 1.

Shallow rainfed conditions prevail in medium-elevation lands where water accumulates at late stages of the monsoon. Generally, photoperiod-sensitive varieties of medium duration are grown in the eastern and northeastern regions (high rainfall) and also in the low-rainfall regions to a limited extent. A major area (about 10 million ha) constitutes the intermediate rainfed lowlands. There is considerable scope in these two water regimes for improving rice productivity through varietal improvement and management practices. In the semideep and deepwater areas water accumulates from the early monsoon, i.e. from late July onwards; once accumulated the water cannot be drained. Seed is mostly broadcast in late May or early June.

Rainfed lowland rice in the low rainfall region

Only transplanted rainfed lowland rice is grown in the low-rainfall region. Farmers wait for the intensive monsoon for

Table 1. Lowland areas under different water depths in India.

Water depth	Lowland area (million ha)				Kharif area (%)
	Transplanted		Broadcast		
	Photoperiod sensitive	Photoperiod insensitive	Photoperiod sensitive	Photoperiod insensitive	
Shallow rainfed (5-15 cm water)	3.0	2.0	nil	nil	13.27
Intermediate rainfed (16-49 cm)	6.0	nil	4.5	nil	27.88
Semideep rainfed (50-100 cm)	nil	nil	1.5	nil	3.98
Deepwater (>100 cm)	nil	nil	2.5	nil	6.63
Total	9.0	2.0	8.5	-	51.76

land preparation and transplanting. Depending on rainfall, transplanting may take place from mid-August to late September, sometimes with 60- to 80-day-old seedlings.

Yield trend in irrigated lowlands and rainfed lowlands in high- and low-rainfall zones

The irrigated lowlands and rainfed lowlands in high-rainfall zones receive no special advantage from irrigation because they are prone to waterlogging. Irrigated lowlands in the low-rainfall zones, on the other hand, are greatly benefited by irrigation.

Dr. M. S. Swaminathan, director general of the Indian Council for Agricultural Research, recently said, "Productivity and production of rice in India's low-lying areas have remained stagnant. Most of the rice-growing regions of West Bengal, Assam, North Bihar, eastern Uttar Pradesh, and Orissa have been bypassed by the high yield rice technology because some of the basic needs of low-lying areas, e.g. the breeding of high yielding varieties tolerant of waterlogging and flooding, improved fertilizer and management practices, and better postharvest technology, have not received adequate attention. The untapped yield reservoir of low-lying areas is large. Hence, the major gaps in the current rice technology for low-lying areas should be identified, and our efforts to develop a technology that combines high yield potential with low risk and is suited to the environment of eastern India should be redoubled."

The general problems for rainfed lowland rice are:

- Uneven distribution of rainfall during June, July, and August,
- Poor establishment of seedlings due to partial submergence,
- Premature lodging of the crop,
- Low photosynthetic efficiency of the varieties due to reduced light intensity normally prevailing in kharif,
- Accumulation of toxic soil substances in ill-drained fields, and
- Severe pest occurrence during the monsoon.

In certain areas, soil factors such as salinity, alkalinity, and zinc deficiency interfere with rice production. Environmental effects of low light intensity and inclement weather are also felt.

CLIMATOLOGICAL CONSTRAINTS

Because 70% of India's rice area is rainfed, the success of the rice crop depends on the uniform distribution of June-August

rainfall. Late onset of the monsoon can cause considerable delay in all field operations. A record yield of 48.74 million (1.25 t/ha) was obtained in 1975-76 when rainfall distribution was uniform. In 1974-75 production was 40.25 million (1.06 t/ha); in 1976-77 it was 42.78 million (1.11 t/ha).

Temperature, sunshine, and solar radiation in high-rainfall zones

Low rice yields during kharif are attributed partly to low solar radiation (250-300 cal/day) coupled with high temperature at tillering and flower initiation. The unfavorable conditions result in impaired total dry matter production, high tiller mortality, high spikelet sterility, and reduced harvest index. Solar radiation and day and night temperature are more favorable from panicle initiation to grain filling during November and December.

PRESENT STATUS OF VARIETIES FOR WATERLOGGED AREAS

In the waterlogged areas photoperiod-sensitive varieties of 150- to 170-day duration are invariably grown because they are ready to harvest after the monsoon and withdrawal of water from the fields. In the medium elevation lands where water is expected to recede earlier, medium-duration photoperiod-sensitive varieties are grown. In the deep lowlands, long-duration varieties are grown. Hence, photoperiod-sensitive varieties are the only answer to the requirements of waterlogged areas. The list of varieties from the rice-growing states is in Table 2. Most of the varieties are tall with a tendency for rank growth, more so after small doses of nitrogen. They are all weak strawed, and considerable yield losses occur due to lodging. A yield of 4 to 5 t/ha was obtained by preventing lodging; the crop that lodged gave only 2 t/ha. The varieties are well adapted to waterlogged soils and monsoon growing conditions, except lodging. Incorporation of the stiff straw character into such varieties is, therefore, essential.

Earlier, attempts to breed stiff-strawed late-duration varieties suitable for lowlands were made at the Central Rice Research Institute. Promising lines adaptable to lowlands were obtained from crosses with bulu varieties from Indonesia. Among these lines special mention is made of CR1014, derived from the cross T90/Urang urangan 80, which is being grown extensively in Orissa, parts of Andhra Pradesh, and West Bengal. CR1014 is moderately nonlodging, with excellent grain quality and good tolerance for pests and diseases. It gives stable

Table 2. Popular photoperiod-sensitive varieties in rice-growing states of India.

State	Variety	Grain characteristics
Andhra Pradesh	SL013	Short, bold
	MTU10	Medium, slender
	GEB24	Medium, slender
Bihar	BR8	Long, slender
	BR34	Long, slender
Kerala	Ptb2	Short, bold
	Ptb12	Short, bold
	Ptb15	Short, slender
	Ptb16	Short, slender
	Ptb4	Short, bold
Mysore	GEB24	Medium, slender
	SR26B	Long, slender
	S1092	Medium, slender
Uttar Pradesh	T9	Long, slender
	T100	Short, bold
Assam	Prasadbog	Medium, slender
	Latisail	Medium, slender
	Manoharshali	Long, bold
Tamil Nadu	GEB24	Medium, slender
	CO 25	Short, bold
	ADT5	Short, bold
	ADT9	Long, bold
	CO 29	Long, bold
Madhya Pradesh	Cross 116	Long, bold
	Cross 18	Short, bold
	R10 Chhatri	Medium, slender
	R15 Chinoor	Short, slender
	Safni 17	Long, slender
	CR1014	Medium slender
Orissa	T90	Medium, slender
	Bam. 6	Medium, slender
	Bam. 9	Long, bold
	T1242	Long, bold
	T14	Medium, slender
	CR1014	Medium, slender
	Jagannath	Medium, slender
	SR26B	Long, slender
West Bengal	NC1281	Short, medium
	Latisail	Medium, slender
	Basmanik	Long, slender
	Patnai 23	Long, slender
	Badkalamakati	Long, slender
	Badshabhog	Medium, slender
	CR1014	Medium, slender
	Pankaj	Medium, bold

Deepwater rice varieties of different states.

State	Variety	Remarks
Andhra Pradesh	PLA2	Stands 3 to 6 feet water
Assam	EB1	Stands 10 to 15 feet water
	EB2	Stands 8 to 18 feet water
	AR1	Stands 2 to 6 feet water
	ARC353-148	Stands 2 to 6 feet water
	AR614-25B	Stands 2 to 6 feet water
Kerala	Ptb16	Grown under deepwater conditions
West Bengal	Hybrid 84 (Asr. 108/1 x Patnai 23)	Stands 6 feet of water
	Jaladhi 1	Stands 3 to 6 feet water
	Jaladhi 2	Stands 3 to 6 feet water
Bihar	BR14	Stands 6 to 8 feet water
Uttar Pradesh	Jalmagna	Stands 10 to 15 feet water
	Jassuria	Stands 6 to 8 feet water
	Flood resistant varieties	
FR13a, FR43b, Madhukar, Chakia 59, PLA 4, Ptb 15, Co 14		

yields of 2.5-3.0 t/ha. Although such yields may not be spectacular, an average increase of 0.5 t/ha over large areas may have substantial impact in the farmers' fields. Another variety from Malaysia, Mahsuri, derived from the cross Mayang Ebos 80/Taichu 65//Mayang Ebos 80, has become popular with the cultivators in Andhra Pradesh, Tamil Nadu, Bihar, and other areas during *kharif* because of a moderate nonlodging habit and good grain quality. Pankaj, a sister selection of IR5, and Jagannath, a short-statured mutant from T141, are two other varieties adopted by farmers in Andhra Pradesh, West Bengal, Orissa, and Bihar. They are the only improved types found suitable for use in 5-30 cm of standing water. At present, most of the area is covered by a large number of local types.

WORK IN PROGRESS TO BREED VARIETIES FOR WATERLOGGED AREAS

Several popular rice varieties were tested at different water depth situations in Chinsurah. The results show that Achra 108/1, CNL214, and CNL231 are suitable for shallow, intermediate, and semideep water. Patnai 23, Tilakkachari, Kumargore, CNL270, and NC1281 are suitable for shallow and intermediate water depths. Pankaj, CNL312, NC678, OC1393, IR442-2-58, Kalma, and Raghusail are suitable only for shallow depths. CNL180, CNL31, Chakia-59, and Jalmagna are moderately adapted to semideep lowlands. Nam Sagui and HTA 14 had high seedling survival under submergence.

At the Agricultural Research Station, Maruteru, work was initiated in 1968 to breed late-duration dwarf varieties for

cultivation during kharif. Promising lines were obtained from SL013/IR8 and Mahsuri/Vijaya.

At the Central Rice Research Institute several highly productive, photoperiod-sensitive, nonlodging, medium-tall lines were developed from Pankaj/Jagannath, Pankaj/Kada, CR70/Pankaj, and a Jagannath natural cross (CR1000 series). With average management and minimum plant protection, the new lines gave yields ranging from 4 to 5 t/ha. Several promising lines were also developed from CR1014/Ratna, MTU3/Pankaj, NC1281/Pankaj, Jagannath/Ghana 345, CR1014/Jagannath, Waikoku/CR1014, and dwarf extract 360 (Boak/T141//T141). They are in advanced stages of testing.

In All India Coordinated trials, late-duration photoperiod-sensitive varieties are being tested in UVT 5 and PVT 4 trials. Several promising lines that are better than the traditional tall varieties have been identified. A start has been made to breed varieties with different photoperiod sensitivities to suit low-lying areas.

About 2 million ha of land in the coastal region of the country are saline because of seawater, and the crop yields are generally poor. A few varieties have been identified as relatively salinity tolerant, e.g. Getu, Dasal, MR18, Pokkali, and Hamilton. More of the photoperiod-sensitive long-duration varieties with salt tolerance are required.

FUTURE OUTLOOK AND ACTION PROGRAM

Future research should consider these needs:

- The germplasm collection should be searched for donors for photosynthetic efficiency under low light intensity.
- An international testing program of selected photoperiod-sensitive varieties that have resistance to major pests like leafhopper, gall midge, and stem borer is needed.
- A large number of crosses are needed for testing of early generation breeding material at selected locations. Information on them should be exchanged.

The following are suggestions for breeding procedures:

- Most of the dwarf segregants in the crosses involving late-early parents are photoperiod sensitive. There is not much choice in making effective selections for plant

height in the tall-dwarf crosses. Jagannath, Pankaj, and Boak derivatives are found to be useful donors for greater flexibility in plant height range and photoperiod sensitivity.

- Segregating material should be grown only in the monsoon, and selections should be done only for specific cultural practices and waterlogged conditions.

Rainfed lowland rice in Indonesia

E. S. SURYATNA, IBRAHIM MANWAN, and SUTJIPTO PARTOHARDJONO

In Indonesia, comparison of estimated water requirements for wetland rice and rainfall received suggests that supplemental irrigation is not necessary in many seasons. Total yearly rainfall varies between 700 and 7,000 mm, and permits at least one crop of rainfed lowland rice a year in many parts of the country. The arrival, duration, distribution, and intensity of the rainfall from a monsoon system greatly affect rice production.

Areas with 5 to 9 consecutive wet months and rainfall of 100 to 200 mm/month during the rest of the year, or with a second minor rainfall peak, are well suited to both rice production and year-round rice-based cropping systems.

Supplemental water is needed only in certain years to ensure timely land preparation and planting when the onset of rains is delayed. When rains are late, direct seeding into bunded rainfed lowland paddies contributes greatly to production. Where water is available, farmers prepare terraced or bunded fields to trap it.

Nitrogen and phosphorus in Indonesian soils are generally insufficient, but potash is usually not a limiting factor. Consequently, under intensive management, especially with the use of high yielding varieties, good crop response is obtained from a complete fertilizer (NPK). Fertilizer use in Indonesia increased 70% between 1972 and 1973, with about 60% of the total used for rice. The common fertilizer recommendation for rice is 90 kg N and 45 kg P_2O_5/ha.

LAND SUITABILITY CLASSES FOR RAINFED LOWLAND RICE

The areas for future expansion of irrigated rice and even for rainfed lowland rice are limited. Tidal swamps have received considerable attention as areas for expansion of rainfed lowland rice production. There are an estimated 18 million ha of swampland in Sumatra and 19 million ha in Kalimantan. Several development schemes have been proposed, but there are two main problems. First, it is difficult and expensive to effectively control water during the rainy season. Suitable deepwater rice

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varieties will contribute much to the development of rice production in those areas. Second, it is difficult to provide a high enough water table during the dry season to prevent aerobic decomposition of the organic matter and development of acid sulfate.

Knowledge of present land use, including the site for and distribution of each kind of use, is important to overall planning. It can serve as basis for expansion of desirable practices into areas with similar agroclimatic and economic situations. Land classification systems also are useful in making the decisions needed for technology transfer.

Lowland rice requires areas which can be flooded or at least maintained in a saturated condition. Guidelines used in assigning the development units to suitability classes for wetland rice were based on a FAO report (1974) and on work by Harrop (1973). The main suitability classes and subclasses are described here together with their principal characteristics and limitations: *s* = soil limitation, *x* = salinity, *a* = acidity hazard, *t* = topography limitation, *f* = flooding hazard, and *m* = water limitation. Designations *x* and *a* are included under soil limitation for this exercise. The intensity of the hazard increases according to the class to which it is attached. See Table 1 for distribution of classes in Indonesia.

Class P-II. Well suited to lowland rainfed rice.

Restricting limitations in Class P-II are slight; more than 50% of the unit land surface is level to gently undulating and conditions of soil texture, permeability, and fertility are well

Table 1. Distribution of wetland rice suitability classes in Indonesia, showing breakdown by region.

Location	Class P-II		Class P-III		Class P-IV		Class P-V	
	Area (thousand ha)	% of region	Area (thousand ha)	% of region	Area (thousand ha)	% of region	Area (thousand ha)	% of region
Java and Bali	1,782	12.2	3,517	24.1	1,907	13.1	7,405	50.0
Sumatra	1,009	2.2	5,751	12.6	17,253	37.7	21,759	47.5
Kalimantan	3,480	6.5	729	1.4	8,535	16.0	40,722	76.1
Sulawesi	235	1.4	1,703	9.3	1,090	6.0	15,284	83.3
Nusa Tenggara	83	1.2	106	1.5	126	1.8	6,700	95.5
Irian Jaya	1,859	4.4	4,870	11.6	13,779	32.7	21,598	51.3
Maluku	299	3.8	-	-	1,289	16.4	6,292	79.8
Indonesia	8,747	1.6	16,676	8.8	43,979	23.3	119,760	63.3

suited to paddy rice production. Soils respond well to fertilizers, notably those containing nitrogen. There are no serious problems with drainage or flooding, water is usually sufficient for at least one crop of rice, and prospects of continual irrigation to support year-round cropping are often good.

Class P-III. Land moderately well suited to lowland rice.

- *Subclass P-IIIa.* Excessive wetness due to flooding is a moderate hazard to rice cultivation in some years. Other conditions of soils, relief, and water supplies are favorable to rice growing. Where soils are very poorly drained, there are some restrictions on other crops grown in rotation with rice. Much of the flooding arises from poorly protected watershed areas. Where flooding can be controlled, the land may be upgraded to Class II.

- *Subclass P-IIIt.* Moderate restrictions to wetland rice cultivation are imposed by topography. On dissected plains the topography interferes with the distribution of water supplies and dependency on rice is greater. Less than 50% of the area is in the 0-8° slope class, and there are usually no serious restrictions to other crops grown in rotation with rice.

- *Subclass P-IIIs.* Moderate restrictions imposed by soil conditions are usually low fertility or unfavorable texture and, occasionally, restricted water supply. Without regular fertilizer use, poor soil fertility may restrict the range of crops grown in rotation with rice.

Class P-IV. Land poorly suited to lowland rice.

- *Subclass P-IVa.* A severe flooding hazard causes frequent damage to rice crops. Poor drainage, usually associated with finer-textured soils of this unit, seriously limits the range of other crops that might be grown in rotation with rice. Large-scale drainage and water control schemes are required to improve conditions for rice or other crops to be grown in a rotation.

- *Subclass P-IVt.* An undulating to rolling terrain seriously restricts the use of these units for wetland rice. Great effort is required to construct terraces, and problems with water supply distribution are usually beyond the scope of farmers. Less than 30% of the unit has slopes in the 0-8% class.

- *Subclass P-IVs.* Wetland rice cultivation is severely restricted by poor soil conditions, usually extreme acidity and low

fertility or moderately rapid permeability. Soils may be difficult to puddle because of unfavorable texture. Poor fertility may be difficult and costly to correct.

Class P-V. Land generally unsuitable for lowland rice.

Less than 10% of these units have areas of 0-8% slope; the remainder is dominated by steep slopes. Any rice cultivation must be confined to small narrow valleys representing less than 5% of the total area for many units.

- *Subclass* $P\text{-}V_s$. These land units are generally considered unsuitable for wetland rice because of low fertility, coarse textures, or shallow soils.

- *Subclass* $P\text{-}V_a$. This includes land on which soils are unsuitable for rice because of extreme acidity arising from oxidation of pyrites.

The present estimate of cultivable land resources in Indonesia is 65,350,000 ha, representing 34% of the total land area (Table 2). Appreciable amounts of this land either are of moderately low capability or occur in relatively inaccessible parts of hilly or mountainous country, or both. About 18,000,000 ha presently under some form of forest are suitable for cultivation. The choice of forest areas to be released for cultivation requires consideration of the quality of land made available and the system of farming that will be most feasible. Forested land suitable for cultivation should be identified at an early date.

DIRECT-SEEDED RAINFED LOWLAND

About 1.6 million ha of low-lying areas in Indonesia do not have enough rainfall to allow soil puddling for lowland rice. But those areas, along the northern coast of Java and also in the

Table 2. Estimates of cultivable land in Indonesia.

Physiographic region	Cultivable land area (thousand ha)	%
Lowland plains	47,957	24.8
Upland plains	2,675	1.4
Hilly land	7,800	4.1
Mountainous land	6,918	3.7
Total	65,350	34.0

outer islands, are often flooded with 50 cm or more of standing water. Farmers hesitate to grow transplanted rice because the plants would still be small at the time of flooding. This problem may be solved by planting direct-seeded (*gogo rancah*) rice. The rice seeds are broadcast either just before the rains come, whenever the soil moisture is adequate for germination.

Gogo rancah is also practiced in certain areas in Indonesia where light tillage is done during the dry season. The rice is direct-seeded at the beginning of the rainy season or a few days before its start. The rice grows as a dryland crop in the first weeks. As soon as water is adequate the field is submerged, but without puddling. The amount and depth of water depend entirely on the rainfall.

The direct-seeding system offers a chance to increase cropping intensity in rainfed lowland rice areas. Rice is seeded at the beginning of the rainy season and the crop is usually intercropped with early maturing corn. The corn may be harvested as either mature grain or green ears. If peak rainfall comes too early, the farmers typically use the cornstalks as cattle feed and the young ears as vegetable.

Gogo rancah is versatile: the crop can be submerged if enough rain comes, or it may remain as dryland crop if rainfall is not adequate. The system is also practiced in irrigated paddy fields that characteristically receive water late in the season, which permits one more crop of transplanted rice to be grown after the *gogo rancah* crop is harvested. If a second rice crop is not grown a dryland crop like soybean, sorghum, cowpea, mung bean, watermelon, or onion is planted as a dry season crop.

High yields can be obtained with suitable high yielding varieties and the *gogo rancah* system (Table 3). Yields of rice and corn from an intercrop combination are in Table 4.

Current research seeks rice varieties that are well suited to *gogo rancah*. One objective is to determine the varieties that are suitable for *gogo rancah*, respond well to fertilizer (especially N), and tolerate major pests and diseases in the region. It appears that IR26 and IR34 are suited to *gogo rancah*. Other promising lines were susceptible to the brown planthopper. One of the most important aspects for *gogo rancah* rice is stand establishment. Table 5 shows that a row spacing of 25 cm with a seeding rate of 80 kg/ha gave good yields for IR26 and C4-63. A major problem concerns topdressing of nitrogen fertilizer. Because the soil is not puddled, the fertilizer cannot be easily worked into the mud. For this situation slow-release fertilizers such as sulfur-coated urea (SCU) may be useful. In a study that

Table 3. Maturity and yield of six rice varieties grown as *gogo rancah*. Cropping systems research, Indramayu, 1976-77 wet season.

Variety	Maturity (days)	Yield (t/ha)
IR26	125	6.3
IR28	168	5.4
IR30	113	5.4
C4-63-Gb	123	3.8
IR34	136	5.1
Pelita I/1	139	3.3

Table 4. Yield of *gogo rancah* rice (IR26) and corn (Genjah Madura) grown as intercrops. Cropping systems research, Indramayu, 1976-77 wet season.

Crop	Yield	
	Rice (t/ha)	Corn (ears)
Rice (solid)	5.6	-
Rice + corn	5.3	40,000[a]

[a]About 1 t dry grain.

Table 5. Effects of level of nitrogen and spacing on yield of IR26, C4-63, and a local variety grown as *gogo rancah* (seeding rate 80 kg/ha), 1976-77 wet season, Ngale, East Java.

Amount of N (kg/ha)	Plant spacing (cm)	Yield (t/ha)		
		IR26	C4-63	Trembesi
0	25 x 25	1.7	1.7	8.3
	25 x 15	2.3	1.6	10.2
	25 x in rows	2.4	2.6	1.5
45	25 x 25	2.4	1.9	1.0
	25 x 15	3.4	2.5	1.1
	25 x in rows	4.4	3.2	0.9
90	25 x 25	3.6	3.2	1.2
	25 x 15	3.8	3.3	1.0
	25 x in rows	4.4	3.1	1.4

compared one basal application of SCU with urea applied in three split applications, yields from the SCU- and urea-treated plots were comparable (Table 6). This indicates that, in addition to being equally effective, SCU can reduce the labor requirement.

Table 6. The effects of urea and sulfur-coated urea (SCU) at different levels of application on yields of IR26, Balap Merah, and Trembesi. Indramayu, West Java, and Ngale, East Java, 1976-77 wet season.

Amount (N/ha) and source of fertilizer	Yield (t/ha)			
	Indramayu		Ngale	
	IR26	Balap Merah	IR26	Trembesi
0 (check)	2.9	2.5	3.1	1.3
30 (urea)	3.3	2.3	4.1	1.5
30 (SCU)	3.4	2.6	3.9	1.7
60 (urea)	3.8	2.5	4.8	1.4
60 (SCU)	3.8	2.7	4.3	1.6
90 (urea)	3.9	2.8	5.5	1.8
90 (SCU)	4.1	3.1	4.7	1.9
120 (urea)	4.4	3.1	6.0	2.9
120 (SCU)	4.3	2.8	5.1	1.8

Gogo rancah rice planted at the early part of the rainy season leaves time for growing a second crop of transplanted rice plus one nonrice crop. This is true for the Indramayu area where water from irrigation and rain is available for 5 months. The system gives higher production when lowland rice is not the first crop: lowland rice as the first crop does not permit enough time to get a third crop.

WALIK JERAMI RICE CULTURE

Walik jerami is a management system typically used to grow a second rice crop in Java. Land is prepared by spreading the previous crop's straw over the field while the soil is still wet. After the straw is worked slightly into the soil, by hoe or by foot, a second crop is transplanted. To facilitate the method, the rice field is kept slightly flooded until harvest of the first crop.

Walik jerami is useful in shortening the time period between crops. The method increases the probability of getting water for the second crop, either from remaining rainfall or from irrigation water.

Because *walik jerami* rice is planted without land preparation, the nursery is prepared outside the field. Other practices, such as transplanting, spacing, fertilizing, and controlling pests do not change.

Cropping systems research in the Indramayu area found that ordinary lowland rice varieties such as Pelita I/1, CR-63, IR26,

IR28, and IR30 yielded as well (2.5-3.0 t/ha) as *walik jerami* rice. By using early maturing rice varieties, the prospects of *walik jerami* become better.

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Rainfed lowland rice in the Philippines

T. S. EUGENIO

A large part of the Philippines' rice crop depends on rain brought by the monsoon. Of the total rice area, about 57% is rainfed lowland, only about 43% is irrigated lowland. The rainfed areas include some unbunded upland fields planted to rice at the start of the monsoon, but yields are negligible because of the uncertainty of weather for favorable crop growth.

By the mid-1970s an estimated 80% and 70% of rainfed lowland rice areas were growing high yielding modern varieties.

The distribution of the Philippine rice crop by type of culture and production is shown in Table 1. The national average yield is 1.96 t/ha. Rice is grown in almost all regions of the country. The estimated area and production of the four major rice regions are in Table 2.

CHARACTERISTICS OF RAINFED LOWLAND VARIETIES

The varieties usually grown as rainfed lowland are characterized as follows:

- Early maturing - 95 to 110 days from sowing. A variety should mature in 95 to 110 days if transplanted, and earlier if direct-seeded.
- Vegetative vigor - vigorous growth and tiller production during early stage of growth
- Plant height - short to medium short, ranging from 75 cm to slightly more than 100 cm at maturity
- Straw - stiff and nonlodging
- Plant type - erect tillers and leaves
- Resistant to major pests and diseases
- Dark green color and responsive to fertilizer
- Tolerant of drought

Cultural practices recommended for rainfed lowland rice are summarized in Appendix A.

Rice research and training director, Maligaya Rice Research and Training Center, Bureau of Plant Industry, Nueva Ecija, Philippines.

Table 1. Type of culture, area, and yield of the Philippine rice crop, 1976.

Culture		Area (ha)	Yield (t/ha)
Irrigated lowland		1,494,590	2.25
Wet season	981,000		2.16
Dry season	514,000		3.51
Rainfed-lowland		1,694,680	1.34
Upland (unbunded)		390,050	0.87
Total		3,579,320	

Table 2. Area and yield of four major rice-producing regions in the Philippines, 1976.

Region	Area (ha)	Yield (t/ha)
Central Luzon	486,780	2.20
Southern Luzon	455,640	1.73
Western Visayas	454,510	1.67
Cagayan Valley	410,380	1.70

CROPPING PATTERNS FOR RAINFED LOWLANDS

A main problem of the rainfed lowland rice farmer is maximum use of his land. Direct seeding projects in the provinces of Bulacan and Nueva Ecija have shown that it is feasible to have a second rice crop and that there are distinct advantages in planting promising early maturing selections under rainfed conditions.

- The harvesting period coincides with a period of high rice prices. The farmer has rice to harvest when the national stock starts to dwindle.
- The farmer can plant a second crop on the same piece of land where only one was planted before. Fertility can be increased by using legume crops -- mongo, soybean, tapilan, beans, cowpea, etc.
- Farm family income increases.
- Weed problem of future crops is reduced.

Crops like mongo, cowpea, sorghum, tomato, and other vegetable crops are usually planted after an early crop of direct-seeded rice, depending, however, on market, storage facilities, soil conditions, etc.

PRESENT STATUS AND PRIORITIES OF RAINFED LOWLAND RICE RESEARCH

There is a big gap between the rice yield on the experiment station (6.5 t/ha) and the national average yield (1.6 t/ha). This situation has existed for some time. In the latest research review congress conducted by the Philippine Council for Agriculture and Resources Research (PCARR), the priority research areas for rainfed lowland rice, classified according to discipline in descending order, were established. They are outlined in Appendix B.

Varietal improvement

At the moment there are no high yielding varieties selected mainly for rainfed areas in the different regions of the country. Tests of rainfed rice have not been extensive and the Philippine Seed Board has not recommended varieties specific for rainfed areas. The development and testing, therefore, of high yielding varieties adapted under such conditions are of highest priority.

Culture and management

The second priority is the determination of the appropriate cultural management for rainfed rice where protective research (pest, disease, and weed control) is considered.

The development of a package of rice-based cropping systems technology for maximum utilization of the land in each location is top priority. It is followed by problems of soil fertility and plant nutrition and land preparation and tillage. The production of quality seeds for farmer use is also of prime importance.

Processing and utilization

Processing and utilization are important in at least four regions where facilities and raw materials are available. It includes evaluation of existing farm tools and equipment.

The wastage of grain at harvest is a problem of rainfed rice because in most areas of the country harvesting coincides with the rainy season. Under that situation, drying and subsequent storage on the farm level become priority research.

Economics and marketing

The cost and return analysis, market price, structure and

commodity flow problems in financing and farm organizations should be carefully studied in the various regions.

Sociology and extension

Sociology and extension research includes the adaptation of new technology, problems in extension strategies, and rural sociology.

Appendix A

CULTURAL PRACTICES FOR RAINFED LOWLAND RICE

1. *Field preparation*

a. Seedbed

1) Dry-bed method *(bakal)*. Prepared in mid-June by plowing the field dry. The beds are located where water is available to growing seedlings.

2) Ordinary wet-bed method *(palusot)*. Prepared in mid-June by plowing the field and harrowing two to three times. The field is puddled and pregerminated seeds are sown.

b. Main field

1) Puddled. In most places the main field is plowed in July when there is enough water in the paddies (75 to 100 mm of rainfall) to allow plowing and subsequent puddling of the soil.

2) Dry condition (direct-seeded). The field is prepared 4 to 6 months before sowing by rotovating 7.5-10 cm deep, or plowing 7.5-15 cm deep, and harrowing it while the soil is still moist. Early land preparation helps control weeds that spread from rhizomes or stem cuttings, and which cannot be controlled by preemergence herbicides.

Loam or silt-loam soils are prepared dry 2 months before planting and a light harrowing is done a number of times to kill germinating weeds and keep the surface soil loose. Two days before the seeds are sown, the field is thoroughly harrowed and leveled.

2. *Seed requirement (80% germination)*

The germination test of the seed stock is done 7 days before the seeds are sown.

a. Puddled
   1) Ordinary dry-bed method - 60 kg/ha
   2) Ordinary wet-bed method - 44 kg/ha

b. Direct-seeded
   1) Broadcast methods
      a) Dry-method - 70-80 kg/ha
      b) Wet-puddled soil - 70-80 kg/ha
   2) Drill methods
      a) Six-row seeder (IRRI) - 80-90 kg/ha
      b) Scope seeder (VALREY) - 50-60 kg/ha

3. *Sowing methods for wet and dry conditions*

a. Seedbed (puddled). In the ordinary dry bed *(bakal)* method the soil is prepared dry and the seeds are sown in furrows when there is enough moisture in the soil.

In the ordinary wet-bed *(palusot)* method the field is puddled and the seeds are pregerminated before broadcast.

b. Main field

1) Dry condition or broadcast - The field is prepared dry and the seeds in some cases are sown before the rain starts in May. Furrows are prepared by a native furrower *(lithao)* and the seeds are broadcast over the field. A native harrow is passed lightly along the furrows after broadcasting to put the seeds into the furrows and at the same time cover them.

2) Wet condition

a) Broadcast method. Fertilizer is broadcast as a basal treatment at the rate of 60-30-30 (NPK) and incorporated using the lowland harrow before the pregerminated seeds are broadcast on the field.

b) Drill method planting. With the IRRI seeder the fertilizer is broadcast before final harrowing and leveling, after which the seeds are drilled. With the scope seeder, the presence of a fertilizer hopper allows the fertilizer to be applied simultaneously with the pregerminated seeds.

4. *Weed control*

a. Puddled conditions. For transplanted seedlings the herbicide is broadcast 4-5 days after transplanting.
For broadcast or direct-seeded seedlings, the herbicide is sprayed 2-3 days after sowing.

5. *Topdressing fertilizer*

For direct-seeded rice nitrogen is applied in the paddy water or on moist soil 10-20 days after emergence, and again 30-40 days after emergence. For transplanted rice at least 20 kg N is applied one week before panicle initiation, or earlier, depending on the vigor of the plants.

6. *Care and maintenance*

The fields are observed for insects that may carry virus or other diseases. Hand weeding is as necessary, 20-25 days after sowing.

7. *Draining the field*

Field draining starts 5 to 15 days before harvest.

Appendix B

PRIORITY RESEARCH AREAS FOR
RAINFED LOWLAND RICE

I. Varietal improvement
   - 1.1 Exploration, identification, and introduction of cultivars
   - 1.2 Hybridization
     - 1.2.1 Yield and quality
     - 1.2.2 Pest and disease resistance
     - 1.2.3 Problem areas

II. Cultural management
   - 2.1 Protective research
     - 2.1.1 Pest control
     - 2.1.2 Disease control
     - 2.1.3 Weed control
     - 2.1.4 Biological control
     - 2.1.5 Residue analysis
   - 2.2 Cropping aspects
   - 2.3 Soil fertility and plant nutrition
   - 2.4 Water management
   - 2.5 Land preparation and tillage
   - 2.6 Seed production and technology
   - 2.7 Harvesting methods

III. Processing and utilization
   - 3.1 Evaluation, design, development of farm tools and equipment
   - 3.2 Postharvest handling and storage

3.3 Product and by-product development

IV. Economics and marketing
4.1 Cost and return analysis
4.2 Market price and structure and commodity flow
4.3 Financial scheme
4.4 Farm organization

V. Sociology and extension
5.1 Adoption of new technology
5.2 Extension problems and strategies
5.3 Rural Sociology

Rainfed lowland rice in Thailand

BORIBOON SOMRITH and SERMSAK AWAKUL

Thailand has about 51.8 million ha of land area and about 8.4 million ha are in rice. About 1.9 million ha of the rice land is irrigated and the rest (77%) is nonirrigated or rainfed. Of the rainfed rice, about 0.09 million ha is upland, 5.87 million ha lowland, and 0.51 million ha deepwater. The irrigated areas are in the northern region and in the central plains where double-cropping of rice is also practiced. The major rainfed lowland area is in northeastern Thailand and the deepwater areas are in the central plains.

All irrigated rice lands are planted to modern high yielding varieties. Most of the rainfed lowland and deepwater areas are planted to improved traditional or local photoperiod-sensitive varieties.

RAINFED RICE CULTURE

Upland rice

Upland rice grown in unbunded rainfed fields is generally grown in hilly areas of the north, northeast, and south Thailand. In those areas, shifting cultivation of rice is practiced on newly opened land. Planting is by dibbling in dry soil.

In the southern region, upland rice is grown as an intercrop with young rubber trees and as a sole crop in some hilly areas. The estimated area of upland rice thus does not exceed 0.1 million ha, and yields average 1 t/ha.

Planting is usually in July or August; only nonglutinous types with medium to late maturity are grown.

For north and northeast Thailand, the cropping season for upland rice usually starts in April or May, earlier than for transplanted lowland rice. The upland varieties are mostly early maturing and well adapted to local conditions. Both glutinous and nonglutinous types are grown. Harvest is usually in September and October.

Rice breeder, Khonkaen Rice Experiment Station, and *deputy director,* Rice Division, Department of Agriculture, Bangkok, Thailand.

Deepwater rice

Deepwater, or floating rice, is grown in areas with water depths of 1-3 m. Most deepwater areas are in the central part of Thailand. The area is essentially planted to floating or semifloating varieties. Two varieties, Leb Mue Nahng 111 and Pin Gaew 56, are widely accepted. Floating rice is usually broadcast-seeded in late April or early May after the first few monsoonal rains. The crop grows as the rains increase in intensity and frequency, and elongates with the gradual increase in water level. Harvest is in January or February after the water recedes. Yield of deepwater rice is about 2 t/ha.

Rainfed lowland rice

Rainfed lowland rice on bunded fields occupies a large portion of the rice area. It is grown on about 3.7 million ha of northeastern Thailand. It is estimated that an additional 1.05, 0.90 and 0.55 million ha of rainfed bunded rice land are in the north, central, and south of Thailand, respectively. The classification of estimated areas under different types of rice culture in each geographical region is in Table 1.

RAINFED LOWLAND RICE CLIMATE

In the rainfed lowland area rainfall is the most essential factor for a good crop season. Mean annual rainfall ranges from 775 mm at Chachoengsao in the central plains to more than 3,000 mm at Ranong in the south. However, differences in amount, and monthly fluctuation, of rain are frequently observed in the northeast region.

In north, northeast, and central Thailand the rainy season is from May to October. In the north and northeast regions a sharp decline in rainfall occurs in November; the heaviest rains are in August and September. In the central plains, the decrease of rainfall in November is not as abrupt and the heaviest rains are in August, September, and part of October. In the southern region the heaviest rains are in October, November, and December. The monthly rainfall means for 1968-76 in selected provinces are shown in Table 2.

In terms of temperature, Thailand roughly divides into two regions, upper, and lower Thailand. Upper Thailand includes the north, northeast, and the central plains lying between latitudes 13°-21° N and has a long period of hot weather because of its inland nature and tropical latitudes. The coastal regions where sea breezes of moderate strength have some influence are the exception. Maximum temperatures generally range from 33 to

Table 1. Estimated areas under different types of rice culture in Thailand.

Rice culture	Rice area (million ha)				
	North	Northeast	Central	South	Total
Upland	0.05	0.02	nil	0.02	0.09
Deepwater	nil	0.01	0.50	nil	0.51
Irrigated	0.60	0.28	1.00	0.05	1.93
Rainfed lowland (bunded)					
Shallow rainfed (5-15 cm)	0.60	3.00	nil	nil	3.60
Intermediate rainfed (16-49 cm)	0.40	0.30	0.[illegible]	0.50	1.74
Semideep rainfed (50-100 cm)	0.05	0.07	0.36	0.05	0.53
Total	1.70	3.68	2.40	0.62	8.40

Table 2. Mean monthly rainfall from 1968 to 1976 at selected provinces in four geographical regions, Thailand.

Province	Monthly rainfall (mm)						
	May	June	July	August	September	October	November
North							
Chiengrai	229	259	292	451	262	128	41
Chiengmai	179	146	169	300	220	113	47
Nan	182	175	219	249	148	98	13
Uttaradit	222	257	193	274	240	135	26
Lampang	160	132	151	226	235	128	40
Northeast							
Surin	132	159	168	178	290	140	24
Korat	133	137	116	105	269	118	37
Ubon	181	270	327	348	278	59	33
Roi Et	181	21[illegible]	220	264	256	102	16
Udonthani	200	14[illegible]	230	311	300	89	9
Central							
Chachoengsao	102	71	80	150	163	135	74
Nakorn Sawan	156	124	129	207	194	136	21
Lopburi	137	141	145	193	275	141	33
Bangkok	200	126	134	184	332	220	54
Nakorn Pathom	113	110	110	149	187	169	47
Aranyaprathet	120	178	206	208	266	185	63

Province	Monthly rainfall (mm)								
	June	July	August	September	October	November	December	January	February
South									
Hua Hin	91	80	90	155	219	309	40	58	13
Chumporn	176	184	196	134	272	444	151	128	56
Suratthani	141	156	142	155	260	349	145	79	11
Songkhla	98	93	100	122	300	773	471	88	25
Narathiwat	127	135	111	226	288	711	522	124	43
Petchaburi	77	95	117	117	248	103	43	29	9

38°C. During April, the hottest month, the maximum temperature often reaches much higher values. It went to 43.7°C at Nakorn Sawan in 1941; and to 44.5°C at Uttaradit and 43.9°C at Udonthani in 1960.

During the northeast monsoon, temperatures over upper Thailand are much milder. The period November to February has maximum temperatures of about 31°C and minimum of about 15°C. Occasional inflows of cold air from China reduce temperatures to fairly low levels in the north and northeastern parts. Records show minimum temperatures of 0.1°C at Loei, 1.8°C at Nakorn Panom, and 2.5°C at Udonthani in January 1955.

In southern Thailand, temperatures are generally mild throughout the year. This region is exposed to maritime air in all seasons. The average daily range of temperatures is about 10°C with an average maximum temperature about 31.6°C and minimum 23°C (Meteorological Department 1968).

TOPOGRAPHY AND RICE VARIETIES

North

In the northern region, rice is grown in valleys that have a slight grade. Many fields are provided with irrigation from rivers and small streams. High rice yields are usual in the Chiengmai Valley, which is a double-cropping zone with relatively good soils. Almost all rice fields in the Chiengmai Valley are irrigated by government or traditional systems.

The rainfed lowland rice area is estimated at 0.60 million ha. People in the region consume both glutinous and nonglutinous rices. For the glutinous varieties, most areas are planted to Niaw Sanpatawng and Gam Pai 15. Among the nonglutinous rices, the recommended varieties Khao Dawk Mali 105 and Leuang Yai 148, and a Chiengrai favorite variety, Hawm Mae Jan, are widely grown.

Northeast

The topography of the northeastern region is generally undulating and slopes from the Korat Mountain range at the western border to the Mekong River on the east. Although the annual rainfall in the northeast is not much less than that of the central plains, the region is distinguished by:

- erratic rainfall, which results in drought spell(s) during the cropping season; temperature extremes are vastly different between the dry and wet seasons;

- very low soil fertility; particularly in Korat fine sandy loam, series which covers a large portion of this region;
- high rates of soil erosion that usually occurs during the rainy season because of the degree of sloping; and
- extensive accumulations of salt on the surface soil in many areas due to severe evaporation during the dry season and drought periods in the wet season.

The region has numerous water reservoirs, but most are shallow and allow excessive evaporation and seepage losses. They sometimes are dry during the monsoon erratic rainfall.

During the rainy season, drainage of the northeast region's rice land is provided by the Lam Chi and Moon River systems, but sometimes, because of high-intensity rainfall, the rivers may flood the Tung Kula Ronghai Plain.

Like the northerners, the northeasterners consume both glutinous and nonglutinous rice. Glutinous varieties make up about 60%. Two well-known varieties in the region are Niaw Sanpatawng (glutinous) and Khao Dawk Mali 105 (nonglutinous).

Central plains

The central plains consist of flat to gently sloping deltas and terrace lands developed along the Chao Phya and Nakorn Chai Sri rivers and their branches. The topography and soil type of this area are similar to those of the northern region. Even though the Royal Irrigation Department's Chao Phya Project has improved the irrigation systems of the region, about 0.90 million ha in the upper part of this region, aside from the deepwater areas, are still rainfed.

Only nonglutinous varieties are planted. Three government-recommended varieties, Nahng Mon S-4, Leuang Pratew 123, and Khao Pahk Maw 148 are popular.

South

In southern Thailand, the coastal rice lands are developed along many small and relatively large streams that flow into the Gulf of Thailand. The region has a high annual rainfall with more wet than dry months. Irrigation projects are still under expansion. Rainfed lowland rice fields cover about 88% of the total rice land. Nahng Phya 132 and Peuak Nam 43, two nonglutinous recommended rices, are relatively popular in the south.

RAINFED LOWLAND RICE VARIETIES

The percentage of the government-recommended varieties planted in Thailand is estimated from random samples in surveys by the Planning Division, Department of Agriculture, during 1973 to 1974 (Table 3, Department of Agriculture 1975). The data indicate that farmers in the north, northeast, and south planted more local than recommended varieties. Only the central region used more recommended than local varieties. Table 4 shows the important characteristics of some of the recommended varieties widely grown in rainfed areas of each region.

Average yield and paddy production

Although official statistics on the average paddy yields of rice under different types of culture are not available, we estimate average yield for the country as:

Type of rice culture	*Estimated yield (t/ha)*
Upland	1.0
Irrigated (wet season)	2.5
Irrigated (dry season)	3.5
Shallow rainfed lowland	1.4
Intermediate rainfed lowland	1.8
Semideep rainfed lowland	2.0
Deepwater	2.0

Rice production by regions (Fig. 1) indicates the fluctuation from year to year but the production trend has been an increase because of increased area planted. The trend in production also seems to closely follow that of annual rainfall (Department of Agriculture 1977), and indicates that total production is largely dependent on the amount of rice produced in the rainfed area(s).

CULTURAL PRACTICES AND CROPPING CALENDAR FOR RAINFED LOWLAND RICE

In Thailand, two planting methods -- broadcast and transplanting -- are generally used in rice cultivation. According to surveys during 1973-74 (Department of Agriculture 1975) more than 80% of the rice land in the north and 95% of the northeast practice transplanting in rainfed lowland fields. In the central plains, the two methods are used about equally because broadcasting is practiced in the deepwater and semideep rainfed lowland areas, while transplanting is confined to the intermediate rainfed and double-cropping areas. The broadcast method is also used more than transplant along the eastern coast of south Thailand, but

Table 3. Percentage of regional rainfed lowland rice areas planted to government-recommended and local varieties.

Region	Rice area (%) planted to		Area surveyed (ha)
	Recommended varieties	Local varieties	
North	34	66	1800
Northeast	44	56	1928
Central	68	32	1810
South	8	92	740

Table 4. List of recommended rice varieties widely grown in rainfed lowland areas, Thailand.

Area/variety	Harvesting date	Type[a/]	Kernel size (mm)		Ht (cm)	Blast reaction[b/]	Year of release
			Length	Width			
North							
Niaw Sanpatawng	26 Nov.	G	7.2	2.3	150	3,4	1962
Leuang Yai 148	25 Nov.	NG	7.8	2.6	166	5	1968
Northeast							
Niaw Sanpatawng	26 Nov.	G	7.3	2.2	160	3,4	1962
Khao Dawk Mali 105	20 Nov.	NG	7.6	2.4	150	3,4	1959
Khao Pahk Maw 148	3 Dec.	NG	7.6	2.3	140	3,4	1965
Central							
Nahng Mon S-4	26 Nov.	NG	7.7	2.4	140	4	1956
Khao Pahk Maw 148	3 Dec.	NG	7.6	2.3	140	3,4	1965
Leuang Pratew 123	19 Dec.	NG	7.4	2.3	150	4,5	1965
South							
Nahng Phya 132	16 Feb.	NG	7.6	2.2	178	3,6	1962
Peuak Nam 43	22 Feb.	NG	7.2	2.1	166	[illegible]	1968
Floating rice							
Leb Mue Nahng 111	19 Dec.	NG	7.0	2.3	c/	4	1959
Pin Gaew 56	29 Dec.	NG	7.4	2.2	c/	3	1959

a/G - glutinous; NG - nonglutinous.

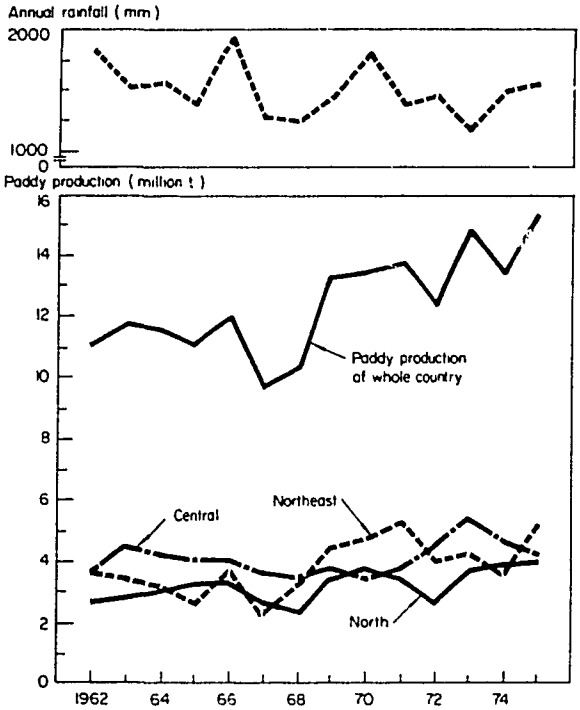
b/On international scale 1-9: 1 = resistant, 9 = susceptible.

c/Height varies markedly with water depth.

in the western coastal area only the transplant method is practiced.

One rice crop per year is the major cropping pattern in the rainfed areas. Only limited areas are replanted after the main rice crop.

In central and northern Thailand, June and July are the best seeding months, and transplanting may start in July or August and continue into September. Harvest is in November or December.



1. Annual production and rainfall for the years 1962–75.

Because of erratic and unpredictable rainfall in northeastern Thailand, rice seeds in rainfed areas are frequently sown during May and August. In years with good rainfall distribution, farmers will seed in May or June and transplant after about 1 month. But in years, when drought occurs at the start of the growing season, transplanting is postponed until rains are sufficient in August or September. In such a case, the farmers use old seedlings or, sometimes, prepare seedbeds a second time. Crop harvest in the northeast is in November and December.

In the central plains, rice is usually broadcast-seeded in May and the crop is ready for harvest in December or January.

Along the east coast of south Thailand, the trade winds from the South China Sea and the Gulf of Thailand start blowing

in October and continue until about February. These offshore winds bring much rain to the windward coasts; thus, October to February is the main rice growing season for the eastern coast.

PRESENT STATUS OF RESEARCH IN RELATION TO RAINFED LOWLAND RICE

The rainfed lowland rice research program in Thailand was expanded by a Rainfed Rice Improvement Pioneer Project initiated in 1973, which concentrated primarily on the northeastern region. A project objective was to reduce the risk of rice farming. The research includes a rice breeding program at Khonkaen Rice Experiment Station and agronomic research under the responsibility of the Agronomic Improvement Branch of the Rice Division, Bangkok.

The main rice breeding activities are a search for both glutinous and nonglutinous varieties that have:

- wide adaptability for cultivation in rainfed lowlands in the northeast; and are drought resistant and salinity tolerant;

- photoperiod sensitivity, with different maturities to fit specific rainfall patterns and topography of different areas; also nonphotoperiod sensitivity with tall plant stature and short growth duration for pre- or post-monsoon cropping; and

- resistance to diseases and insects combined with preferable grain appearance and good cooking quality.

At present the breeding program at Khonkaen has four major aspects:

1. collection, characterization and evaluation of rice germplasm;

2. utilization of germplasm in the hybridization program, handling of hybrid progenies, selection and evaluation of advanced generation breeding lines;

3. station and farmer field trials of promising selections; and

4. national and international collaborative research.

The activities of agronomic improvement, both within and outside rice research stations, include experiments on effects of planting date, age of seedlings, methods of planting, fertilization, weed control, and cropping systems research.

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Varietal Improvement

Alternative plant types and other agronomic characteristics for rainfed lowland rice

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The modern semidwarf rice varieties and technology have touched the lives of less than half of the world's rice farmers. Most of these farmers farm irrigated land, and are reasonably certain of an adequate and continued supply of water. Development of improved varieties and production technology for the millions of farmers who depend solely on the unpredictable monsoon to water their crops has not received special emphasis. Rainfed areas represent diverse ecological conditions ranging from rainfed upland to low-lying deepwater. In such areas yield stability is of crucial concern and a consideration of water excesses and deficits is imperative. There are no improved varieties and new technology that can significantly increase the current level of production in these areas. The total area under such rice culture in South and Southeast Asia is estimated to be about 57 million ha (Table 1, 2, 3).

The International Rice Breeding Symposium in 1971 focused the attention of rice scientists on the improvement of upland rice. Similarly the International Symposium on Deepwater Rice held in Bangladesh in 1973 emphasized the improvement of deepwater rice. The Thai-IRRI Cooperative Deep Water Rice Research Project is an effort in this direction. Thus, it appears that the two extreme areas, the upland and deepwater portions of rainfed rice, have received attention. The development of improved germplasm for rainfed lowland conditions, however, has previously not received special emphasis. Vast rainfed lowland areas are still occupied by traditional varieties. Improved varieties that are reasonably suitable for such conditions are a spillover from rice improvement programs that have focused mainly on irrigated situations.

CHARACTERISTICS OF RAINFED LOWLAND AREAS

The rainfed lowland rice areas are characterized by bunds that trap rainwater. Upland areas are distinguished from rainfed lowland mostly by the fact that they are unbunded. In many cases, the growing conditions may be very similar. At the

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Table 1. World's rice area by type of culture, 1973-75.

Region	Rice area (thousand ha)					
	Total	Irri-gated	Shallow rainfed	Intermediate rainfed	Deepwater	Upland
India	38,402	14,917	12,634	6,080	2,362	2,402
China	34,133	30,718	2,734	0	0	681
Other S & SE Asia	45,133	12,129	15,948	6,791	4,634	5,875
Other developing[a]	10,308	3,936	581	995	0	4,796
USA, Japan, USSR	4,201	4,144	0	0	0	57
Others	5,228	n.a.[b]	n.a.	n.a.	n.a.	n.a.
Total world	137,413	n.a.	n.a.	n.a.	n.a.	n.a.

[a] Korea R., Korea D. P. R., Iran, Afghanistan, all Africa, all Latin America.
[b] Not available.

Table 2. Proportion (%) of rice area of various regions by type of culture.

Region	Rice area (%)					
	Total[a]	Irri-gated	Shallow rainfed	Intermediate rainfed	Deepwater	Upland
India	28	39	33	16	6	6
Other S & SE Asia	33	27	35	15	10	13
China	25	90	8	0	0	2
Other developing	8	38	6	10	0	46
USA, Japan, USSR	3	98	0	0	0	2
Total classified[b]	96	51	24	10	5	10

[a] Refers to % of world's total area; % in other columns refers to % of region in specified culture.

[b] Refers to 96% of total world area classified in Table 1.

opposite end of the spectrum, deepwater areas are distinguished from rainfed lowland also by the absence of bunds.

Rainfed lowland rice may be subject to drought, and flood control may be inadequate. The crop may also be subject to intermittent submergence at different growth stages of the plant. Water depth in lowland rice fields is usually not a static factor. It depends on the total rainfall, its distribution pattern, topography, and soil texture.

Variable hydrological, climatic, and edaphic factors make a specific definition of the rainfed lowland rice-growing system very difficult. However, the following major factors must be considered in characterizing the rainfed lowland rice area:

A. Rainfall

1. Total rainfall
2. Distribution pattern

Table 3. Allocation of gross rice area in major producing countries to 5 types of rice culture, 1973-75 av.

Country	Rice area (thousand ha)						
	Total	Upland	Deepwater	Irrigated	Shallow rainfed	Intermediate rainfed	Dry season rice area
South and SE Asia							
India	38,402	2,402	2,362	14,917	12,634	6,080	1,724
Bangladesh	9,463	2,286	1,979	1,058	2,286	2,286	1,065
Indonesia	8,513	1,413	414	3,354	1,677	1,677	1,286
Thailand	8,218	822	1,734	2,048	1,955	1,655	512
Burma	5,147	4	38	779	4,111	201	45
Philippines	3,518	454	0	1,446	1,618	0	1,069
Vietnam (former S)	2,962	207	266	385	1,659	444	118
Vietnam (former N)	2,250	157	202	292	1,260	337	90
Pakistan	1,598	0	0	1,598	0	0	1,598
Nepal	1,226	110	1	196	919	0	n.a.
Sri Lanka	592	103	0	329	124	32	208
Laos	677	198	0	159	159	159	n.a.
W. Malaysia	779	10	0	485	102	0	216
Sarawak	145	85	0	0	60	0	n.a.
Sabah	45	26	0	0	18	0	n.a.
Total, S & SE Asia	83,535	5,277	6,996	27,046	28,582	12,871	n.a.
Other Asia							
China	34,133	681	0	30,718	2,734	0	n.a.
Japan	2,702	57	0	2,645	0	0	0
Korea, Rep.	1,201	12	0	1,097	90	0	0
Korea, D.P.R.	700	7	0	639	52	0	0
Iran	300	0	0	300	0	0	0
Afghanistan	210	0	0	210	0	0	0
Total, other Asia	39,246	757	0	35,609	2,876	0	n.a.
Other regions							
Brazil	4,836	3,723	0	556	0	556	n.a.
Malagasy	1,142	177	0	321	321	321	n.a.
USA	1,013	0	0	1,013	0	0	1,013
USSR	486						
Egypt	454	0	0	454	0	0	454
Guinea	423	254	0	56	56	56	n.a.
Ivory Coast	344	306	0	13	13	13	n.a.
Colombia	339	97	0	241	0	0	n.a.
Sierra Leone	367	220	0	49	49	49	n.a.

B. Hydrology

1. Water depth in the field with reference to the stage of crop growth
2. Probable period of submergence during flooding

C. Temperature

1. Temperature variation during the crop season

D. Edaphic factors

1. Physical characteristics of the soil
2. Inherent fertility status

For a working principle, we have recognized three broad categories of the rainfed lowland rice area:

1. Shallow - where water depth does not exceed more than 30 cm except during flooding; areas generally having one or more periods of drought.

2. Intermediate - where water depth does not exceed 60 cm except during flooding; areas which generally have consecutive deficits and excess of water.

3. Medium - where the water depth does not exceed 100 cm in the field except during flooding; areas which generally have an excess of water.

The three broad categories are recognized mainly by the water depth in the field during the cropping season. The other variables may be superimposed to define the growing condition. It is hoped that a better system of classification will be evolved during this conference.

BREEDING OBJECTIVES

It is not possible to precisely elaborate combinations of traits that would be desirable in rainfed lowland varieties. Conditions are far too variable among locations to allow that to be done with any degree of confidence. However, in discussions with rice scientists from a number of countries where large areas are under rainfed lowland rice, some of the more important plant characteristics that need to be stressed were identified.

Drought resistance

Rainfed lowland rice is primarily dependent on natural precipitation. Unfortunately, the monsoon is highly erratic in its distribution and total precipitation. Hence the crop is subject to water stress at different growth stages. Severe drought during September and November occurs once in every 5 years in western districts of West Bengal, India. In the same areas, moderate drought occurs 2 out of every 5 years and excess rainfall in 1 out of 5 years. Farmers in rainfed lowland areas of northeastern Thailand raise seedbeds in May-June and transplant their crops in late June and early July. In July and August, when the crop is about 1 month old, drought stress often occurs,

affecting from 30 to 40% of the entire rice-growing area. During the 1977 wet season, about 3 million ha were affected by drought. In Burma rainfed lowland areas often suffer from drought early as well as late in the season. Early drought forces the farmers to transplant very old seedlings (45-60 days). Late drought hits the crop at the reproductive stage, substantially reducing the grain yield.

The improved germplasm for the rainfed shallow and intermediate lowland conditions should have drought resistance at different growth stages of the crop. For rainfed medium lowland conditions, drought resistance at the early vegetative stage would be desirable.

Flood tolerance

Flood tolerance would be a desirable characteristic for all rainfed lowland varieties. Even drought-prone northeast Thailand was subject to floods during the 1977 growing season. Flood is of common occurrence in northeast India, Bangladesh, and Burma a season, affecting the crop at different stages of growth. Flooding duration varies, and so does the water depth. After the flood recedes the depth of standing water in the field may be from 15 cm to a maximum of 1 m. There is a vast area where the water depth rarely exceeds 50 cm.

For the shallow areas that appear to compose the majority of rainfed lowlands, submergence tolerance may be emphasized. Submergence tolerance and elongation ability may be desirable in the intermediate-depth areas where water depth increases gradually with the advance of the monsoon season. However, the elongation ability may be a disadvantage to a variety when flooding is early and of short duration; it may lead to severe lodging. Under such a situation, emphasis may be on incorporation in the improved germplasm of strong submergence tolerance and ability of the leaf sheath and the leaf blade to elongate. For medium water depths, however, improved germplasm should have strong internode elongation ability along with submergence tolerance.

Growth duration

The major factor determining the growth duration of varieties is the rainfall distribution pattern. Rainfed lowland areas require varieties that may flower near the end of monsoon when there is greatest assurance of adequate moisture, and yet can be harvested under dry conditions that may greatly favor grain storage.

In areas where the rainfall distribution pattern is unimodal and of short duration as in northeast India rice varieties of

very short growth duration would be desirable for shallow water depths, because soil moisture is rapidly lost soon after the cessation of monsoon rains. However, for intermediate water depths where soil moisture is not so critical, varieties with long growth duration will be needed. Where the rainfall distribution pattern is unimodal and is spread over a long period, the growth duration of varieties may be dependent on the cropping pattern, i.e. it may be short or long. For example, in Kalimantan the first rainfed crop from November to February has short growth duration, and the main crop from November to August has long growth duration.

Where the rainfall distribution pattern is bimodal, varieties with long growth duration would usually be preferred.

The desirability of photoperiod sensitivity in the rainfed lowland rice varieties will be discussed in detail later in this session. However, we may point out that where the rainfall is erratic, seedlings may be kept in the seedbed for 50 to 70 days if the rains are delayed. When transplanting is delayed, varieties insensitive to day length start tillering in the seedbed and lose tillering capacity when transplanted. Thus, there is a drastic reduction in yield. On the other hand, photoperiod-sensitive varieties have a longer vegetative period and consequently 60- to 90-day-old seedlings continue to tiller after transplanting and yield better. Thus, photoperiod sensitivity stabilizes rice yield under suboptimum growing conditions.

In Burma, Indonesia, Malaysia, and India, IR5 and its sister lines have gained wide acceptance in the transplanted rainfed areas probably because of their growth duration and ability to produce reasonable grain yields even if old and tall seedlings are used. The popularity of IR5, C4-63, and Mahsuri in many areas of Southeast Asia where rice is transplanted and the uncontrolled water level rises to more than 30 cm but less than 60 cm indicates that those conditions require varieties with long growth duration (140 to 160 days). Such varieties need not be strongly photoperiod sensitive. However, in areas where water recedes late, and for intermediate water depth, growth duration longer than 160 days will be needed. In this case, photoperiod sensitivity is required -- there are no known photoperiod-insensitive varieties with growth durations longer than 160 days.

In areas with shallow water depth where the rainfall distribution is unimodal and depends on the duration of the monsoon, the growth duration of varieties may vary from 90 to 140 days (photoperiod insensitive). Where the rainfall follows a bimodal pattern, and in areas with intermediate water depths,

varieties with long growth duration that are either photoperiod-insensitive or sensitive will be preferred. However, in areas with medium water depths, photoperiod-sensitive varieties will be preferred.

In many cases, it would appear that varieties of specific duration would take greater advantage of the prevailing rainfall patterns in areas that have traditionally utilized photoperiod-sensitive varieties. In such areas, the rains often terminate well before the day length allows photoperiod-sensitive types to mature. It would probably be wise to develop both photoperiod-sensitive and insensitive types of different growth durations and see which are more satisfactory.

Cold tolerance

Low temperatures (less than 21°C) at panicle initiation and anthesis may result in high sterility and eventually low grain yield. Most rainfed lowland rices are grown from June to December. They flower from October onward. In countries at high latitudes, like India and Bangladesh, the low temperature during October-November coincides with the reproductive and ripening stages of the crop. Cold tolerance at the reproductive stage in the improved rainfed lowland germplasm for such areas will be a desirable character.

Grain quality

Grain appearance and appropriate milling and cooking characteristics are extremely important considerations in developing improved varieties for rainfed lowland areas. Rainfed lowland rice is grown mostly for local consumption and eating quality will play a very important role in a farmer's decision to adopt a new variety. Among many desirable traits, grain quality has played a major role in the popularity of Mahsuri in many countries. Consumer preference for grain quality differs from country to country and even within a country from region to region. In northeast Thailand glutinous rice is preferred in one sector and nonglutinous rice is preferred in another. Niaw San Pah-Tawng (a glutinous variety introduced in 1962) and Khao Dawk Mali 105 (a nonglutinous variety introduced in 1959) are still the predominant varieties in northeast Thailand because of their adaptability to northeast conditions. They have acceptable cooking and eating qualities for household consumption and good milling quality for which millers pay a small premium. In India, Burma, Bangladesh, and Indonesia, primarily nonglutinous rices are grown and rices with good cooking quality are preferred. Intermediate amylose content, which seems to be widely acceptable, needs to be stressed in

generating improved germplasm for rainfed lowland rices. Nevertheless, low amylose and waxy endosperm must not be ignored.

SEEDLING CHARACTERISTICS

Varieties suited for direct seeding will become increasingly important with the design of new and more productive cropping systems for rainfed lowland conditions. In vast areas in northeastern India and Bangladesh, rice (sprouted seed) is sown directly on wet soil. Many traditional systems, such as *gogo rancah* in Indonesia, involve direct seeding.

The results of experiments on direct seeding conducted at Korat, northeast Thailand, in 1976 appeared promising. In the 1977 season when drought was severe and prolonged, direct-seeded plots appeared better. The direct-seeded crop also withstood the flood better than the late transplanted crop because of its good anchorage and growth. Under certain situations direct seeding appears to be important. Early seedling vigor and a competitive growth habit in the vegetative stage are considered essential to direct seeding. These traits are conducive to good stand establishment. Vigorous growth of seedlings enables them to effectively compete with weeds. Considerable variation in seedling vigor exists in the germplasm for tall as well as semidwarf cultivars that may be utilized to generate improved germplasm for the lowland rainfed culture.

Transplanting is also widely practiced in rainfed lowland areas. Water depth at the time of transplanting varies considerably. Often transplanting is done in standing water 20-30 cm deep. Under these situations optimum seedling height is important. Varieties with fast seedling growth should be preferred. Variability in this trait exists. Chandina is one of the shortest varieties. But at transplanting its seedlings are taller than Biplab.

PLANT HEIGHT AND CULM CHARACTERISTICS

Opinions differ on the desirable plant height for varieties meant for the rainfed lowland areas. Semidwarf rice varieties have the greatest impact in irrigated areas where there are practically no physiological stresses and plant nutrients are available in abundance. However, in rainfed lowland situations rice varieties will be faced with one or more of the physiological stresses of drought, flood, and cold. These varieties will continue to be cultivated under moderate levels of fertility. For rainfed lowland situations varieties with intermediate height (130-140 cm) and sturdy culm will probably be desirable because:

1. The traditional rainfed lowland varieties are tall and lodge even under moderate fertility, whereas varieties with intermediate height and sturdy culm should not lodge at moderate fertility.

2. Moderately tall plant type with long and droopy leaves have been reported to be better suited to upland culture where drought is the major physiological stress. In rainfed lowland rice culture, drought is one of the major stresses and plants with intermediate height may do better.

3. Although more confirmatory studies on the seedling height and mature plant height are needed, there may be a positive relationship between the mature plant height and seedling height, and tall seedling height is a desirable character for the rainfed lowland culture.

4. Water depths in the rainfed lowland areas will be varied. They may range from 15 cm to 60 cm or more at different growth

Table 4. Rainfed lowland varietal types.

Type	Major characteristics	Adaptation
Base	1. High yield potential 2. Intermediate height 3. Sturdy culm 4. Drought resistance 5. Submergence tolerance 6. High tillering 7. Moderately long erect leaves 8. Low tiller mortality 9. Good panicle exsertion 10. Long panicles 11. High number of grains/panicle 12. Adequate grain dormancy 13. Resistance to major diseases and insects 14. Acceptable grain quality	Essential or desirable for all areas
Type I	1. Base type characteristics 2. Photoperiod insensitivity (90-140 days duration) 3. Strong seedling vigor 4. Rapid vegetative development 5. Intermediate leaf angle	Monomodal rainfall, shor wet season, flood prone, standing water usually never exceeds more than 30 cm except during the brief period of flooding causing submergence. Shallow lowland

Type II	1. Base type characteristics 2. Type I characteristics (except duration) 3. Photoperiod (sensitive or long duration insensitive) 4. Strong submergence tolerance 5. Strong grain dormancy 6. Ability to tiller in waterlogged conditions 7. Adaptation to delayed transplanting	Monomodal rainfall, long wet season, flood prone, water depth less than 60 cm. Intermediate lowland
Type III	1. Base type characteristics 2. Photoperiod sensitivity 3. Leaf sheath and blade elongation 4. Adaptation to delayed transplanting 5. Erect leaves 6. Cold tolerance at reproductive phase	Regions with bimodal rainfall distribution pattern and/or erratic rainfall, delayed planting of aged seedlings, drought as well as flood prone, water depth usually does not exceed 60 cm except during floods. Intermediate lowland
Type IV	1. Base type characteristics 2. Type III characteristics 3. Strong internode elongation ability	Regions where water depth exceeds 60 cm but less than 100 cm, low-lying areas except during floods. Medium lowland

stages. Where water depth is shallow to intermediate, plants with intermediate height may not be submerged for a long period. If internode elongation ability is not stressed under these situations, certainly intermediate plant stature would offer an advantage.

Besides intermediate stature combined with sturdy stems, erect tough leaves would also be desirable. Waterlogged conditions retard tillering ability. It would be essential for the rainfed lowland varieties to possess the inherent ability for profuse tillering. Other plant characteristics that need to be stressed are 1) high grain number per panicle, 2) strong grain dormancy, and 3) good panicle exsertion.

DISEASE AND INSECT RESISTANCE

Susceptibility to diseases and insect pests seriously limits the production potential of varieties. It is essential that improved varieties be resistant to major diseases and insect pests present in the respective areas.

CHARACTER COMBINATIONS

Varieties capable of producing high grain yields under conditions of widely fluctuating seasonal environments will differ in growth form and physiology. Although one can define certain plant characteristics suited to specific environments, it is difficult, if not impossible, to define all possible combinations of characteristics necessary to suit widely fluctuating agroclimatic situations as are met in the rainfed lowland rice culture. In Table 4 we summarized the major character combinations that may be considered in generating improved germplasm for the different types of rainfed lowland rice culture.

Photoperiod sensitivity in rainfed lowland rice

M. S. AHMAD

Most regions where rice is grown are characterized by rainfed lowland conditions. This particular ecological pattern was conducive to the evolution of a major group of rice varieties that is photoperiod sensitive.

DISTRIBUTION OF RAINFED LOWLAND RICE IN BANGLADESH

Rainfed lowland rice in Bangladesh includes about 60-70% of the aus crop, 15-30% of deepwater rice (broadcast aman), and 100% of transplant aman rice. The rice planted as broadcast and transplant aman are photoperiod sensitive. The total area of the two categories is about 4.43 million ha, more or less uniformly distributed in Bangladesh. Hundreds of indigenous and modern varieties in each category are cultivated.

PROBLEMS OF RAINFED LOWLAND RICE

The crop season for most of the lowland rainfed rice starts in April and ends in December. At both ends of the season drought may be a problem. In the beginning of the season, direct-seeded aus suffers from drought at the early vegetative phase; at the end of the season transplant aman suffers at the reproductive stage. The aus crop suffers from water stagnation beyond an optimum depth, or even submergence, at the reproductive phase. Because of the possibility of drought or an early flood, 30-40% of the aus crop is planted mixed with broadcast aman rice. If aus is lost, the survival of broadcast aman is assured by its elongation capacity or drought tolerance, or both.

Uncontrollable water depth is a major problem for the transplant aman crop. Seedling or plant height is a serious limitation in the use of the modern varieties.

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Weather from May to mid-September is almost continuously cloudy, often with heavy showers. During that period light intensity is a limiting factor to rice growth. High temperature prevails throughout the season; therefore, the photosynthesis-respiration balance is at a minimum. Susceptibility of the rice plant to diseases and insects increases during the period of high humidity and temperature, and pest populations remain at a high level. The reproductive phase of the aus crop and the vegetative phase of transplant aman face all these problems.

At the end of the monsoon (from mid-October), temperature, particularly during the night, becomes critically low for proper panicle emergence, good spikelet fertility, and grain development. Most of the modern rice varieties are affected if planted late in the season, i.e. in September. About 50% of the transplant aman crop has to be transplanted in September because of late harvest of aus rice or jute. A considerable area is also transplanted in September after the floods recede.

Advantages of photoperiod sensitivity for rainfed lowland rice

Photoperiod sensitivity is associated with timely floral initiation. Because rice is a short-day plant, photoperiod-sensitive varieties initiate flowering during September when days are short. If planted early, they complete the active vegetative phase and pass through a lag vegetative phase to wait for the appropriate day length. If they are planted late, the early advent of appropriate day length causes the initiation of flowering just after a minimum period required for the active vegetative phase. By these physiological adjustments, the varieties complete their reproductive phase in weather with high intensity of sunlight, cooler temperature, and less pest problems. They also avoid the problems associated with drought and low temperature.

All local varieties of transplant aman and broadcast aman developed photoperiod sensitivity through centuries. Unlike boro and aus varieties, the aman varieties are harvested in dry fields and in dry climate, factors important for less post-harvest loss and better grain quality.

The natural advantages of photoperiod sensitivity for rainfed lowland crop conditions are important and cannot be overlooked.

CLASSIFICATION OF PHOTOPERIOD-SENSITIVE VARIETIES

Photoperiod sensitivity is a general characteristic of transplant aman rice varieties. Its intensity, however, differs

and the varieties can be broadly classified into the weak, intermediate, and strong sensitivity groups. The modern rice varieties are weakly sensitive. Such varieties generally mature late. The popular varieties may be classified as follows:

- Weak photoperiod sensitivity (early maturity) - DA31, Rajasail, Manikmadhu, Madhumala, Malati, IR5, and Brrisail.
- Intermediate photoperiod sensitivity (medium maturity) - Latisail, Chandrasail, Patnai 23, and DA29.
- Strong sensitivity (late maturity) - Nizersail, Tilokkachari, Kumragoir, Dudmona, and Haloi.

Breeding for photoperiod sensitivity

The Bangladesh Rice Research Institute (BRRI) considers photoperiod sensitivity as an essential character for varieties for the transplant aman season. Many crosses have been made between photoperiod-insensitive, high yielding varieties or progeny lines and traditional photoperiod-sensitive varieties. Some weakly sensitive progeny lines and varieties with high yield potential have been identified, but no progeny lines with strong or intermediate sensitivity have been identified.

Two crosses, BR51 (IR20 x IR5-114-3-1) and BR52 (IR20 x IR5-47-2), have shown good combining ability along with weak photoperiod sensitivity. BR51-94-6, which has been named as BR4 or Brrisail, and other progeny lines such as BR51-46-1-1/C 1, BR51-46-5, BR51-74-6, BR51-49-6, BR52-87-1, BR52-90-2, etc. are promising. Most of the materials are being evaluated in regional yield trials or purified through head rows.

Floating or deepwater rices are essentially the same as transplant aman in respect of photoperiod sensitivity. Suitable progeny lines for transplant aman conditions are being selected from the progenies of the crosses between floating rice and high-yield-potential short breeding lines.

BRRI has initiated some genetic studies on the inheritance pattern of photoperiod sensitivity. According to the data obtained up to F_3, the pattern appears to be complicated. There is some association between photoperiod sensitivity and traditional plant type. Most semidwarf or short segregants are either photoperiod insensitive or have a long vegetative phase. Some segregants appear to be weakly sensitive, but under field conditions it is not possible to identify the photoperiod-sensitive segregants with certainty. A technique

for observing the inheritance pattern under controlled conditions with artificial light is needed. There is a possibility that the single seed descent technique may be used for the purpose.

Photoperiod sensitivity in rainfed rice

SUVIT PUSHPAVESA and B. R. JACKSON

The term *rainfed rice* in this paper refers to the traditional varieties and cultural practices that have been in use for many years in the rainfed lowland areas of Asia. Our thesis is that one reason (but not the only one) vast numbers of farmers plant traditional rather than the modern dwarf varieties is the desirability of photoperiod sensitivity. Unless plant breeders recognize the real needs of farmers in rainfed areas there is little chance of making a significant impact on the production problems.

The following points clarify why farmers grow photoperiod-sensitive varieties. They represent our views based on observations of farmers in the rainfed regions of Thailand.

PHOTOPERIOD SENSITIVITY IN RAINFED RICE

Several reasons explain farmers' preference for photoperiod sensitivity in rainfed rice.

1. Photoperiod sensitivity ensures that the rice crop will flower near the end of the monsoon.
2. The farmers can plant early or late depending on the onset of the monsoon.
3. Plants do not suffer serious damage if left in the seedbed for prolonged periods.
4. Harvesting and drying are simplified.
5. Photoperiod-sensitive varieties permit transplanting when water is closest to optimum in the field.
6. Varieties can be selected for maturity that fits water conditions.
7. Land preparation and transplanting can be staggered.

PHOTOPERIOD SENSITIVITY AND RAINFALL DISTRIBUTION

Figure 1 illustrates the point that photoperiod sensitivity permits the farmer to plant with the rhythm of the particular monsoon. The popular traditional varieties Khao Dawk Mali 105 (KDML) and Peuak Nam 43 (PN 43) represent the medium and the very late maturing varieties for the northeast and southern

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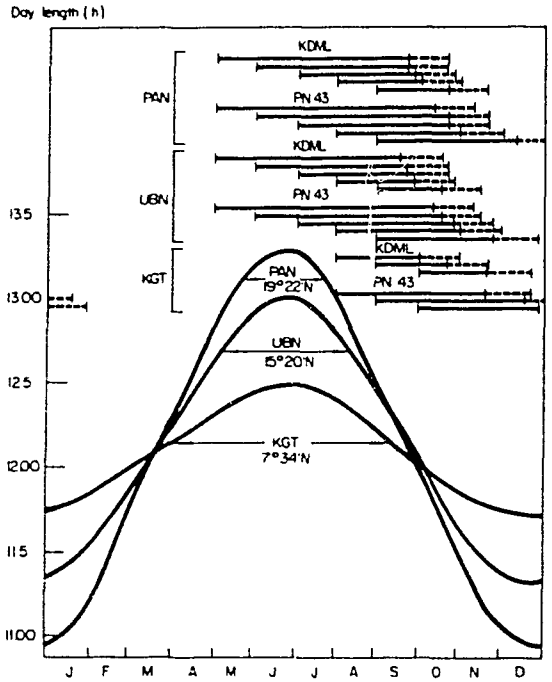


1. Seeding date, growth period, and day length curves for two photoperiod-sensitive varieties planted at three widely different locations in Thailand. KDML = Khao Dawk Mali 105, PN43 = Peuak Nam 43, PAN = north, UBN = northeast, KGT = Kuan Gut. Broken line indicates panicle initiation stage.

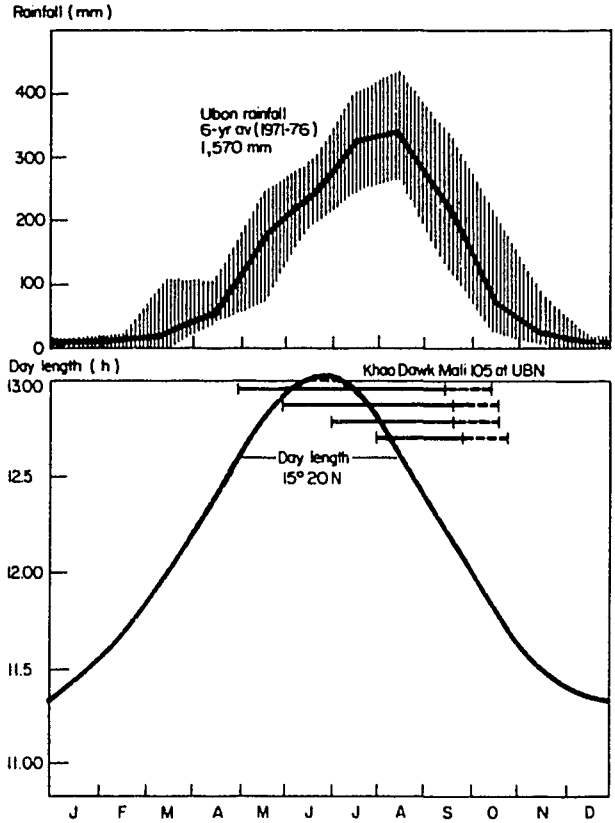
regions of Thailand. KDML usually flowers well within the usual monsoon season in the northeast, which ends abruptly in October; PN 43 is a late maturing cultivar well adapted to the southern peninsula region's prolonged rainfall conditions.

Figure 1 shows that KDML sown in the north (PAN) or northeast (UBN) matures on about the same date whether planted in May, June, July, or August. On the other hand, PN 43 is too late for all four seeding dates in those regions. At the southern station at Kuan Gut (KGT), KDML ripens by mid-December even at the October sowing date, which also coincides with the season of heavy rainfall. In contrast, PN 43, which originated in the south, is not ripe until mid-January at the earliest sowing date (August). If seeding is further delayed until September or October, harvest can be accomplished in late January or mid-February, which is the harvest date desired by farmers.

Attention is also directed to the day length curves for the three sites. Although there is relatively little variation

in the day length in the south throughout the year, it is sufficient to affect the flowering dates of both KDML and PN 43 drastically as the planting date is shifted toward the end of the year. It is much greater, in effect, than the variations in the north or northeast.

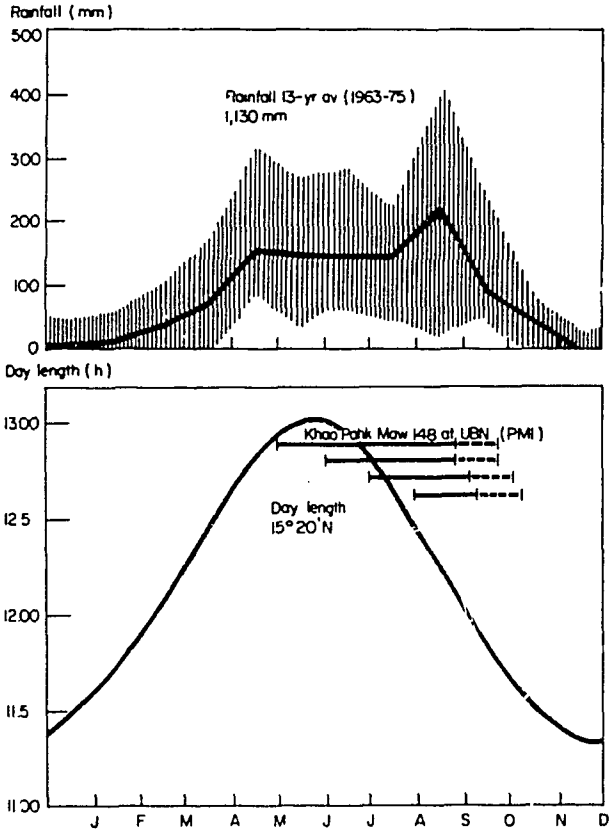
Figure 2 gives information on rainfall, seeding date of KDML, and day length curve for the Ubon Station located in the northeast in a major rainfed area. Rainfall distribution is shown on the basis of the yearly extremes (shaded area) and the 6-year average. In some years, seedbeds can be established in May when rainfall is at least 100 mm. However, there were years when the total precipitation for May was only 50 mm. Such low precipitation delayed seedbed establishment or caused the



2. Annual (shaded) and long-term rainfall distribution, day length variation and flowering date response of Khao Dawk Mali 105 at Ubon Rice Experiment Station in northeast Thailand. Broken lines indicate panicle initiation stage.

retention of more than 30-day old seedlings. The panicle initiation stage of KDML (dotted line) was reached in late September or early October regardless of whether seeding was in May, June, July, or August. Flowering generally began in October, coinciding with a marked reduction in rainfall; but that is also the time when the paddy fields are full of water. The small amount of rain that falls in November supplies some supplementary water, but the important moisture supply for grain maturation falls in September.

A second site in the northeast is shown in Figure 3 -- the Pimai (PMI) rice station, which is near the city of Korat. Comparison of the rainfall distribution at Ubon (Fig. 2) and at PMI reveals a marked difference. Rainfall at PMI shows a much more erratic distribution. Attention is directed to the



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

wide variation in the minimum and maximum rainfall for May, June, July, August, and September, the heart of the monsoon. This suggests that predictability of planting date is hazardous during any given month of the main monsoon.

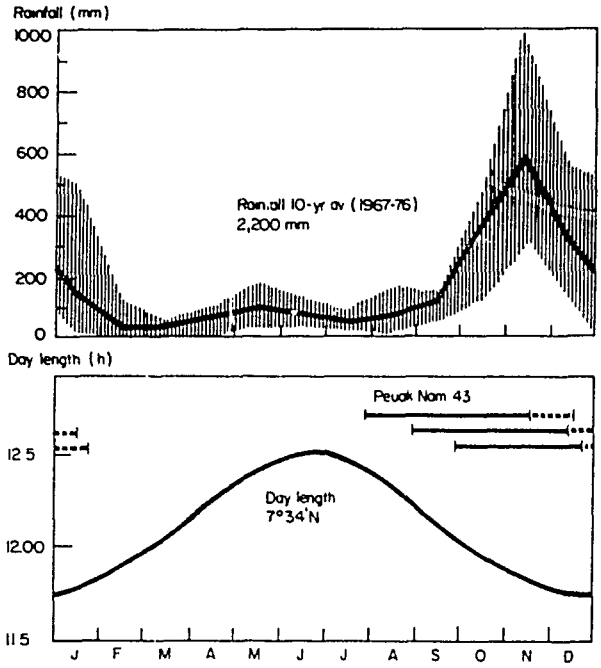
Rice farmers in the area have found that the variety Khao Pahk Maw 148 (KPM) produces relatively stable yields despite being slightly later maturing (about 2 weeks) than KDML. The slightly later maturity permits KPM to take advantage of the late monsoon showers that persist longer than in the Ubon area. An additional two weeks for growing can be important if drought has delayed transplanting until August.

Figure 4 represents the rainfed conditions farmers face in the long peninsular area of southern Thailand where annual rainfall exceeds 2,000 mm. The recommended variety PN 43 fits the growing season well since farmers need to start their rice in August or September and get their plants well established before the heavy rains occur in November and December. Harvesting should begin no earlier than mid-January, and February is preferable as it provides good weather for harvesting, drying, and storage. A sensitive variety planted under such conditions would need to have a maturity of over 200 days if planted in August, 180 days if seeded in September, and 150 days if planted in October. It is sometimes precarious to delay planting until October since water levels in the field may be too deep for the seedlings.

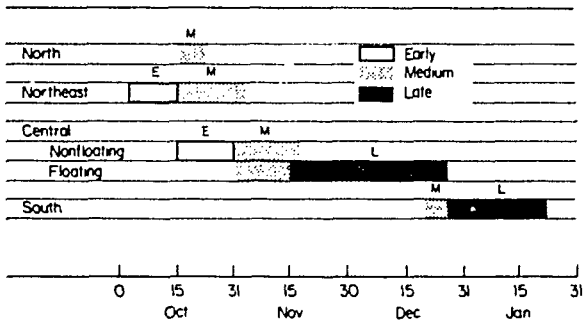
FLOWERING DATES BY REGION

For many years, Thai Government varieties have been selected by photoperiod-sensitivity classes and recommended for the different regions on the basis of popular demand by farmers as related to rainfall patterns. Although maturity class is not the only criterion for selection, varieties that are too early or too late to coincide with the monsoon rains are not considered acceptable by farmers, especially in the rainfed areas.

Figure 5 illustrates the various maturity groups by region for the presently recommended government varieties. For example, in the north all recommended varieties fall in the medium maturity class (flowering from October 15 to October 28). However, some farmers still grow an early variety where it is important to harvest near the end of the monsoon to allow a tobacco crop in the dry season. Unfortunately, the early maturing variety currently in use does not meet the Thai Government standards for other characteristics. Thus, breeders are continuing their search for an acceptable variety possessing early photoperiod sensitivity, i.e. one that will flower on or



4. Annual (shaded) and long-term rainfall distribution, day length variation, and flowering date of Peuak Nam 43 at Kuan Gut Rice Experiment Station in southern Thailand. Broken lines indicate panicle initiation stage.



5. Flowering dates of photoperiod-sensitive varieties recommended by the Thai Government, according to region.

slightly before October 1. The northern region's rainfall pattern is relatively consistent throughout the area, hence, the relatively narrow range in maturity of the recommended varieties in contrast with that of varieties for the northeast, which is the largest rice-growing region. The wide range in maturity primarily reflects the large differences in rainfall patterns within the region.

Two distinct types of rice, floating and nonfloating, are grown in the central plain. Maturity differences in the nonfloating forms may be attributed to 1) different rainfall patterns in the region, and 2) date when the monsoon floodwaters recede, which varies closely with topography. Photoperiod-sensitivity classes for floating varieties are closely related to the timing of the floods and strongly reflect the late drainage of the rice fields.

In the southern peninsula region, rains generally do not stop until mid- to late January; harvest is in February. Therefore, most rice farmers desire varieties whose panicle initiation stage closely coincides with the shortest day of the year. One major objective of Thai breeders is the selection of late and very late photoperiod-sensitive varieties. We believe that the southern farmers lack interest in the present recommended varieties because these varieties are not sufficiently late maturing. Examination of Figure 4 shows that as much as 500 mm of rain can be expected in January at Phattalung (Kuan Gut Rice Station). Under the existing natural weather conditions, there would be serious problems in harvesting and drying.

IMPROVEMENT OF PHOTOPERIOD-SENSITIVE VARIETIES

The early Thai work on varietal improvement was based on selection within existing varieties for desired flowering date, grain quality, and yield. Later on, hybridization of the local varieties was begun in an attempt to incorporate better blast resistance and higher yield. About 6 years ago, work aimed at selecting photoperiod-sensitive semidwarf types was undertaken, to obtain greater response to fertilizer.

A few experimental lines have now been selected and sufficiently stabilized to permit extensive yield testing at different fertilizer levels. We observe that photoperiod-sensitive semidwarf segregates exhibit wide yield variations similar to those of photoperiod-insensitive semidwarf forms. Yield in response to fertilizer of two promising experimental lines and a popular, widely adapted, traditional, tall, photoperiod-sensitive variety is given in Table 1. All data were obtained from monsoon results since flowering does not

Table 1. Yield and agronomic data for two photoperiod-sensitive lines compared with Niaw San Patong at 5 different fertilizer levels (Rice Fertilization Research Section, Rice Division).

Variety or cross	Selection	Flowering date	Ht. (cm)	Yield (t/ha) at given fertilizer level[a]				
				1	2	3	4	5
PN16/PKR//C4-63	BKN6819-36-3-1	4 Oct.	114	2.7	2.8	3.5	3.9	4.3
NSPT[2]/IR262	BKN6721-5-39-1(1)	17 Oct.	136	2.5	2.6	3.3	3.6	3.5
Niaw San Patong	-	26 Oct.	164	2.5	2.7	3.0	3.5	3.2

[a]Fertilizer levels range from 0 in level 1 to 112 kg N/ha for level 5.

occur in the dry season. The line PN 16/PKR//C4-63 obtained its sensitivity from Puang Nahk 16, a late flowering variety (about 1 December) adapted to the central plain; the second line inherited genes for photoperiod sensitivity from Niaw San Patong (NSPT). Both lines show strong sensitivity to photoperiod, but are earlier than the sensitive parents. A range of maturities that will permit selection for different rainfall patterns can be obtained from such crosses. Fertilizer levels ranged from 0 for level 1 to 112 kg N/ha for level 5.

Starting with 37 kg N/ha for level 3, fertilizer increments were 37 kg N each for levels 4 and 5, with phosphorus and potassium maintained at 37 and 25 kg/ha, respectively.

The results shown in Table 1 are encouraging, especially at levels 4 and 5. They suggest that greater fertilizer responsiveness can be obtained with proper breeding and selection.

Work continues on the production of additional semidwarf hybrids having photoperiod sensitivity, as well as of new types that can elongate if floodwaters become deep, and possess drought tolerance in the vegetative stage and flood tolerance when completely submerged for up to 10 days.

It is still too early to predict whether semidwarf photoperiod-sensitive varieties will find widespread acceptance among rainfed rice farmers. We proceed on the assumption that sensitivity combined with other desirable characters will provide the yield stability that is required to help increase rice production in the rainfed areas. We are optimistic that the answer is forthcoming.

Persons who are interested in the subject of photoperiod sensitivity may refer to the papers presented at the international seminar on photoperiod-sensitive transplanted rice, held at the Bangladesh Rice Research Institute, Joydebpur, Dacca, 24-28 October 1977.

Potential for improving drought resistance in rainfed lowland rice

T. T. CHANG, BORIBOON SOMRITH, and J. C. O'TOOLE

Rice, a semiaquatic species, thrives best when water is continually provided. To millions of rice farmers in nonirrigated areas, however, the success of each cropping season is dependent on unpredictable monsoon rains. To these farmers, stability of yield is perhaps more important than occasional high yields. The response of a rice variety to the growth stage-drought interactions endemic to a particular location is a significant component of the variety's yield stability. In breeding improved varieties, the need to maintain or improve the drought resistance component along with other characteristics necessary for local adaptation is obvious.

Rainfed lowland rice occupies about one-half of the world's rice area. In South and Southeast Asia where 66% of the region's 84.4 million ha is rainfed, 48% may be classified as rainfed lowland rice because of the physiographic and hydrologic characterization of the landscape and the cultural practices utilized.

In this paper, we discuss the nature of drought in the rainfed lowland ecological background in relation to the better researched upland rice situation. Current evaluation of rice germplasm for drought response in rainfed lowland culture will be reviewed. Problems encountered and progress in varietal improvement made at IRRI and in the drought-prone area of northeast Thailand will be reported.

Geneticist, International Rice Research Institute (IRRI); *rice breeder*, Khon Kaen Rice Experiment Station, Khon Kaen, Thailand; and *associate agronomist* (IRRI), Los Baños, Philippines. The authors are indebted to Genoveva C. Loresto, Oscar Tagumpay, Julie Jose, and Roger Parreño of the Plant Breeding Department; Jaime Padilla of the Agronomy Department, IRRI, S. I. Bhuiyan and staff members of the Irrigation and Water Management Department, IRRI, stationed in Central Luzon; and the technical staff of the Khon Kaen and Chum Phae Rice Experiment Stations and of the Northeast Agricultural Research Center, Thailand, for their invaluable help on the technical operations of the research programs.

SOME CHARACTERISTIC DROUGHT CONDITIONS

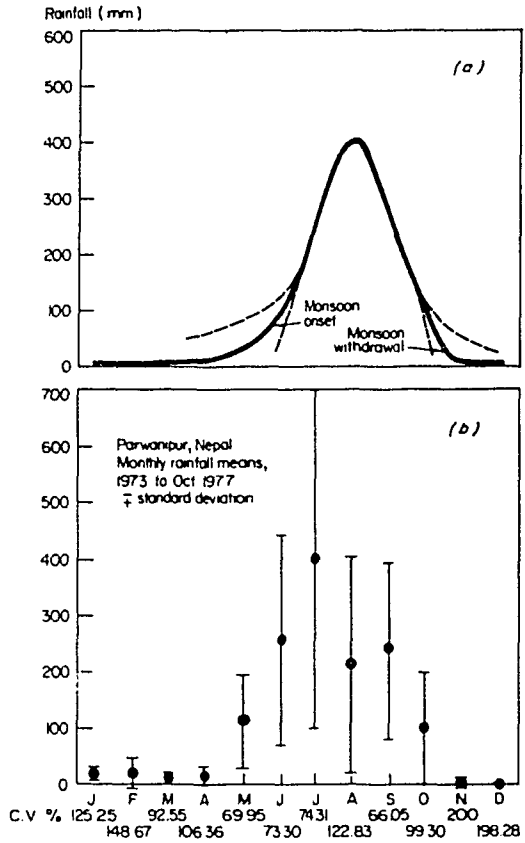
To rice researchers working in the diverse ecological backgrounds in which rainfed rice is cultured, drought often includes a variety of different situations. Basically, drought is a period of below-normal rainfall whose duration and intensity often have great spatial and temporal variations. Both duration and intensity are greatly modified by the soil physical properties of a given site. To simplify, drought may be considered as a water deficit-crop growth stage interaction.

That interaction is frequently an endemic characteristic of a site's rainfall distribution pattern. Such areas as northeast Thailand and southeastern India have chronic problems of crop establishment in the early weeks of the monsoon (Fig. 1a). Other areas such as central and northern India characteristically have drought conditions associated with early withdrawal of the monsoon rains, which adversely affect flowering and grain filling (Fig. 1a). But in much of Nepal's tropical Tarai and northeast India, the problem is not definitely related to a particular growth stage. Nor are these areas considered drought-prone by surveys or maps, based on monthly means or annual rainfall totals. Figure 1b illustrates the problem. At Parwanipur (Nepal) all monthly means during the crop season (June through October) are over 200 mm. However, the variance associated with the monthly means illustrates that drought (or perhaps excess water) can occur at any growth stage.

Within an agroclimatically similar area, soil characteristics such as texture and potential rooting depth vary greatly. These soil parameters as well as the major physiographic and hydrologic characteristics must also be considered in characterizing or diagnosing the location-specific parameters of drought, before embarking on a varietal improvement effort.

DROUGHT IN UPLAND AND RAINFED LOWLAND CULTURES

In recent years considerable effort has gone into studying the upland rice environment and the adapted varieties. The elucidation of the varietal adaptations responsible for the apparent drought resistance was a major research activity at IRRI (IRRI 1975b). Our studies have indicated some of the principal soil and atmospheric factors associated with drought under upland culture. These are related to the primary adaptive mechanisms for drought resistance found in the rice germplasm (O'Toole and Chang 1978). Similar studies in



1. a) Annual rainfall distribution illustrating the extent of variability (dotted lines) associated with monsoon onset and withdrawal periods. b) Rainfall distribution and variability common to the tropical Tarai of Nepal and northern India.

drought-prone, rainfed lowland rice environments have not been made on an equally intensive scale, however.

The basic features of upland and lowland rice environments differ. The climatic, edaphic, hydrologic, and agronomic parameters may produce significant interactions in times of below-normal rainfall:

- Upland climates are generally characterized by 500 to 1,500 mm annual rainfall with a period of 3 to 4 months having monthly means exceeding 200 mm. Lowland climates are generally characterized by 700 to 2,000 mm annual rainfall with 3 to 7 months exceeding 200 mm each.

- Upland soils are usually deep, light-textured, high in hydraulic conductivity, and aerobic. Lowland soils are generally shallow with a hard pan, heavy textured, and anaerobic during most of the crop season.

- Upland soils are well drained, with low water tables; they rarely experience prolonged flooding. Lowland areas are often poorly drained, with high water tables; they may experience water excesses alternating with drought.

- Land preparation for upland rice is dry. The crop is direct-sown and the use of agrochemicals is negligible. Lowland fields are usually prepared wet and puddled, the crop is established by transplanting or broadcasting, and the wide range of agrochemical use is associated with water dependability and control.

Certain drought-resistant adaptive mechanisms,such as early maturity or photoperiodic control of the reproductive process and a deep and thick root system, which are highly effective in conferring the escape or avoidance component of drought resistance under upland culture, may also apply to rainfed lowland culture. The more subtle yield-reducing effects of water deficit under rainfed lowland culture would require more refined techniques in research, however. Thus, knowledge gained in studies of upland drought will have limitations when directly extrapolated to apply to lowland conditions. We need to initiate and sustain research directed toward understanding the intricacies of the major drought-prone, rainfed lowland cultural systems.

GERMPLASM EVALUATION AT IRRI

Drought resistance under upland conditions

Since the development of the mass-screening method for drought resistance in upland nurseries (Chang et al 1974), IRRI breeders and agronomists have evaluated about 9,193 accessions from IRRI's germplasm bank and more than 7,000 breeding lines. About 2,000 more accessions have been evaluated by agronomists in the special greenhouse. Drought reactions obtained at two growth stages from 9,720 accessions are summarized in Table 1.

To sum up the 4-year screening work, we emphasize the following:

- Drought resistance at the vegetative phase is more readily found than resistance at the reproductive phase (IRRI 1978).

Table 1. Summary of field scores on drought resistance of 9,720 varieties and lines, International Rice Research Institute, Plant Breeding Department, 1973-76 dry season.

Varieties	Entries tested (no.)	Varieties (%) at vegetative stage with a score of									Entries tested (no.)	Varieties (%) at reproductive stage[a] with a score of								
		1	2	3	4	5	6	7	8	9		1	2	3	4	5	6	7	8	9
Traditional upland varieties	2326	0.1	1.9	13.7	28.2	44.0	10.0	1.2	0.9	-	528	0.2	-	4.9	4.4	10.8	7.6	39.0	3.4	29.7
African *sativa* varieties	471	-	0.2	6.8	34.8	32.5	20.8	3.2	1.5	0.2	303	0.2	-	4.6	0.9	6.3	4.6	31.6	2.0	51.1
Upland breeding lines of IRRI	1432	-	0.1	2.2	18.0	46.3	27.8	5.1	0.5	-	639	-	-	0.6	-	2.5	0.6	42.1	3.3	50.9
Lowland breeding lines of IRRI	2025	-	-	0.3	6.0	35.4	41.9	13.4	2.7	0.4	1300	-	-	0.1	0.1	1.6	1.6	37.0	4.7	54.9
Upland breeding lines from other countries	312	-	0.6	-	4.8	34.0	42.0	13.5	3.2	1.9	94	-	-	2.1	-	1.1	-	45.7	9.6	41.5
Traditional rainfed lowland varieties	326	0.6	14.4	8.0	22.1	24.2	27.3	3.4	-	-	326	-	0.3	0.6	0.3	3.4	-	21.8	4.6	69.0
Floating varieties	105	-	-	3.8	23.8	53.3	18.1	0.9	-	-	36	-	-	-	2.8	5.6	11.1	47.2	8.3	25.0
100-day varieties	969	0.1	21.1	9.9	20.9	28.6	16.7	1.8	0.6	0.2	969	0.6	1.6	6.8	3.0	9.7	6.3	25.6	11.8	34.6
ARC varieties (India)	361	-	11.4	13.6	28.2	24.6	19.4	2.8	-	-	361	-	0.2	2.4	1.7	8.9	4.7	19.7	1.7	60.7
Bulu varieties of Indonesia	318	-	1.9	7.9	16.7	41.2	31.5	0.9	-	-	211	-	-	1.4	0.5	4.7	1.9	16.1	1.9	73.5
Salt-resistant varieties	127	-	-	3.9	32.3	46.5	17.3	-	-	-	127	-	-	-	-	-	1.6	33.8	11.8	52.8
Cold-tolerant varieties	151	-	-	-	29.8	68.9	1.3	-	-	-	151	-	-	-	-	4.6	0.7	7.3	7.9	79.5
O. glaberrima varieties	[illegible]	0.6	33.2	7.9	9.2	29.7	17.0	2.1	0.1	-	350	-	-	34.6	13.1	8.0	4.3	15.4	-	24.6
Total											5395									

[a] Data on reproductive stage [illegible] season only.

- Drought resistance has relatively high heritability and can be found in progenies of double-crosses that involve one resistant parent only (IRRI 1976).

- Drought resistance and the ability to recover are independent traits (Chang et al 1972, IRRI 1975b).

Drought resistance under rainfed lowland conditions

Since the wet season of 1976, IRRI geneticists and breeders have been testing diverse rice germplasm under rainfed lowland culture (simulated in the dry seasons) and a continuously irrigated culture. So far, 1,419 varieties and lines have been evaluated in the 1976 and 1977 crop seasons. Because facilities for this kind of evaluation are rather limited, we drew on information obtained earlier from the upland screening experiments to reduce the number of test varieties.

When prolonged drought occurred (in the wet season) or was imposed (in the dry season), the susceptible varieties manifested the same syndrome that was observed earlier in mass-screening under upland conditions (Chang et al 1972, 1974; Loresto et al 1976): marked rolling of leaves, death of lower leaves, stunted plant growth, reduced tillering, delayed heading, incomplete panicle exsertion, reduced panicle size, panicle sterility, and decrease in grain weight (IRRI 1977, 1978). For the intermediate and more resistant genotypes, the varietal differences were relatively smaller and it was necessary to compare the above traits between the rainfed lowland planting and a fully irrigated planting obtained in the same season or at an earlier date.

Promising genotypes identified from the evaluation experiments are grouped as follows:

1. Improved lowland varieties and lines -- Pelita I-1, Pelita I-2, BPI-76 (n.s.), Sigadis, Mahsuri, Niaw Sanpahtawng, Knlb-368-1-8-6-7, B981d-si-46-2, BKN 6809-74-40, Bala, IR34, IR2035-108-2, IR3941-25, and IR4707-123-3.

2. Purified farmers' varieties -- Carreon, DJ 29, BR3, BK 88/BR6, Kuan Tung Tsao Sheng, JC 81, and Nam Sagui 19.

3. Improved upland lines -- IR3880-13-5, IR3880-13-11, IR3646-8-1-1, IR3646-8-1-5, and IR3646-13-2-2.

During 1977 and 1978, many crosses made at IRRI involved the following drought-resistant parents: BPI-76 (n.s.), JC 81, Khao Dawk Mali 105, Mahsuri, Nam Sagui 19, Sigadis, IR34,

IR2035-108-2, IR3646-13-2-2, IR3880-13-5, IR4422-6-2 and IR4432-28-5.

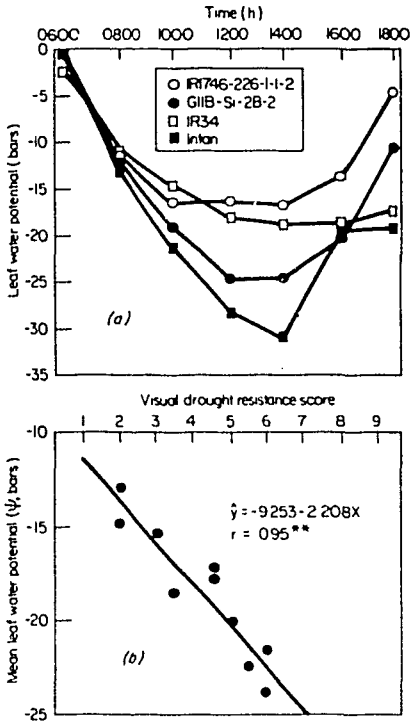
In earlier results from dry season upland field screening, we reported a close association between visual scoring based on leaf rolling (Loresto et al 1976) and varietal capability to maintain high leaf water potential (O'Toole and Chang 1978). The maintenance of a high water status in these upland adapted varieties was predictable from earlier studies of rooting depth and root thickness (Loresto and Chang 1971, Chang et al 1972, IRRI 1975a, Parao et al 1976). During the 1977 dry season field screening in lowland culture, we again observed this relationship. Figure 2a illustrates the diurnal pattern of leaf water potential in four varieties screened for drought response in a dry season lowland experiment. It is clear that the varieties are experiencing different levels of internal plant water deficit during the day. Figure 2b shows that the visual drought resistance score is highly correlated with daily mean leaf water potential. Thus the varietal trait, maintenance of a favorable plant-water potential, appears to be a common factor determining the visual drought resistance score regardless of the cultural system employed.

It is worth noting, however, that soil depth or potential rooting depth may be restricted in many rainfed lowland fields. In situations where prolonged maintenance of plant water potential is not possible, we may find that alternative adaptations for coping with internal water deficits have evolved. In figure 2a the Indonesian lowland variety Intan appears to be poorly adapted for maintaining high water potential. Nevertheless, it has a favorable reputation in the drought-prone rainfed sites of Indonesia and has recently been adopted by rainfed rice farmers in Karnataka State, India.

Observations such as these further indicate the embryonic state of our current research on varietal adaptation to rainfed lowland environments, and stress the need for more refined studies.

COMPARISON AMONG FULLY IRRIGATED, PARTIALLY IRRIGATED, AND RAINFED LOWLAND CULTURES IN CENTRAL LUZON, PHILIPPINES

To extend the research on drought resistance in rainfed lowland culture to areas where large proportions of the rice crop are planted under nonirrigated conditions, field experiments were initiated in farmers' fields near Gapan and Talavera, Central Luzon, Philippines, in the 1977 wet season. In both



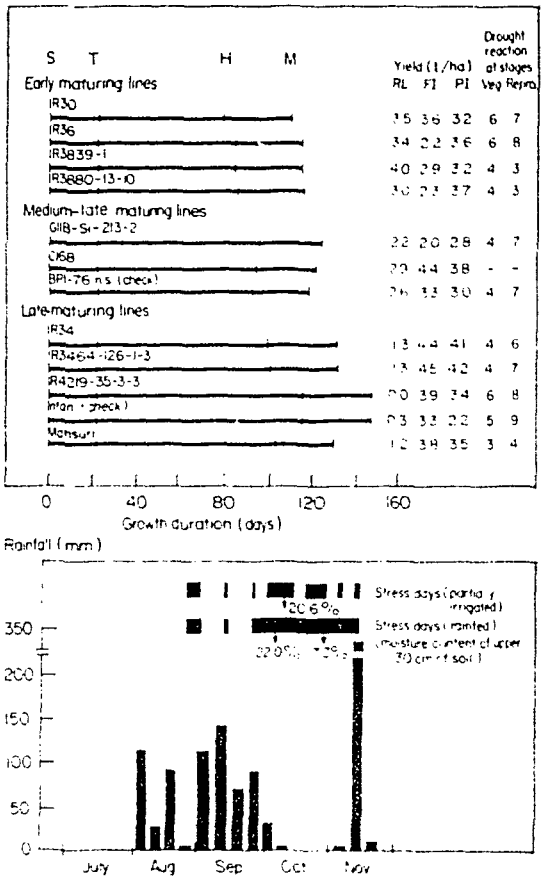
2. a) Diurnal change in leaf water potential of four rice varieties on 28 March 1977. b) Relationship between visual drought resistance scores of 10 rice varieties and the mean leaf water potential (Ψ) over the day $\left[\sum_{0600}^{1800} \Psi\, 2\,h/7\right]$, 28 March 1977. Lowland field screening, IRRI.

places, three sites were selected to represent fully irrigated, partially irrigated, and rainfed water regimes. At each site 12 rices known to react differently to moisture stress were planted.

Most sites had light soils: sandy loam, loam, or sandy clay loam.

Fortunately, the experiments ran into protracted dry weather that began in late September. Distinct differences in yield performance among varieties were observed.

Figures 3 and 4 combine information on the drought resistance scores, vegetative and reproductive growth phases of test varieties, the rainfall distribution at two sites from August through November, the occurrence of stress in the partially irrigated and rainfed plots, and the yields of the 12 varieties under each treatment.



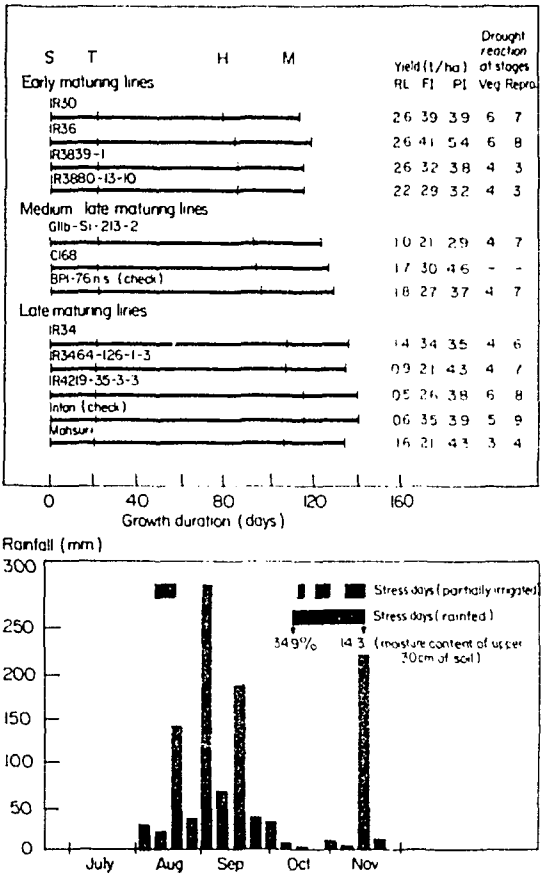
3. Rainfed distribution, stress days, growth duration, drought reactions, and yields of 12 rices tested at Talavera, Nueva Ecija province, Philippines, 1977 wet season. S = seeding, T = tillering, H = heading, M = *maturity*, RL = *rainfed lowland*, FI = fully irrigated, PI = partially irrigated

The following inferences may be drawn from the experiments:

- Water stress during the reproductive period (from panicle initiation to grain ripening) has adverse effects on grain yield.

- The early maturing varieties are less affected by water stress during the later part of the crop season mainly because they are able to escape severe water deficit at the grain ripening stage.

- The medium- and late-maturing varieties are much more adversely affected by water stress that occurs after heading. The late varieties produce less than the medium-maturing ones.



4. Rainfall distribution, stress days, growth duration, drought reactions, and yields of 12 rices tested at *Gapan, Nueva Ecija province,* Philippines, 1977 wet season. S = seeding, T = tillering, H = heading, M = maturity, RL = rainfed lowland, FI = fully irrigated, PI = partially irrigated.

- Among varieties in the medium- and late-maturing groups with similar growth durations, genotypes significantly differ in their resistance to drought.

- Drought reactions under upland culture obtained from mass-screening tests are positively correlated with drought responses under rainfed lowland culture.

The findings of the 1977 experiments carried out in Central Luzon have indicated great promise in the genetic approach for coping with drought resistance under rainfed lowland culture.

BREEDING PROGRAM IN THAILAND

Statistics compiled by the Thai Royal Irrigation Department (Thai Department of Agriculture 1977) show that during a

126-year period (1831-1957) substantial losses in rice production could be ascribed to adverse weather conditions (drought or flood or both) that prevailed in 64 years of the period. Drought occurred in 60 of the 64 years. During the 1977 wet season, drought damage accounted for production losses ranging from 9.62 to 38.32% in the rainfed lowland areas of 16 provinces in the northeast. For the total planted area, the average loss amounted to 28.49% (Thai Department of Agricultural Extension 1978). Therefore, drought resistance was included as one of the major breeding objectives in 1954, and was reemphasized in 1972. Research work in the northeast was expanded when the Rainfed Rice Improvement Pilot Project was launched in 1972. The Khon Kaen Rice Experiment Station has been serving as the breeding center for the northeast region.

Some of the recommended lowland varieties of the northeast region, such as Nam Sagui 19, Niaw Sanpahtawng, Khao Dawk Mali 105, and RD6 (KDML '65G2U-68-254) have moderate levels of drought resistance. Candidates for varietal release in 1978, KDML '65G1-U-45 and KKN6721-5-7-4 also have good resistance in upland screening tests. The upland drought screening tests have been implemented at several sites in the region since 1975. Test materials include local varieties, accessions from the IRRI germplasm bank and IRTP nurseries, IRRI breeding lines, and breeding lines from different experiment stations in Thailand. The promising sources of drought resistance identified during 1976-77 are listed in Table 2.

Since 1975 the Khon Kaen Station has made about 500 crosses, of which 70% were aimed to improve the level of drought resistance. The F_2 populations were supplied to the following stations: Pimai Rice Experiment Station (RES), Surin RES, Sakonnakorn RES, Khon Kaen Field Crop Experiment Station, Chiengrai Crop Experiment Station, Pitsanulock RES, Pahn Chiengrai RES, Chum Phae RES, Ubon RES, and the NE Agricultural Research Center. We also exchange early generation lines and F_2 bulks with IRRI.

In 1977, we started collaborating with IRRI in carrying out drought screening experiments under rainfed lowland culture at Khon Kaen and Chum Phae stations. The 10 top yielding entries at Chum Phae station were: KDML '65-G1-U-45, KKN 6721-5-7-4, KDML 105, IR3464-126-1-3, BKN6721-13-5-3, KDML 65-G2-U-68-254, BKN 6801-5-1, IR3646-9-2-1, IR1529-430-3, and BPI-76 (n.s.). The yield ranged from 2.27 t/ha (BPI-76 n.s.) to 3.18 t/ha (KDML '65-G1-U-45). There was no significant difference among the means of the entries. Popular varieties such as Nam Sagui 19 and the blast-resistant Mahsuri yielded 2.23 and 2.13 t/ha, respectively. Their yields did not differ significantly from

Table 2. List of 20 drought-resistant selections in the International Upland Rice Observational Nursery at Northeast Agricultural Center Farm, Khon Kaen, Thailand, 1976 and 1977 wet seasons.[a]

1976		1977	
Selection	Drought score	Selection	Drought score
IR1545	3	Aus 61	4
IR1721-14-6	4	B981k-123	3
IR1746-F_5B-24	3	B981d-Si-28-2	3
IR1746-88-1-2-1	3	IR1746-88-1-2-1	4
IR1746-194-1-1-1	3	IR1750-F_5B-5	4
IR1746-226-1-1-2	3	C121-94	3
IR1746-226-1-1-3	3	C166-135	3
IR1746-226-1-1-4	2	Kinandang Patong	4
IR1746-226-2-2-2	3	62-355	4
IR1746-226-1-2-3	3	IR36	4
IR1750-F_5B-2	4	IR442-2-58	4
IR1750-F_5B-3	3	IR2061-522-6-9	3
IR1750-F_5B-5	3	IR3839-1	3
IR1750-F_5B-16	2	IR3880-13	3
IR2734-F_3B-20-1	3	IR3880-17	5
IR2735-F_3B-35-1	2	IRAT13	3
A6-10-37	3	C22	4
E425	2	C46-15/IR24[2]	5
IRAT9	4	IR1754-F_5B-22	3
IRAT13	2	IR3880-5	3

[a] Drought score based on scale of 1-9: 1 = none to very slight effects of stress, 9 = all plants apparently dead.

those of the top 10 entries, however. On the other hand, IR36 yielded only 1.78 t/ha; Intan, a check variety from Indonesia, yielded 1.83 t/ha.

We also test promising materials under two direct-seeding methods: dibbling and drilling. Improved varieties sown by these methods could outyield the old varieties grown by transplanting. Row seeding appears to be slightly superior to other methods.

The new selections KDML '65-G1-U-45, KKN6721-5-7-4, SPT6118-34, and RD6 produced higher yields than the popular varieties (Khao Dawk Mali, Khao Pahk Maw, and Niaw Sanpahtawng) in variety-planting method trials at several stations in the northeast during 1977 (Table 3, 4). KDML '65-G1-U-45 performed well probably because it matures earlier than the standard local varieties.

We believe that a combination of superior varieties and proper cultural practices offers the greatest opportunity for rainfed rice improvement in northeast Thailand.

Table 3. Grain yield of glutinous rice varieties and breeding lines in seeding[a] method-variety trial and demonstration in farmers' fields. Northeast Thailand, 1977 wet season.

Variety or line	Method	Grain yield (kg/rai[b])				Av
		Yasothon		Ubon		
		Meuang Yasothon (28 June)	Kham Kheuan Caew (25 July)	Warin Chamrab (27 June)	Det Udom (19 July)	
Niaw Sanpahtawng	Dibbling (D)	408	123	331	166	257
	Row (R)	375	154	315	233	269
RD6	D	486	120	470	163	310
	R	403	154	383	310	312
KKN6712-5-7-4	D	452	120	406	252	307
	R	447	152	424	349	343
BKN6721-13-5-3 (1)	D	496	97	268	202	266
	R	494	136	236	335	300
Local variety (transplanted)		285[c]	167[d]	254[d]	185[c]	223

[a] Seeding dates are in parentheses.
[b] 6.25 rai equals 1 ha.
[c] Niaw Sanpahtawng.

Table 4. Grain yield of nonglutinous rice varieties and breeding lines in seeding[a] method-variety trial and demonstration in farmers' fields, 1977 wet season, northeast Thailand.

Variety or line	Method	Grain yield (kg/rai[b])			Av
		Dan Khuntod (Korat) (15 July)	Pratai (Korat) (22 July)	Srisharapoom (Surin) (17 July)	
Khao Dawk Mali 105	Dibbling (D)	255	366	269	298
	Row (R)	368	371	329	356
KDML '65-G1-U-45	D	284	371	379	328
	R	363	433	341	379
BKN6113-79	D	351	186	251	263
	R	472	118	208	266
SPT6118-34	D	462	355	312	376
	R	492	343	283	373
Local variety (transplanted)		204[c]	203[d]	398[c]	270

[a] Seeding dates are in parentheses.
[b] 6.25 rai equals 1 ha.
[c] Khao Dawk Mali.
[d] Khao Pahk Maw.

FUTURE DIRECTIONS FOR RESEARCH

We make eight observations to point out future research directions.

1. There is great potential for incorporating drought resistance into high yielding rice genotypes intended for rainfed lowland culture by the combined efforts of breeders, geneticists, crop physiologists, and agronomists.

2. Enormous variation exists among genotypes with respect to drought resistance at the vegetative phase. Relatively few accessions are drought resistant at the reproductive period. We need to intensify our search for resistance that functions at the later growth period.

3. Early maturity frequently aids drought escape in areas with a short rainy season. Photoperiod-sensitive genotypes fitting well into the rainfall pattern of specific areas can be useful.

4. Substantial correlation exists between drought resistance scores obtained in upland screening and varietal behavior in rainfed lowland plantings. But we need to know more about the component-mechanism of drought resistance under rainfed lowland culture.

5. Progenies of crosses intended for upland cultures should also be tested and selected for those suitable under rainfed lowland culture and vice versa. By making full use of many drought-resistant sources, we may develop a wide spectrum of progenies that can adapt to the full array of climatic, hydrologic, and edaphic conditions.

6. Although drought resistance is a highly complex trait, research findings to date indicate that it has rather high heritability and expressivity. The inclusion of a drought-resistant parent in three-way or multiple crosses is essential.

7. As was the case with upland rice (Chang et al 1975), some modifications in the improved plant type will be needed: intermediate plant height, moderate tillering ability, adequate panicle size, and good panicle exsertion.

8. Varietal improvement programs for rainfed lowland areas will call for a greater degree of international and interinstitutional collaboration than for irrigated rice culture because of the marked variations in location-specific ecological factors. Testing in farmers' fields at representative sites is essential to complement and supplement testing at experiment stations.

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Potential for improving submergence tolerance in rainfed lowland rice

N. SUPAPOJ, D. HILLERISLAMBERS, C. BOONWITE, and S. KARIN

In rainfed areas, flooding is a serious constraint to rice yields. Water from flash floods may remain on rice fields for periods of 7-10 days. It has been suggested that flood damage to rice is mainly due to:

- the force of the water, which uproots rice plants;
- death of plants, particularly from lack of an adequate oxygen supply for respiration; and
- lowered photosynthetic activity resulting in a shortage of respiratory substrates (Yamada 1959).

In countries where sudden flooding occurs, varietal tolerance for submergence should be an important goal in the rice breeding program. Methods for testing the tolerance of varieties for submergence should be developed.

Many locally adapted varieties grown in rainfed areas were subjected to periodic flooding throughout a long history of cultivation. Some of these acquired genetic tolerance for flooding, or they would not have survived such a period of natural selection. Therefore, a logical place to look for flood-tolerant sources should be in areas where floods frequently occur. In India, for example, flood-tolerant varieties such as FR 13A were obtained by saving the surviving plants from flood-damaged fields.

MAGNITUDE OF THE SUBMERGENCE PROBLEM

In rainfed areas, water is generally the factor limiting the yield of rice. Sufficient fertilizer and good soil preparation may not deliver expected high rice yields because of too little or too much water. There may be insufficient rain at the

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Rice breeder, Deepwater Rice Breeding Branch, Rice Division, Department of Agriculture; *breeder*, Thai-IRRI Cooperative Deepwater Project; and *rice breeders*, Bangkhen, Bangkok, Thailand.

seedling stage and the resulting drought causes seedlings to be stunted, reduces tillering, and sometimes destroys the plants altogether. In depressions or in areas close to rivers, however, floods can occur anytime after transplanting. In 1975, an unexpected flood severely damaged Thailand's wet season rice crop in the middle of the growing season, particularly in the central plain. Estimates of the resulting flood damage in irrigated and nonirrigated areas are in Table 1. The table shows the impact of flooding on the rainfed areas.

Floods such as those in 1975 frequently occur in the main rice-growing areas of southern Thailand, and occurred in the rainfed areas of the northeast in 1977. They came too late in the season to allow replanting of the rice crop.

FIELD SCREENING

The International Rice Research Institute developed methods several years ago for the laboratory screening of rice seedlings for submergence tolerance (Vergara and Mazaredo 1975). Major factors, such as water temperature, light intensity, and water depth were controlled. As a result, information from each screening has high repeatability. However, for screening in the field, control of such factors is difficult, if not impossible. Factors within experimental control require study in order to develop reliable field screening tests. Some of them are:

- age of seedling,
- method of planting,
- plot size,
- depth of water, and
- period of submergence.

In Thailand there is no standard method yet for submergence tolerance screening. Several studies dealing with submergence tolerance of rice have, however, been conducted. The different procedures used are summarized in Table 2. From the information, procedures of screening for submergence tolerance have been refined. In test 1 (Weerapat and Woraniman 1974) using clear water and potted plants, Nam Sagui 19, Gow Ruang 88, Bangkhen 293, and Khao Dawk Mali 105 -- all Thai tall nonfloating varieties -- showed high percentages of emergence through water after 7 days. RD1 and RD2, the short-stature, high yielding varieties released by the Rice Division, performed poorly (0% emergence after 7 days of submergence). In test 2 (Jaileuk 1975), using a deep pond and maintaining seedling age and water depth similar to those in Weerapat and Woraniman's

Table 1. Rice cultivated area, area damaged by floods, harvested area, and yield of rice in 1975 (RID 1976).

Type of rice area	Area grown to rice (thousand ha)			Yield		
	Total	Damaged by floods	Harvested	Total (thousand t)	Av (t/ha)	Estimated loss (thousand t)
Irrigated	1,882	37	1,845	4,744	2.57	95
Nonirrigated	6,530	551	5,978	11,014	1.84	1,014

Table 2. Procedures of various submergence tests in Thailand.

Test	Planting method	Seedling age at submergence (days)	Water depth (cm)	Submergence duration (days)	Data collected
1	Potted plants	10	50	14	% emergence through water
2	Direct-seeded	10	35 45	21	% emergence through water
3	Direct-seeded	10	75	10	% survival
4	Transplanted	40	90 104 134 154	7	1 to 9 score
5	Direct-seeded Transplanted Transplanted	20 50 70	115	7	% survival 1 to 9 score

test, Bangkhen 293, Gow Ruang 88, Leuang Tawng, Nahng Mon S-4, BKN6613-28-1-2, BKN6652-225-1-1-2, W1252, and GS1989 showed good submergence tolerance.

As a result of the initial studies, Nam Sagui 19 and RD1 were selected as the respective resistant and susceptible checks in succeeding submergence tests.

Boonwite (1977) conducted submergence tolerance screening at the Klong Luang Rice Experiment Station. Several promising lines and varieties were identified. The 20 best lines from 480 entries tested (Table 3) have at least one parent that has been reported to possess tolerance for submergence. Seven of the best lines originated from the cross GEU76042, which contains SML Temerin; and six additional lines were from IR8234, which has Nam Sagui 19. Both SML Temerin and Nam Sagui 19 have shown relatively good submergence tolerance in laboratory tests at IRRI. Nam Sagui 19 was first reported to possess submergence

Table 3. Lines and varieties showing good tolerance for submergence at the Klong Luang Rice Experiment Station in 1977 (Boonwite 1977).

Designation	Parents	% survival (av from 2 replications)
IR8234-9T-4	NS19/IR1721-11-6-8//IR2061-213-2-16	99.5
GEU76042-3K-10	SML Temerin/BG90-2//bulk F_1's pollen	99.0
GEU76042-4K-12	SML Temerin/BG90-2//bulk F_1's pollen	94.0
IR8234-0T-27	NS 19/IR1721-11-6-8//IR2061-213-2-16	91.0
IR8234-14T-2	NS19/IR1721-11-6-8//IR2061-213-2-16	90.0
IR7065-0T-16	NS19/IR2031-724-2-3-2	88.0
GEU76042-3K-19	NS19/IR1721-11-6-8//IR2061-213-2-16	87.0
IR8235-8T-2	NS19/IR2031-720-2//IR2061-213-2-16	85.5
BKNFR76106-9	IR1561-228-3-3/FR13A	85.0
GEU76042-4K-15	SML Temerin/BG90-2//bulk F_1's pollen	84.0
IR8234-4T-3	NS19/IR1721-11-6-8//IR2061-213-2-16	84.0
BKNFR76112-5	NS19/IR1721-11-6-8//IR2061-213-2-16	83.0
RD11	RD1/IR661	83.0
BKNFR76106-13	IR1561-228-3-3/FR13A	82.5
GEU76042-2K-25	SML Temerin/BG90-2//bulk F_1's pollen	82.5
GEU76042-4K-16	SML Temerin/BG90-2//bulk F_1's pollen	81.0
IR7065-0T-41	NS19/IR2031-724-2-3-2	81.0
GEU76042-4K-11	SML Temerin/BG90-2//bulk F_1's pollen	80.5
IR8234-11T-3	NS19/IR1721-11-6-8//IR2061-213-2-16	79.5
IR8234-2T-4	NS19/IR1721-11-6-8//IR2061-213-2-16	79.0

tolerance by Weerapat and Woraniman (1974) and has been used as the standard check variety for tolerance at IRRI for several years.

Test 4 (Table 2) was conducted in a pond at the Huntra Rice Experiment Station, Ayuthaya province. The major objective was to assess the effect of submergence on varieties in terms of four different water depths. All rice plants submerged at the two deepest levels (134 cm, 153 cm) were completely destroyed. However, at the 90- and 104-cm depths survival was sufficient to permit recovery scores and yield estimates. These are summarized in Table 4. The 90-cm water depth did not do much damage, and the photoperiod-sensitive varieties, as a group, yielded less than the photoperiod-insensitive materials. The latter probably is more related to the planting date and the consequent forcing into flowering of the sensitive lines than to any relevant submergence phenomenon.

The test also suggested a rather narrow interval in water depth between the 104-cm depth, with overall acceptable survival and yield, and the 134-cm depth, with no survival. This led us to adopt the intermediate water depth of 115 cm in test 5 (Table 2).

Additionally, seedlings aged 20, 50, and 70 days before submergence were respectively direct seeded, transplanted, and transplanted. Scoring was at weekly intervals starting 2 weeks after the plots were drained. Both visual percentage estimates and 1-9 visual recovery scores were recorded. Table 5 gives a tentative comparison of the relative efficiencies of the 24 possible combinations of scoring methods (2), seedling ages before submergence (3), and time of scoring after draining (4). The significance of varietal differences was poorest with the

Table 4. Average yield estimates and recovery scores made for 10 varieties 29 days after drainage after submergence in 90 and 104 cm of water for 7 days, Huntra Rice Experiment Station, Thailand, 1977.

Variety	90-cm depth		104-cm depth	
	Av yield (g/plot)	Av score[a]	Av yield (g/plot)	Av score[a]
	[illegible]			
BKN6986-66-2	667.0	1.8	488.0	6.5
BKN6986-108-3	436.0	2.0	328.0	3.5
BKN6987-68-7	635.0	1.5	585.0	4.5
BKN6987-82	442.0	2.0	582.0	2.0
RD7	566.0	1.5	566.0	6.0
Av	549.6		509.8	
	[illegible]			
BKN6986-147-2	292.0	2.5	258.0	5.5
BKN6986-161-3	309.0	2.8	314.0	1.8
BKN6986-167-2	370.0	2.3	416.0	4.5
Nam Sagui 19	286.0	2.0	333.0[b]	7.0[b]
Khao Ta Haeng	494.0	2.0	305.0	5.5
Av	350.2		344.0	

[a] Score based on 1 = plants fully recovered, 9 = no recovery.

[b] Av yield and av score obtained from the second replication.

70-day-old seedlings. It appears that little was gained from postponing the scoring to 4 or more weeks after draining. More experiments are needed to distinguish differences among scoring methods, between 20- and 50-day-old seedlings, and between scoring at 2 and 3 weeks after drainage.

Figure 1 illustrates the findings for 20-day-old seedlings, scored at 14 days after drainage. It shows the distinctive reactions of the entries, ranging from complete destruction in the case of Nam Sagui 19, to 90% survival for BKN6986-108-3. This high degree of differentiation is a welcome change from the incomplete destruction of the nonresistant materials and the generally haphazard results encountered in previous tests at shallower water depths.

Table 5. F values obtained as relative measures of efficiency of the 24 different component tests on the basis of 2 scoring methods, 3 seedling ages before submergence, and 4 moments of scoring (6 varieties, 2 replications and 1 block each).[a]

Seedling age at start of submergence	Scoring at number of weeks after draining plots			
	2	3	4	5
	1-9 visual scores			
20 days	81.0**	10.8*	5.7*	8.3*
50 days	9.0*	6.0*	3.1	1.1
70 days	1.8	3.4	3.5	7.0*
	Estimated percentages			
20 days	9.8*	10.4*	8.2*	8.0*
50 days	17.9**	61.4**	6.0*	9.2*
70 days	3.7	4.2	2.8	4.5

[a] * = significant at the 5% level, ** = significant at the 1% level.

TESTING METHODS

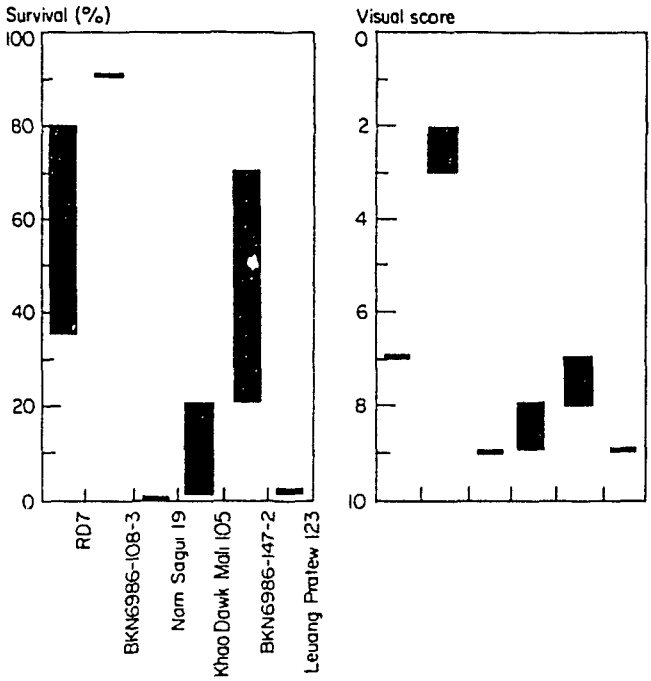
Submergence tolerance, as a trait in a breeding program, suffers from a lack of natural testing sites with predictable occurrence of temporary flooding. Consequently, there is much reliance on testing in controlled conditions at the experiment station. But, to what extent do the various tests that have been and are being done correspond with each other?

No systematic studies using a single array of varieties, and subjected to different testing methods have been used yet, but there is enough overlap between the tests (Table 2) to suggest the following:

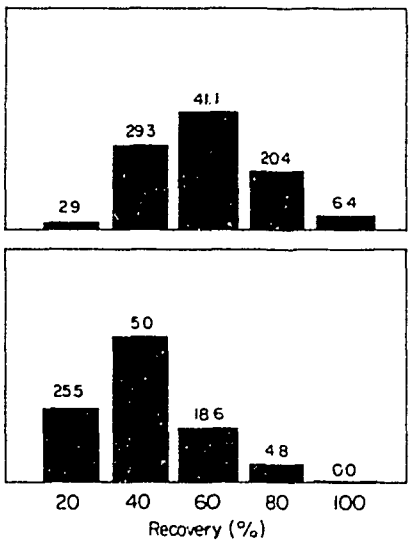
- Tests 1 and 2 employed shallow water and scored for the ability to grow through the water. As a group, the two appear distinct from the other tests, where water depths increased, culminating in the 115-cm depth of test 5, and where in general the varieties that earned distinction in tests 1 and 2 (Nam Sagui 19 and Khao Dawk Mali 105) were at the bottom of the performance scale.

- Correspondence of test 3 with the screenhouse tests of IRRI is suggested by the superior performance of derivatives from varieties with good performance in IRRI tests, compared with derivatives of varieties without such distinction (Fig. 2).

- Correspondence among the various field tests in ability to show repeatable varietal differences for submergence tolerance



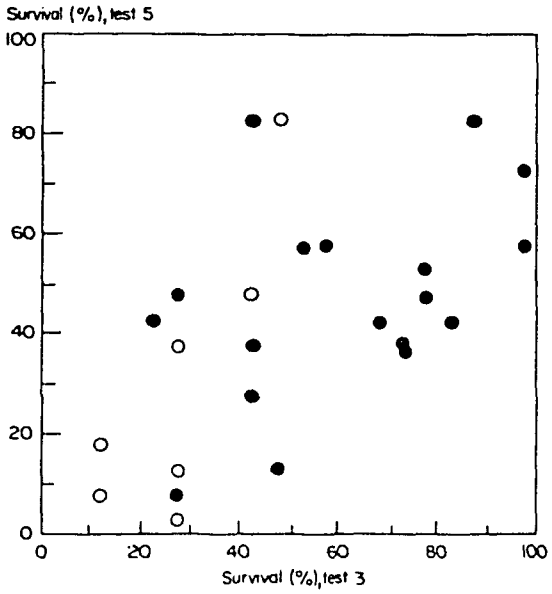
1. Survival after submergence of 20-day-old seedlings 14 days after draining the water. Survival percentages are compared with visual scores on a scale of 1–9.



2. Relative frequencies of recovery percentages (Test 3) in lines derived from Nam Sagui 19, FR43B, and SML Temerin (top), and lines derived from parents without known distinction in submergence tolerance (bottom).

is illustrated in Figure 3, where varieties and lines common to two different tests are plotted in a scatter diagram showing correlation of the results.

The continuing problem of the tests for submergence tolerance is the high degree of environmental influence on test results. It manifests itself in low correspondence even between replications of the same test, and should lead to caution in interpreting results of single tests. It also strongly points to the need for frequent interspersal of varieties of known submergence tolerance as checks in submergence tests.



3. Scatter diagram of varieties and lines common to test 3 (Table 2) and to a supplement to test 5 (Table 2).

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Varietal tolerance for mineral stresses in rainfed wetland rice fields

F. N. PONNAMPERUMA and H. IKEHASHI

Adapting rice plants to grow in adverse environments has recently assumed increasing importance. This trend stems mainly from the pressing need to use marginal land for crop production. Emphasis is shifting from changing the environment to suit the plant (as was done in the past) to tailoring the plant to fit the environment. Recent advances in identifying or developing varieties tolerant of iron deficiency (Brown 1977), aluminum toxicity (Ponnamperuma 1974, 1975a; Howeler and Cadavid 1976), acidity (Spain 1977), salinity-alkalinity, iron toxicity, phosphorus deficiency, and zinc deficiency (Ikehashi and Ponnamperuma 1978), and problems of organic soils (IRRI 1978) hold promise of success in developing varieties suited to rainfed wetland rice soils.

The first problem is to define rainfed wetland rice. The next problem is to identify the stresses to the wetland rice plant in the environments in which it grows. The final task is to produce varieties with an acceptable degree of tolerance for the stresses.

We attempt to identify the mineral stresses in rainfed wetland rice fields and to evaluate the prospects of breeding varieties with tolerance for the stresses.

RAINFED WETLAND RICE

Rainfed wetland rice is difficult to define.

First, *rainfed* is a contradiction in terms. Rain implies uncertainties that go with vagaries of the weather, while feeding suggests a controlled supply. Without going further into semantics, we assume that *rainfed* means that the main source of water for the rice crop is local rains.

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Second, there is a question. Must the water supply be direct rainfall or does it include stream water and underground water? In undulating terrain, interflow and streams activated by local rains are common sources of water for rice fields; in basins, deltas, estuaries, and lake fringes the water table rises during the rainy season and comes within easy reach of rice roots. Thus, the water regime in rainfed wetland rice fields depends not only on the intensity and distribution of rainfall but also on the hydrology of the rice fields.

Third is the ambiguity of the term *wetland rice*. Although rice is usually sown or transplanted in puddled fields, there are considerable areas where seeds are broadcast or drilled in the dry soil, germinate after the first rains, and grow in a soil that may become submerged to a depth of 5 m.

Provisionally, we define rainfed wetland rice-growing soils as soils on bunded fields that are submerged or saturated as a result of direct or indirect action of local rains, and are anaerobic for more than 50% of the time the crop is on the land. The period of nonsubmergence, or unsaturation and aerobiosis, may come at any time from sowing or transplanting until 2 weeks before harvest and may be intermittent or continuous.

THE CHEMICAL REGIME IN RAINFED WETLAND RICE SOILS

The chemical regime in the soil holds the key to understanding the mineral stresses that rainfed wetland rice plants undergo. In rainfed rice soils the chemical milieu depends on the water regime, which is characterized by alternate flooding and drying.

When a soil is submerged the following changes occur (Ponnamperuma 1972):

- redox potential decreases,
- pH of acid soils increases,
- pH of calcareous and sodic soils decreases,
- electrical conductivity increases in normal soils but decreases in saline soils,
- nitrate disappears,
- ammonium accumulates,
- sulfate is converted to hydrogen sulfide and insoluble sulfides,
- the solubility of iron, manganese, phosphorus, and silicon increases,
- the solubility of zinc and copper decreases,
- carbon dioxide accumulates, and
- toxic organic substances form.

Drying a soil reverses these changes; reflooding renews them.

Of the changes, the following benefit rice:

- decrease in redox potential,
- changes in pH,
- accumulation of ammonium, and
- the increase in solubility of iron, manganese, phosphorus and silicon.

The other changes may harm rice.

MINERAL STRESSES IN RAINFED WETLAND RICE-GROWING SOILS

The mineral stresses in rainfed wetland rice-growing soils are associated with the electrochemical and chemical changes due to alternate wetting and drying. The main chemical stresses are toxicities and deficiencies. Their nature and severity depend on soil properties, and time and duration of drying (Table 1). The chief physical mineral stress is aggravation of osmotic imbalance in saline soils.

Redox potential and mineral stresses

The decrease in redox potential increases the availability of nitrogen, phosphorus, iron, and silicon but decreases the

Table 1. Influence of soil and time of drying on mineral stresses in wetland rice soils.

		Stress	
Soil	Time	During drying	After reflooding
Neutral soils	Early	Fe deficiency, P deficiency	N deficiency
	Late	Fe deficiency	-
Strong acid soils	Early	P deficiency	Iron toxicity
	Late	Mn toxicity	-
Acid sulfate soils	Early	Al toxicity, P deficiency	Fe toxicity
	Late	Al toxicity	-
Calcareous soils	Early	Fe deficiency	Zn deficiency, N deficiency
	Late	Fe deficiency	-
Alkali soils	Early	Fe deficiency, Ca deficiency	Zn deficiency, N deficiency
	Late	Fe deficiency	-
Saline soils	Early	Severe osmotic stress	Osmotic stress
	Late	Osmotic stress	Osmotic stress

availability of sulfur, zinc, and copper. On balance, a redox potential below 0.2 V at pH 7 benefits rice.

When the rains fail and the soil dries, oxygen enters the soil, oxidizes it, and raises the potential. If the potential remains high for more than 2 weeks, rice may suffer from iron deficiency on neutral and calcareous soils and manganese toxicity on acid soils (Ponnamperuma 1975b).

pH and mineral stresses

The increase in pH of acid soils and decrease in pH of calcareous and alkali soils are important benefits of flooding. When a soil dries the changes are reversed, imposing:

- aluminum toxicity in strongly acid soils,
- manganese toxicity in moderately acid soils,
- phosphorus deficiency in strongly acid soils, and
- iron deficiency in calcareous and sodic soils.

Electrical conductivity and mineral stresses

Flooding a soil depresses the electrical conductivity of the soil solution of saline soils because of dilution of the soluble salts. That benefits rice in saline soils. When a soil dries, the water films on soil particles and on the roots increasingly become thinner, and the plants are subjected to an increasing concentration of salts. That causes severe osmotic stress and perhaps specific ion toxicities.

Nitrogen transformations and mineral stresses

In dry or aerobic soils the end product of the mineralization of organic nitrogen is nitrate. When such a soil is flooded nitrate disappears within a few days, mainly as nitrogen gas. The loss of nitrate nitrogen averaged 26 kg/ha per season for 280 Philippine wetland soils. Denitrification is one disadvantage of flooding rice-growing soils, but accumulation of ammonium benefits rice. The process of alternate wetting and drying increases nitrogen losses by denitrification, and can lead to substantial losses of nitrogen in fertilized rainfed wetland rice fields. On the other hand, drying and reflooding a submerged soil may increase mineralization of soil nitrogen, especially in unfertilized fields.

Nitrogen deficiency may occur in soils that undergo alternate wetting and drying before the establishment of an actively growing rice crop.

Nutrient transformations and mineral stresses

Drying a submerged soil decreases the availability of phosphorus, iron, and silicon.

Phosphorus deficiency may seriously impair tillering, delay maturity, and reduce crop yield if the soil is dry for more than 2 weeks during the first 8-10 weeks after sowing or transplanting of rice, especially on strongly acid soils. Iron deficiency can be severe on calcareous and sodic soils that remain dry for more than 2 weeks. Drying a sodic soil in the early stage of rice growth may aggravate calcium deficiency.

IMPLICATIONS FOR BREEDING

Apart from drought resistance, rices grown in rainfed wetland fields should have tolerance for mineral stresses. These mineral stresses depend mainly on the soil characteristics listed.

Soil	*Desired tolerance*
• Neutral soils	Iron deficiency, phosphorus deficiency
• Strongly acid soils	Phosphorus deficiency; iron and manganese toxicities
• Acid sulfate soils	Aluminum and iron toxicities; phosphorus deficiency
• Calcareous soils	Iron deficiency, zinc deficiency
• Sodic soils	Iron deficiency; calcium deficiency; zinc deficiency
• Saline soils	Osmotic stress

BREEDING FOR RAINFED WETLAND CONDITIONS

Adaptability of rice to adverse soils: a neglected issue

Despite widespread adverse soil conditions and inherently low fertility of rainfed rice fields, work to adapt the rice plant to such conditions has largely been neglected. The lack of appreciation of varietal adaptation to adverse soils, however, does not imply that the matter is insignificant. Little attention has been paid to this area for several reasons:

- Varietal adaptability to adverse soils has been

considered as part of the adaptability of rice to specific sites, often without identification of the specific problems involved.

- Scientists have only recently recognized the genetic diversity of varieties and their adaptability to mineral stresses as a possible way of coping with adverse soils.

- Most areas of existing adverse soils have been the objective of amelioration rather than being regarded as areas in which varietal adaptability would provide at least a partial solution.

Intermediate plant height and longer growth duration, which have specific advantages for rainfed wetland conditions, have been thought of in terms of adaptability to water regime. But the plant type may also relate to nutritional status of the rainfed field. Plants of intermediate height, which can tolerate moderately deep water, would also be productive in areas of lower fertility, where the danger of lodging is less. The optimum growth duration is affected by varietal character, cultural practices, and soil fertility, and longer in lower fertility as an adaptation to rainfed field.

Tolerance for soil problems in widely accepted rices

So far there has been little organized work to distribute tolerant rices to problem-soil areas (except for salinity tolerance, in which specific projects have been conducted for 3 decades). But some widely grown rice varieties have been found tolerant of one or two widespread soil problems.

Mahsuri had been grown in a rice project area in Malaysia where iron toxicity is widespread on acid sulfate soils. Repeated tests of Mahsuri at IRRI substantiate its tolerance for iron toxicity. This tolerance, which would be pronounced in acid lateritic soils, may partly explain Mahsuri's wide acceptance. In the wet zone of Sri Lanka, the bronzing problem is said to have decreased after H-4 became popular among farmers.

Similarly IET 1444, which has been recommended in many states of India for its earliness and drought resistance, has been identified as tolerant of phosphorus deficiency (Katyal et al 1975). Some native rices in Thailand were recently found to perform well in phosphorus-fixing acid sulfate soils (Koyama et al 1973, Yagi and Jugsujinda, unpubl.).

Many tall traditional dryland rices have been found tolerant of aluminum toxicity in aerobic acidic soil (Howeler and

Cadavid 1976), although it is unlikely that those rices had been consciously selected for that soil problem. IR36 and an IR1514 line were recently noted for their higher tolerance for iron deficiency; they gave substantial yield increases when direct-seeded in an alkaline soil in the Philippines. Tissue analysis showed that IR36 contained significantly more iron than a local check variety (Gines et al 1977).

In many other instances, the reason for wider acceptance of a variety can be partly explained by its specific tolerance for adverse soils. An important conclusion from this understanding is that systematic testing for varietal tolerance for adverse soils and distribution of tolerant rices to problem-soil areas would help to stabilize rice production. Furthermore, the prerelease check of promising breeding lines against adverse soils, and the rejection of sensitive lines would avoid some unexpected lower performance of rice in farmers' fields. To provide farmers with varieties that perform well, even in nutrient-deficient soils, it is important to conduct performance tests under incomplete fertilization as it has been conducted at the International Institute of Tropical Agriculture (Alluri and Buddenhagen 1977).

Association of Peat Soils and Blast

The occurrence of Helminthosporium disease has been related to nutritional deficiencies, especially of potassium. But this disease also seems to be associated with alkali soil problems (Tanaka and Yoshida 1970, Ismunadji et al 1973). In an alkali soil in Bohol, a local variety yielded best, but Helminthosporium severely damaged IR34 (IRRI 1978).

We observe in varietal tests in peat soils of Leyte (Philippines) and Palembang (Sumatra, Indonesia) that the incidence of blast *Pyricularia oryzae* is a factor limiting yield. Probably mineral deficiencies in plants that are well supplied with nitrogen would cause the association between blast outbreaks and peat soil problems. Some minerals, such as silica, are noted for their protecting role against blast.

Such incidences lead us to assume that improved rice capability for nutritional uptake would partially prevent disease infection. This postulate awaits further research; right now, it is worthwhile knowing that varietal adaptability to problem soils would complicate varietal resistance to fungal diseases.

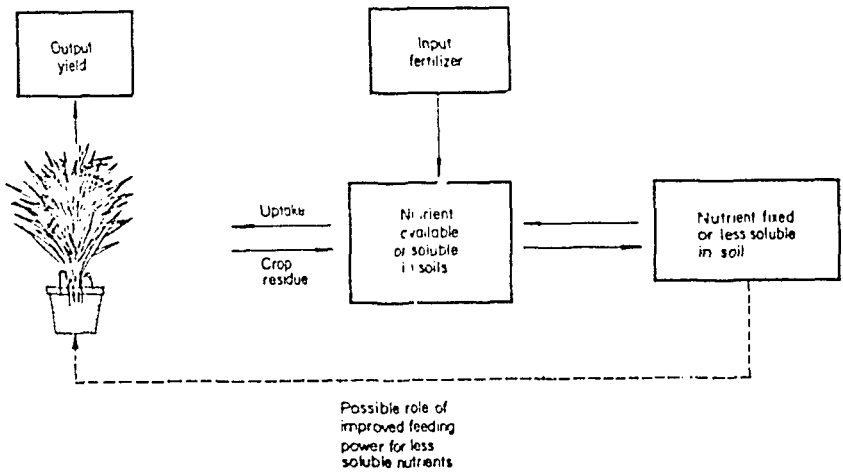
Implications of varietal tolerance for nutrition deficiency

No variety can tolerate acute deficiency of an essential element. But some varieties can more efficiently extract essential elements from soils in which such elements are deficient. A variety that tolerates phosphorus deficiency has a higher feeding power for soil phosphorus than a sensitive variety (Koyama et al 1973). A variety tolerant of iron deficiency takes up more iron than a sensitive variety (Gines et al 1977). Therefore, tolerance for nutrient deficiencies can be defined as high feeding power for a soil nutrient that is normally unavailable.

Implications of the genetically improved feeding power for less soluble nutrients will be clear if the balance sheet of the nutrition is studied (Fig. 1) Varietal characteristics favorable for the rapid uptake of soluble nutrients as well as to utilization of less soluble nutritional elements would probably be beneficial in the total flow of nutrition, particularly in the soil where nutrients become easily fixed.

STRATEGY TO BREED AND DISSEMINATE ADAPTED RICE

Systematic screening of rices against major soil problems, which was implemented in 1972, has shown that rices respond differentially to excess of toxic elements, nutritional deficiencies, or to complexes of those factors in acid-sulfate



1. Possible role of improved mineral uptake in the balance sheet of nutrition.

or in peat soils (Ponnamperuma 1977). A remarkable finding from this problem is that many advanced breeding lines from general breeding programs seem to have excellent tolerance for problem soils. This tolerance possibly comes from widely accepted source varieties and is enhanced by genetic recombinations of physiological traits into varieties that are often more superior in tolerance than their parents.

The two breeding objectives are incorporation of better agronomic traits and pest resistance into the existing level of adverse soil tolerance (horizontal improvement), and enhancement of the existing level of tolerance (vertical improvement). The possibility of vertical improvement would be enhanced by more intensified approaches, but horizontal improvement is presently accessible and potentially profitable if an appropriate system is developed.

When planning an appropriate dissemination program, three points should be considered:

1. Although differential tolerance of rice for each problem has become familiar to rice workers, little work has been done to relate such tolerance to actual yields in suboptimum soil conditions, which would be a characteristic feature of rainfed wetland soils. An IRRI program focuses on this but more research is needed because soil problems are site specific.

2. An understanding of the recovery of tolerant plant materials from general breeding programs is essential. So far it seems highly possible to find elite breeding lines with good tolerance for adverse soils (except salinity tolerance). This suggests that systematic screening of advanced breeding lines from international and national programs should yield lines suited to various problem soils. Screening should be conducted in adverse soils that are uniform and extensive enough to accommodate a large number of materials and that are easily accessible to and manageable by rice scientists. The search for and utilization of such fields would be beneficial to each national project.

3. To disseminate material adapted to each of the adverse soil conditions, it is important to survey such areas and map the soil problem in each country, particularly for rainfed wetland rice.

An international collaborative project will be necessary to implement the above activities and facilitate the flow of materials and information. Flexibility should guide the

selection of materials for testing: a large number of early generation pedigree lines could be efficiently used in a well-equipped station, but a few of the best selections with assured tolerance could be provided to small local stations. A composite of varieties and lines should be tested for areas of complex mineral stresses, where there are Histosols and acid sulfate soils.

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Crop Management

Land preparation and crop establishment for rainfed lowland rice

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Millions of experienced rice farmers prepare land for a rainfed rice crop guided by their judgment of soil texture, soil moisture and rainfall patterns, topography, and degree of weed infestation. They use tillage methods that are within their labor and power resources. Stable yields and high returns are the objective of their field work but regardless of the strategies they use, yields vary from year to year and field to field. Thus, when deciding on tillage and stand establishment methods, farmers who grow rainfed rice must keep in mind the expected, but often uncertain, rainfall.

For any crop, tillage practices greatly affect plant growth during the germination, seedling emergence, and stand establishment stages (Larson 1963).

Tillage practices that create conditions for rapid intake and temporary storage of water in the surface soil or in the tilled layer are needed to prevent runoff. If a farmer is asked why he performs a particular tillage operation, he may give different reasons. It is therefore imperative to seek answers to the questions relating to every tillage operation: Is it necessary? Would the crop grow as well or perhaps better without it? Is there value in plowing to loosen the soil only to repack it to the same bulk density it had before plowing? These and other questions should be carefully posed to select tillage practices based on sound scientific research (Blake 1963). Our discussion centers on land preparation and crop establishment methods for lowland rainfed rice. We examine tillage operations and establishment methods and discuss how they may vary depending on the moisture available from rainfall, soil factors, and resources available to the farmer.

SYSTEMS OF LAND PREPARATION AND CROP ESTABLISHMENT IN RAINFED LOWLAND RICE

For rainfed rice, the onset of the monsoon and, thus, the day length and solar radiation available during the growing season

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determine planting time. Usually, tillage for rainfed rice is performed either when soil water is nearly saturated or saturated (wetland tillage) or when soil water is at less than field capacity (dryland tillage). A puddled seedbed is the objective of wetland tillage whereas a loose, granular seedbed is the objective of dryland tillage.

Rainfed wetland tillage

Wetland tillage. Before an alternative tillage method is advocated, the benefits of land preparation by traditional puddling must be considered.

During plowing, weeds and stubble are plowed under. Harrowing -- actually several harrowings at shallow depths before rice seedlings are transplanted -- turns the remaining weeds and stubble into the reduced soil layer. The lack of oxygen in the reduced layer inhibits weed germination and greatly reduces the weed population (De Datta 1973). In addition, soil puddling caused by tillage substantially increases the water retained by the soil (Fukuda and Tsutsui 1968, Sanchez 1973, De Datta and Kerim 1974, Wickham and Singh 1978). Because puddling reduces the chance of soil drying, the rainfed puddled system should produce a higher rice yield than a rainfed nonpuddled system.

The soil's penetration resistance decreases drastically after a soil has been soaked only a few days (Choon 1974). That decrease has two important implications.

- Draft requirements for plowing come into a range suitable for draft animals and power tillers.

- The soil's load-bearing capacity decreases and rolling resistance increases, both of which hamper tillage by large tractors.

When clay soils are plowed and harrowed at about soil saturation, several changes -- for example, markedly reduced air-filled pore volume, lower permeability, increase in moisture suction, lower resistance to raindrops, and increase in deformability -- take place in the soil (Koenigs 1963). An important difference between a dry soil and a puddled soil is the presence of oxidized and reduced soil layers. Ponnamperuma (1977) discussed electrochemical changes of submergence and the beneficial effects of reduction on the availability of nutrients to rice.

Although it involves a great amount of labor, puddling as practiced in much of tropical Asia has been widely accepted. The major advantages of rainfed wetland tillage are as follows:

- Improved weed control.
- Ease of transplanting.
- Establishment of a reduced soil condition, which improves soil fertility and fertilizer management.
- Reduced draft requirements for tillage.
- Reduced percolation losses, and therefore conservation of rainfall as standing water during crop growth.
- Time delay imposed by puddling requirements increases chances of sustained rainfall.

The major disadvantages of wetland tillage for rainfed rice follow:

- Delayed planting and harvesting, which may subject the crop to late season drought or reduce the possibility of successfully growing a second rice crop.
- The transplanting labor requirement (where topographical characteristics dictate transplanting must be practiced to avoid seed and young seedling submergence).
- Limitations on characteristics of power units suitable for tillage in wetland fields.

Crop establishment method following wetland tillage. Once a soil has been puddled, manual transplanting of 20- to 40-day-old seedlings is by far the most common method. Broadcast seeding of pregerminated seeds ranks a distant second. Other methods such as mechanical transplanting, dapog transplanting, and drilling of seeds have not been perfected for use in rainfed fields.

Water control is more critical for broadcast-seeded than for transplanted rice. Broadcast seeding of pregerminated seed has limited adaptation to the rainfed rice field because of the requirement of good drainage control, which means that the rice fields must be on land with sufficient slope to drain away undesired water from early heavy rains. Furthermore, broadcast seeding requires a puddled surface that is level and smooth so that water will not accumulate in depressions and drown seedlings shortly after germination.

Where paddies are located in landscapes with enough relief to effect timely surface drainage and reduce flooding after

intense early rainstorms, farmers can broadcast-seed rice with minor stand loss. In a Philippine Bureau of Plant Industry-IRRI cropping systems project at Iloilo, farmer-cooperators achieved high yields for the first crop in a rainfed 2-crop pattern for 2 years through broadcast seeding methods (Table 1). The broadcast method reduced labor input and eliminated the difficulty in making proper seedling age coincide with completion of puddling for transplanting.

Weed control is an important consideration in determining whether transplanting or broadcasting should be used as a method of planting. Weed problems are greater in the broadcast-seed method than in transplanted rice (De Datta and Bernasor 1973).

Rainfed dryland tillage

Dryland tillage for lowland rice production in tropical Asia is practiced on a limited area. However, recent technological advances may cause an increase in area where dryland cultivation is suitable.

For many years, farmers in Bangladesh, northeast India, and Indonesia have seeded rainfed wetland rice directly on nonpuddled soils in bunded fields at the beginning of the rainy season. This method of rice culture is called *aus* cropping in Bangladesh and northeast India, and *gogo rancah* in Indonesia.

The method takes advantage of early rainfall and allows time for a second crop of rice to be grown. The soil is tilled dry either manually or by animal-drawn implements. Often, the field is not prepared to a fine surface, rice does not germinate uniformly, and weeds grow vigorously. The risk of drought damage also increases.

Table 1. Farmer-cooperator yields of first rainfed direct-seeded (broadcast) and second rainfed direct-seeded and transplanted rice crops, 1976-77 and 1977-78 wet seasons,[a] Iloilo province, Philippines.

	First crop			Second crop					
				Direct-seeded			Transplanted		
Season	Observations (no.)	Yield (t/ha)	SD (t/ha)	Observations (no.)	Yield (t/ha)	SD (t/ha)	Observations (no.)	Yield (t/ha)	SD (t/ha)
1976-77	41	5.3	1.5	37	2.2	1.6	4	3.5	1.4
1977-78	22	5.9	1.1	13	1.4	1.8	9	1.7	1.2

[a] SD = standard deviation.

The *aus* and *gogo rancah* systems evolved locally in response to biological, physical, and economic factors. However, the following developments may make dryland tillage techniques economically feasible for a wider area:

- Early-maturing modern rice cultivars allow the growing of two rice crops if the first crop can be harvested sufficiently early.

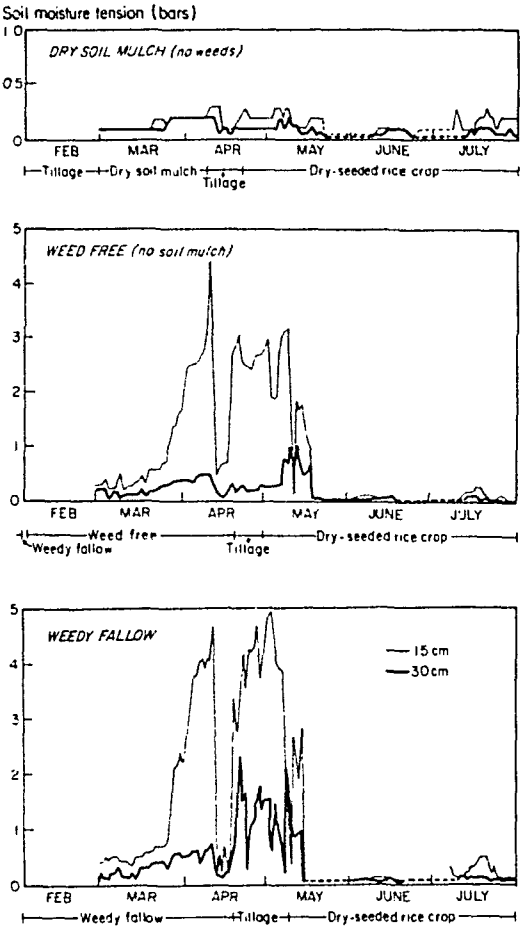
- Power tillers and small tractors are manufactured in several tropical Asian countries at comparatively low costs and can be used for tillage and interrow cultivation; the greatest problem of using the *aus* and *gogo rancah* systems over wider areas is a need for quick tillage of a dry field.

- Low-cost herbicides aid in combating early weed growth.
- Expanding population pressure, which simultaneously increases food demand and increases the agricultural labor force, has put more pressure on the land for increased food production.

Dry seeding of rainfed rice was tried recently in limited areas in the Philippines. In applied research trials at Bulacan, it was observed that on land prepared at the end of the previous wet season, a newly emerged rice crop survived a period of drought. In contrast, a crop seeded at the same time on land prepared just before seeding suffered considerable drought damage. It was suggested that crop survival was due to the availability of soil moisture covered by a soil mulch during the dry season.

Bolton and De Datta (1977) ran experiments at IRRI in the dry and wet seasons to verify the conservation of soil moisture by a soil mulch, and to determine whether moisture was conserved because of weed control or because of the dry soil mulch. They also compared the time required for early dry seeding of a rice crop after the dry soil mulch and that required for transplanting a crop after traditional wetland tillage.

Plots where land preparation was at the end of the previous wet season had a dry soil mulch from February to May. The soil moisture tension (SMT) under the mulch never exceeded 33 centibars. In contrast, the SMT in weedy-fallow plots was 5 bars at a depth of 15 cm by the end of the dry season despite a water table within 1 m of the soil surface during the whole period. Weed-free untilled plots conserved some moisture, but not as much as that conserved with the dry soil mulch (Fig. 1). Use of a dry soil mulch has potential in conserving soil moisture for early direct-seeded rice.



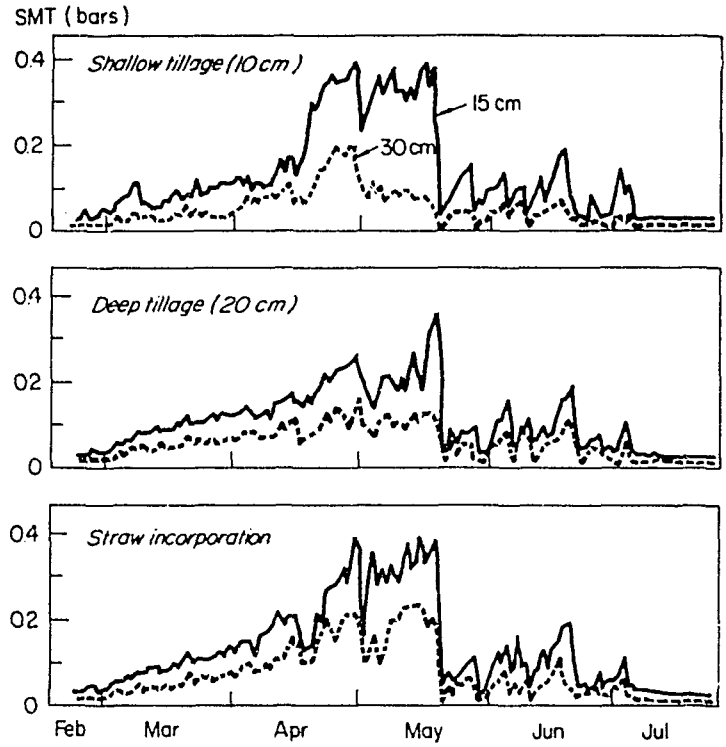
1. Soil moisture tension under a dry soil mulch did not exceed 33 centibars at any time during the 1976 dry season. Some moisture was conserved by keeping the plots weed-free, but moisture tension was higher than in the soil mulched plots. Plots that were fallow and on which weeds were allowed to grow had 5 bars of soil moisture tension at a 15-cm depth by the end of the dry season. IRRI, 1976 (Bolton and De Datta 1977).

During the 1977 crop season, Singh and De Datta (1978) conducted a similar experiment. The tillage treatments are summarized in Table 2. All dry season treatments were followed by a dry-seeded crop, except for a weedy fallow followed by puddling and transplanting, the system practiced by most rice

Table 2. Summary of treatments used in 1977 soil-water conservation experiments.

Dry season operations		First crop			Second crop	
Treatment	Tillage	Planting operations	Planting date	Range of harvest dates	Transplanting date[a]	Range of harvest dates
Dry soil mulch, 10-cm tillage	Rotovating thrice in January and February, rotovating once 30 April	Dry seeding - furrows spaced at 25 cm, 80 kg seed/ha	30 April	10-28 Sept.	3 Oct.	11-23 Jan.
Dry soil mulch 20-cm tillage	-do-	-do-	30 April	-do-	3 Oct.	-do-
Straw incorporation (5 t/ha rice straw, incorporation by 10-cm tillage)	-do-	-do-	30 April	-do-	3 Oct.	-do-
Straw mulch (5 t/ha rice straw)	Rotovating thrice between 30 April and planting	-do-	10 May	17 Sept.-4 Oct.	10 Oct.	17-29 Jan.
Weed-free fallow (herbicide treated)	Rotovating twice between 30 April and planting	-do-	2 May	11-29 Sept.	3 Oct.	11-23 Jan.
Weedy fallow, dry-seeding	Plowing once on 9 May rotovating thrice between 10 May and 24 May	-do-	24 May	29 Sept.-15 Oct.	20 Oct.	27 Jan.-9 Feb.
Weedy fallow, transplanting	Plowing and harrowing twice between 1 July and 20 July	Transplanting 28-day-old seedlings in 20 x 20-cm hills, 2-4 seedlings/hill	20 July	4-21 Nov.		

[a]In preparation for transplanting, all plots were plowed once and harrowed twice between the last date in the range of harvest date and the transplanting date.



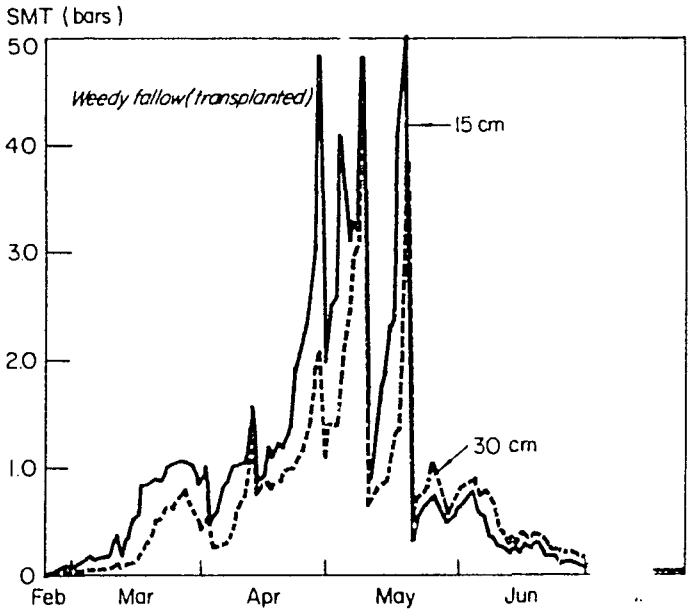
2. Effect on soil moisture tension of a dry soil mulch generated by shallow tillage (10 cm deep) and deep tillage (20 cm deep) and straw incorporation at 5 t/ha (10 cm deep) during the dry season followed by (fb) a dry-seeded rice crop. Tillage consisted of 3 rotovations in January–February fb 1 rotovation in April. Rices were dry-seeded on 30 April. IRRI, 1977 dry and wet seasons (Singh and De Datta 1978).

farmers in rainfed areas in tropical Asia. The latter treatment was not part of the main experiment but was imposed adjacent to the main experimental plots. Four cultivars (IR1529-430-3, IR2035-117-3, IR9575, and IR20) were dry-seeded or transplanted as subplots on the main tillage-mulch plots. Because the four cultivars had different growth durations, harvesting occurred over a range of dates for all tillage treatments.

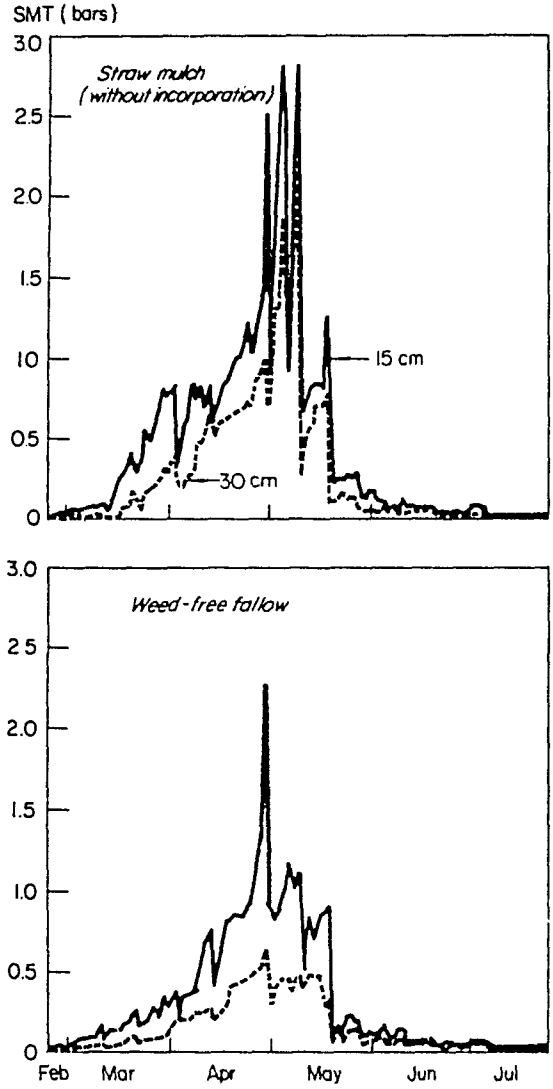
During the dry season (February to late May), after shallow tillage (10 cm), deep tillage (20 cm), and straw incorporation, SMT did not exceed 40 centibars when land preparation was completed at the end of the previous wet season (Fig. 2). By

comparison, SMT at 15 cm in weedy-fallow plots rose to 5 bars by the end of the dry season (Fig. 3). SMT was lower in weed-free fallow and straw-mulch treatments (Fig. 4), than in the weedy-fallow treatment (Fig. 3), but higher than in treatments involving tillage operations during the dry season (Fig. 2).

Straw mulching and weed-free fallowing during the dry season conserved about equal soil moisture, but the amount was less than that conserved with shallow tillage, deep tillage, and straw incorporation. Furthermore, after the dry season shallow tillage, deep tillage, and straw incorporation, rice could be seeded 2 days earlier than after the weed-free treatment, 10 days earlier than after the straw-mulch treatment, and 24 days earlier than after the weedy-fallow treatment. Insufficient rains for puddling delayed land preparation for the transplanted crop until the beginning of July. Harvest dates were 5 to 8 weeks later than those of the same cultivar planted with one of the dry-seeding tillage systems. Thus, two crops of transplanted rice could be grown on dry-seeded plots, but only one could be grown on puddled soil.



3. Effect on soil moisture tension of a dry season weedy fallow followed by a transplanted rice crop. Tillage consisted of 2 plowings and 2 harrowings. The seedbed was sown 22 June and seedlings were transplanted 20 July. IRRI, 1977 dry and wet seasons (Singh and De Datta 1978).



4. Effect on soil moisture tension of straw mulch at 5 t/ha (without incorporation) and weed-free fallow treatments during the dry season followed by a dry-seeded rice crop. Tillage consisted of 3 rotovations in straw mulch and 2 rotovations in weed-free fallow plots. Rices were dry-seeded on 10 May and 2 May in straw mulch and weed-free fallow plots, respectively. IRRI, 1977 dry and wet seasons (Singh and De Datta 1978).

Yields from all tillage treatments are in Table 3. Varietal differences were apparent. Across tillage treatments, IR9575 yielded highest (4.4 t/ha) and IR20 lowest (2.4 t/ha), but a variety-tillage interaction was not detected.

The IRRI studies demonstrated moisture conservation in a montmorillonite clay soil with a dry-soil mulch during the dry season. Most of the moisture was conserved by soil mulching, not by weed control. Although such stored moisture could be of value to rice seedlings encountering drought at the onset of the wet season, a major benefit of early dry season land preparation is time saved for the following wet season crop. The earlier, more timely establishment of the first crop allowed a second crop later in the wet season. Although the second crop produced considerably lower grain yield than the first, the two-crop total for rainfed dry-seeded rice was 2 t/ha higher than that for the transplanted rice grown after weedy fallow (Table 3). Yields were also poor for a weedy fallow during the dry season, followed by first a dry-seeded and then a transplanted crop.

Using a somewhat different approach to examine the effect of preseason tillage on rainfed rice yields in Surinam, Hasselbach and van Amson (1965) found differences due to early and late fallow period disking on soils with a long history of rice production, even though soils were puddled before planting and after all disk treatments. Preseason disking increased yields by as much as 1.1 t/ha. In a follow-up test, both late disking and wet fallow produced statistically significant responses on 23 yellow mottled and 9 sandy clay soils, but not on

Table 3. Grain yields of rainfed-lowland rice as influenced by different dry-soil mulch and straw mulch treatments, IRRI, 1977 wet season.

Crop	Grain yield[a] (t/ha)						
	Shallow tillage (10-cm)	Deep tillage (20-cm)	Straw incorporated (5 t/ha)	Straw mulch (5 t/ha)	Weed-free fallow	Weedy fallow, dry-seeded	Weedy fallow, transplanted[b]
First	1.6	3.6	3.7	3.4	3.2	2.5	3.1
Second	1.6	1.6	1.8	1.4	1.7	1.1	-
Total	3.2	5.2	5.5	4.8	4.9	3.6	3.1

[a]Av. of 4 replications and 4 varieties. [b]Not included in the experiment analysis but tested in adjacent areas.

7 other soils. The responses were 0.29 t/ha and 0.25 t/ha, respectively, for fallow period disking and flooding. There was no interaction between treatments. These experiments suggest that other factors besides soil water conservation may lead to increased rice yields following dryland preparation.

The type of tillage a farmer chooses depends on a number of factors, but in tropical Asia, the puddling system evolved out of necessity. If there is a switch to direct-seeded rice on dry soil, the puddling process must be evaluated against salient land and rainfall factors.

The major advantages of dryland tillage for rice follow:

- Initial crop growth is obtained from early monsoon rainfall; in wetland preparation the rainfall is used for land-soaking and puddling.
- Labor associated with seedbed preparation-land preparation-transplanting operations is reduced.
- Large power units can be employed for primary and secondary tillage operations.
- Where a nonrice crop follows an unpuddled rice crop, soil structure is more favorable for stand establishment and root development of the nonrice crop.
- Insect and disease sources that increase on alternate hosts during the period required for wetland soaking and puddling are avoided.

Dryland preparation has some major disadvantages:

- Draft power requirements are high and often beyond the financial reach of rice farmers in the Asian tropics.
- Early weed control requirements are comparatively exacting and critical.
- Percolation losses are comparatively high, leaving the crop more susceptible to periodic drought stress.
- The crop may be exposed to several soil-inhabiting insects and to blast before the accumulation of standing water.
- Fertilizer requirements will often be higher.

Crop establishment methods following dryland tillage

As with puddling, dryland tillage restricts methods of rice crop establishment. To most farmers of tropical Asia, mechanical drilling is not a foreseeable alternative. Common alternative methods are:

- broadcast seeding on a level field,
- broadcast seeding over shallow furrows and passing a spike-toothed harrow at 45° to concentrate seeds in rows,
- hand-drilling -- placing seed in shallow furrows opened by an animal-drawn apparatus -- and
- dibbling seed so that seedlings emerge in hills at uniform spacings.

Broadcast method. Few experiments have compared dryland tillage methods for establishment of rainfed lowland rice. One such comparison we made showed little difference between grain yield obtained by broadcasting on leveled field and seeding on furrows opened with a *lithao* (Table 4). The *lithao* is satisfactorily used on loose upland soils, but not on heavy, cloddy wetland soils. Furthermore, the *lithao* method requires extra field operations.

Hand-drill method. Hand-drilling produced yields that averaged more than 4 t/ha on 48 farmer-cooperators' fields during the 1977 wet season in Pangasinan (Table 5). The table includes data combined for rainfed and partially irrigated fields, but the effect of irrigation was nil during the wet season. Rainfed yields were in fact higher. Of the 48 observations, the first 24 farmers to plant obtained yields that averaged 0.4 t/ha more than on the other 24 farms.

Dibbling method. The dibbling method permits easier weed control and produces an environment less suitable for insects and diseases. Moreover, placement of the seed below the soil surface may reduce lodging susceptibility. Dibbling in dry soil is practiced in parts of Java. Scientists of the Central Research Institute for Agriculture report that yields exceed 4 t/ha if adapted varieties are grown with appropriate fertilization and weed control (Fagi 1974, Saefuddin et al 1978). Dibbling is labor-intensive, but as water accumulates in the field, the farmers use a two-direction rotary or *landak* weeding, which improves weed control.

Table 4. Grain yields (av of IR1561-228-3 and IR30) as affected by 7 patterns of rainfall in the Philippines and 2 methods of stand establishment by dry seeding.

Rainfall pattern[a]	Grain yield (t/ha)	
	Dry-seeded in rows opened with *litha*[b]	Dry-seeded broadcast
A	3.2	3.3
B	1.9	2.3
C	4.2	3.8
D	2.1	2.1
E	2.9	2.9
F	5.3	5.5
G	4.5	4.8
Av	3.4	3.5

[a]Description of rainfall pattern not essential to comparison of the two seeding methods. In the Philippines, rainfall pattern Type A and Type B each have a long wet season (WS) during the high sun period (HSP) (April through September); pattern A has a 5-month dry season (DS) and pattern B has a 4-month DS. Type C and Type D each have a short DS (1-3 months). The DS of Type C occurs during the low sun period (LSP) (October through March), while the DS of Type D is during the HSP. Type E and Type F each have a marked WS of heavy rainfall; the WS of Type E occurs during the LSP and the WS of Type F is during the HSP; Type G has an even distribution of rainfall with no marked seasonality.

[b]The *litha* is a carabao-drawn farm implement with 5 teeth spaced at 20 cm. It is used primarily to make furrows in planting upland rice, and is indigenous to the provinces of Cavite and Batangas, Philippines.

Table 5. Yields of dry-seeded rice, 48 farmers' fields, combined rainfed and partially irrigated observations. Crop year 1977-78, Manaoag, Pangasinan, Philippines.

Yield range (t/ha)	Observations (no.)	Av yield (t/ha)
< 3.5	7	3.1
≥ 3.5 < 4.5	16	4.2
≥ 4.5 < 5.5	17	5.0
≥ 5.5 < 6.5	5	6.1
> 6.5	3	6.9
	48	5.06

Two 1977 wet season experiments in rainfed fields determined how far in advance of the onset of rains rice could be seeded in dry soil without adverse emergence, stand establishment, and yield effects. We found that seed could remain in the soil for several weeks without major adverse effects. That implies that farmers can plant rice well ahead of the onset of the rains if land can be prepared (Table 6). Regardless of planting date, seed planted before the onset of rains germinated after the initial soaking rains.

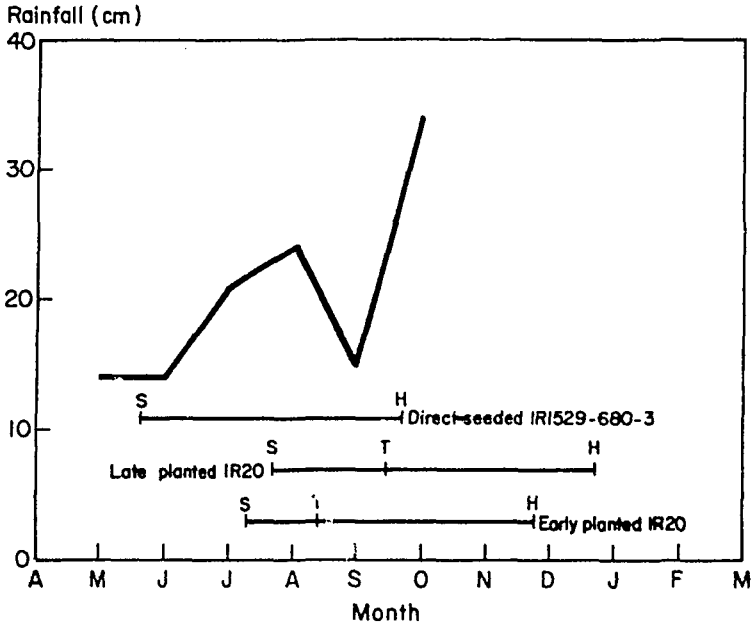
INCREASING YIELDS OF THE SECOND RAINFED RICE CROP

With modern, early maturing rice varieties, the possibility of increasing rice production by growing two rainfed rice crops is a viable possibility in regions receiving 6-7 months or more of rainfall at a rate exceeding 200 mm/month. In some areas with only 5-6 months of rainfall, two rainfed rice crops are possible. The performance of the second crop depends heavily on avoidance of late season drought. Three major considerations for reduced drought stress on the second crop are:

1. earliness in planting of the first crop,
2. second crop establishment method, and
3. reduced, faster tillage for the second crop.

Table 6. Effect of seeding date on yield of dry-seeded rice in Pangasinan and Iloilo, Philippines, 1977 wet season.

Pangasinan		Iloilo	
Seeding date	Yield (t/ha)	Seeding date	Yield (t/ha)
22 April	4.5	6 May	3.6
27 April	5.0	11 May	4.2
2 May	4.9	16 May	4.0
7 May	4.6	21 May	3.7
12 May	5.1	26 May	3.8
17 May	4.6	31 May	3.7
22 May	5.0	5 June	4.5
27 May	3.9	10 June	4.5
Treatment MS	652899^{ns}	537695^{ns}	
$s_{\bar{x}}$	300	371	
C.V. (%)	13	18	



5. Time of seeding and harvesting of direct-seeded IR1529-680-3 and transplanted IR20 in relation to amount of rainfall. San Rafael, Bulacan, Philippines, 1973 wet season. IRRI, 1974. S = seeding, T = tilling, H = harvest.

Early planting of first crop

Early first crop plantings are possible through dry-seeding, as mentioned previously. Figure 5 shows the differences in time of harvest between dry-seeding of IR1529-680-3 and transplanting of IR20 in a Philippine study (IRRI 1974). IR20 was not transplanted until sufficient water had accumulated to allow puddling in late July.

IRRI water management research shows that from 200 to 700 mm of water is used during the land preparation operations before rice transplanting (Wickham and Sen 1978). Analysis of rainfall data indicates that a dry-seeded rice crop in experiments at Pangasinan and Iloilo, Philippines, completed 30-50 days of growth before 400 mm of rainfall had accumulated.

Dry-seeding gave a net time saving of more than 4 weeks for the second rice crop in Pangasinan but only of 1 week in Iloilo, assuming 3-week-old seedlings would have been transplanted as

the first crop after the fields were puddled. Similar advantages attributable to dry-seeding of the first crop were obtained by Singh and De Datta (1978). They showed that the delay in transplanting the first crop on a puddled soil left insufficient time to plant a second crop within the same season.

Second crop establishment

Transplanting may reduce the field duration of a second crop by 2 or 3 weeks, lowering the risk of late season drought stress during the critical grain-filling period. Evidence of this effect is in Table 1 -- higher yields and lower yield variability associated with transplanted second crops compared with those associated with direct-seeded crops. Furthermore, the frequency of crop failures after direct-seeding was twice that for transplanting.

Second crop tillage

Another factor in delayed planting of a second rice crop is the time to prepare land for the second crop. Studies in several rice-growing regions of Asia -- Sri Lanka (Mittra and Pieris 1968), Malaysia (Seth et al 1971), Indonesia (Varley 1970), and the Philippines (Moomaw et al 1968, De Datta et al 1977) -- demonstrate that the degree and duration of tillage operations may be substantially reduced without adversely affecting crop growth and yield of rice. However, the trials were conducted at experiment stations with mechanized tillage, and most had good water conditions. Reduced tillage operations and reduced turnaround time for rainfed rice systems require study with farmers' resources and tillage implements.

ECONOMIC FACTORS AFFECTING CHOICE OF LAND PREPARATION AND CROP ESTABLISHMENT

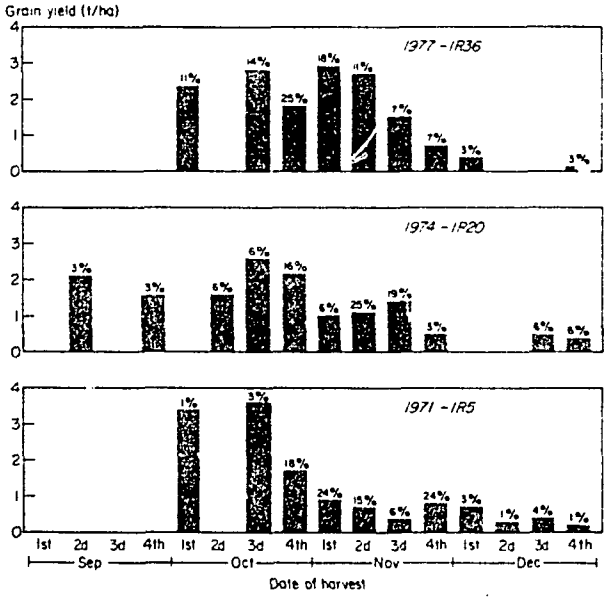
As already noted, a wide range of land preparation and crop establishment practices is being used because of a wide diversity in the rainfed rice-growing environment. Ultimately, the choice of appropriate land preparation and crop establishment in a given area is determined by the benefits and costs associated with alternative methods. The benefits can be measured in terms of higher yields, greater cropping intensity, or reduction in risk of yield loss. The costs include power for tillage, planting or transplanting labor, and weed control.

In much of the rainfed rice-growing environment, delayed planting results in a yield loss because of the greater probability

of drought in the crop-ripening stage and a change in environmental factors such as solar energy and temperature. The pattern of yield reduction varies from year to year and from place to place and even among varieties.

An example of the types of yield reduction encountered is illustrated in Figure 6, which is based on three surveys in a rainfed rice-growing area of Central Luzon. Modern varieties were grown on two-thirds of the farms as early as 1971. As the harvest extended into November and December, the average yield reduction appeared to be about 30 kg/day. However, the introduction of IR36, an early maturing variety (100-110 days for IR36 vs 120-140 days for IR8 and IR20), had a dramatic impact on production and yield because farmers advanced their harvesting date.

It takes about a month after the onset of rains before there is sufficient moisture for puddling. Thus, rainfed area farmers typically transplant and harvest a month later than many farmers with good irrigation. It is practical in many rainfed areas to consider alternative methods of land preparation and planting.



6. Average rice yield of the most widely planted variety in each of 3 years, by date of harvest, in rainfed areas of Bulacan and Nueva Ecija, Philippines, 1971 to 1977. (The figure above each bar refers to percentage of area harvested).

Power requirements

A study by Orcino and Duff (1974) determined power requirements and yield differences when rice fields were prepared with different combinations of animal and tractor power on three irrigated and one rainfed site (Table 7, 8). It cannot be assumed from the results that tillage of rainfed soils typically requires more power input per hectare. However, penetrometer readings on the rainfed soil were twice as high as those in the irrigated soil, indicating that the rainfed fields were not as well soaked. If a water buffalo works 6 hours/day, a hectare of rainfed Kapalangan soils can be prepared in about 3 weeks. But there is only from 0.5 to 1.0 working animal/ha on rainfed farms in this area. Thus, with the animal power available, a month or more may be required to prepare a hectare.

An economic survey in the same rainfed barrios indicated that use of 4-wheel tractor for primary tillage reduced land preparation time from 37 to 27 days (Bautista and Wickham 1974). Assuming that this reduction in time could be translated into higher yields (Fig. 6), the value of the 300-kg additional yield is only slightly higher than the custom rate for rotovating 1 ha. A few farmers hire tractors, but only when planting is delayed because of late rains. The average rainfed-area farmers, who grow only 1 crop of rice and obtain yields of less than 2 t/ha, cannot afford the power investment needed to reduce the time required for puddling and transplanting the monsoon crop.

Table 7. Land preparation treatments in 3 barrios, Nueva Ecija, Philippines, 1973 wet season.

Treatment	Land preparation method			
	Primary		Secondary[a]	
	Power source	Implement	Power source	Implement
1	65-hp tractor	Rotary tiller	Carabao	Comb harrow
2	14-hp tiller	Rotary tiller	Carabao	Comb harrow
3	7-hp tiller	Moldboard plow	7-hp tiller	Comb harrow
4	Water buffalo	Moldboard plow	7-hp tiller	Comb harrow
5	Water buffalo	Moldboard plow	Carabao	Comb harrow

[a]Secondary tillage consists of 2 passes over the field repeated 3 times at 1-week intervals. Source: Orcino and Duff 1974.

Table 8. Site characteristics, soil conditions, and level of inputs used in land preparation trials in 3 barrios, Nueva Ecija, Philippines, 1973 wet season.

Site treatment	Labor inputs (hour/ha)			Soil penetrometer reading[a] (depth in cm for 35 psi)	Mean yield[b] (t/ha)
	Plow	Harrow	Total		
			Baluarte (shallow hardpan)		
T1	4	30	34	11.5	3.85
T2	6	30	36	12.1	3.80
T3	12	12	24	11.5	3.65
T4	27	11	38	12.3	3.88
T5	27	31	58	11.2	3.74
			Pulo I (medium hardpan)		
T1	5	40	45	6.8	3.97
T2	8	41	49	8.8	4.00
T3	13	21	34	7.5	4.14
T4	34	20	54	7.7	4.01
T5	32	40	72	8.6	3.94
			Pulo II (deep hardpan)		
T1	4	42	46	10.9	3.53
T2	7	42	49	10.9	3.57
T3	9	20	29	11.0	3.65
T4	27	21	48	9.0	3.57
T5	27	39	66	9.3	3.71
			Kapalanpan (rainfed)		
T1	7	47	54	6.6	3.08
T2	11	53	64	6.0	2.93
T3	-	-	-	-	-
T4	61	21	82	5.1	2.97
T5	63	66	129	6.2	3.01

[a]At beginning of land preparation. [b]Averaged over the 3 weed treatments. Source: Orcino and Duff 1974.

Double cropping

The introduction of a short season variety such as IR36 clearly has a much greater impact on production and profits than the increase in farm power. The situation may differ in areas where double-cropping is feasible.

IRRI cropping systems research (municipalities of Oton and Tigbauan, Iloilo province, Philippines) provides one example of a rainfed area that can be partly double-cropped. Lands prepared before 1 July are wet-seeded (broadcast on puddled soil) to early maturing varieties. The wet-seeding method saves time and labor, and facilitates the growing of two crops (Table 9). There

Table 9. Most important advantages and disadvantages of planting wet-seeded rice reported by 39 farmer-respondents in Iloilo, 1976.[a]

Advantages and disadvantages	Farmers reporting (%)
Advantages	
Labor is less.	74
Cost is lower.	72
Double-cropping possible	61
More tillers	51
Good yield	46
Disadvantages	
Water availability early in season	67
Weed problem	67
Risk is great.	61
High seed requirement	46
High fertilizer requirement	41

[a]Source: Roxas et al 1977.

appears to be little difference in yield between wet-seeded and transplanted rice, although this observation is not well documented. On lands prepared after 1 July, late maturing varieties are transplanted and only a single crop is harvested.

The Iloilo case shows a particularly skillful adjustment by rainfed farmers to make more efficient use of limited power and water supplies. Although animals are now the principal source of power, the potential for increasing productivity by double-cropping may require mechanization of land preparation in the future.

On much of the central plain of Thailand, water control is poor. Land is tilled dry, and rice is sown on dry soil before the rains come. Since weed control is a serious problem, yields are substantially lower. Where water control is adequate, farmers normally shift to transplanting. But one study (Lokaphadhana 1976) shows some farmers switching from transplanted to wet-seeded rice. The situation appears to be similar to that in Iloilo where two crops of rice are grown. The major reasons Thai farmers gave for broadcasting and transplanting are in Table 10.

Labor costs

Perhaps the most dramatic shift in method of rice stand establishment in recent times occurred in Burma. The motivating force was a rise in the wage rate for labor relative to the farm rice price. Richter (1976) reports that as a result of the wage-price changes, an estimated 1.4 million ha of formerly transplanted land was broadcast-seeded and the estimated reduction in yield was 0.5 t or more per ha.

Table 10. Major reasons given by a sample of 94 farmers[a] for either broadcasting or transplanting rice. Amphoe Bang Nam Prieo, Changwat Chachoengsuo, Thailand, 1975.

Reason	Farmers reporting (%)
For broadcasting only (75%)	
Cost is lower.	38
Cost is lower and yield is same or higher.	26
Labor is less.	23
Other reasons	11
	100
For transplanting only (10%)	
Sure that yield will be higher	33
Weeds are easier to control.	17
Less fertilizer is required.	15
Other reasons	35
	100

[a]Source: Lokaphadhana 1976.

Weed control

The decision on method of tillage for rainfed rice is also related to weed control. Land preparation is in fact a form of weed control. More thorough tillage reduces the weed problem later. But we have clearly observed that rainfed farms are likely to be underpowered. Furthermore, intermittent rains lead to drying of the paddy, which not only encourages weed growth but also makes it impossible to recommend the inexpensive preemergence herbicide treatments used in irrigated areas. If weeds are not adequately controlled in the early stages of stand establishment, the yield losses in broadcast rice may be severe. That is one of the risks particularly associated with dryland preparation.

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Influence of water-related factors on land preparation, cropping intensity, and yield of rainfed lowland rice in Central Luzon, Philippines

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BACKGROUND

About 50% of the lowland rice hectarage in South and Southeast Asia, which contributes about 42% to total rice production, is completely dependent on rainfall (Barker 1970). In the Philippines about 47% of the rice area is rainfed lowland rice and the average yield is about 1.5 t/ha. In Central Luzon, the "rice bowl" of the Philippines, rainfed lowland constitutes about 33% of the region's total rice production area and yields approximately 1.9 t/ha (Table 1).

Research trials under lowland rainfed conditions have consistently yielded 3 to 4 t/ha, even higher, in Central Luzon (IRRI 1974). What factors are responsible for the low yields in farmers' fields? Of all possible factors, water availability certainly plays a crucial role. The rainfed paddies often suffer from periodic drought and the consequent moisture stress injury. Soil moisture tension as low as 15 centibars was found sufficient to reduce the grain yield of rainfed lowland rice in field studies at IRRI (De Datta et al 1973). Moisture stress during the early vegetative stage may reduce tillering; during the late vegetative and reproductive stages, it results in decreased grain yield caused by a reduction in number of grains per panicle, percentage of filled grains, and the grain weight (De Datta et al 1973). the grain weight (De Datta et al 1973).

Climate and rice cultivation in Central Luzon

The Central Luzon region has two distinct seasons: the dry season lasting from December through April, and the wet season covering the rest of the year. During the dry season, the northeasterly wind prevails over the region and brings an average of less than 5 cm rain/month. The wet season starts with the advent of the southwest monsoon in late April or early May, and the maximum rainfall occurs in July, August, and September. In October, the amount drops sharply, marking the transition to the dry season (Fig. 1).

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Table 1. Hectarage and yield of rainfed lowland rice in the Philippines, by region, 1976-77.[a]

Region	Total rice producing area[b] (ha)	Rainfed lowland rice area[b] (ha)	Rainfed area as % of total	Yield[b] (t/ha)
Ilocos	326,725	172,305	53	1.5
Cagayan Valley	425,650	161,135	38	1.4
Central Luzon	438,465	145,710	33	1.9
Southern Tagalog	458,600	142,230	31	1.4
Bicol	336,500	158,380	47	1.7
Eastern Visayas	180,865	123,080	68	1.1
Western Visayas	461,450	338,940	74	1.6
Central Visayas	88,800	56,450	64	1.4
Northern Mindanao	322,170	112,730	35	1.4
Southern Mindanao	382,235	197,075	52	1.1
Western Mindanao	146,950	67,010	46	1.9
Philippines	3,563,410	1,675,045	47	1.5

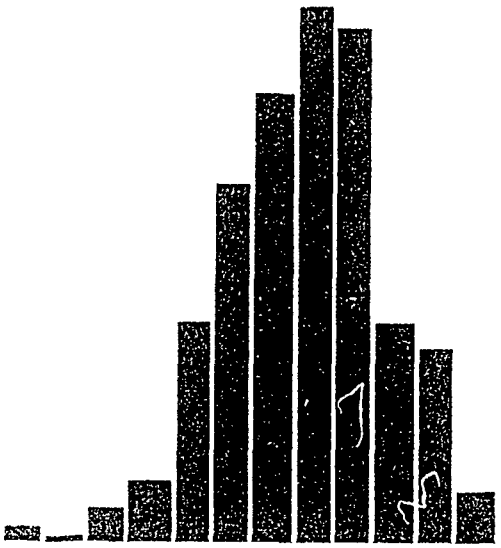
[a]Data from the Bureau of Agricultural Economics, Philippines.
[b]Average of the 2 years.

October and November are usually the months of peak typhoon activity in Central Luzon. Most rainfed rice paddies are in the flowering and ripening stages during those months and may suffer yield loss due to either lodging or inundation, or both, when a typhoon hits the area.

In the case of rainfed lowland rice, farmers' crop planning is influenced largely by the amount of rainfall that has occurred up to a given time. There is usually a threshold of minimum cumulative amount below which farmers do not consider it advisable to start preparing the land for seedbed. Once the seedbed is prepared and seeds are sown, the farmers transplant about 30-day-old seedlings if they are growing modern varieties, but older seedlings of local varieties are transplanted. If the availability of water from rainfall does not permit proper land preparation when the seedlings are ready, the farmers either transplant in hastily and poorly prepared land, or plan to transplant older seedlings at a suitable later time, or start preparing a second seedbed. In the first case, the plants suffer from high weed population and low tillering. In the others, the critical stages of plant growth are very likely to enter the receding period of the monsoon, and the plants will suffer from water shortage and give poor yields.

Approaches to production increase

Rice production in rainfed areas can be increased by increasing either the per hectare production of the most prevalent one-crop-a-year system or the cropping intensity, i.e. growing more crops



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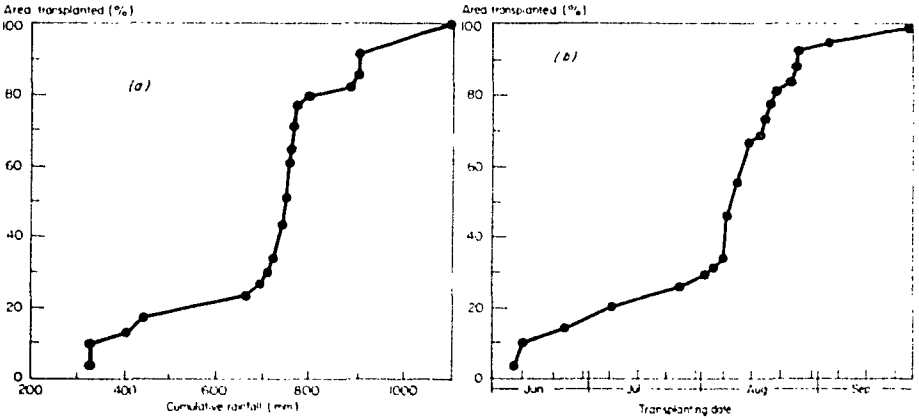
LAND PREPARATION AND YIELD

Effect of rainfall

In transplanted lowland rice culture, the water requirement for land preparation must be met before transplanting can take place. There is a minimum cumulative amount of rainfall that permits farmers to start plowing for seedbeds and then the whole farm. In an irrigated area in Central Luzon, a linear relationship was demonstrated between the date of first plowing and the date of transplanting of a paddy (Valera 1977). A similar relationship may be assumed for a rainfed lowland rice area because most farmers prepare the seedbed at the time of first plowing and then transplant about 30-day-old seedlings.

Prediction of transplanting dates

The relationship between the progress of land preparation and cumulative amounts of rainfall from the beginning of the wet season (Fig. 2) was based on a 1973 study in a typical rainfed area in Gapan, Nueva Ecija. The 1973 rainfall could be considered representative of the mean rainfall pattern over several years in Gapan (IRRI 1976). The percentage of area transplanted at any given time, A, was related to the cumulative rainfall amounts through the equation:



2. a) Cumulative rainfall and area transplanted (%); and b) transplanting dates and area transplanted (%). Gapan, Nueva Ecija, Philippines, 1973 wet season.

$$A = \left(\frac{1}{1 - R_f} - \frac{1}{0.922R_f}\right) \times 100$$

where R_f is the ratio between the cumulative rainfall amount at that time and the cumulative rainfall amount at which the whole area was transplanted. The equation is based on 20 observation points and has $R^2 = 0.99$.

It is evident from Fig. 2a that a number of farms were transplanted early at relatively small amounts of cumulative rainfall, while most were transplanted at higher but a narrow range of cumulative rainfall amounts. Some farms were transplanted at still higher amounts of rainfall. Fig. 2b illustrates the relationship of the dates of transplanting with percent area transplanted.[1]

Using equation (1), the average cumulative rainfall values for three groups of farms - first 25%, middle 60%, and last 15% - of the transplanted area were calculated. The values were used to predict at two levels of probability, 0.5 and 0.75, the dates in any given year by which the rainfall amounts would be equaled or exceeded (Table 2). Twenty-four years (1951-74) of rainfall data for Cabanatuan City[2] were analyzed and used for the purpose (Fig. 3). The predicted transplanting dates for the first, middle, and last group of farms were 11 July, 7 August, and 19 August, respectively, at rainfall probability of 50%. At 75% probability level, the dates were 1 August, 20 August, and 30 August.

Estimation of stress days

The predicted transplanting dates were used to estimate the degree of water deficiency during the growing season for 6 years, 1969 to 1974. A daily water requirement of 10 mm was considered sufficient to meet the evapotranspiration (ET) needs, estimated at 4 mm/day. The seepage and percolation (S&P) requirements were estimated at a relatively high value of 6 mm/day, given the lighter texture of the soil in the area.

A daily accounting method was used to calculate the number of rainfall deficit days in a week. This method was followed during 10 weeks of the growing period starting from 4 days after transplanting. It was assumed that the bunded paddies can hold a maximum of 60 mm of rainwater from 1 day's total rainfall. Any

[1] A similar pattern of relationship was found true for irrigated areas in Central Luzon (Valera 1977).

Table 2. Expected dates of transplanting of rainfed lowland rice in Gapan, Nueva, Ecija, Philippines.

Area ransplanted[a] (%)	Av cumulative rainfall at transplanting (mm)[a]	Expected date of transplanting[b] in any given year at 0.5 probability	0.75 probability
First 25%	510	11 July	1 Aug.
Middle 60%	792	7 Aug.	20 Aug.
Last 15%	982	19 Aug.	31 Aug.

[a]Calculation based on 1973 wet season data for Gapan.

[b]Calculation based on 24-year (1951-74) daily rainfall data for Cabanatuan City, Nueva Ecija, Philippines.

daily rainfall in excess of 60 mm was considered to have drained out of the paddy. For converting the rainfall deficit days into stress days, i.e. days in excess of 3 without standing water in the paddy, a set of 1977 wet season field measurements of rainfall and stress days in a rainfed area in Gapan were used. The equation developed is:

$$S = -0.01 + 0.82\,n$$

$$(R^2 = 0.60;\ \text{no. obs.} = 105) \qquad (2)$$

where S is the number of stress days in a week and n is the number of rainfall deficit days during the same week. The S values obtained for 6 years from computed values of n and use of equation (2) are presented in Table 3.

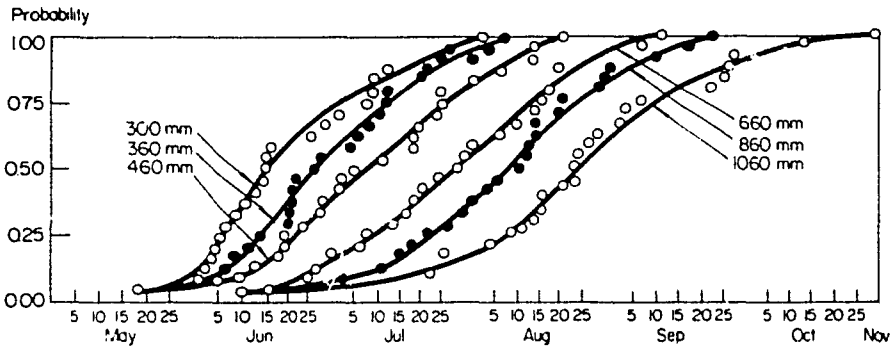
Estimation of yields

Yield estimates for the 6 years were made using the model:

$$Y = 2197 + 16.2\,N - 0.06N^2 - 47.8\,S - 0.39\,NS \qquad (3)$$

where Y is yield (kg/ha); N is the optimum nitrogen use (43 kg N/ha), which is defined as the point at which the marginal value of rice is two times the marginal cost of nitrogen; and S is the number of stress days during the growing season (IRRI 1977).

[2]Cabanatuan City is approximately 30 km north of Gapan, and the two places are considered to have the same rainfall.



3. Time and probability relationship for cumulative rainfall amounts for Cabanatuan City, Nueva Ecija, Philippines, based on 24-year (1951–74) rainfall data.

Yields were estimated using the different planting dates and individual year's known rainfall pattern for the 6 years. Equations (2) and (3) were successively used for each planting date to estimate the final yield values shown in Table 4.

Delays in transplanting produced significant differences between the average yield values for the 6 years when the transplanting date was shifted from 11 July to 7 August and from 11 July to 19 August for 50% probability situations. There was, however, no significant difference between the yields from transplanting dates of 7 August and 19 August at 50% probability. The situation for the 75% probability level is similar (Table 4).

The percentage of yield losses due to delayed transplanting with respect to the earlier transplanting date are shown in Table 5. On the average, 25 and 35% yield losses resulted from shifting the transplanting date by 26 days from 11 July and 18 days from 1 August at 0.6 and 0.75 probability levels, respectively. At 0.5 probability level, the 11-day delay from 7 August to 19 August affected yield losses as much as the 26-day shift from 11 July because the growing season in the latter date suffered more stress days during the critical stages of growth.

Table 3. Estimated stress days for 6 years (1969-74) for different transplanting dates at 2 levels of rainfall probability. Gapan, Nueva Ecija, Philippines.

Transplanting date	Stress days (no.)						
	1969	1970	1971	1972	1973	1974	Av[a]
			0.5 probability				
11 July	19.6	23.7	23.7	4.1	17.2	14.7	17.2 a
7 Aug.	27.0	22.0	23.7	18.0	27.8	22.9	23.6 ab
19 Aug.	28.6	23.7	24.5	29.4	39.3	25.3	28.5 b
			0.75 probability				
1 Aug.	22.3	22.3	23.7	12.3	22.1	22.9	20.9 a
20 Aug.	28.6	23.7	24.5	29.4	39.[illegible]	25.3	28.5 bc
31 Aug.	35.2	24.4	27.8	36.0	49.[illegible]	20.4	32.15 c

[a]Means followed by the same letter are not significantly different at 0.05 level.

Table 4. Estimated yields for 6 years (1969-74) for different transplanting dates at 2 levels of rainfall probability, Cabanatuan, Nueva Ecija, Philippines.

Transplanting date	Estimated yields (t/ha)						
	1969	1970	1971	1972	1973	1974	Av[a]
			0.5 probability				
11 July	1.52	1.25	1.25	2.52	1.67	1.83	1.67 a
7 Aug.	1.04	1.36	1.25	1.62	0.98	1.30	1.26 bc
19 Aug.	0.93	1.25	1.20	0.88	0.25	1.15	0.94 cd
			0.75 probability				
1 Aug.	1.41	1.41	1.25	1.99	1.36	1.30	1.45 ab
20 Aug.	0.93	1.25	1.20	0.88	0.25	1.15	0.94 cd
31 Aug.	0.51	0.56	0.99	0.46	0.00	1.46	0.66 d

[a]Means followed by the same letter are not significantly different at 0.05 level.

The rainfall pattern of some years, for example 1972 and 1973, produced very drastic yield reductions -- much higher than the average (Table 5) from shifts in the transplanting dates -- because of a greater number of stress days occurring in those years due to the shifts (Table 3).

INCREASING CROPPING INTENSITY

Evaluation of two crops of rainfed rice

Availability of modern varieties of short growth duration and the direct seeding technique have made possible two rainfed rice crops

a year in areas of favorable rainfall pattern. In 1974 the Philippine Government started a program of encouraging farmers to adopt the two-crop technology in some areas including Bulacan province of Central Luzon. A field study made in Bulacan in 1976 determined the water management factors that influence the successful adoption of the two-crop technology under actual farmer management conditions (IRRI 1977).

Table 5. Estimated yield losses for 6 years (1969-74), resulting from delayed transplanting at two levels of rainfall probability. Gapan, Nueva Ecija, Philippines.

Year	Yield loss (%) due to delayed transplanting		
	0.5 probability		
	11 July vs 7 Aug.	7 Aug. vs 19 Aug.	11 July 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[a]	25	26	44
	0.75 probability		
	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[a]	35	30	55

[a] Computed on the basis of average yield values in Table 4.

Methodology. Fourteen pairs of paddies were considered. Each pair comprised a two-crop and a one-crop paddy adjacent to each other. Half of the two-crop paddies were located at a relatively high elevation, and the remainder at a relatively low elevation. High elevations were associated with steep terraces, little surface runoff from the watershed, and substantial depths to the water table; low elevations were associated with flatter areas that received considerable water draining from higher elevation. The farmers' practices were not intentionally influenced by the study.

IR1561 was planted on all two-crop farms and either IR1561 or the local variety Tjeremas was planted on the one-crop farms. Field data collected included rate of S&P; occurrence of stress

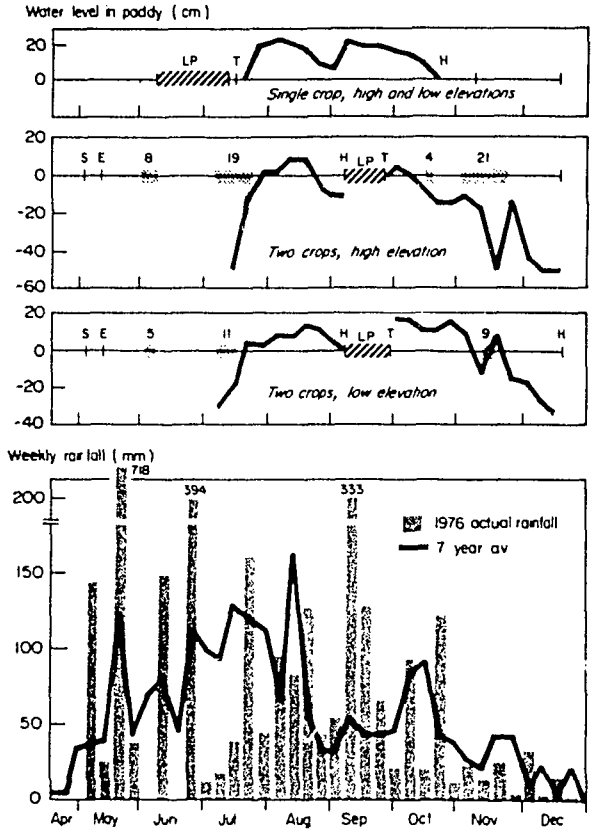
days, which were measured as days in excess of two for which there was no standing water in the paddy; and rice yields. Stress days occurring between transplanting or emergence of direct-seeded rice and 60 days before harvest were considered early stress days (S_1), while those between 60 and 26 days before harvest were considered late stress days (S_2). Data on fertilizer use and other management practices by farmers were collected by interview. Agroclimatological data like rainfall, evaporation, and water table depths were gathered in the field with standard techniques.

Seepage and percolation rates. S&P rate was consistently less for low-elevation paddies than for those at high elevation, as expected (Table 6). The unpuddled soils of the first crop had slightly less S&P rates than the puddled soils of the second crop. This unexpected low rate can be explained by subsurface movement. The soil is underlain by semipermeable limestone at depths as shallow as 1 m, which restricts vertical water movement. Piezometric observations confirmed positive hydrostatic pressure after heavy rains. Because the rainfall was much greater during the first crop, S&P rates were low for the first crop season even though the soil was more porous then.

Stress days. Stress days were numerous during the early growth stage (S_1) of the first crop and during the late growth stage (S_2) of the second crop on the two-crop farms (Table 6). The effect of relative elevation on S_2 was significant for both crops, with more than twice as many stress days for high elevation farms as for low ones. Stress days were slightly more numerous for the first crop than for the second, despite the greater rainfall for the first. The rainfall distribution was uneven during the first crop, with rainfall below 45 mm/week in 3 consecutive weeks in July (Fig. 4). In addition, the direct-seeded first crop was exposed to early stress over a longer period. One-crop farms at either elevation experienced only a few days of early stress and no late stress (Table 6).

Grain yield and net farm income. In the computation of farm income, gross income was estimated by valuing production at US$149/t. Family labor was valued at US$1.35/man-day, which was the lowest rate for attracting agricultural labor in the area.

Yields and net farm income for the direct-seeded first crop were significantly greater on the low-elevation farms than on the high-elevation farms (Table 7). The effect of elevation was small for the second crop, however, and negligible for the one-crop system. The total production for the year on high-elevation farms was 4.44 t/ha for two-crop farms, and 3.34 t/ha for one-crop farms (3.82 t/ha for single crops of IR1561). At low



4. Average weekly rainfall for 1970–76 and weekly rainfall for 1976 at San Ildefonso, Bulacan, cropping schedule for two crops and one crop of rainfed rice; depth of water and stress days in the paddies. Av for two barrios, Bulacan, Philippines, 1976. S = seeding, E = emergence, LP = land preparation, H = harvest, T = transplanting, ▒ = stress days.

elevations, two crops produced 5.92 t/ha and the corresponding one-crop farms produced 3.35 t/ha.

Farmers reported weed control as a major production constraint in the direct-seeded first crop. Weed competition was negligible on all transplanted paddies in the one-crop or two-crop farms. Insect and pest control were cited as the most important problem of the second crop. Rats, brown planthoppers, and green leafhoppers concentrated on the second-crop farms after the harvest of the neighboring one-crop farms.

Table 6. Mean rates of seepage and percolation, rainfall, and stress days for two-crop and one-crop rainfed farms at different elevations. Bulacan, Philippines, 1976 wet season.[a]

Crop, elevation	Seepage and percolation: Observation (no.)	Seepage and percolation: Rate (mm/day)	Mean rainfall (mm/day)	Stress days (no.): Early[b]	Stress days (no.): Late[c]
		Two-crop farms			
First crop (direct seeded)					
High elevation	70	3.8 ab	127 a	12.7 a	14.3 b
Low elevation	50	3.0 b	121 a	16.1 a	6.9 c
Second crop (transplanted)					
High elevation	56	5.6 a	54 c	2.9 b	22.1 a
Low elevation	121	3.3 ab	44 c	0.4 b	9.6 bc
		One-crop farms			
High elevation	150	4.0 ab	94 b	1.4 b	0.0 d
Low elevation	122	3.0 b	89 b	2.3 b	0.0 d

[a]Means in the same column followed by the same letter are not significantly different at the 5% level. Testing based on differences between crops at both elevations.

[b]From date of emergence or transplanting to 60 days before harvest (DBH).

[c]From 60 to 26 DBH.

The net yearly income from the high-elevation one-crop farms was about the same as that from the high-elevation two-crop farms. For farms at low elevation, the net yearly income was US$298/ha for one crop and US$477/ha for two crops (Table 7). The combined data for both elevations give a 29% greater annual net income from two-crop farms than from the one-crop farms, but the greatest advantage occurs with the two-crop low-elevation farms, whose net income was 61% greater than that of the one-crop farms at the same position. Comparisons of net family incomes tnat exclude the cost of family labor present a somewhat more favorable picture of the two-crop practice because of the greater labor requirements of two crops.

Modeling for different rainfall patterns

Yield response model. The previous section was the result of a study for one season, the 1976 wet season. This section relates grain yield to rainfall patterns of different years to determine the long-term feasibility of two crops of rainfed rice.

A multiple regression model based on stress days was used to estimate the effects on yield of water shortage in combination with other important factors (IRRI 1977). The two equations computed for the two crops follow:

For the direct-seeded first crop:

$$Y = 4140 + 36.6\,N - 0.4\,N^2 - 63\,S_1 - 36\,S_2 - 1365\,W + 0.4\,S_1N + 2.3\,NW \qquad (4)$$

$$(R^2 = 0.89;\ \text{no. obs.} = 15)$$

For the transplanted second crop:

$$Y = 1240 + 42.3\,N - 14\,S_2 - 6.4\,A \qquad (5)$$

$$(R^2 = 0.80;\ \text{no. obs.} = 11)$$

where Y is grain yield (kg/ha); N is nitrogen used (kg N/ha); S_1 and S_2 are stress days in the vegetative and reproductive growth stages, respectively; and W is a measure of weed control estimated by visual observation or spot check to conform to the scale: 0 = negligible weed growth, 1 = weed growth whose dry weight (excluding roots) is less than 200 g/m^2, and 2 = weed growth in excess of 200 g/m^2 of dry weight. A is age in days of seedlings at transplanting. All seedlings were transplanted at an age greater than 28 days; therefore the coefficient was

Table 7. Grain yield, total costs, gross income, and net income[a] for two-crop and one-crop rainfed farms at different elevations. Bulacan, Philippines, 1976 wet season.

Crop, elevation	Observations (no.)	Grain yield (t/ha)	Total cost[b] (US$/ha)	Income (US$/ha) Gross	Net farm	Net family
		Two-crop farms				
First crop (direct seeded)						
High elevation[c]	7	1.52**	142	271	115**	157**
Low elevation	7	1.81	195	447	252	296
Second crop (transplanted)						
High elevation	7	2.62	209	389	181	220
Low elevation	7	2.91	203	433	225	260
		One-crop farms				
All varieties (transplanted)						
High elevation	7	3.34	195	496	301	345
Low elevation	7	3.35	199	498	298	340
IR1561 only[d]	4	3.82	211	568	294	327

[a]Philippine ₱7.4 = US$1.
[b]Including family labor costs at US$1.35/man-day
[c]Asterisks denote significant difference at the 1% level between one-crop and the indicated two-crop farms at the same elevation. Only grain yield and net income are tested. Differences between elevations are significant only in the direct-seeded first crop. Single crops of IR1561 only are not included in significance testing.
[d]Two observations at high elevations and two at low.

negative. The intercept of the equation for the transplanted second crop is lower than expected, partly as a result of insect and pest damage that was not directly incorporated in the model.

Weed growth in the direct-seeded first crop accounted for more than 2 t/ha yield loss, and water stress (S_1 and S_2) for about 1.2 t/ha. Nitrogen accounted for 1.1 t/ha gain. N in the transplanted second crop accounted for almost 2 t/ha yield gain, and S_2 and A each contributed 0.3 t/ha loss.

Prediction of stress days. A water-deficit model was developed to predict stress days based on daily rainfall and daily water use as S&P and ET (IRRI 1976). The total daily water use was estimated at 8 mm/day, and the days in a week when rainfall supply was less than the 8-mm demand were counted. To account for residual lag efforts, deficit days were excluded for the first day after rainfall in excess of 10 mm, and for 2 days after a day of 20 mm or more rainfall. Thus, a weekly series of deficit days, n, that was developed was found to be related to the mean number of observed stress days during the corresponding week through the equations:

For the first crop: $S = 0.7 + 0.41\,n$ (6)

($R^2 = 0.76$; no. obs. = 10)

For the second crop: $S = 0.3 + 0.23\,n$ (7)

($R^2 = 0.81$; no. obs. = 9)

where S is the number of stress days per week and n is the number of deficit days for the same week.

Prediction of yield. With the water-deficit model, expected stress days for each crop season in 1970-76 were computed from rainfall data. Calculations began in the 20th week of the year (mid-May). The analysis spanned 15 weeks for the first crop and 12 weeks for the second, with 3 weeks of land preparation between crops. Nitrogen used was set at 45 kg N/ha and weed growth W for the direct-seeded first crop was assumed equal to the mean value recorded in 1976, i.e. $W = 1.21$. Seedlings for the transplanted crops were assumed to be 38 days old for the second crop and 30 days old for the single crop. Stress days and yields predicted by this procedure approximate the measured values for 1976 (Table 8).

The analysis demonstrated the vulnerability of the second crop to water shortage. In 3 out of 7 years, essentially complete failure of the second crop due to inadequate rainfall

was predicted. In 2 of those years, inadequate rainfall during the land preparation period would have delayed transplanting of the second crop and caused severe stress later in crop growth. Mean yields for the 7 years were 2.8 t/ha for the first crop and 1.4 t/ha for the second crop.

Effects of elevation on yields. To bring out the effects of elevation, the equation predicting S from rainfall deficit days n was recomputed separately for the two topographic regimes. With the use of the 1976 data and the same method, the combined results for both crops follow:

$$\text{For high elevations: } S = 0.00 + 0.37\,n \quad (R^2 = 0.71;\ \text{no. obs.} = 16) \tag{8}$$

$$\text{For low elevations: } S = -0.80 + 0.29\,n \quad (R^2 = 0.66;\ \text{no. obs.} = 16)$$

The same rate of nitrogen use (45 kg N/ha) was assumed for both crops, and the 1976 mean weed index of 1.57 for high-elevation farms and 0.86 for low-elevation farms were used in the responses. The simulated yields for all 7 years were then averaged to find the mean effect of relative elevation for that period.

Table 8. Estimated stress days[a] and yields based on weekly rainfall in San Ildefonso, Bulacan, Philippines, for two crops of rainfed rice on high and low elevations. 1970-76 wet seasons.

Year	First crop			Second crop		
	Stress days (no.)		Yield	Stress days (no.)		Yield
	S_1	S_2	(t/ha)	S_1	S_2	(t/ha)
			Measured			
1976	14.4	10.6	2.4	1.4	15.9	2.8
			Estimated			
1976	13.5	9.0	2.8	2.5	15.0	2.6
1975	4.0	4.0	3.1	7.5	16	0[b]
1974	10.5	5.0	2.8	-	-	0[c]
1973	7.5	15.5	2.5	10.5	17.5	2.5
1972	7.0	0.0	3.1	-	-	0[c]
1971	4.0	4.0	3.1	3.5	8.5	2.7
1970	13.0	13.0	2.3	2.0	18.5	2.4
Mean	8.5	7.2	2.8			1.4

[a] S_1 = stress at early stage of crop growth, S_2 = stress at late stage.

[b] Because the entire second growth period would be composed of stress days, zero yield was assumed.

[c] Total rainfall during the first 5 weeks after harvest of the first crop was less than 40 mm; thus the second crop would have been delayed and harvested well beyond the period of late season rainfall; zero yield was therefore assumed.

Table 9. Mean stress days and yields computed for farms at two relative elevations. Means for 7 seasons with two crops and single crops of rainfed rice, 1970-76.[a]

Crop	Stress days (no.)		Grain yield[b] (t/ha)
	Early	Late	
High elevation[c]			
First crop (direct seeded)	10.0	8.0	2.1
Second crop (transplanted)	6.0	22.7	1.5
Combined first & second crops			3.6
Single crop (transplanted)	8.0	12.4	2.8
Low elevation[d]			
First crop (direct-seeded)	6.0	3.0	3.5
Second crop (transplanted)	2.2	15.3	1.6
Combined first & second crops			5.1
Single crop (transplanted)	3.2	5.6	2.9

[a]Based on daily rainfall records from San Ildefonso, Bulacan, Philippines, 1970-76.

[b]Assuming 45 kg/ha of N use.

[c]Stress days computed from $S = 0.0 + 0.37\,n$.

[d]Stress days computed from $S = -0.8 + 0.29\,n$.

The mean yields (Table 9) were lower than those measured in the 1976 field study and indicated that 1976 was a year of better-than-average rainfall. The relative production advantage of two crops over one crop was, however, about the same for the 1976 data and the 7-year means.

MANAGEMENT OF PADDY BUNDS AND EFFECTIVE USE OF RAINFALL

Farmers' practices

Rainfed farmers generally make some improvements on the bunds before the onset of the monsoon so that paddies can retain more water from the rainfall. These improvements may include one or more of the following: 1) repairing or rebuilding bunds to make them stable; 2) repairing cracks, holes, or openings, and lining the inner faces with clay mud to reduce seepage leaks; and 3) increasing bund height and the spillway[3] height to impound more water.

[3]Spillway in rice paddies is the portion of the bund, the upper level of which determines the maximum depth of water to be retained in the paddy and spills the excess.

Effect of bund height on water availability

The usefulness of farmers' management practices to stabilize the bund and reduce seepage leaks is well recognized. The extent to which additional water could be retained in a paddy by effectively raising the bund height was earlier investigated by use of a simulation model for Central Luzon. Wickham (1973) showed that increasing the effective bund height from 2 cm to 4, 6, and 8 cm gave no significant increase in the water retained in the paddies. Reduction in the number of stress days during the growing period was small and consequent increase in yield was insignificant.

A recent study in Gapan, Central Luzon, in the wet season of 1976 investigated the effects of different spillway heights on the water stored, number of stress days, and effective rainfall amounts[4] in a paddy (Sen 1977). No difference in effective rainfall amounts was found between the 6-cm and 12-cm spillway heights. But when the model was applied to the rainfall patterns for each of 11 years (1964-74) of rainfall data for Cabanatuan City, Central Luzon, significant differences in effective rainfall amounts were found among spillway heights 2, 5, 8, and 12 cm. The total number of stress days and mean water depths were computed from daily rainfall data for the 11 years (Table 10). Each successive increase in the spillway height from 2 cm reduced the mean stress days by about 50%. The mean depth of water in the paddy was about 9 times greater when the spillway height was

Table 10. Total stress days[a] and mean water depth for different spillway heights in rainfed conditions, computed by the simulation model from daily rainfall at Cabanatuan, Nueva Ecija, June-September 1964-74.

Year	Stress days (no.)				Water depth (mm)			
	2-cm spillways	5-cm spillways	8-cm spillways	12-cm spillways	2-cm spillways	5-cm spillways	8-cm spillways	12-cm spillways
1964	11	1	4	1	9	33	61	94
1965	9	9	1	9	10	35	64	104
1966	6	6	3	1	6	23	36	62
1967	14	4	2	5	12	36	62	101
1968	21	15	5	4	10	30	50	72
1969	24	17	9	3	8	24	42	65
1970	15	10	7	5	7	21	46	59
1971	14	7	4	0	8	24	41	63
1972	11	10	6	6	11	32	55	83
1973	5	1	3	3	9	27	54	94
1974	12	6	3	1	7	18	36	68
Mean	12	7	4	2	9	28	49	79

[a]Total days in excess of 3 days the water depth was continuously below ground level during the period between transplanting and 25 days before harvest.

[4]Effective rainfall is the total minus the excessive rainfall that cannot be stored or used in the paddy field.

increased from 2 to 12 cm. Approximately three times more water was retained by raising the spillway height from 2 to 5 cm. Water retained with the 8-cm high spillway was intermediate between the extremes.

The 1977 study also indicated that the intensity of daily rainfall had an impact on the effectiveness of that rainfall. At a daily rainfall intensity of less than 10 mm, 100% of the rainfall was effective for all the spillway height treatments. As the daily rainfall intensity increased, its effectiveness in all treatments decreased considerably in all treatments, but the decrease was consistently less with the increase in spillway height (Table 11).

Table 11. Mean effective rainfall for 4 spillway heights and 4 intensity ranges of daily rainfall computed by the simulation model for rainfall conditions at Cabanatuan City, Nueva Ecija, June-September 1966-76.

Daily rainfall intensity (mm)	Daily observations (no.)	Mean effective rainfall (%)[a]			
		2-cm spillways	5-cm spillways	8-cm spillways	12-cm spillways
Less than 10	519	100 a	100 a	100 a	100 a
10-20	421	84 a	89 a	90 b	90 b
20-40	112	57 a	65 b	68 b	69 b
Greater than 40	98	27 a	40 b	45 bc	50 c
Weighted mean[b]		52 a	61 b	64 c	67 d

[a]Means in the same row followed by the same letter are not significantly different at the 0.05 leve

[b]Weighted means followed by the same letter are not significantly different at 0.05 level.

As part of the study, a survey of 40 rainfed farmers was conducted to assess farmers' views on the effects of paddy water depth on tillering, yield, and damage from rats, insect pests, and diseases of rice. About 68% indicated that high water depths, defined as water depths in excess of about 7 cm, decreased tillering and yield. The majority of the respondents associated higher water depth with greater crop damage from diseases. The pattern of response regarding damage by rats and insect pests was inconclusive (Sen and Wickham 1977).

CONCLUSIONS

The conclusions we make, although specific to Central Luzon in the Philippines, should be relevant to other regions having similar agroclimate and soils.

• Even in a one-crop-a-year system of rainfed lowland rice in Central Luzon, the total rainfall amount at which most Central Luzon farmers complete land preparation by traditional methods and transplanting usually falls quite late in the season. That often leads to water stress in the crop during its critical stage of development and a consequent yield loss. More research is needed to find ways to prepare land quicker so that transplanting becomes possible early in the season.

• In the practice of the two-crop system in Bulacan, Central Luzon, the second rice crop is vulnerable to water shortage. In 3 out of 7 years, essentially complete failure of the second crop due to inadequate rainfall can be predicted. In 1976, two-crop farmers in relatively high elevations produced about 33% more rice than the one-crop farmers, but their net farm income was about the same because of the higher labor requirement in the direct-seeded first crop in the two-crop system. By utilizing the relatively greater water availability in the lower elevations, the two-crop farms had 61% more net income than the one-crop farms.

For the rainfall pattern of Central Luzon, varieties of short growth duration would do better in the one-crop as well as in the two-crop system as far as water availability is concerned. Varieties with a growth duration of 90 days or even less would have great advantage. Modern varieties are becoming popular in the rainfed areas, possibly because farmers realize the vulnerability of traditional longer-duration varieties to water shortage toward the end of the season.

Further field research is needed to determine the possible benefits from increasing the effective bund height under different topographic and soil conditions. Such studies should look not only into the aspects of water retention in the paddy and short-term yield values, but also into the longer-term relationship of water depth to the incidence of insect pests, diseases, and the rat problem.

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Weed control in rainfed rice

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Weeds are a serious problem in the production of dry-seeded rice. More weeds occur and the composition of the weed flora is different when rice is planted in dry soil than when it is planted in soil that has been puddled (Table 1). In some instances, weed competition is so intense that failure to control weeds in dry-seeded rice may result in no yield.

Yamane (1976) reported that a 6-week weed-free period after rice sowing was all that was needed to ensure optimum yields in dry-seeded rice. Only a small number of weeds emerged after that period and no yield loss was recorded. Ahmad (1976), however, reported that the crop need be weed-free only from the fourth to the sixth week of growth to achieve maximum yields. IRRI (International Rice Research Institute) research has indicated that maximum yields can be obtained if 3 weedings are done during the first 8 weeks of crop growth. When weed growth is light or water is impounded early, 2 weedings during the first 5 weeks of growth may suffice.

Early weeding is essential, but often the timing of weeding is dependent on visual evidence of weed growth. Farmers prefer to wait until they know that weeds are present, until there are plenty of weeds or until the weeds reach a certain height before they weed. By then, it is probably too late -- the weeds may have already competed with the crop and caused yield reductions.

The length of time that the dry-seeded rice crop should be weeded after planting or emergence varies with many factors such as weed flora, growth characteristics of rice and weeds, cultural practices, and environmental factors. It is, therefore, difficult to generally state how long after seeding a crop should be weeded.

Weed control or suppression techniques

One important technique for suppression of weeds in rice is the use of water. In dry-seeded rice, the crop begins its life cycle as a dryland crop and finishes as a wetland crop. Better weed control

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Table 1. Effect of different methods of land preparation on weeds growing in association with rice 4 weeks after planting.

Method of land preparation	Type of rice culture	Composition of weed flora (%)			Weed wt (kg/ha)
		Broadleaf weeds	Grasses	Sedges	
Puddled	Wet-seeded	57	35	8	72
Puddled	Transplanted	83	7	10	106
Dry	Upland	39	56	5	1519
Dry	Rainfed bunded	33	64	3	1582

would be obtained if soil flooding occurs soon after stand establishment.

Weed growth is stimulated if nitrogen is incorporated into the soil before planting. Smith (1960) observed that rice that was not fertilized and was free of weeds yielded as much as rice that was heavily infested with weeds and received more than 100 kg N/ha. When infestation of *Echinochloa crus-galli* (L.) Beauv was heavy, the best yield was obtained when nitrogen was applied when the grass was heading, 8 weeks after seeding. Thus, in dry-seeded rice, nitrogen application should be timed so as to prevent weed proliferation and yet obtain maximum benefit from the fertilizer applied. It may be wise to wait until after the first weeding to apply nitrogen, instead of applying it basally. Weed growth would be less if this technique is used.

Row seeding is rare for dry-seeded rice. In Bangladesh, Mian and Karim (1970) found that the row-seeded crop was easier to weed and weeding was more efficient than with the broadcast-seeded crop. Less seed, less lodging, and significantly higher grain yields were additional advantages of row seeding. With row seeding, interrow cultivation can be used for weed control. However, the weeds adjacent to the crop rows are not controlled and yield reduction due to them can be appreciable. Such weeds can be removed by hand or by combining an overall or band application of herbicide with interrow cultivation. Equipment presently available for seeding and cultivation in dry-seeded rice leaves much to be desired. Suitable equipment must be developed or modified before row seeding can gain widespread acceptance.

Reducing the spacing between rows or increasing the seeding rate should result in greater competition against weeds and therefore less weeds. However, in a trial conducted in Pangasinan, Philippines, reducing the spacing between rows from 25 to 20 cm or increasing the seeding rate from 80 to 120 and finally to 160

kg/ha had no significant effect on the weeds growing in association with rice, nor on the rice yield.

Land preparation during the dry season

A common practice in rainfed rice-growing areas is to leave the field fallow during the dry season following rice harvest. Weeds grow and shed their seed or multiply vegetatively. Animals graze on these weeds and at the same time introduce weed seeds from outside sources. As a result, intense weed problems can be encountered if a dry-seeded crop is sown at the start of the rains. Repeated tillage during the fallow period, to prevent weeds from seeding and to expose vegetative propagules to drying, should result in a significant depletion in weed reserves in the soil.

By keeping plots free of weeds by tillage during the dry season, Bolton and De Datta (1977) succeeded in conserving considerable amounts of soil moisture compared with the moisture in plots left weedy during the dry season. An additional benefit to keeping the land weed-free during the dry season was that land preparation time and the number of tillage operations for the following rice crop were halved thus saving 10 days' potential growing time.

Bolton (IRRI, personal communication) noted a decrease in total weed weight and a marked reduction in the number of perennials growing in association with rice in plots that had been plowed at the end of the crop compared with those in plots that had been plowed at the start of the next rainy season.

Mahyuddin and Soeharsono (1976) suggested that in rainfed areas, a dryland crop should be grown after rice, instead of merely keeping the soil tilled during the dry season. Such a crop should be either of short duration or drought resistant to survive on residual moisture and end-of-season rainfall. The land preparation for the dryland crop, plus interrow cultivation, plus any within-row weeding should result in almost the same weed control benefits for the crop to be planted at the start of the next rainy season as if no crop had been planted during the dry season and the soil had been continuously tilled.

However, in a trial conducted in five farmers' fields in Pangasinan, Philippines, planting a mung bean crop and weeding it once was generally inferior to maintaining a weed-free fallow during the dry season (Table 2). In three fields, the plots that had been kept weed-free by tillage during the dry season had significantly less weeds than the other plots. In one field, the previous treatments had no effect on the total number of weeds, but in another, there were significantly more weeds in the plots that

Table 2. Effect of previous treatments on the total number of weeds growing in association with dry-seeded rice 5 weeks after seeding in three barrios in Pangasinan, Philippines, 1977.

Previous treatment	Weeds[a] (no.)				
	Pao		Lipit		Caaringayan
	Field I	Field II	Field I	Field II	Field I
Unweeded mung bean	647 b	415 b	192 b	81 a	87 ab
Mung bean - weeded once	469 b	480 b	221 b	66 a	122 bc
Weedy fallow	720 b	347 b	200 b	68 a	71 a
Weed-free fallow	197 a	98 a	48 a	90 a	140 c

[a]In a column, means followed by the same letter are not significantly different at the 5% level.

Table 3. Effect of previous treatments on the number of broadleaf weeds growing in association with, dry-seeded rainfed bunded rice 5 weeks after seeding in three barrios in Pangasinan, Philippines, 1977.

Previous treatment	Broadleaf weeds[a] (no.)				
	Pao		Lipit		Caaringayan
	Field I	Field II	Field I	Field II	Field I
Unweeded mung bean	26 bc	4 ab	6 a	3 ab	5 a
Mung bean - weeded once	18 ab	2 a	9 ab	2 a	8 a
Weedy fallow	11 a	6 ab	17 b	4 ab	9 a
Weed-free fallow	35 c	7 b	11 ab	8 b	49 b

[a]In a column, means followed by the same letter are not significantly different at the 5% level.

had been kept weed-free than in the plots that had not been weeded.

A similar relationship was observed for grasses and sedges in all fields except one. In that field, the greatest number of sedges was observed in the plots that had previously been planted to mung bean but no effect of the previous treatments could be detected in the number of grasses that grew in association with the rice. There tended to be more broadleaf weeds in the plots that were previously maintained weed-free by tillage (Table 3).

There were significantly more *Echinochloa colona* (L.) Link and there tended to be significantly less *Cyperus rotundus* L. and *Cynodon dactylon* (L.) Pers. in the plots that were maintained weed-free by tillage during the dry season.

Weed growth should also be less the sooner planting is done after the rains have started. In a 1977 trial at IRRI in unweeded dry-seeded rice plots, the weed weight increased as the date of planting was delayed from 5 to 27 May. Thus, delayed planting can result in more weeds and probably more difficulties with respect to their control (IRRI 1978).

Crafts (1975) is pessimistic about the successful use of tillage during the dry season for weed control. He wrote that

"when one considers the longevity of buried weed seeds, weed seed dormancy, the possible presence of weeds that produce wind-borne seeds, and the common neglect of weed control along fences, roadsides, and other uncropped areas, it seems that tillage control of weed seed populations in soil is quite futile under most cropping systems."

Use of stale-seedbed technique

It may be possible to reduce weeds in the dry-seeded rice crop by using the stale-seedbed technique. After land preparation, planting is delayed until the first flush of weeds has emerged. The weeds are killed with a nonselective nonresidual herbicide or by a tillage operation that disturbs the soil as little as possible. The crop is then planted with minimum disturbance to the soil. Theoretically, less weeds should grow in association with the rice as most of those in the favorable zone for germination have been killed, and few additional weed seeds are brought into this zone. If the tillage operation that is used to kill the first flush of weeds is too deep, more weed seeds are brought to the soil surface where conditions favorable for germination exist, and no advantage would be gained from the technique. This method has been used successfully for dry-seeded rice establishment in India and Sri Lanka, but results at IRRI were inconclusive. Further research on the technique is needed.

Herbicides

In Japan, a weed control system based on weed ecology, time of weed emergence, and low crop phytotoxicity has been developed for dry-seeded rice (Yamane 1976). The system is described in Table 4. Herbicide combinations control more species of weeds than single herbicide treatments and effective control should last longer than with single treatments. Temporary rice injury manifested as leaf-tip burning, leaf chlorosis, and stunting of plant growth frequently occurs with combination herbicides such as thiobencarb + propanil, butachlor + propanil, and oxadiazon + propanil. The rice usually recovers after 2 or 3 weeks. Increased percentage of productive tillers or increased ratio of grain to straw has been observed, and yields do not appear to have suffered because of the temporary setback.

Ninety percent kill of weeds was achieved in the People's Republic of China when thiobencarb at 1.5 kg/ha combined with propanil at 1.6 kg/ha was applied 7 days after emergence. When this treatment followed a preemergence application of 2.4 kg chlornitrofen/ha on moist soil, 99% weed kill was achieved. Chlornitrofen applied alone was only 80% effective against annual weeds, and had a residual effect for 20 days. For optimum yields,

Table 4. Weed control system for dry-seeded rice in Japan (Yamane 1976).

Weed control system	
Time	Control measure
Before seeding	
>1 month before	Plowing
20-10 days before	Paraquat 0.5-0.8 kg/ha
Just before	Harrowing
After emergence	
0.5-1.5 leaf stage of rice	Propanil 1.8-2.0 kg/ha + thiobencarb 4.0-5.0 kg/ha
3-4 leaf stage of rice	Propanil 1.4-1.6 kg/ha + thiobencarb 2.0-2.5 kg/ha

this treatment must be followed by hand weeding. If hand weeding is omitted, a plot with a 6 t/ha yield potential may yield only 4.5 t/ha (Zandstra et al 1977).

Such high herbicide inputs as those suggested for Japan are probably economically impractical in tropical Asia. But because the labor requirement for manual or hand weeding in dry-seeded rice is high, weed control in this type of rice cultivation is not likely to be successful unless herbicides are used. Considerable research is needed to determine suitable herbicides, and their rates and time of application.

In trials conducted in the Philippines, many of the herbicides are either phytotoxic or fail to give adequate weed control. The most promising compounds for use in dry-seeded rice in the Philippines are thiobencarb, butachlor, butralin, and oxadiazon (Table 5). Compounds such as pendimethalin and dinitramine are erratic in performance -- performing well in one site in 1 year and poorly at another site in the same year or in a different year. Differences in weed population, soil type, and climate could be responsible for the variation.

The time of application of the herbicide is important with respect to weed control and crop damage. When the herbicide is applied immediately after seeding, several weeks may pass before sufficient rain falls to move it into the soil zone where it is needed for activity. During this time, herbicide breakdown may occur and weed control will be less than if rain had fallen immediately after seeding. Heavy rain soon after herbicide application that results in ponding of water on the field for several days is also undesirable. Under this condition, stand reductions due to herbicide damage may occur.

Table 5. Effect of different weed control treatments on yield of dry-seeded rainfed bunded rice. Pangasinan, Philippines, 1977.

Treatment	Herbicide rate (kg a.i./ha)	Yield[a] (t/ha)
Oxadiazon	0.75	3.3 a
Thiobencarb	3.0	3.0 ab
Butralin	2.0	2.7 abc
Butachlor	2.0	2.6 abc
Antor (Hercules 22234)	1.0	2.5 abc
USB 3153	1.5	2.4 abc
Weeded three times	-	1.9 abc
Pendimethalin	2.0	1.8 bc
Dinitramine	1.5	1.6 cd
Untreated	-	0.5 d

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

Application of herbicides on a moist or wet soil and adequate moisture through timely rains or irrigation during the first 3 or 4 weeks after herbicide application are the conditions that seem to effectively activate preemergence herbicides and give prolonged weed control with little crop damage. The possibility of reducing crop damage further by applying herbicides as an early postcrop-emergence treatment should be investigated.

The residual effects of the preemergence herbicides mentioned above are usually too short to provide season-long control. To prevent yield reductions, a follow-up hand weeding about 6 weeks after crop emergence may be needed.

In Indonesia, thiobencarb and prometryne applied together at the rate of 5.5 kg/ha have provided effective weed control in dry-seeded rice (Pane, IRRI, pers. comm.). These herbicides are phytotoxic in the Philippines, however, when applied at the combined rate of 3 kg/ha.

Mian and Rahman (1969) reported that control of *E. crus-galli* and *E. colona* was excellent when propanil was applied as Stam F-34 at 3.2 kg/ha, at the 2- to 3-leaf stage of the weeds 20 days after *aus* rice was grown. The two weed species constituted 86% of the weed population. The yield from the propanil-treated plot was 31% higher than that from the plot that was weeded twice 15 and 30 days after sowing, and the cost was cheaper. Propanil applied as Rogue was more toxic to the crop than Stam F-34 and as a result, yields were lower (Table 6). In the Philippines, results with propanil have been inconsistent. The compound will not control weeds satisfactorily unless a rain-free period of at least 6 hours follows treatment. It is also incompatible with a number of insecticides, particularly the carbamates and organophosphorus compounds.

Table 6. Effect of different weed control treatments on yield of dry-seeded rice (adapted from Mian and Rahman 1969).

Treatment	Rate (kg/ha)	Time of application (DS)[a]	Yield[b]
Propanil (as Stam F-34)	3.2	20	4.4 a
Propanil (as Rogue)	2.6	20	3.8 ab
Planavin	0.7	2	3.8 ab
Hand weeded	-	15 and 30	3.3 b
2,4-D	2.7	35	1.8 c
Prefix	0.7	35	1.4 c
Unweeded	-	-	1.4 c

[a]Days after seeding.

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

Table 7. Effect of herbicides on yield of rainfed wet-seeded rice (adapted from IRRI 1977).

Herbicide[a]	Application		Yield[b]
	Rate (kg/ha)	Time (days after seeding)	(t/ha)
Thiobencarb/2,4-D	1.0/0.5	7	4.4 a
Benzglycereth (WL 29226)	0.75	7	4.2 a
X-52/2,4-D	1.4/0.5	7	4.1 ab
MT-101	2.0	7	3.9 abc
NTN 5810/2,4-D	1.4/0.3	7	3.9 abc
NTN 6867/2,4-D	1.4/0.3	7	3.6 bc
NTN 5810	2.0	7	3.5 c
MCPA/TBA	0.6/0.[illegible]	7	3.4 c
Prodotto D 75	2.0	11	3.4 c
Oxadiazon	1.0	7	2.5 d
Untreated	-	-	0 e

[a]A slant bar indicates that the two herbicides were formulated on the same carrier or mixed together and applied as a single treatment.

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

Wet-seeded rice

Weed control is much more difficult in rainfed lowland rice -- both wet-seeded and transplanted -- than in irrigated lowland rice. More weeds grow in rainfed lowland conditions than in irrigated conditions. In addition, herbicides do not perform as well in the rainfed situation. Failure to control weeds because of lack of water, or herbicide damage to the crop because more than 50% of the rice plant is submerged at or soon after herbicide application, particularly with wet-seeded rice, may be experienced.

At IRRI in 1976 (IRRI 1977), most of the herbicides were toxic to 7-day-old rice seedlings because the trial plots were almost continuously flooded. However, the weeds were adequately controlled and good yields were obtained from plots treated with thiobencarb/2,4-D (Table 7), Benzglycereth, X-52/2,4-D, MT-101, and NTN 5810/2,4-D. In 1977, however, none of the tested herbicides controlled weeds adequately because lack of rain shortly after seeding resulted in an unusually heavy weed infestation.

In another trial, thiobencarb followed by 2,4-D, propanil, and propanil/fenoprop performed consistently well across a range of different water regimes.

Transplanted rice

Weeds were not as great a problem in transplanted rainfed rice (the transplanted *aman* crop) as they were in dry-seeded rice (the broadcast *aus* crop) in Bangladesh (Mian and Gaffer 1968). However,

Table 8. Effect of herbicides on yield of transplanted rainfed rice, IRRI, 1977 (adapted from IRRI 1978).

Treatment	Application		Yield[b] (t/ha)
	Rate (kg/ha)	Time (days after transplanting)	
R-40244	1.0	4	2.4 a
Hand weeded once	-	25	2.2 a
Fluridone	0.08	4	2.2 a
RH 6201	0.96	10	2.2 a
CGA 26423	1.0	4	2.1 a
Oxyfluorfen	0.25	4	1.9 a
Thiobencarb/2,4-D[a]	1.0/0.5	4	1.4 ab
Untreated	-	-	0.5 bc
HOE 23408	1.0	4	0 c

[a]The slant bar indicates that the herbicides were formulated or mixed together and applied as a single treatment.

[b]Means followed by the same letter are not significantly different at the 5% level.

yield reductions due to weeds can be substantial in the transplanted *aman* crop if they are not controlled adequately.

De Datta and Bernasor (1977) reviewed the subject of weed control in rainfed transplanted rice. They reported that herbicides such as nitrofen, butachlor, NTN 5810/2,4-D, EXP 3316, and Prodotto D 75 appeared outstanding for weed control under these conditions. Other compounds that performed well in 1977 are given in Table 8. Yields from the best of the herbicide treatments were not superior to those from the plot that was

weeded once. To be acceptable to the farmers, a herbicide must cost no more than what would be spent for one hand weeding. Inexpensive herbicides such as 2,4-D do not perform well when applied at preemergence of rainfed transplanted rice because the water supply may be unreliable.

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Diseases of lowland rainfed rice

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Limited research has been focused on rainfed lowland rice and its disease problems. Because of the different growing seasons and cultural practices, the disease patterns in different countries vary.

- In most of tropical Asia, the wet season is from May to October (Oka 1975). The extended duration of cloudy and humid conditions affects the incidence and severity of foliar diseases.

- Planting practices may result in dense plant stands, enhancing the development of some diseases. If the stubble of the previous crop is not totally decomposed when the rainfed crop is planted, diseased stubble may serve as a potential inoculum source.

- Flooding and drought are commonly associated with rainfed rice. The alternate wetting and drying of fields may have either harmful or beneficial effects on disease development.

- If susceptible varieties are planted, increasing the level of soil fertility increases disease incidence and severity, and improved crop management may enhance disease problems. On the other hand, it is not known whether low soil fertility levels or poor crop management, which are frequently associated with rainfed rice, reduces the severity or incidence of some diseases.

The lack of information on diseases and their epidemics in rainfed lowlands makes it difficult to formulate strategies for their control. We attempt to compile the available information on diseases of lowland rainfed rice. Most of the rice diseases reported here are described in detail in books by Padwick (1950) and Ou (1972).

TYPES OF DISEASES

Diseases of rice grown in rainfed lowland fields are similar to those of irrigated rice and have been described by Ou et al

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(1975). The diseases may be manifested on seedlings, foliage, sheaths, roots, culms, panicles, or the entire plants. They may be caused by fungi, bacteria, viruses, or nematodes.

Seedling diseases such as blight, seed-rot, or damping-off may be observed in early growth stages in rainfed fields. Mew (1977) observed leaf scald, neck blast, udbatta, stack burn, bacterial blight, some grain spots, and brown spot on rainfed rice in southern and southeastern India and severe tungro infection in rainfed rice in Thailand. Whether the diseases are more severe in rainfed than in irrigated rice remains to be confirmed.

Of the nematode diseases, ufra (stem nematode), white tip, and cyst nematode have been observed on rainfed lowland rice on the Indian subcontinent as well as in Africa (Bidaux 1973, Van Nieuwenhuyzan 1973).

MAGNITUDE OF THE DISEASES

Rice blast, caused by *Pyricularia oryzae* is considered one of the most important diseases of rainfed rice in many countries. Neck blast affects photoperiod-sensitive transplanted varieties of rainfed lowland rice in Bangladesh, India, and Nepal during the later growth stages. Mew (1977) attributed neck blast incidence to the cool temperature, heavy dew formation, and prolonged dew period during later growth stages. Continuous rainfall during early crop growth has been observed to reduce leaf blast incidence (Chakrabarti 1977).

Brown spot, caused by *Cochliobolus miyabeanus*, is especially severe in India and Bangladesh on kharif or transplanted aman rice (Chakrabarti 1977, IRRI 1977). Other fungal diseases, and their causal agents, that affect lowland rainfed rice are leaf scald, *Rhynchosporium oryzae*, sheath blight, *Thanatephorus cucumeris*; and sheath rot, *Acrocylindrium oryzae*. Diseases associated with rainfed rice are narrow brown spot, kernel smut, leaf smut, udbatta, and stem rot. They have been commonly observed by researchers, but not studied in detail.

Bacterial blight may be as important in rainfed lowland rice as in irrigated rice. In a recent survey, farmers and researchers considered bacterial blight a major limiting factor in a medium-deep rainfed rice area in the eastern states of India (IRRI 1977, Mew 1977).

Continuous heavy rainfall and poor crop management may help suppress the vectors of such virus diseases of rice as

tungro and grassy stunt (Kim 1969, Lowe 1970, Lowe and Nandi 1972, and Kisimoto and Dyck 1976). Detailed studies of the vectors and the virus diseases are lacking in lowland rainfed rice.

A similar statement can be made for rice nematode problems, even though their incidence in some African and Asian rice-growing areas has increased (Van Nieuwenhuyzan 1973, Frohlich and Rodewald 1973, Delassus 1973).

MANAGEMENT EFFORTS AND PROBABLE FUTURE STRATEGIES

At IRRI and in many national rice improvement programs, sources of resistance to many of the major diseases have been identified and are being used in breeding programs (Table 1, Ou et al 1975). The major breeding effort, however, strongly emphasizes the curtailment of disease outbreaks or epidemics. Scientists should be alert to the so-called *minor* or *unnoticed diseases*, and those that are endemic to specific rainfed rice regions.

From the plant pathologist's point of view, information on rainfed lowland rice diseases is lacking. Although the diseases of rainfed rice may not differ from those of irrigated

Table 1. Sources of resistance to major rice diseases.

Disease	Sources
Bacterial blight	DZ192, BJ1, TKM6, Chinsura Boro II, DA29, DV85, Nagkayat, Malagkit Sungsong, Zenith, Sigadis, Remadja, W1263
Blast	Carreon, Tetep, Dawn, Mamoriaka, Colombia 1, Ram Tulasi, Kataktara, DA2, Zenith, Tadukan, C46-15.
Brown spot	Dakar Nagra, Nagra 41-14, Patnai 23, Kalma 219, Ch13, Ch45, T141, T498-2A, BAM10, Hainan 217, Chiu Tiu Chiu, Norin 17, CI9515, etc.
Sheath blight	Laka, Ta-poo-Cho-Z, 46 Palman, Dudsar, NC678, Bahagia, Mehran, Pankaj, DZ192, Dular, Hashikalmi, Ctg1206, etc.
Tungro	Basmati 370, Basmati 37, Bengawan, Ram Tulasi, Raj mundal Baran, Peta, Pankhari 203, PTB18, H4, H21, TKM6, Sigadis, Latisail, DA29, Indrasail Habiganj Duamon #8, JC170, Mala, Kataribhog, Kalijeera (fifty other lines by Anjanayulu 1977)

rice, disease patterns of the same diseases may vary from region to region. The distinct difference in growing seasons and, thus, the different agroclimatic conditions, undoubtedly influence the development of epidemics.

Because the major effort in resistance breeding across regions is basically concerned with the *major diseases*, outbreaks or epidemics of *minor diseases*, *unnoticed diseases*, or *diseases of endemic nature* may also occur. As rice improvement programs place more emphasis on lowland rainfed areas, remember that the minor diseases today could be the major ones tomorrow. At the moment, we cannot predict or estimate their occurrence and economic impact. Therefore, we urge fellow pathologists to be watchful and to exert their research efforts on both the major and minor diseases of rainfed rice -- an area of rice pathology that has been neglected in the past.

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Cropping Patterns Involving Rainfed Rice

Land and climate in relation to cropping patterns

R. A. MORRIS and H. G. ZANDSTRA

Knowledge of cropping pattern determinants can be used to select research areas with unexploited production potentials, to design improved cropping patterns and locally adapted crop management components, and to specify concisely the domain of adaptation of tested cropping patterns. For these reasons, soil and climatic determinants, as one component of the cropping systems research method, have been studied in relation to cropping patterns.

A rainfall pattern classification based on typical monthly crop water requirements (Table 1) was the product of an early effort to identify and classify determinants for rice-based cropping systems (IRRI 1974, Oldeman and Suardi 1976, IRRI 1977). The first level of the classification denotes the length of the dry season -- the number of consecutive months with less than 100 mm rain. The second level denotes the length of the wet season -- the number of consecutive months with more than 200 mm rain. Additional levels allow the insertion of information about other rainfall pattern characteristics such as rapid transition from wet to dry months. The criteria of 100 mm and 200 mm were selected on the basis of the monthly water requirements of rice and other field crops. The classification provides general information on average durations of rain available to sustain crops. An earlier version of it was used to develop agroclimatic maps for the Philippines, Bangladesh, and the islands of Java and Sulawesi in Indonesia.

This wet-month, dry-month rainfall classification loosely defines agricultural production potentials for rainfed conditions, but because it is based on monthly means, it masks variability in the distribution of rainfall from season to season and during the season. Furthermore, it suggests nothing about how soil-related factors (or, in more general terms, land-related factors) modify the rate of accumulation and the duration of water in rice paddies. Knowledge of rainfall variability and land-induced modifications of paddy water regimes is important to the full understanding of the farmers' present cropping strategies, and of course to research for improved technology to help the farmer improve his cropping patterns and associated management strategies.

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Table 1. Rainfall classification system of the Philippines.

Climate type	Dry and wet months[a]
	< 2 DM and
1.1	> 9 WM
1.2	7-9 WM
1.3	5-6 WM
1.4	3-4 WM
1.5	< 3 WM
	2-4 DM and
2.1	> 9 WM
2.2	7-9 WM
2.3	5-6 WM
2.4	3-4 WM
2.5	< 3 WM
	5-6 DM and
3.1 (not possible)	> 9 WM
3.2	7-9 WM
3.3	5-6 WM
3.4	3-4 WM
3.5	< 3 WM
	> 6 DM and
4.1 (not possible)	> 9 WM
4.2 (not possible)	7-9 WM
4.3	5-6 WM
4.4	3-4 WM
4.5	< 3 WM

[a]DM = consecutive dry months with 100 mm rain, WM = consecutive wet months with 200 mm rain.

In this paper, we present the partial results of an analysis of the onset and termination of wet-season rainfall, based on historical daily rainfall records, and an analysis of land-related factors that modify paddy water regimes. The analyses pertain to two cooperative Philippine Bureau of Plant Industry (BPI)-International Rice Research Institute (IRRI) cropping systems project sites, both of which are now in their fourth year of operation. The sites are in Manaoag, Pangasinan province and in Oton-Tigbauan, Iloilo province. Salient physical characteristics of the sites are in Table 2. Although the sites include both rainfed and partially irrigated sectors, the data and discussion we present refer only to rainfed fields.

RAINFALL ONSET AND TERMINATION

For a rainfed crop, farmers' cropping strategies are undoubtedly influenced by the variability they have experienced in the onset and termination of the wet seasons. To develop more efficient

Table 2. General physical characteristics of the Pangasinan and Iloilo cropping systems sites.

	Pangasinan	Iloilo
Rainfall - months with more than 200 mm	3-4	5-6
- months with less than 100 mm	5-6	2-4
- type designation	3.4	2.3
Great soil group	Eutropepts	Pelluderts, Eutropepts, Tropfluvents
Dominant surface soil textures	Clay loam	Clays, silty clays
Dominant soil pH range	6.9 - 7.8	5.0 - 6.7
Dominant soil organic matter range (%)	1.5 - 2.6	2.0 - 3.0
Land system classes	a) Flat plains of a river terrace subsystem	a) Interhill miniplains and lower colluvial slopes of an alluvio-colluvial subsystem
	b) Levees of an alluvial subsystem	b) Flat plains of a river terrace subsystem

early crop establishment methods and to determine the risk associated with cropping patterns that include a second rainfed rice crop, the variability in onset and termination of rainfall should be better understood.

Using rainfall data from Tigbauan (Iloilo) and Dagupan (Pangasinan), variation in onset was examined on the basis of rainfall accumulations summed forward daily for each year starting at 1 April; variation in termination was examined on the basis of rainfall accumulations summed backward daily for each year from 31 March.[1] For each year, several accumulation criteria were used to investigate the onset of the wet season: 25, 50, 75, 100, 125, and 200 mm. The lower values (25 to 75 mm) correspond to the approximate amounts of rainfall necessary to obtain emergence and early growth of dry-seeded rice (Furoc et al 1978). The highest value (200 mm) corresponds to the approximate amounts needed to initiate puddling. The dates when the accumulations were reached for each year between 1950 and 1970 for Tigbauan, and between 1949 and 1970 for Dagupan, were ranked from earliest to latest to obtain the empirical cumulative distributions presented on the left side of Figures 1 and 2. The average onset dates based on these criteria are given

[1] As a follow-up comparison, the onset and termination dates determined by accumulations of weekly totals differed only slightly from those determined on the basis of daily precipitation (Appendix Table 1). Therefore weekly records can be used to determine the distributions, which will reduce the computational workload.

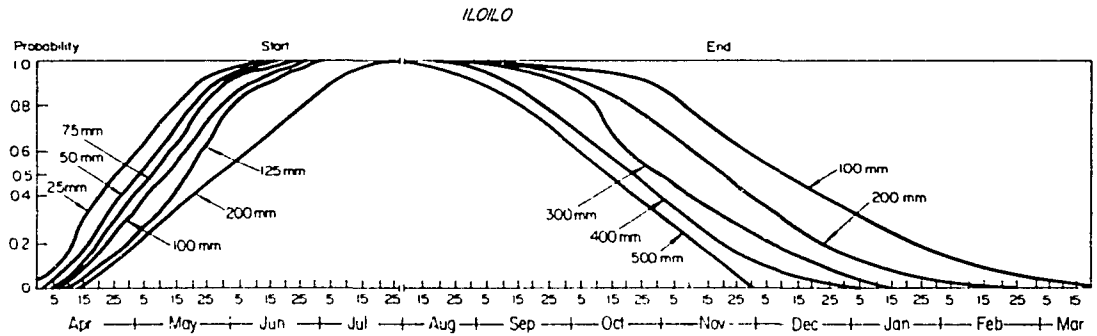
Table 3. Average dates of onset and termination of rainfall in the growing season.

Rainfall (mm)	Pangasinan	Iloilo
Onset[a]		
25	15 Apr. (11)	2 May (21)
50	24 Apr. (14)	8 May (19)
75	27 Apr. (14)	12 May (20)
100	4 May (13)	17 May (21)
125	7 May (14)	22 May (20)
200	18 May (12)	3 June (27)
Termination		
500	4 Sept. (19)	9 Oct. (29)
400	12 Sept. (16)	20 Oct. (30)
300	23 Sept. (17)	2 Nov. (32)
200	3 Oct. (17)	17 Nov. (35)
100	15 Nov. (55)	10 Dec. (42)

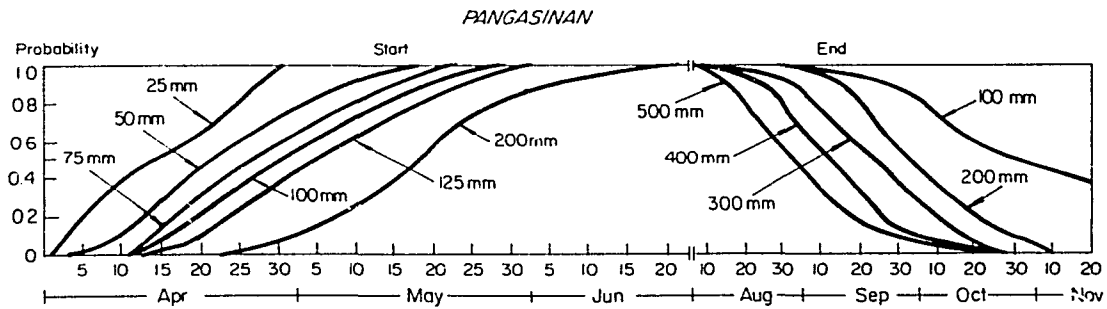
[a] Average date on which indicated rainfall has been received. Figures in parentheses are standard deviation.

in Table 3. Figures 1 and 2 and the higher standard deviations associated with average dates in Table 3 show that the onset of rain is more variable in Iloilo than in Pangasinan. The expected onset is from 9 days (at 25 mm) to 15 days (at 200 mm) earlier in Pangasinan at the 50% probability level. At the 80% probability level, the difference ranged from 20 days (at 25 mm) to 24 days (at 200 mm) earlier (Zandstra and Maligalig 1978).

Several accumulation criteria were also used to investigate the wet season termination: 100, 200, 300, 400, and 500 mm. The lowest value (100 mm) would normally represent the date after which only light sporadic rains would fall late in the transition period between rainy and dry season or during the dry season, and the higher values (500 to 300 mm) represent dates after which sufficient rain would be expected to sustain a second rice or other short-duration field crop, assuming a fully charged profile at planting. Note that standard deviations were greater for the 100-mm accumulations than for the higher valued termination criteria.



1. Cumulative probabilities of having received a given amount of rain on a certain date (start) and of still receiving a certain amount of rain after a given date (end) for the Iloilo rainy season (Tigbauan rainfall records 1950–70).



2. Cumulative probabilities of having received a given amount of rain on a certain date (start) and of still receiving a certain amount of rain after a given date (end) for the Pangasinan rainy season (Dagupan rainfall records 1949–70).

A transplanted second rice crop can be used as an example to demonstrate the application of the criteria to cropping pattern design. If it is assumed that 360 mm of water is used for evapotranspiration of an 80-day rice crop, 100 mm is used during land preparation, and 50 to 100 mm of extractable water remains in the profile before land preparation, water requirements to be met by rainfall are in the vicinity of 400 mm at low seepage and percolation levels (0.0 to 0.5 mm/day in low landscape positions or fields over shallow water tables), and 500 mm at moderate levels of seepage and percolation (1.0 to 2.0 mm/day in intermediate landscape positions, or fields over deep water tables)(Zandstra and Maligalig 1978).

Average termination dates based on the four criteria are presented in Table 3. Empirical cumulative distributions are presented on the right side of Figures 1 and 2. Excluding the 100 mm criterion, average termination dates in Iloilo are about 5 to 7 weeks later than those in Pangasinan. The standard deviations associated with the different criteria, except for 100 mm (Table 3), and the cumulative distributions (Fig. 1, 2) indicate that Iloilo experiences greater variation in termination dates than Pangasinan.

With the use of the empirical distributions in Figures 1 and 2, the dates determined by each criterion at 20%, 50%, and 80%

Table 4. Dates associated with the selected probabilities of received and remaining rainfall in Iloilo and Pangasinan.

Received rainfall (mm)	Onset[a] P (0.2)	Onset[a] P (0.5)[b]	Onset[a] P (0.8)	Remaining rainfall (mm)	Termination[c] P (0.2)[b]	Termination[c] P (0.8)
			Pangasinan			
25	5 April	15 April	26 April	500	3 Sept.	20 Aug.
50	13 April	21 April	5 May	450	12 Sept.	30 Aug.
75	17 April	27 April	11 May	400	24 Sept.	10 Sept.
100	19 April	1 May	15 May	200	3 Oct.	20 Sept.
125	24 April	7 May	17 May	125	22 Oct.	4 Oct.
200	7 May	19 May	29 May			
			Iloilo			
25	12 April	24 April	14 May	500	12 Oct.	24 Sept.
50	16 April	2 May	19 May	400	22 Oct.	30 Sept.
75	19 April	9 May	25 May	300	2 Nov.	9 Oct.
100	23 April	17 May	30 May	200	15 Nov.	21 Oct.
125	30 April	19 May	2 June	100	10 Dec.	12 Nov.
200	3 May	3 June	23 June			

[a] Date on which indicated rainfall has been received.

[b] Expected date of onset or termination based on empirical cumulative frequency distribution.

[c] Date after which indicated rainfall amount has been received.

probabilities for onset and at 50% and 80% probabilities for termination are presented in Table 4. On the basis of the dates, 75 mm of rain would fall by 9 May in Iloilo and 27 April in Pangasinan in 50% of the years. Assuming 75 mm will be sufficient to obtain emergence and sustain early growth, farmers should dry-seed before those dates to derive greatest benefit from early rainfall in 1 year out of 2. To derive this benefit in 4 years out of 5, they should seed before 19 April in Iloilo and 17 April in Pangasinan. To successfully grow a transplanted rice crop with 80-day field duration in 4 out of 5 years, the crop should be planted before 24 September in Iloilo and 20 August in Pangasinan assuming moderate (1.0 to 2.0 mm/day) seepage and percolation losses so that only 500 mm of rainfall would be required. With low seepage and percolation losses (0.0 to 0.5 mm/day), and for a requirement of 400 mm, the corresponding dates would be 30 September and 24 August.

As an extension of the procedures illustrated in the preceding paragraph, the expected days available for the first crop, given 400 or 500 mm of rainfall remaining for the second crop, were determined for 50% and 80% probabilities (Table 5). The total expected growth duration available for both crops, assuming the first crop's emergence as dry-seeded rice at 75 mm accumulation and the second crop's termination as a transplanted crop with only 100 mm expected after harvest, were also determined (Table 6).[2/] The table shows that the Iloilo

Table 5. Expected days available for growth of a direct-seeded rainfed first rice crop, given 400 mm and 500 mm of rainfall remaining for a transplanted second crop in Pangasinan and Iloilo.

Location	Probability	Expected date of 75 mm accumulation	Expected remaining rainfall (mm)	Date for planting second crop	Days (no.) available for growth
Pangasinan	0.8	11 May	400	30 Aug.	111
"	0.8	11 May	500	20 Aug.	101
"	0.5	27 Apr.	400	12 Sept.	138
"	0.5	27 Apr.	500	3 Sept.	129
Iloilo	0.8	25 May	400	30 Sept.	128
"	0.8	25 May	500	24 Sept.	122
"	0.5	9 May	400	22 Oct.	166
"	0.5	9 May	500	12 Oct.	156

Table 6. Total days available for first and second rainfed rice crops.

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

environment should be more favorable than the Pangasinan environment for a two-rice cropping sequence. In fact, trials in farmers' rainfed fields in the cropping systems programs have shown that many more farmers planted a second rice crop in Iloilo than in Pangasinan. However, the Pangasinan farmers used the dry-seeded method, while the Iloilo farmers opted for the wet-seeded method. The results of the trials will be discussed in the section on land-related determinants.

MODIFICATIONS OF FIELD FLOODING REGIMES BY LAND-RELATED FACTORS

The previous section showed how the variability of wet-season onset and termination may affect cropping strategies and the duration of the growth period available for rainfed rice production. Within a given locality, however, land-related factors alter the net water supply by influencing the rate of surface and subsurface drainage into and out of a field. Field flooding regimes can be shortened or lengthened by natural and farmer-induced land drainage factors, relative to regimes that are the *normal* expression of a given rainfall distribution. The same

[2] In constructing the tables, it was assumed that the onset and termination dates in each year are independent. Simple correlations on two pairs of criteria (100 mm and 200 mm), taken at both sites indicate the dates are unrelated, except for the 100 mm pair at Dagupan, for which a moderate negative correlation (–0.49*) was obtained. Therefore, the Pangasinan durations may be overestimated.

land-related factors that shorten or lengthen the normal regimes are also factors that affect the domain of adaptation of rice-based cropping patterns.

Data from cropping systems research in Pangasinan and Iloilo have led to the hypothesis that several factors play roles in modifying flooding regimes in rice fields. The factors are landscape position, water table depth, soil texture, and water source. Because the special focus of this conference is rainfed rice culture, we will concentrate on rainfed aspects. Details of analytical methods and a more complete discussion of Pangasinan and Iloilo analyses can be found in Morris et al (1978).

In the analysis of land-related factor effects, a flooded-status-day (FSD) concept has been used. It is basically the reverse of the stress day (SD) concept used by IRRI scientists in other studies (Wickham 1973, Wickham 1977, IRRI 1977). There are two important differences in the concepts. A FSD is any day during which there is standing water on the field; a SD is any day beyond 3 successive days during which there is no standing water on the field. The other difference lies in the application of the two concepts. For this analysis, FSD were counted daily over about a 6-month period, whether or not a crop was on the field; SD were counted only during the period a crop was actually being grown. In practice, FSD and SD for the same period are highly correlated. Such characteristics as the rapidity of FSD increase at the beginning of the season, the reliability of FSD over the season, and the rate of FSD decline at the end of the season are important factors that affect pattern performance and thereby influence the domain of pattern adaptation.

Pangasinan:

To place designed cropping patterns into suitable environments, cropping systems researchers divided the Pangasinan site into several environmental complexes (IRRI 1977, Herrera et al 1975, Gines et al 1977). The major division between complexes was based on depth of water table. Further divisions were based on differences in soil texture, water source, and relative elevation. Relative elevation refers to the difference between fields located in waterways (i.e. broad, natural occurring drainageways) and in non-waterways.

The hypothesis that the environmental complexes affect cropping pattern performance is implicit. For an evaluation of land-related factors, changes in FSD were examined in data collected in crop year 1976-77. The effects of land-related

factors were examined over the season to understand better the role of each factor as the season progresses.

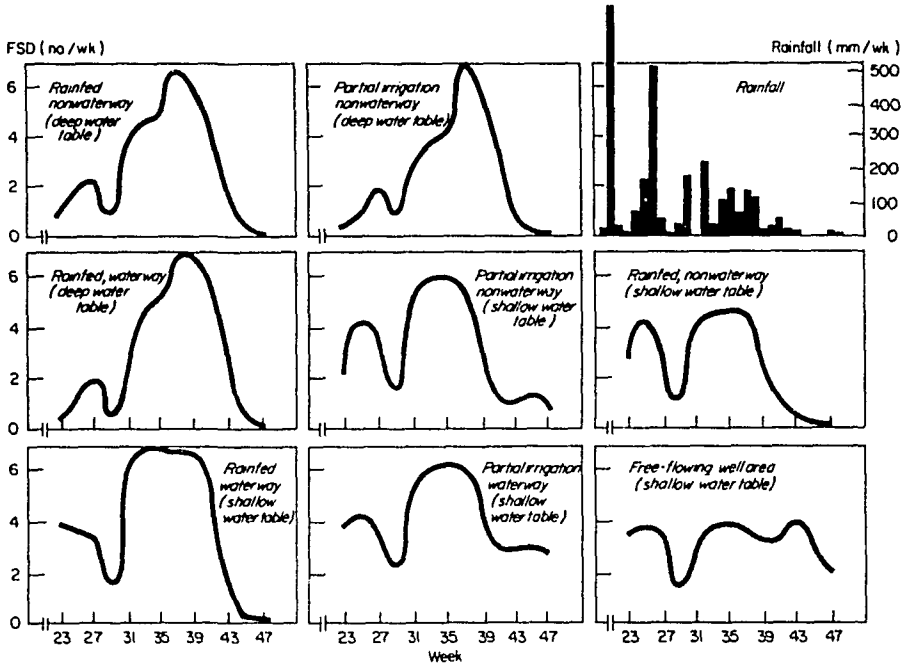
For the Pangasinan data, computations were made using the number of FSD observed at 3-week intervals as 13 sets of dependent variables for a model containing land-related classification factors as independent variables. The 13 dependent variables were obtained by summing the number of observed FSD in weeks 1 to 3, in weeks 3 to 5, in weeks 5 to 7, etc. starting with 26 May, 1976. The 1-week overlap was incorporated to reduce the effect of farmers' field operations, such as drainage before harvesting, on the number of FSD observed.

The land-related factors that influenced FSD regimes were water table depth class, water source class within water table depth class, and relative elevation within the water table depth and water source classes. The four rainfed diagrams in Figure 3 contain estimated FSD frequencies for land units for a 27-week period. To join the points, smooth curves were drawn through the 13 FSD estimates for each classification. The diagrams show that water table depth was the major factor differentiating land units.

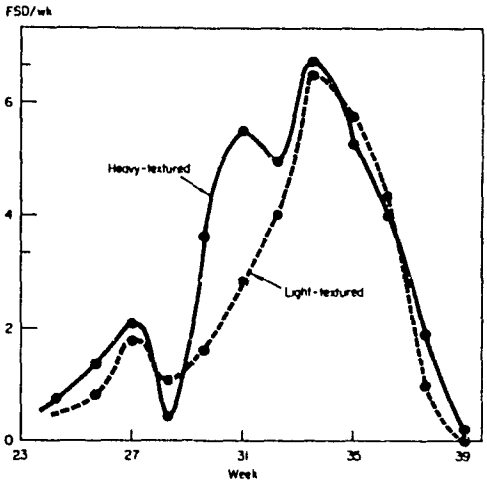
The two major differences between rainfed shallow and deep water table land units, as characterized by the FSD regimes, were an earlier increase in FSD, and a broader interval of peak FSD frequencies in the shallow water table units. In the same units, much less rainfall was required to recharge the subsoil, and the saturated substrata reduced deep percolation losses. It is apparent that substantial early rainfall was used to recharge the deep water table units. Soils in the deep water table sector are very permeable, and rainfall rapidly infiltrates and percolates to deep soil layers.

Contrary to the hypothesis, the FSD regimes of fields located within relative depressions or waterways did not differ markedly in the deep water table sector. Differences, however, were noted in the shallow water table sector.

Soil texture has also been postulated as a factor modifying FSD regimes. However, early models indicated that texture was less important overall than relative elevation differences. Soil texture was therefore abandoned as an explanatory variable so that model degrees of freedom would be reduced. Composite FSD estimates from an early model, which included the textural class of the second soil horizon as an independent variable for the land unit containing the greatest number of observations, are presented in Figure 4. The difference between estimates



3. Weekly total rainfall and estimated flooded status day (FSD) regimes for 8 Pangasinan land units, weeks 19 to 47, 1976.



4. Estimated flooded status day (FSD) regimes for heavy-textured and light-textured, rainfed, nonwaterway, deep water table land units, Pangasinan, Philippines, weeks 23 to 39, 1976.

indicates that soil texture altered the regimes in favor of heavy-textured soils but the difference occurred during the rise of maximum FSD frequency.

Over the period examined, changes in model sum of squares, total sum of squares, and intercept values reflected the influence of rainfall distribution on FSD, especially after the land units had been recharged. The model indicated that water table depth was the dominant factor explaining the difference between land units, and its importance was greatest during the first three-quarters of the period examined.

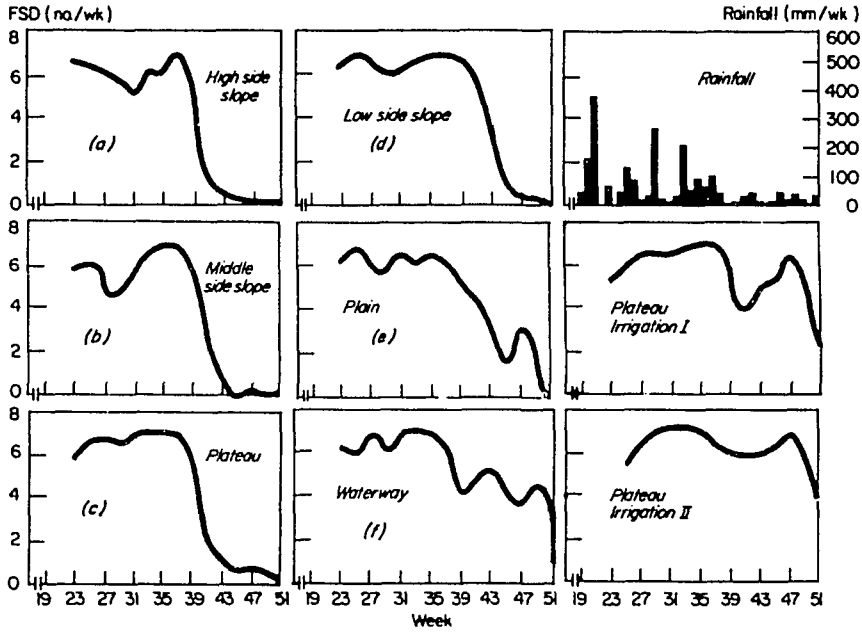
Iloilo

Statements of the expected effect of landscape and soil factors on cropping pattern adaptation have been clearly expressed for the Iloilo site (IRRI 1976, Magbanua et al 1977). The procedures used to analyze the Iloilo FSD data were the same as those applied to the Pangasinan data. The period of Iloilo data collection was, however, slightly longer and the factors examined were, of course, appropriate to Iloilo land systems.

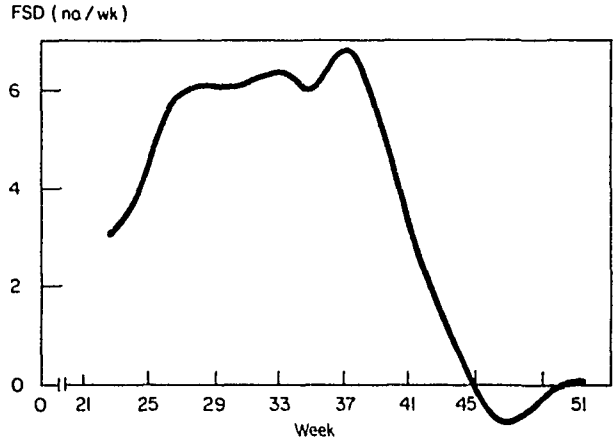
Although rainfall has a major influence on FSD regimes, landscape class modified FSD regimes on heavy-textured fields (Fig. 5 a-f). Relative elevations within a landscape class, as indicated by low, middle and high classes, were important only for side slopes. Smooth curves have been drawn through the 15 estimates for each unit. For the rainfed units, a trend toward decreased FSD frequency, when progressing from waterways to high side slopes, was apparent. The major differences between units occurred after the 37th week, reflecting a greater decline in frequency for the higher landscape positions. There was little difference in FSD regimes between the medium and high side slope and between the plateau and low side slopes.

For the Iloilo rainfed units, all FSD estimates began at high frequencies because of heavy rainfall that preceded the start of data recording. In the lower landscape positions, the extension of FSD beyond the end of the peak rainy periods arose through late surface-flow and interflow from higher elevations.

Composite FSD frequency estimates from four rainfed fields located on plateaus having medium- or light-textured soils are presented in Figure 6. Comparing Figure 6 with the rainfed plateau diagram in Figure 5 suggests that a medium- or light-textured second soil horizon hampers the formation of a perched water table. Pseudo-gley soil profiles indicate that perched water table effect is common in Iloilo.



5. Weekly total rainfall and estimated flooded status day (FSD) regimes for 8 heavy-textured rainfed and irrigated Iloilo land units, weeks 19 to 51, 1976.



6. Estimated flooded status day (FSD) regimes for rainfed medium- and light-textured plateau land units, Iloilo, Philippines, weeks 21 to 51, 1976.

As in the Pangasinan analysis, model sum of squares, total sum of squares, and intercept values reflected the dominance of rainfall at the peak of the wet season. The role of landscape was moderately important over all 15 periods. The effect of relative elevation within side slope positions was moderately important during a few days toward the middle of the wet season and again at the end of the season. The effect of texture was important during the first four periods, as medium- and light-textured soils were being recharged, whereas perched water tables formed on the heavy-textured soils.

PATTERN PRODUCTION AND FARMERS' RESPONSES

Two questions naturally arise:

1. What are the implications of these analyses for crop performance?

2. What are the implications for farmers' cropping strategies?

In the research methods employed at the Pangasinan and Iloilo sites, the management decisions made by farmer-cooperators under field situations are used, together with crop performance data, to evaluate cropping pattern performance and effects of environment. Because the two projects are primarily research-methods oriented, changes other than in rainfall distribution (varieties, fertilizer level, etc.) that have occurred during the 2 years make interpretation more difficult. However, differences in farmer response and crop performance obtained were sufficient to support current interpretations of the rainfall and land-factor analyses.

Rainfed rice yield data, summarized from the Pangasinan and Iloilo cropping systems project for crop years (CY) 1976-77 and 1977-78, are presented in Tables 7, 8, and 9 to aid in the discussion that follows.

The rainfed rice yield averages in Table 7 show higher yield potentials in Iloilo than in Pangasinan. This is believed to be a result of more reliable field flooding regimes in Iloilo, although other factors such as differences in inherent soil fertility may also be operating.

Pangasinan

In Pangasinan, most CY 76-77 first rice crops were transplanted because of farmer skepticism about dry seeding.

Table 7. Average yields of single- and double-cropped rainfed rice, Pangasinan and Iloilo cropping systems sites, crop year 1976-77 and crop year 1977-78.

Crop year	Yield[a] (t/ha)			
	Pangasinan		Iloilo	
	Single	Double	Single	Double
1976-77	3.3 (28)	4.7 + 2.8 (5)	5.3 (7)	5.3 + 2.3 (41)
1977-78	3.7 (24)	5.1 + 1.9 (21)	4.8 (69)	5.9 + 1.6 (25)

[a] Figures in parentheses are number of observations.

Table 8. Average yields of single- and double-cropped rice for Pangasinan, crop years 1976-77 and 1977-78, by water table depth.[a]

Crop year	Yield (t/ha)			
	Deep water table		Shallow water table	
	Single	Double	Single	Double
1976-77	3.6 (16)	4.7 + 2.8 (5)	3.1 (12)	None
1977-78	4.1 (15)	5.9 + 1.7 (8)	3.6 (9)	4.9 + 2.1 (13)

[a] Figures in parentheses are number of observations.

Table 9. Average yields of single- and double-cropped rice for Iloilo, crop years 1976-77 and 1977-78, by landscape position.[a]

Crop year	Yield (t/ha)					
	Side slope		Plateau		Plain & waterways	
	Single	Double	Single	Double	Single	Double
1976-77	5.1 (5)	5.0 + 1.7 (10)	5.2 (2)	5.3 + 2.3 (30)	4.4 (1)	5.5 + 3.4 (4)
1977-78	4.6 (28)	6.9 + 1.0 (2)	5.2 (27)	5.8 + 0 (1)	4.5 (10)	5.8 + 1.8 (22)

[a] Figures in parentheses are number of observations.

Patterns were started later than possible, and only 15% of the farmer-cooperators on rainfed fields attempted a second rice crop. After overcoming skepticism for dry seeding, 47% of the farmer-cooperators of rainfed fields attempted a second rice crop in CY 77-78, mainly because dry seeding permitted the first crop to be harvested early enough to transplant a second one. In both years, all farmer-cooperators who planted two rainfed rice crops used dry seeding to establish the first crop. Compared with farmers in the deep water table sector, a larger portion of the farmer-cooperators in the shallow water table sector attempted a second drop. The observation suggests that farmers perceived the shallow water sector to be more suitable for double rainfed rice crops.

In the shallow water table sector, all of the CY 77-78 double rice crops were grown in waterway positions. The slightly higher yields of the CY 77-78 second crop confirmed the hypothesis that the shallow water table sector is more adapted for growing two rainfed rice crops (Table 8). However, lower single rice crop and first rice crop yields were obtained in the shallow water table sector than in the deep water table sector. The lower yields may have been caused by deeper than optimum water at the peak of the wet season, but the association has not yet been documented.

The Pangasinan data suggest that in rainfall regimes where only 4 months with greater than 200 mm of rainfall are expected, prospects for growing 2 rainfed rice crops will be enhanced by dry-seeding the first crop and by selecting landscape positions that will lengthen field flooding beyond the normal duration. For both years, the estimated growing season durations were slightly more than 170 days, assuming 75 mm for onset and 100 mm for termination (Table 10). It is unlikely, however, that a second rainfed crop will be consistently high yielding in localities with rainfall patterns similar to those of Pangasinan.

Iloilo

From the Iloilo data, the contrast between years is obvious from the average second crop yield (Table 7). CY 76-77 as determined by 75 mm onset and 100 mm termination dates, was rather long, but CY 77-78 was extremely short (Table 10). In CY 76-77, 91% of the rainfed farmer-cooperators grew two rice crops, but only 27% did in CY 77-78. On all landscape positions, second crop yields averaged 2.3 in CY 76-77 and 1.6 t/ha, in CY 77-78. But because of changes in water regime, the percentage of farmers growing second crops on each landscape position, as well as average yields, changed between years.

Table 10. Growing season duration for Pangasinan and Iloilo, based on the criteria 75 mm for onset and 100 mm for termination, crop years 1976-77 and 1977-78.

Crop year	Duration (days)	
	Pangasinan	Iloilo
1976-77	173	225
1977-78	171	151

The majority of Iloilo farmer-cooperators broadcast their first rice crop on puddled soil; dry seeding has not worked well because of difficulties in preparing the heavy clay soils when dry. Most farmer-cooperators also preferred the labor-saving broadcast method to transplanting for establishing their second rice crop, despite the greater probability that a broadcast second crop would incur late season drought stress.[3]

The Iloilo results suggest that high yielding first rice crops or single rice crops can be expected on all landscape positions, under wet seasons that are either much longer or much shorter than average. But only the lower landscape units (plains and waterways) appear capable of sustaining second crop yields when an abbreviated wet season is experienced. In CY 77-78, most farmers in higher land units realized that they would experience low yields or failures and did not attempt a second crop. A few accepted the risk and obtained no yield (for the yields of farmers who planted a crop but experienced failure, 0 was entered in the computation of means in Tables 7, 8, and 9).

In typical years, it appears that most Iloilo farmers in low landscape positions can successfully grow second rice crops using wet broadcast methods for one or both crops. In most years farmers in intermediate landscape positions may successfully grow second crops if they dry-seed the first rice crop and transplant the second, which would lead to earlier harvests of both crops.

[3]This behavior may be risk avoiding – the high, early cost of transplanting is offset by a lower and later cost of weeding, which allows farmers to condition their inputs to the quality of the crop at that time.

CONCLUSIONS

It is apparent that the onset and termination of the growing season are variable within a locality, and between localities. The variability in both dates was much greater in Iloilo than in Pangasinan. Differences in variability undoubtedly lead to differences in cropping pattern adaptation and in the strategies farmers use to grow the patterns. In the sites studied, the differences in crop performance between two crop years agreed with the interpretation of the analysis, although changes in factors other than rainfall distribution occurred between the years in question.

There are identifiable land unit differences within the rainfed Pangasinan and Iloilo sectors. Landscape, soil texture, and water table depth factors play important roles in modifying the number of days paddy fields are flooded, and their effect changes as the season progresses. Crop performance and farmer practices responded to the differences in FSD regimes as well as to differences in rainfall distributions between CY 76-77 and 77-78.

Because climatic and land-related factors affect the adaptation of rainfed rice-based cropping patterns, a clearer understanding of the behavior of the factors is required. This will aid in focusing agronomic and economic research on priority problems that need to be solved to improve the adaptation of more intense patterns for rainfed agriculture. The temporal variability associated with the climatic factors and the spatial variability associated with the land factors alter production potentials not only directly, but also indirectly because farmers are not likely to apply costly inputs to increase output from risky rainfed systems. Farmers are keenly aware of the variability in these factors, but the variability often seems overlooked by others. An increased understanding of the differences observed should aid dialogue among the farmer, the change agent, the production program formulator, and the researcher. The resulting improvement in allocation of private and public resources can lead to increased benefits.

As more data from the Pangasinan and Iloilo sites become available, additional analyses will add to the knowledge of the variability and behavior of the climatic and land factors. Additional sites will be selected to examine the extent of variability over a wider range of rainfed environments.

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Appendix Table 1. Dates associated with the probability (P=0.5 and P=0.8) of received and remaining rainfall at Pangasinan and Iloilo, as determined from weekly rainfall totals.

Onset			Termination		
Received rainfall(mm)	P(0.5)	P(0.8)	Remaining rainfall(mm)	P(0.5)	P(0.8)
		Pangasinan			
25	13 April	26 April	500	2 Sept	19 Aug.
50	20 April	5 May	400	10 Sept	29 Aug.
75	26 April	11 May	300	23 Sept	7 Sept.
100	31 April	17 May	200	1 Oct	16 Sept.
125	7 May	20 May	100	28 Oct	3 Oct.
200	18 May	27 May			
		Iloilo			
25	26 April	15 May	500	11 Oct.	19 Sept.
50	6 May	22 May	400	20 Oct.	30 Sept.
75	11 May	27 May	300	31 Oct.	14 Oct.
100	17 May	29 May	200	23 Nov.	22 Oct.
125	21 May	3 June	100	12 Dec.	10 Nov.
200	5 June	19 June			

Indian cropping patterns for possible use in rainfed lowlands

M. V. RAO

It is difficult to precisely indicate the extent of rainfed lowlands in India. Most rice workers feel that of 39.5 million ha in rice, about 5 million ha could grow shallow-rainfed rice (5 to 15 cm); 10 million ha, intermediate-rainfed (16 to 49 cm); and 4 million ha semideep and deepwater rice (50 cm or deeper).

In the shallow-rainfed regions, photoperiod-insensitive varieties of 130-135 days as well as photoperiod-sensitive varieties flowering in October are grown. With either type, the rice crop is harvested by the end of November, or earlier. In the intermediate-rainfed lowlands, only photoperiod-sensitive varieties are grown, which are harvested by mid-December. It is reasonable to assume that the major area growing rabi pulses (Table 1) is planted after harvest of that rice crop. For example, in 80% of the rice area in Madhya Pradesh where rainfall is from 1,270 to 1,620 mm, rice is grown year after year as a kharif crop and followed by black gram (Shrivastava and Choudhary 1974).

The only apparent way of improving the cropping pattern of kharif rice followed by rabi pulse is by varietal improvement. Kanwar (1972) stressed the need for varieties of pulse crops for the predominantly monoculture paddy areas of West Bengal, eastern Uttar Pradesh, and Bihar.

Everyone is aware of the vagaries of the monsoon in India and the unpredictable land submergence during crop growth. This paper presents the results of studies on the jute-rice sequence at the Central Rice Research Institute (CRRI) over a 3-year period. The results could be useful for areas in the shallow-rainfed and intermediate-rainfed category.

RESEARCH ON JUTE (FIRST CROP)

Of two species of cultivated jute, *capsularis* jute is the one grown on lands subject to submergence because it can tolerate waterlogging at late growth stages. Presently, 0.75 million ha jute is grown primarily in eastern and northeastern India (West Bengal, Orissa, Assam, Bihar, Uttar Pradesh, Manipur, Tripura, Meghalaya, and Nagaland). Because of a worldwide demand for jute

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Table 1. Area in India growing rabi pulses, 1975-76.

State	Area (thousand ha)	
	Gram	Other pulses
Andhra Pradesh	90	510
Assam	-	80
Bihar	250	910
Madhya Pradesh	1900	1320
Orissa	40	930
Uttar Pradesh	1730	730
West Bengal	100	540
Maharastra and Karnataka	650	380
Other NE regions	20	050
Total	4780	5450
Mean yield (kg/ha)	730	500

Table 2. Fiber yield of *capsularis* jute varieties at the Central Rice Research Institute (CRRI) lowlands.

Variety	Fiber yield (kg/ha)[a]		
	1971[b]	1972	1973
JRC 7447[c]	1948	3122	3477
JRC 1108[c]	1879	2997	3415
JRC 5854	1942	2993	3042
JRC 201	2014	2873	3072
JRC 890	1728	2988	3351
JRC 6340	1609	3027	2908
JRC 1172	1784	2769	3141
JRC 4444	1749	2917	3225
JRC 6382	1527	3055	3181
JRC 212	1882	2876	3168
JRC 978	1678	2982	3252
JRC 3121	1837	3015	3324

[a] Seeding dates: 1 April 1971, 28 April 1972, 17 May 1973.
[b] Low yields in 1971 were due to heavy rainfall during the growing period (1,400 mm as against 20-year average of 900 mm).
[c] Released for farmer cultivation.

the area maybe extended without adverse effect on the agricultural economy.

Initial CRRI studies (1971-73), in collaboration with the Jute Agricultural Research Institute, Barrackpore, evaluated 12 *capsularis* varieties on clay loam where water started accumulating at the end of July. In general, the water was 15 to 30 cm deep, occasionally increasing to 45 cm after heavy rain. Water started receding in November and the land surface remained moist until the first week of December. Subsoil moisture continued to be adequate for another 2 weeks. Jute yields are in Table 2. Neither the jute crop nor the rice crop were irrigated.

Table 3. Performance of rice varieties after *capsularis* jute. Central Rice Research Institute (CRRI), 1971.

	Jagannath	T 141	Vijaya
Date of sowing	28 June	28 June	18 July
Date of planting	23 August	26 August	26 August
Spacing	15 x 15 cm	15 x 20 cm	15 x 20 cm
Fertilizer level			
N(kg/ha)	110	60	120
P_2O_5(kg/ha)	40	20	40
K_2O (kg/ha)	40	20	40
Date of flowering	8 November	26 October	4 November
Date of harvest	8 December	28 November	4 December
Plot size (m^2)	1050	1100	370
Grain yield (kg/ha)	2520	2000	3105

In 1974 the study was extended to determine the performance of jute that was sown late, i.e. 4 June. Heavy rains severely affected the crop, and remedial measures such as resowing, additional nitrogen, and foliar spray of urea did not improve it. The yield was only 30 kg/ha. Delayed sowing of jute appears risky for *capsularis*, and early sowing with premonsoon showers -- with a deadline around 15 May -- are better.

SECOND CROP (RICE)

In 1971, rice varieties Jagannath, T 141, and Vijaya, were grown after jute harvest. The data indicate that planting of old seedlings coupled with high fertilizer level gave good yields (Table 3). The yields were considered satisfactory, considering the major damage that the trial suffered from a severe cyclone on 29 October.

In 1972, 12 rice varieties tested included some cold-tolerant early varieties. All were planted at a 15- x 15-cm spacing and received 100 kg N/ha and 40 kg/ha each of P_2O_5 and K_2O. Crop details and yields are in Table 4.

The data indicated the suitability of Jagannath to follow *capsularis* jute. CR 1014, NC 1281, and T 141 also were suitable. Among the cold-tolerant varieties, Kalinga 2 was the best and was 15 days earlier than others.

In 1973, the rice varietal trial was continued with the same fertilizer level and cultural practices. Some of the gall midge-

Table 4. Performance of rice varieties (planted on 22 September) after *capsularis* jute. Central Rice Research Institute (CRRI), 1972.

Variety	Age of seedling	Date of harvest	Grain yield (kg/ha)	Remarks[a]
Jagannath	45	27 Dec. 72	4098	P, D, I
NC 1281	45	27 Dec. 72	3728	P, T, I
CR 1014	75	27 Dec. 72	3857	P, T, I; superfine grain
Vijaja	45	6 Jan. 73	2920	Medium duration D, I
CR 126-33-1 (Kalinga 1)	45	13 Dec. 72	3511	CT early variety; coarse grain
CR 126-42-2 (Kalinga 2)	45	12 Dec. 72	3852	- do -
CR 126-27-15	45	12 Dec. 72	3354	- do -
CR 126-53-1	45	12 Dec. 72	2512	- do -
CR 126-42-1	45	12 Dec. 72	3308	- do -
CR 126-42-3	45	12 Dec. 72	2654	- do -
CR 126-42-5	45	12 Dec. 72	3643	- do -
CR 123-32	45	12 Dec. 72	3730	- do -
Pankaj[b]	45	8 Jan. 73	2563	P, D, I
CR 1014[b]	75	27 Dec. 72	4216	P, T, I
T 141[b]	73	12 Dec. 72	4448	P, T, I; medium grain; popular in Orissa
C.D. (.05) to compare varieties			659	

[a]P = photoperiod sensitive, D = dwarf, T = tall, I = indica, CT = cold tolerant.
[b]Bulk crop grown in 300 to 400 m^2.

resistant cultures and a few other medium-duration varieties like Vijaya were included. Mahsuri, which has become popular in recent years in Andhra Pradesh and other states, was also included. Data on varietal performance are in Table 5.

Data for the 1971-73 trials indicate that the photoperiod-sensitive varieties are more suitable for late planting after jute. In addition, old seedlings are preferred because they are taller at planting and capable of withstanding any unprecedented heavy rain; they are practically free from tungro virus; and their height at harvest is reduced because of a reduced vegetative phase, resulting in nonlodging at maturity. The cold-tolerant cultures and the medium duration high yielding varieties, which did well in earlier years, performed poorly because of a fairly severe incidence of tungro virus.

In 1971-73 the rice varieties were grown at high fertilizer input because the period available for tiller production was shorter. In 1974, the trial was modified to include selected

Table 5. Performance of rice varieties (planted 19 September) after *capsularis* jute, Central Rice Research Institute (CRRI), 1973.

Variety	Age (days) of seedling	Date of harvest	Grain yield (kg/ha)	Remarks[a]
Kalinga 1	30	7 Dec. 73	1112	CT
Kalinga 2	30	7 Dec. 73	1424	CT
CR 123-22	30	7 Dec. 73	1053	CT
Jayanthi	30	29 Dec. 73	1769	Medium duration MV; superfine grain
CR 93-4-2 (Shakti)	30	24 Dec. 73	1969	Gall midge resistant
CR 94-MR 1550	30	29 Dec. 73	1498	Gall midge resistant
CR 140-62	40	17 Dec. 73	2674	Late duration D, I
Jagannath	30	22 Dec. 73	1745	P, D, I
Jagannath	90	12 Dec. 73	3103	P, D, I
NC 1281	30	31 Dec. 73	1428	P, T, I
NC 1281	90	21 Dec. 73	2605	P, T, I
GEB 24	90	10 Dec. 73	3043	P, T, I
CR 1014	80	24 Dec. 73	3096	P, T, I
Mahsuri	45	31 Dec. 73	714	Indo-japonica hybrid; T and photoperiod insensitive

[a]P = photoperiod sensitive, CT = cold tolerant, I = indica, D = dwarf, T = tall, MV = modern variety. C.D. (.05) to compare varieties-270 kg.

varieties and three levels of nitrogen (50, 75, and 100 kg N/ha) to determine whether a high nitrogen level was actually needed. Details are presented in Table 6.

It was observed that 50 kg N/ha was adequate, and that extra yield, if any, at a higher level of nitrogen, was marginal. Planting old seedlings of Jagannath again proved best -- yield was 4,195 kg/ha at 50 kg N/ha. Patel (1975) also reported the suitability of Jagannath in a jute-rice rotation in the lowlands of West Bengal.

Among the photoperiod-sensitive tall indicas, NC 1281 was the best (yield of 3,602 kg/ha at 50 kg N/ha), followed by Bam 6 and CR 1014. Of interest was the yield (3,488 kg/ha at 50 kg N/ha) of Tainan 3 mutant (387-4), which had performed miserably in 1977 when planted in October. Among the medium-duration varieties, IR20 and CR93-4-3 (Shakti) did well. Mahsuri had imperfect exsertion of panicles, and flowering was not uniform.

In kharif 1977, nine early varieties and five photoperiod-sensitive varieties were tested for suitability for planting as late as 1 October. Spacing was 15 x 15 cm and fertilization was 60 kg N and 20 kg/ha each of P_2O_5 and K_2O. Within the first two weeks of crop growth, the crop remained submerged for 2 days after the sudden accumulation of water following rains. Results from this trial are presented in Table 7.

Table 6. Nitrogen x variety trial of rice varieties (planted on 24 September) after jute on lowlands. Central Rice Research Institute, 1974.

Variety	Age (days) of seedlings	Date of harvest	Grain yield (kg/ha) 50 kg N/ha	75 kg N/ha	100 kg N/ha
CR 93-4-2	45	26 Dec. 74	3211	2536	3021
IR20	45	27 Dec. 74	2867	3316	3297
Jayanthi	45	31 Dec. 74	2421	2378	2346
CR 140-62	45	3 Jan. 75	983	1137	573
CR 94-MR 1550	48	1 Jan. 75	2365	1864	2005
Vijaya	45	3 Jan. 75	2265	2156	1623
CR 1014	58	30 Dec. 74	3215	3454	2926
Bam 6	58	27 Dec. 74	3323	2644	2254
NC 1281	58	1 Jan. 75	3602	3865	4071
T 141	58	10 Dec. 74	2863	3209	3108
T 90	58	28 Dec. 74	3004	3017	2721
Jagannath	75	3 Jan. 75	4195	4027	4161
Tainan 3 mutant (387-4)	25	27 Dec. 74	3488	3721	3742

C.D. (.05) to compare varieties - 444 kg/ha.
N. V x N not significant.
C.V. for main plots (N) - 9.0%.
C.V. for subplots (V) - 13.3%.

Table 7. Varietal trial with late planting, 1 October. Central Rice Research Institute, 1977.

Variety	Age (days) of seedlings	Grain yield (kg/ha)	Remarks
Supriya	28	566	High incidence of tungro
Ratna	28	2185	Free from tungro
CR 44-1	28	835	High incidence of tungro
JS 52-202	28	840	- do -
Annapurna	28	856	- do -
Kalinga 1	28	894	- do -
Pusa 2-21	28	878	- do -
Tainan 3 mutant	28	795	- do -
CR 141-192	28	failed	Practically no tillering
Vijaya	28	874	Free from tungro
CR 1014	65	2132	- do -
CR 1009	65	2555	- do -
CR 1005	65	2069	- do -
Jagannath	65	861	- do -

TESTS IN FARMERS' FIELDS

The jute-rice pattern was included in the 1971-74 national demonstrations by CRRI on farmers' fields where a *capsularis* jute was followed by photoperiod-sensitive Jagannath. Trials were in shallow lowlands where jute, harvested in the first week of September, was followed by rice. A NPK fertilizer level of 40-20-20 kg/ha for jute and 80-40-40 for rice was adopted. Data from 20 such trials indicate the feasibility of the jute-rice rotation in rainfed lowlands (Table 8).

During kharif 1976, CRRI tested the jute-rice rotation in seven farmers' fields on intermediate rainfed lowlands. Jute

Table 8. Jute-rice in Central Rice Research Institute trials in farmers' fields, 1971-74 and 1976.

Crop	Variety	Trials (no.)	Yield range (t/ha)	Mean yield (t/ha)
	National demonstrations in India (1971-74)			
Jute	JRC 7447	20	1.8-3.0	2.4
Rice	Jagannath	20	3.3-6.7	4.7
	Kharif 1976			
Jute	JRC 7447	7	1.2-3.1	2.3
Rice	CR 1014	7	2.0-3.2	3.6

(JRC7447) was sown in May and harvested in mid-September. Sixty-day-old seedlings of CR 1014 rice were planted in the third week of September. The fertilizer level was 60-20-20 kg NPK/ha for the jute crop and 50-20-20 kg NPK/ha for the rice crop. The results of the demonstrations are in Table 7.

The data indicate that jute followed by rice (preferably photoperiod-sensitive) may be used in rainfed lowlands of shallow to intermediate submergence.

OTHER POSSIBLE CROPPING PATTERNS

Several workers have suggested such patterns as rice-wheat, rice-pea, early rice-late rice, and rice-pulse for specific regions. A summary of the recommendations is given in Table 9.

Table 9. Suggested cropping patterns for different regions of India.

Region	Possible cropping patterns	Reference
Lower Assam valley and North Bengal	Jute-rice (Manoharsali, photoperiod sensitive)	Kakati and Borthakur 1971, Ghosh 1972
Kosi area (lowland) of Bihar	Jute-late rice; rice-onion	Ghosh 1972
Northwest Bihar and eastern U.P.	Jute-wheat; jute-pea	Ghosh 1972
Gangetic West Bengal	Jute-rice (T 141, photoperiod-sensitive)	Ghosh 1972, Pande and Mittra 1978
Cuttack, Puri, Balasore area of Orissa	Jute-rice	Ghosh 1972
Chattisgarh, M.P.	Rice-linseed, black gram	Jethamalani and Choubey 1972
Goalpara, Kamrup, Nowgong (Assam)	Jute-tall indica; early rice-deep water rice	Mahanta and Borthakur 1972
Orissa (lowlands)	Rice-pulse; jute-rice; early rice-late rice	Das and Sahu 1972, Misra 1978
Orissa (medium lands)	Early rice-late rice (Jagannath) Jute-late rice (Jagannath) Finger millet-late rice (Jagannath)	Misra 1978
West Bengal	Jute-wheat; jute-mustard	Patel 1971
South Bihar	Rice-pulses	Pande and Mittra 1978
South Bihar (high)	Fallow-pulse	Pande and Mittra 1978

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Cropping patterns for rainfed lowland rice areas in Indonesia

SURYATNA EFFENDI S., J. L. MCINTOSH, SOETJIPTO PARTOHARDJONO, and HAERRUDIN TASLIM

The soil and rainfall conditions for rainfed lowland rice have been adequately described in the papers. Their effects on rice production and cropping patterns are basically the same from place to place and country to country. The interaction of agroclimatic factors with availability of supplemental water for irrigation and local markets determine, for the most part, the cropping patterns farmers will use.

Many times in Indonesia there is no distinct separation between irrigated and nonirrigated areas. If the source of irrigation water is small streams or flow from paddy to paddy, the situation is most accurately described as a distribution system rather than irrigation, or as an irrigation system that is rainfall dependent.

Vast underdeveloped areas in Indonesia have tremendous potentials for rice production, but they are rainfall dependent and do not fall within the typical rainfed rice classification. They include the swampy and tidal areas of Sumatra and Kalimantan. The swampy (*lebak*) areas are considered deepwater rice areas. The tidal (*pasang surut*) areas are also rainfall dependent because they are usually drained and the tidal influence is removed before development. Soil management and cultural practices are different, but the risks due to inadequate water control are about the same as those for rainfed lowland rice.

The availability of water tends to be the most dominant factor in rainfed rice culture and for the cropping patterns into which the rice crop fits. Even the effects of such important factors as soil and slope tend to be masked by the leveling, bunding, and flooding for lowland rice culture. The classification of rice land in Table 1 shows the relative importance of rainfed- and rainfall-dependent rice in Indonesia.

Cropping systems agronomist, Central Research Institute for Agriculture (CRIA); *cropping systems agronomist*, CRIA and Cooperative CRIA/IRRI Program; and *cropping systems agronomist*, CRIA, Bogor.

Table 1. Present classification and area of rice land in Indonesia.[a]

Classification		Area	Rice crops/	Crop area
English	Indonesian	(thousand ha)	year	(thousand ha/yr)
Upland	Padi gogo	1,168	1	1,168
Irrigated lowland:	Pengairan Padi sawah:			
Guaranteed	Teratur	1,071	2	2,142
Partial	Setengah teratur	890	1-2	1,557[b]
Simple	Sederhana	1,982	1-2	2,972[c]
Rainfed lowland	Tadah hujan	1,772	1-2	2,216[d]
Swamp	Lebak	254	1-2	317[d]
Tidal	Pasang surut	558	1-2	697[d]
Polder	Polder	10	1-2	12[d]

[a]Compiled from various sources by Dr. Haeruddin Taslim.
[b]Assumes 75% double-cropping.
[c]Assumes 50% double-cropping.
[d]Assumes 25% double-cropping.

RAINFED LOWLAND RICE

For the purpose of this paper we will not discuss the rice land areas classified in Table 1 as upland, fully irrigated (guaranteed), or polder. The swamp and tidal areas are classified as rainfed but will be discussed only indirectly.

The areas with partial and simple irrigation systems will be included in the area classified as rainfed lowland. The dominant factor influencing crop production in the first two areas is the uncertainty of water availability. The same uncertainty exists for the strictly rainfed lowland areas. Some uncertainty is removed from much of the rainfed lowland area in Indonesia by the movement of water laterally either through the soil or through the paddies. Consequently, cropping patterns designed by farmers may be much the same for all three areas.

Cropping patterns for partially irrigated areas

The partially irrigated areas are said to have semitechnical irrigation from the engineering point of view. Water control in the systems is considerable but not enough to cope with extremes of heavy rains and prolonged drought. Usually there is no impoundment and a stream serves as the water source.

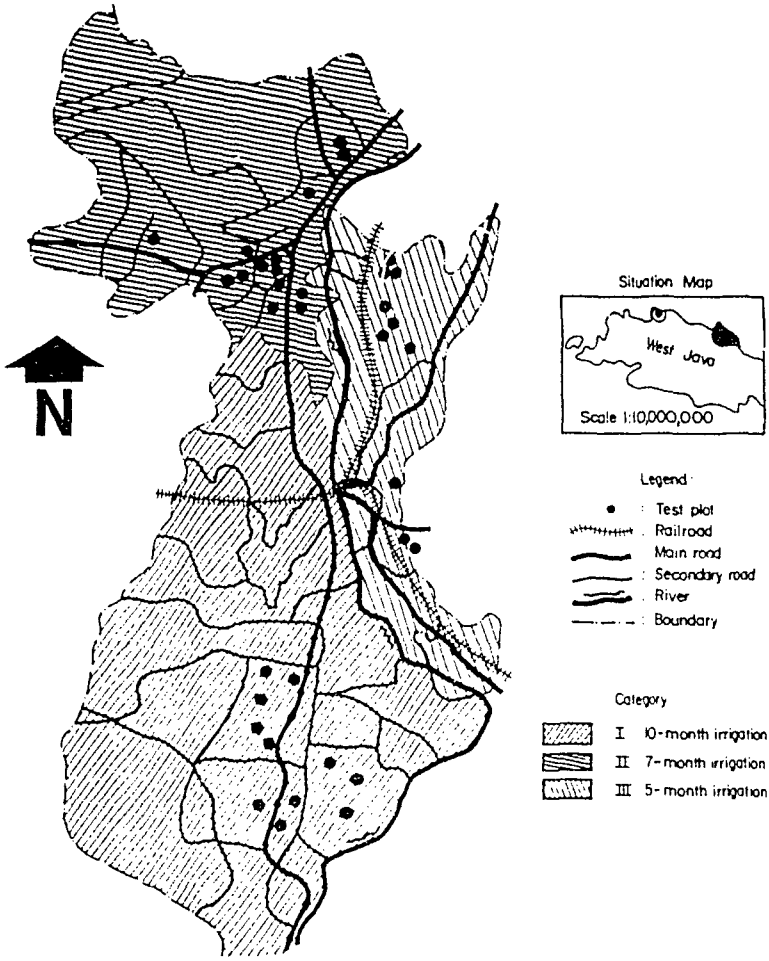
There are large areas of partially irrigated rice lands along the north coast of Java and in the outer islands. In Java

the systems may supply irrigation for 5-7 months. Usually the rains start in October and irrigation in December. The length of irrigation time depends on rainfall in the area and watershed of the source. The following discussion is based on data from cropping systems research in the annual report for 1975-76 (Saefuddin et al 1977).

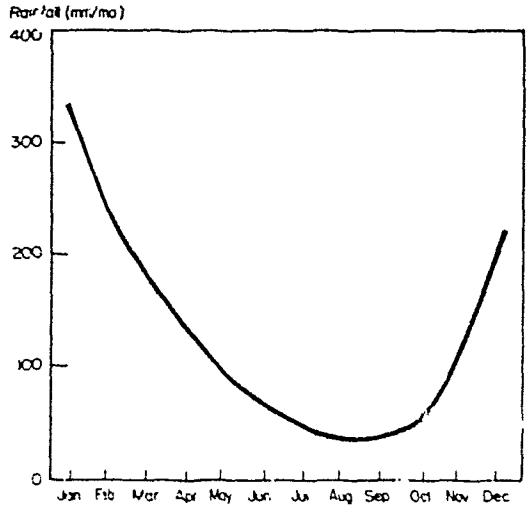
Figure 1 shows the target area for our research in West Java. It also shows the distribution of irrigation water in this part of the system and the length of time water was scheduled to be available. The 1966-74 rainfall distribution is shown in Figure 2. Figures 3 and 4 show the actual rainfall distribution for 1975-76, length of time irrigation water was available (scheduled irrigation time cross hatched), and 3 different cropping patterns that were evaluated in the areas. Cropping patterns II A and III A were checks using the farmers' usual cropping patterns, II B and III B were the farmers' cropping patterns with their felt constraints removed (or without constraints), and II C and III C were the introduced cropping patterns based on our previous research and experience. Data for yield and analyses of costs and returns are in Tables 2 and 3.

The data for the 7-month irrigation area show the need for early maturing rice and fast turnaround time for cropping patterns in the partially irrigated area. Farmers in Indonesia tend to plant rice even when the risk is high. They tend to reduce the labor and input costs for the high-risk second crop. But it is obvious from the data that if irrigation water had ended on schedule and 1 or 2 rain showers had not occurred, the second crop in both irrigation categories would have been almost complete failures for both farmers' cropping patterns. On the other hand, two early maturing varieties and a secondary crop were easily grown in the introduced cropping patterns.

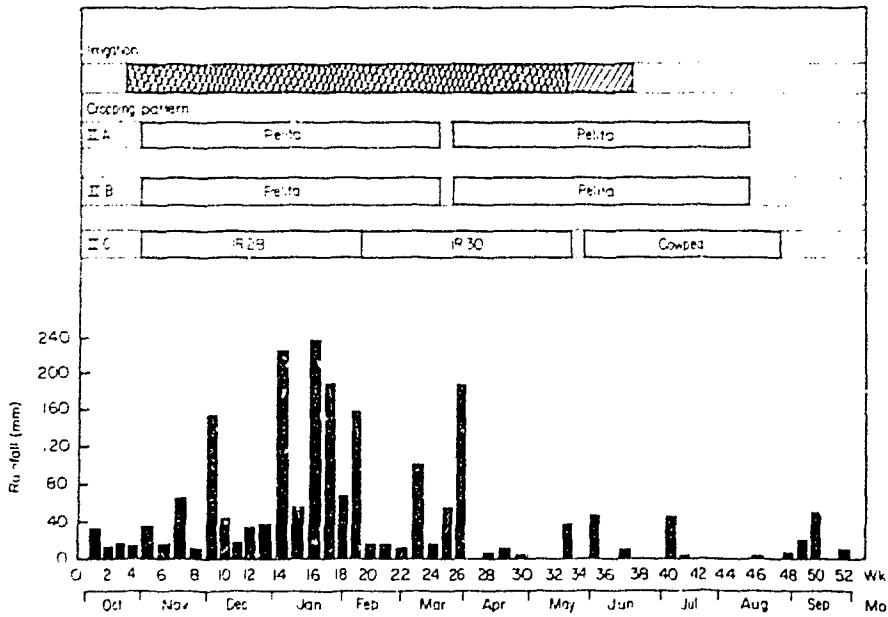
The data for the 5-month irrigation area illustrate a strategy to increase crop production by crop management. For the introduced cropping patterns rice was direct-seeded on aerobic soils at the beginning of the rainy season. The fields were bunded and allowed to flood water 30-40 days when sufficient rainfall or irrigation water arrived. The method, called *tapo nandi*, has been used extensively in some areas of Indonesia for many years. This crop was immediately followed by another rice crop transplanted into the just harvested area without tilling the soil. The straw was cut, placed in rows, and worked into the soil by the feet. This is the *valik jerami* method of rice culture and is used when the turnaround time must be reduced to get a second rice crop.



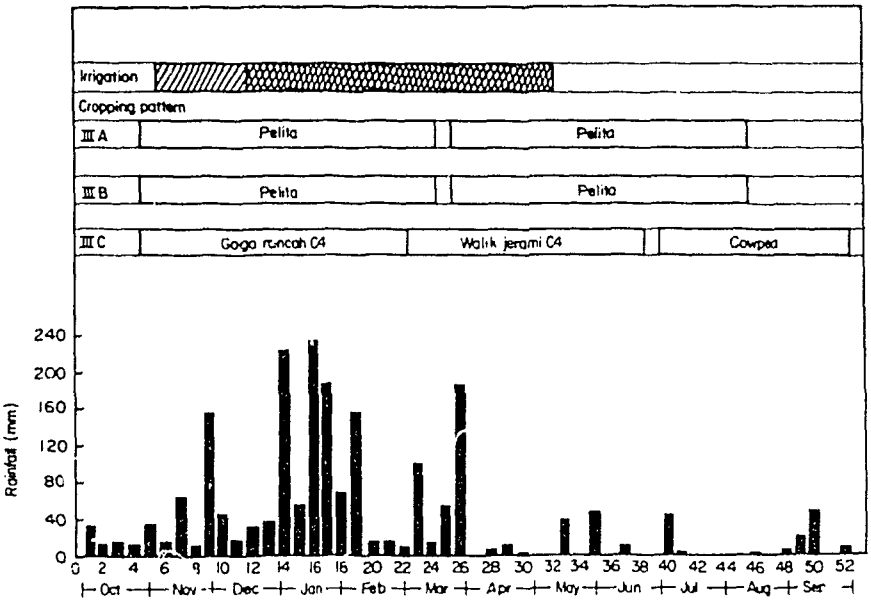
1. The cropping systems outreach site in Indramayu, Indonesia. Scale = 1 56,250



2. Average monthly rainfall for Indramayu, Indonesia, 1968–74



3. Weekly rainfall distribution, duration of water supply from irrigation, and cropping patterns in 7 month (II) irrigated area, Indramayu, Indonesia, 1975–76.



4. Weekly rainfall distribution, duration of water supply from irrigation, and cropping patterns in 5 month (III) irrigation area Indramayu, Indonesia, 1975–76.

In 1975 some early maturing varieties had not yet been tested for [illegible] and [illegible]. C4-63 was used in the introduced cropping patterns. As usual in their patterns, the farmers attempted to grow two consecutive crops of Pelita rice. The results in Table 3 show that the second crop in the two farmers' cropping patterns were virtually failures. No doubt the farmers were encouraged to attempt the second rice crop because heavy rains had started early in the rainy season and they were able to plant rice in October. Furthermore, the irrigation canals had excess water that was released about 35 days ahead of schedule. The planting dates for all three patterns were almost exactly the same.

This example illustrates why the partially irrigated area is included in the strictly rainfed rice areas for management purposes. The hazards are similar and the strategy for avoiding the hazards is basically the same.

One other point should be made. Irrigation authorities perform a disservice when they break their schedules and release water early. Many farmers in the 5-month irrigation area had planned to grow [illegible] rice. They had prepared the land and were ready to plant when the irrigation water arrived. The fields

Table 2. Cropping pattern, yield and analysis of costs and returns for each cropping pattern in a 7-month irrigation area (category II). Indramayu, Indonesia, 1975-76.

Cropping[a] pattern	Av yield (kg/ha)	Gross return (Rp/ha)	Labor cost (Rp/ha)	Material cost (Rp/ha)	Crop net return (Rp/ha)	Pattern net return (Rp/ha)
IIA						
LLR	5,818	363,646	132,254	38,119	193,273	
WJR	1,577	107,214	59,672	23,570	23,972	
Fallow	-	-				217,245
IIB						
LLR	6,892	430,833	145,355	36,122	249,356	
WJR	2,393	162,746	73,944	32,548	56,254	
Cowpea	-	-				305,610
IIC						
LLR	5,422	338,875	126,427	34,060	178,388	
WJR	4,837	328,893	105,473	38,830	184,590	
Cowpea	916	229,075	122,061	20,000	87,014	
						449,992

[a]See Figure 3 for pattern description. LLR = first crop, WJR = second crop.

Table 3. Cropping pattern, yield and analysis of costs and returns for each cropping pattern in a 5-month irrigation area (category III). Indramayu, Indonesia, 1975-76.

Cropping[a] pattern	Av yield (kg/ha)	Gross return (Rp/ha)	Labor cost (Rp/ha)	Material cost (Rp/ha)	Crop net return (Rp/ha)	Pattern net return (Rp/ha)
IIIA						
LLR	4,497	[illegible]	117,044	35,563	159,080	
WJR	756	[illegible]	[illegible]	21,730	- 35,651	
Fallow	-	-				123,429
IIIB						
LLR	5,257	329,342	142,233	34,197	152,107	
WJR	1,747	119,774	81,321	32,220	5,233	
Cowpea	-	-				157,340
IIIC						
GRR	4,502	281,375	181,558	39,300	60,517	
WJR	4,140	281,526	101,690	37,632	142,204	
Cowpea	460	116,600	77,267	20,000	18,733	
						221,454

[a]See Figure 4 for pattern description. LLR = first crop, WJR = second crop, GRR = gogo rancah.

became flooded and the farmers had to rework and puddle the soil. Then a seedbed had to be made. The operations required time and extra expense by the farmers. By allowing the irrigation water to continue after the scheduled cutoff date, the personnel may also create serious problems for some farmers. Excess water long after the scheduled cutoff for irrigation inhibits planting and production of secondary crops after the rice.

We summarize the needs for partially irrigated areas.

1. The cropping patterns commonly used for the partially irrigated areas vary according to water availability. The following illustrates the cropping patterns that are commonly used as the water decreases from *a* to *e*.

   a. Lowland rice-lowland rice
   b. Gogo rancah-lowland rice
   c. Gogo rancah-*walik jerami*
   d. Lowland rice-legume (soybean or cowpea)
   e. Lowland rice-fallow

2. Some agronomic problems need further research. For gogo rancah labor requirements and costs for land preparation and weeding must be reduced. Intensive year-round patterns are helpful. It is inevitable that some mechanization and herbicides will be used in the near future.

3. Two problems that cause considerable loss of yield could be solved by varietal improvement. We need a variety of first rice crop with tolerance for flooding and a gall midge-resistant variety for the second crop. The absence of such varieties has been a major constraint to double rice crops in the low-lying areas along the north coast of Java. Because of early planting, gogo rancah helps solve the flooding problem, but tolerance for flooding for a period of 5-10 days would be useful. Elongating varieties seem unnecessary. Rats are a serious problem for any early maturing crop grown out of sequence with the surrounding areas.

4. Market constraints exist for many secondary crops. We have studied sorghum but do not include it in our patterns because of marketing difficulties. Cropping systems research and development must include close cooperation with governmental agencies responsible for market and infrastructure development. In Indonesia new research projects are developed within the framework of the provincial planning agency (BAPPEPA).

Cropping patterns for areas with simple irrigation

The simple irrigation systems are mostly rainfall dependent. They are located in hilly areas at intermediate elevations (200 to 500 m). The water comes from small streams and springs. The latter provide year-round water. The areas tend to be well drained and the soils are either Latosols or Andosols. The conditions are conducive to crop production and the cropping patterns are usually more intensive than those for the partially irrigated areas.

Very little research has been done on cropping patterns for such areas. The main research emphasis has been on development of component technology for the existing cropping patterns. In many instances the farmers prefer long-season, high-quality local rice varieties. The paddies may also be used for fish culture. Vegetable crops such as green beans, sweet potato, and yard-long bean are common. Near the cities cassava and taro are grown profitably for the fresh market.

We summarize the needs for simple irrigated areas.

1. The cropping patterns for the simple irrigation systems vary according to water availability and markets. The following illustrates the cropping patterns that are commonly used as the water decreases from *a* to *f*.

   a. Lowland rice-lowland rice
   b. Lowland rice-sweet potato
   c. Lowland rice-sweet potato + corn
   d. Lowland rice-corn or soybean
   e. Lowland rice-yard-long beans or kidney beans
   f. Lowland rice-cassava or taro
   g. Lowland rice-fallow

2. Agronomic problems associated with soils are minor. In the past it was difficult to obtain fertilizers and insecticides, which were officially restricted to lowland rice areas with good water control. The most serious problem for the areas that have plenty of water is rats.

3. Rice varieties used in fully irrigated systems perform satisfactorily in the areas of simple irrigation. At higher elevations where the irrigation water is cold, rice sterility is a problem. Early maturing varieties that are tolerant of the problem have been developed. High yielding improved varieties with insect resistance and high quality are needed.

4. Most of the production is directly for local consumption or is transported to nearby urban areas. The local varieties of rice, such as Cianjur from the Cianjur area, are high quality and command high market prices. Production of secondary crops is closely related to the available markets.

Cropping patterns for rainfed lowland rice areas

Rainfall in practically all of Indonesia is sufficient to support at least one crop of rice a year without irrigation. Where the land has soil with sufficient clay, or is in a low-lying area, lowland rice is usually transplanted and grown in puddled soil.

There are some exceptions. For example, *gogo rancah* rice grows on heavy clay soils in low-lying areas, but the rice is planted and grows like upland rice for the first 30-40 days. This unique practice for a unique situation is designed to circumvent flooding and make use of available water before irrigation water arrives. But it is also contingent on soil and topographic conditions. The clay soil holds water well and the topography assures a gradual rise in the level of the water table as the rains come. Attempts to grow *gogo rancah* on Latosols in the Bogor area have not been as successful. The rapid downward movement of water leaches nutrients and causes drought stress after 2-3 days without rain.

Rice grown in the tidal and swampy areas of Sumatra and Kalimantan may be classified as rainfall-dependent lowland rice. Again the soil is not puddled, but is allowed to accumulate water and soak. Weeds are then rolled up in bundles, and the rice seedlings are transplanted into the soil. This is possible because the soil is highly organic and soft.

The area of rainfed lowland rice in Indonesia covers about 1.8 million ha, about 25% of the total rice-producing area in Indonesia. This cultural method is supposedly dependent on rain that falls directly into the paddy, with a minimum of lateral movement of water into the paddy. It is difficult to find rice paddies in Indonesia where these conditions are fulfilled. Many times there is flow of water from paddy to paddy, and there is almost invariably lateral movement of soil water. This classification is delineated mainly because there is no organized effort to irrigate.

Because irrigation water is widely available in Indonesia, the areas for rainfed rice tend to be fragmented. Some of the largest contiguous areas occur along the north coast of Java and the west coast of South Sulawesi. The partially irrigated areas in Indramayu, West Java, are intermixed with rainfed rice. Serang (West Java) and Lamongan (East Java) have large areas of rainfed rice. The rainy period (more than 200 mm/month) does not usually exceed 4 months. There are problems in getting the rice crop planted early enough in the rainy season to avoid drought stress at the heading and filling stages.

Little research has been done on cropping patterns for these areas. The farmers have adopted the new varieties, but many used less management inputs than those for irrigated lowland rice. Sometimes the land is not planted to any crop if weather and market conditions are unfavorable. This is particularly true near large cities where off-farm employment is available. It is true in the outer islands where the farmers may have employment in forestry or estates and a source of food (cassava or *sagu* and fish).

We examine the needs for rainfed lowland area.

1. Cropping patterns for the rainfed lowland areas tend to be simple. Rice is the crop that offers the most opportunity for income and food at the present time, but in East Java and eastern Indonesia corn is often substituted for rice. The rainfall usually varies from 5 consecutive wet months with more than 200 mm to 4 or less consecutive wet months. The following illustrates some of the cropping patterns that are commonly used.

   a. Lowland rice-secondary crop (soybean and cowpea)
   b. Lowland rice-ratoon
   c. Lowland rice-sorghum
   d. Lowland rice-fallow
   e. corn + peanut-fallow
   f. Peanut + cassava-fallow
   g. Corn + cassava-fallow

2. The opportunity for increased production of rice in the lowland rainfed areas is considerable. There is need to introduce the gogo rancah method, which has been done to a limited extent. Where we attempted to introduce gogo rancah weeds have been much more serious than in the traditional gogo rancah areas. The farmers are not used to the system and the problems with weeds, rats, and birds for the *out-of-place* crop are severe. Flooding often occurs because the drainage systems have not been developed. Direct-seeded, and early maturing rice varieties with flooding tolerance could help solve the problems. Unfortunately, farmers in the areas have traditionally grown only one crop a year and then allowed the land to fallow.

   In the higher elevation areas farmers may grow upland crops during the rainy season. In other areas, particularly near cities, farmers develop a ridge-furrow system to control water. Beds are about 3 m wide. Furrows between the beds vary in depth and width, depending on the severity of the flooding during the rainy season. High-valued, upland crops such as tomato, bean, chili, eggplant, and cassava for fresh root are grown on the beds during the rainy season. Rice is grown in the furrows. It can be planted earlier because water accumulates in a smaller area and land preparation can begin earlier. This system, called *gonjan*, is concentrated in some areas of Java and the tidal areas. It has been introduced into problem areas in Lombok. The system offers a means by which farmers, on their own initiative, can develop an effective means of water control.

3. The development of markets for crops other than rice remains one of the major problems for rainfed lowland rice areas. Extension has paid much more attention to rice in fully irrigated areas. Cropping systems research designed to identify and remove the constraints to production can be effective simply because little research has been done in the past. All research should involve the provincial planning agencies.

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Socioeconomic Aspects

Rainfed lowland rice farming in Bangladesh — productivity and constraints

EKRAMUL AHSAN

Bangladesh is one of the world's largest deltaic countries. It consists of the floodplains of three major rivers -- the Ganges, the Brahmaputra, and the Meghna -- and their tributaries and distributaries. The land to the west of the Brahmaputra is generally higher than that on the east. During the process of delta building, several depressions were formed as a result of geological faults. The pronounced depressions are in the northwest (Rajshahi, Pabna, and Bogra districts), northeast (Sylhet-Mymensingh Haor areas), and in the south (*beel* areas of Khulna, Faridpur, and Barisal). These areas are inundated with the advent of the monsoon and remain waterlogged to different depths until November.

Bangladesh has a total rice area of 10.3 million ha, which includes single-, double-, and triple-cropped rice. Type of rice culture, varietal groups, and characteristics of the rainfed lowland crop are covered by Ahmad and Nasiruddin (this volume).

PRODUCTIVITY OF RICE IN RAINFED LOWLAND AREAS

A farm survey in selected rice-growing areas of Bangladesh revealed that the average yield of rough rice is lower in the rainfed areas than in the irrigated (Table 1). The differences within each rice group are not significant, except in boro where the gap between irrigated and rainfed yields is 1.17 t/ha. Table 1 also reveals that rice yields for the survey farms were consistently higher than the national averages.

A substantial range of differences exists among rice yields in aus, aman, and boro seasons. One noticeable feature is that transplanted rice has consistently higher yields than broadcast rice. The high yield of broadcast aman in 1977 was due to an unusually good year for the crop. Historically the yield of broadcast aman is much lower.

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Table 1. Average yield of rice under different rice-growing conditions in Bangladesh, 1977.

Type of rice	Yield (t/ha)	
	Survey	National av
Aus (av)	1.78	1.43
Rainfed broadcast	0.92	-
Rainfed transplanted	2.63	-
Irrigated transplanted	2.95	-
Aman (av)	2.09	1.81
Rainfed broadcast	2.75	1.37
Rainfed transplanted	2.61	-
Irrigated transplanted	2.94	-
Transplanted aman (together)	2.77	1.99
Boro (av)	3.43	2.99
Rainfed transplanted	3.3[illegible]	-
Irrigated transplanted	4.21	-

Constraints to rainfed lowland rice farming

No specific study has determined the constraints to improvements in rainfed lowland rice farming. The constraints, particularly the socioeconomic ones, may be similar to those of other types of rice cultivation. The rainfed lowland rice areas, however, may have some specific biophysical constraints that are different from those of irrigated and upland rice farming.

Biophysical constraints. One of the basic biophysical constraints in the rainfed lowland areas is uncontrollable water. The entire lowland area in Bangladesh is vulnerable to flood (Fig. 1). Cultivation in the rainfed areas is the direct function of time, amount, and distribution of rainfall. The consequence is uncertainty in rice cultivation, particularly for aus rice. Almost every year the rice crop in one or more seasons is destroyed by drought, flood, or both. Table 2 gives a resume of flood damage to the rice crop for 1973-75.

Most of the rainfed lowland rice areas are double-cropped with aus rice (either broadcast or transplanted) followed by transplant aman. In some places, transplant aman rice is preceded by a non-rice crop such as jute. If the first crop (either aus or jute) is delayed by late rain, cultivation of transplant aman is also delayed. The existing modern varieties are not suitable for such conditions because most are photoperiod-insensitive. In addition, they are not adaptable to water depths as high as 100 cm.

Although photoperiod-sensitivity is not required for aus and the modern rice varieties are otherwise fit for cultivation,

1. [illegible]

Table 2. Total rice area affected by flood and estimated loss in production in Bangladesh 1973-75 (Bangladesh Water Development Board, 1973, 1974, 1975).

Year	Rice area damaged by flood (thousand ha)				Loss in production (t)
	Aus	T. aman	Boro	Total	
1973	244.9	392.4	56.5	693.8	797.9
1974	543.8	120.1	115.0	778.9	942.9
1975	70.9	6.1	24.0	101.0	110.6

the uncertainty of rainfall, and early drought as well as flood in later stages remain barriers to successful cultivation of the modern rices in aus. Suitable varieties are lacking, so the basic constraint to higher productivity of rice in both aus and transplant aman is the lack of a variety for the rainfed lowland areas.

No variety of broadcast aman rice, which is grown in semideep lowland areas (water depth to 100 cm), has high yield potential, and cultivation is restricted to traditional varieties. A traditional practice mixes the cultivation of aus and broadcast aman. Improved cultivation technology for such a situation is practically nonexistent.

Field experiments in selected areas to identify constraints to higher aus rice yields showed that levels of inputs and management practices higher than the level the farmers used did not bring about significantly higher yields. The farmers' level of management in the study areas during aus gave reasonable yields. A comparison of modern and local varieties, however, indicated the modern varieties could give about 1 t additional rough rice/ha (Table 3). Economic evaluation indicated that high input use in aus was not profitable; however, insect control gave a marginal positive added profit.

Similar field trials for transplant aman rice, which is common in lowland areas, showed that significant yield increase and economic returns could be obtained with a level of inputs and management practices higher than the farmers' level (Table 4). Field trials in boro also gave significantly higher rice yields and economic returns with higher levels of inputs and management practices (Table 5).

Socioeconomic constraints. The findings of the agronomic field trials led to a socioeconomic study to identify why rice farmers used low levels of fertilizers and other inputs. Farm

Table 3. Yield (t/ha) of modern and local rice varieties, with farmers' level of inputs and management and high inputs and management. Joydebpur, 1976 aus (Ahsan and Hoque 1977).

Variety	Yield (t/ha)	
	Farmers' level	High level
Modern	3.8	3.7
Local	2.7	2.8
Difference	1.1	0.9

Table 4. Economic comparison of different levels of management with the farmers' level (M_1) for rice. BRRI Pilot Project area, t. aman, 1975.

Treatment	Yield (t/ha)	Added yield over M_1 (t/ha)	Value of added yield	Cost of added inputs (Tk)[a]	Added profit over M_1
M_1	1.7	-	-	-	-
M_2	2.2	0.5	1000	367	633
M_3	2.6	0.9	1800	695	1105
M_4	2.9	1.3	2600	944	1656
M_5	2.9	1.2	2600	1193	1407

[a] Taka (Tk) 15.5 = US$1.00.

Table 5. Profitability of different levels of management as compared to the lowest level in boro, 1975-76.

Management level	Grain yield (kg/ha)	Extra yield over M_1	Value of extra yield (Tk/ha)[a]	Cost of extra inputs over M_1 (Tk/ha)	Profit over M_1 (Tk/ha)
M_1	2416	-	-	-	-
M_2	2636	220	433	432	1
M_3	3427	1011	1992	786	1206
M_4	3384	968	1907	1031	876

[a] Taka (Tk) 15.5 = US$1.00.

Table 6. Percent of survey farmers indicating availability of various inputs for rice cultivation in Joydebpur, 1975-76 (Ahsan and Hoque 1977).

Input	Farmers (%) indicating	
	Availability on time	Adequacy
Fertilizers	13.02	6.08
Insecticides	1.93	-
Sprayers	0.96	-

surveys revealed that inputs, namely fertilizers, insecticides, and sprayers, were not adequately available to the farmers (Table 6).

A survey in 1976-77 showed better availability of fertilizers in the study area, but fertilizer use was low. Two reasons were identified: farmers' lack of capital to invest in fertilizers, and farmers' experience with crop loss, particularly in rainfed lowland rice farming systems.

There has been a general reluctance among the rice farmers to use credit. Farm surveys in different seasons for a number of years showed that only 2 to 2.5% of rice farmers used credit for crop production. When the Bangladesh Government recently initiated a crop production credit program with easier terms, more farmers asked for credit. But the impact on inputs and productivity increase has not yet been determined.

As regards farmers' experiences with hazard and crop failure and their influence on fertilizer use, rice farmers have been found to be averse to risk. A correlation analysis with farmers' hazard experience and use of fertilizers revealed a highly significant negative relationship, implying farmers' unwillingness to invest under uncertainty.

CONCLUSIONS

Rainfed lowland rice farming presents a combination of problems in Bangladesh. Modern rice varieties have performed well on irrigated land but have met an unfavorable situation in rainfed lowland rice areas. The rainfed areas are subject to drought and are vulnerable to flood and crop damage. Farmers' incentives for higher investment in rice cultivation in such areas are lacking. The situation is varied and the problems are diverse.

The solutions are difficult and their prospects are low. The available improved rice production technology does not fit the area.

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Productivity and constraints in rainfed lowland rice farming in eastern India

T. K. PAL

I base this paper on my experience as a member of an Indian Council of Agricultural Research-IRRI team for a production-oriented survey in Bihar, West Bengal, and Orissa 9-24 September 1977. The team had the broad objective of identifying production constraints in rainfed rice and making suggestions for improving rice yield in general. The extreme situations of unbunded uplands and deep water are excluded. The extent of the rainfed rice area in the three states is presented in Table 1. The data, however, are only knowledgeable guesses by researchers with years of experience in rice.

Of the 15 million ha of rice land in the three states, 7.5 million ha are considered upland bunded and shallow to semideep rainfed lowland. About 6.5 million ha of that are in transplanted rice, and the remaining 1 million ha have broadcast rice. Transplanted rice on 1.5 million ha and broadcast rice on 0.5 million ha belong to the photoperiod-insensitive type; all grow on either bunded uplands or shallow rainfed areas with water depths ranging from 0 to 15 cm. Photoperiod-insensitive rice, is, however, not to be confused with modern rices. In 1976, 2.5 million ha -- representing 17% of the rice area -- grew modern rices in the three states.

The overwhelming reliance on the photoperiod-sensitive varieties for the rainfed rice areas has become an issue. One view favors the photoperiod-sensitive types because most of the modern insensitive varieties are unsuitable for areas of increased water depth. Pankaj, Jagannath, and Mahsuri, which are among the most widely planted modern varieties in the area, perform well only to a water depth of 30 cm. The other view maintains that the monsoon in the region typically ends in late September or early October when the longer-duration photoperiod-sensitive varieties are at the flowering stage.

The second view appears to have more weight for the water regimes considered here. At the same time, the criticism against the existing photoperiod-insensitive varieties remains valid. Such varieties may be modified either by increasing their height or by incorporating some tolerance for submergence.

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Table 1. Rice area in Bihar, Orissa, and West Bengal, India, by specified characteristics, September 1977.

Type of culture, topographic position, and water depth	Transplanted area (million ha)		Broadcast area (million ha)		Total
	Photo-period sensitive	Photo-period insensitive	Photo-period sensitive	Photo-period insensitive	
Upland, bunded	1.5	1.0	-	0.5	3.0
Lowland (wet season)					
Shallow rainfed (0-15 cm)	0.5	0.5	-	-	1.0
Intermediate rainfed (16-29 cm)	1.5	-	-	-	1.5
Semideep (30-50 cm)	1.5	-	0.5	-	2.0
Total	5.0	1.5	0.5	0.5	7.5

A FIVE-VILLAGE SURVEY

The choice of varieties, the prevailing soil-water relationship, and the social, economic, and institutional characteristics of the region are reflected in low rice yields. Discussions with small groups of farmers in eight villages in the three states yielded information on some of those aspects. Three of the villages had irrigation facilities for a major part of the rice in the wet season and are left out of the discussion.

Selected factors from a survey of the remaining five villages in Bihar and West Bengal are in Table 2. The most striking feature in all the villages is the preponderance of small holdings and the large number of fragments per hectare. Both have serious implications for the introduction of modern technologies, because of the limitation imposed by the inability to purchase modern inputs like fertilizers and insecticides, and poor management due to wide scattering of tiny plots.

The normal yield levels as well as the best and poorest yields in the villages are presented in Table 3. Not only the average yields are low; even the best yields normally obtained in the villages are poor. The farmers were asked to explain the differences between the best and the poorest yields in each village. Their perception of the problem is reported in Table 4. In three villages farmers ranked favorable soil-water relationship as the most important reason for observed yield differences. These villages are in areas where floods are common. In the two other villages, use of greater amounts of fertilizers was seen as most important.

I wanted to know 1) if the farmers perceived any potential for increased rice yield with no improvement in the water condition on the farms, and 2) what the barriers to achieving

Table 2. Selected factors from a survey of five villages in Bihar and West Bengal, India, September 1977.

Factor	Bihar			West Bengal	
	Baruari	Ramdas-Majhauli	Kokdoro	Natua	Chak Manohari
Population	3500	1698	1175	34	350
Cultivated ha	333	180	205	42	75
People per cultivated ha	10	9	6	8	5
Landless persons (%)	35	20	2	17	30
Size of farm (ha)	0.8	1.0	0.6	0.4	0.4
No. of fragments on typical farm	7	11	15	5	9
Trend in yield over 10 years	same	down	up	up	down
Kg N/kg paddy	6.0	6.0	6.9	4.8	4.5

Table 3. Ranges of yield of paddy (t/ha) in five villages of Bihar and West Bengal, India, September 1977.

Village	Best yield	Av yield	Lowest yield
Bihar			
Baruari	2.0	1.0	0.5
Ramdas Majhauli	1.5	1.0	0.75
Kokdoro	2.0	1.3	1.0
West Bengal			
Natua	1.0	0.8	0.3
Chak Manohari	2.4	1.5	0.6

Table 4. Ranking of reasons for differences in best and lowest yields in five villages in India, September 1977.

Village	Rank of reasons[a]		
	Better management	Favorable soil-water condition	Ability to buy fertilizer
Bihar			
Baruari	3	1	2
Ramdas Majhauli	b	1	b
Kokdoro	2	b	1
West Bengal			
Natua	2	b	1
Chak Manohari	b	1	2

[a] 1 = most important, 3 = least important.

[b] Not important in explaining yield differences.

this potential were. In two villages in Bihar the farmers were convinced that with the existing water situation, no further improvement on the existing yields was possible (Table 5). This is a serious indictment of the current available technology. Both villages are in flood-affected areas with quite high water pressure on the rice lands. Until suitable varieties for such conditions are evolved, significant improvements in rice yields cannot be secured.

In three other villages the maximum potential yields are higher than the current best yields. The potential can, however, be achieved only through the use of larger quantities of fertilizers, for which most farmers do not have the required purchasing power. In one village, replacing existing varieties with improved ones is recognized as another measure for improving yields.

The characteristic feature of all five villages was the growing of traditional photoperiod-sensitive varieties. The typical farmer had a pair of animals (in many cases in poor health) and a country plow. The quality of land preparation leaves much to be desired. Planting is often delayed, resulting in low yields. Very little or no chemical fertilizers are used, although almost all farmers use some farmyard manure. By the time the varieties are at the flowering stage, the monsoon has receded and the rice fields have begun to dry.

Relatively shorter-duration, photoperiod-insensitive varieties would enable the farmers to escape the drought stress late in the season; however, they can be used only if they fit into the existing soil-water conditions.

Table 5. Potential maximum yield consistent with existing soil-water condition and barriers to achieving them in five villages in India, September 1977.

Village	Potential yield (t/ha)	Barriers
Bihar		
Baruari	[a]	-
Ramdas Majhauli	[a]	-
Kokdoro	4.0	Variety and fertilizer
West Bengal		
Natua	2.1	Fertilizer
Chak Manohari	3.0	Fertilizer and control of aquatic weeds

[a]Under existing conditions, yields higher than current best yields are not possible.

Table 6. Farmers' experience with high yielding rice (HYV) in five villages of Bihar and West Bengal, India, September 1977.

Village	Was HYV ever tried?	How did they perform, compared with traditional varieties?	If better, why aren't they grown now?
Bihar			
Baruari	No		
Ramdas Majhauli	Yes	Failed as rainfed	
Kokdoro	Yes	Better	High cost
West Bengal			
Natua	Yes	Better	High cost
Chak Manchari	Yes	Better	High cost

Table 6 shows farmers' experiences with rice in the wet season. In four villages modern rice had been tried in the past. In three, modern rice performed better than traditional rice. Nevertheless, modern rice is not being grown in any significant manner because of its invariably higher input requirements, especially for chemical fertilizers. Most farmers are not in a position to buy such inputs.

It appears that poverty is the most serious constraint to the use of modern rices. None of the villages suffered, however, from the total absence of some source of credit. Commercial banks had branches close to the villages. Block offices and cooperative societies offering agricultural credit were also available -- if not in the village, at least within a distance of 10-15 km. We therefore attempted to assess the need for extra funds and additional returns from modern rice in one village in West Bengal. We found that growing modern rice would involve an additional cost of Rs 900/ha to produce an extra yield of 2.2 t/ha. At current market prices the value of the added production, worked out at Rs 1,650/ha, gave a benefit-cost ratio of 1.8.

Had crop enterprises been risk-free, farmers would not have hesitated to trek a few kilometers to secure credit. Because rice cultivation shows a high degree of risk, a poor farmer shies away from borrowing. In bad years the farmers' need for borrowing increases; but as he does not meet the repayment schedule for his past borrowing he is generally ticked off the list of eligible borrowers. The team, therefore, looked into the incidence of crop losses higher than 20% during the past 5 years.

Generally, in every 2 of the last 5 years (except in Chak Manohari), the farmers experienced crop losses of more than 20% (Table 7). Drought and flood were the major sources of risk.

Table 7. Years of crop loss of more than 20% from 1972 to 1976 in five villages in India.

Reason	Years of crop loss of more than 20%				
	Bihar			West Bengal	
	Barusari	Ramdas Hajhauli	Kokdoro	Natua	Chak Manohari
Drought		1973	1975,1976	1971,1972	1976
Flood	1974,1975	1974,1975			1972
Insects	1974	1972			
Diseases		1972,1973			
Others (specify)					Aquatic weeds; every year

Contrary to general belief, insects or diseases were less frequent as a major source of crop loss.

The high risk in rice farming has discouraged the use not only of photoperiod-insensitive rice varieties, but also of modern inputs like chemical fertilizers for the traditional rices. The traditional varieties do not respond well to high dosages of chemical fertilizers, but they give moderate yield increases at low fertilizer rates. Most farmers, however, complained that they could not afford the input. Extension workers, in general, seemed to share this view. The team examined profit margins and found the prevailing nitrogen-to-paddy-price rate to be 6.0 (nitrogen price = Rs 4.50/kg, paddy price at harvest time = Rs 0.75/kg). This does not take into account the interest charged, which can often be as high as 50%, as well as risks involved. If the typical conversion of 1 kg N applied for a paddy yield increase of 10 kg is assumed, the use of nitrogen does not appear to be attractive enough.

ANALYSIS OF CONSTRAINTS

It is recognized that a proper analysis of the production constraints must look into the production system as a whole and the strengths and weaknesses of the linkages between the different subsystems in it. A recent report of the Indian Institute of Management identified three subsystems of the agricultural system:

1. producer-farmer subsystem,
2. credit and input delivery subsystem, and
3. government administrator subsystem.

The objectives of the decision makers in each subsystem differ and often conflict.

Within the subsystems, I stress farmer-seed-delivery-research and farmer-extension-research. It need not be stressed that the communication linkage should be two-way among the subsystems, rather than from the top downward as is current. A variety that fits the farmer's on-farm soil-water condition and the weather of growing season should be made available. Haye these objectives been reflected in the breeding objectives of the rice breeders until recently? Hargrove (1977) has shown that while the rice breeders perceived excessive monsoon cloudiness, drought, diseases, insects, and injurious soils as the major limiting factors to rice production, these factors received relatively lower priorities (except diseases and insects) in the breeding objectives. It takes about 10 years from the first cross to the release of a new variety, but even after the variety is released. the existing seed production program cannot ensure the availability of the seed to the ultimate users in 3 to 4 years.

As regards the second area of interest, it is common experience that the extension system in eastern India falls much below expectation. At present it is undergoing a major revision based on the training and visit system. The success of the extension program will ultimately depend on the availability of research information and new technology to feed into the system.

CONCLUSION

The prevailing low yields of rice in eastern India may be attributed to the small size of holdings and the poverty of the farmers. The land situation and extremes of weather condition have introduced an element of risk that discourages farmers from using modern inputs like chemical fertilizers. Current fertilizer prices are rather high and act as a disincentive to use. Farmers' requirements for improved rice varieties have not received adequate recognition in the breeding objectives of the rice breeders. The extension system has not acted as an effective intermediary between farmers and research workers.

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Socioeconomic aspects of rainfed rice production in northeast Thailand

KAMPHOL ADULAVIDHAYA

This paper presents a general view of the problems and socio-economic factors related to rainfed rice farming in northeastern Thailand with comparisons, wherever possible, with rice farming (both rainfed and irrigated) in the Central Plain.

THE PROBLEM

Boriboon and Sermsak (1979) discuss the area and yields of rice under different types of rainfed and irrigated conditions. They give the average rainfall in different parts of Thailand, the year-to-year variability in total rainfall and in its patterns, and the differences in topography and soils among the regions.

Rainfed rice production in different regions is affected by many factors: the differences in the physical conditions of production, along with differences in consumption patterns, transportation conditions, and milling patterns; the introduction of new crops in different regions; increasing levels of education; the increasing indications of rapid decline in population growth rates; the long-term policy of reducing the rice premium, thus increasing the price received by farmers relative to world market rice prices; and the rapid rate of growth in off-season rice production in the irrigated areas.

Farmers in the areas of floating paddy have little alternative to producing paddy. Those in the upland areas may be better off producing other crops.

The estimated 3.6 million ha of the shallow rainfed (5-15 cm) rice area represents 43% of the total rice area but only about one-third of the total production; the 23% of the total irrigated area may represent as much as 40% of the total production. Much of the increase in area planted to rice -- about 30% between 1965 and 1976 -- has been on marginal rice land.

Most of the shallow rainfed rice production is in Northeast Thailand; the remainder is in the north where people consume mainly glutinous rice -- the type very little of which is exported.

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Cassava production has increased sevenfold in the past 11 years; much of the increase has been in the northeast.

These factors make generalizations about the socioeconomic problems of producers of rainfed rice difficult.

WEATHER AND SOILS

Northeast Thailand is one of the poorest regions in the country. Weather conditions are much worse than in other regions, not because the average yearly rainfall is substantially less than in other regions but because the year-to-year variation and the seasonal distribution pattern are uneven. The rain may start as early as May in some years and as late as September in others. The arrival of substantial rain is entirely unpredictable. The uncertain rainfall pattern of Nakhon Rachasima in the northeast, for example, is notorious for causing drought damage (Table 1). In some years the rains end early, and in some years there may be a long dry spell in the middle. The variability has considerable effect on the year-to-year variation in rice production in the northeast. In addition, the northeast paddy soils are extremely sandy, compared with the heavy clay soils of the Central Plain. The maximum water-holding capacity and moisture equivalent of northeast soils are substantially lower than those of soils in the other regions. This difference aggravates the drought conditions in the northeast. An attempt was made to correlate the national paddy production with regional production for the period 1962-75. Year-to-year variation in production in the northeast and in the north was most closely related to the national variation, i.e. the variation in national production was strongly influenced by production in the northeast and north regions. This is understandable. In the Central Plain irrigation facilities are well developed and rice production is relatively free from damage by drought, but in the northeast and in the north irrigation facilities are much less developed and mostly rainfed. Therefore, rice production in these regions are at the mercy of the vagaries of the weather.

YIELD AND FARM SIZE

The 25 and 13 million rai (1 rai = .16 ha) of rainfed rice in the northeast and the Central Plain in 1976 represented about 47% and 24% respectively of the total rainfed rice area in the country. However, the yield in the northeast (1.3 t/ha) was much lower than the average at the Central Plain (1.7 t/ha) and the national average of 1.6 t/ha (Table 2).

Table 1. Rainfall at Nakhon Rachasima, northeast Thailand.

Year	Rainfall (mm)							Remarks
	May	June	July	Aug.	Sept.	Oct.	Nov.	
50-year mean	167	119	121	148	240	170	35	
1968	176	147	143	175	243	36	0	Early cessation
1972	32	136	50	57	425	193	50	Middle break
1975	175	122	202	62	228	133	51	Best year by record

Source: Department of Agriculture, Ministry of Agriculture and Cooperatives 1977.

Table 2. Planted area and yield of rainfed rice by regions, Thailand, 1975 and 1976.

Region	1975		1976	
	Area (ha)	Yield (t/ha)	Area (ha)	Yield (t/ha)
North	1,628,960	0.23	1,863,680	2.2
Northeast	3,301,600	1.14	3,998,488	1.3
Central Plain	2,118,080	1.9	2,105,398	1.7
South	602,720	1.43	551,858	1.8
Kingdom	7,651,360	1.62	8,519,026	1.7

Source: Division of Agricultural Economics, Ministry of Agriculture and Cooperatives 1975.

Both the northeast and Central Plain Regions grow dry season or irrigated rice. In 1976, the dry season rice area in the northeast was less than 1% of the country's total; that in the Central Plain was about 82%. Dry season rice yields are much higher than rainfed yields -- about 508 kg/rai or 3.2 t/ha in the Central Plain in 1976 (Table 3).

Size of farmholding varies within and among regions. Considering the area planted to both upland crops and rice, the average holding is larger in the Central Plain than in the northeast. Considering paddy area only, the farm size in both regions is about the same -- 30 rai or 4.8 ha. However, most farmers have holdings of less than 30 rai. Although farms in both regions are small, the higher yields in the Central Plain implv a higher total farm income per farm.

Table 3. Planted area and yield of dry season rice by region, 1975 and 1976.

Region	1975		1976	
	Area (ha)	Yield (t/ha)	Area (ha)	Yield (t/ha)
North	56,892	3.5	39,852	1.5
Northeast	4,092	0.6	3,978	3.8
Central Plain	303,921	1.4	360,301	3.2
South	12,377	1.8	33,596	2.9
Kingdom	2,358,012	3.2	437,727	3.2

Source: Department of Agriculture, Ministry of Agriculture and Cooperatives 1977.

CULTURAL PRACTICES

Most rice producers in the northeast still use draft animals, usually a pair of buffaloes or oxen, for plowing. In the Central Plain, land preparation is largely performed by tractors, especially two-wheel tractors and small tractors of less than 45 hp. In 1976, the 68,271 two-wheel tractors in the Central Plain and about 3,058 in the northeast represented about 76% and 3%, respectively, of the total in the country (Table 4). In both regions, transplanting and harvesting of rice are primarily done by hand. Most threshing is done by human and animal labor in the northeast; in the Central Plain it is done by tractor. In the northeast, weather variability often keeps farmers from finishing land preparation and transplanting after the rains begin. Land preparation is therefore poor and adversely affects rice yields. Under these conditions, rented tractors may increasingly be used for at least the first plowing and for other land preparation activities for rice.

Fertilizer use is increasing. For the period 1966-76, the amount used increased from 144,025 to 618,084 t -- 4.3 times the quantity used in 1966. The amount used per hectare, however, was still small: about 62.5 kg/ha for rainfed rice and about 200 kg/ha for dry season rice in 1976 for the whole kingdom. The northeast region used the lowest amount -- about 31 kg/ha for rainfed rice and 125 kg/ha for dry season rice. Farmers in the Central Plain used about 75 kg/ha for rainfed rice and about 220 kg/ha for dry season rice.

Table 5 gives some 1973-74 data on fertilizer use. In general farmers in Thailand use very little fertilizer because its price is more than two times the price of rice. In addition, uncertain weather, rice diseases and insects, and crabs and rats discourage investment in fertilizer.

Table 4. Number of tractors and size by region, Thailand, 1975-76.[a]

Region	4-wheel tractor < 45 hp No.	%	4-wheel tractor > 45 hp No.	%	2-wheel tractor No.	%	Total
North	4,109	24 (21)	4,474	34 (23)	11,220	13 (56)	19,803
Northeast	1,401	8 (18)	3,164	24 (42)	3,058	3 (40)	7,623
Central Plain	10,902	65 (13)	5,103	38 (6)	68,271	76 (81)	84,276
South	480	3 (6)	597	4 (7)	7,452	8 (87)	8,529
Kingdom	16,892	100 [14]	13,338	100 [11]	90,001	100 [75]	120,231

[a]Numbers in parentheses are percent of regional total; numbers in brackets are percent of national total.
Source: Adulavidhaya et al 1977.

Table 5. Fertilizer used for rainfed and dry season rice in Thailand by region, 1973-74.

Region, rice type	Fertilizer (t)	Kg/ha of planted area	Kg/ha of fertilized area	Areas using fertilizer (%)
NORTH				
Rainfed				
Nonglutinous	662	5.38	94.25	5.70
Glutinous	2,094	2.94	12.31	24.27
Dry season	1,740	99.88	142.69	70.00
NORTHEAST				
Rainfed				
Nonglutinous	20,751	25.44	34.31	74.15
Glutinous	45,242	21.44	33.63	63.83
Dry season	177	6.97	123.19	13.34
CENTRAL PLAIN				
Rainfed				
Nonglutinous	137,969	32.94	77.31	42.60
Glutinous	167	0.69	46.31	1.48
Dry season	11,688	53.88	221.94	24.28
SOUTH				
Rainfed	10,651	52.75	82.94	63.64
Dry season	848	109.06	206.88	52.71
KINGDOM				
Rainfed				
Nonglutinous	170,033	32.50	62.25	52.25
Glutinous	47,503	17.38	32.06	54.23
Dry season	14,453	56.25	207.13	27.16

Source: Division of Agricultural Economics, Ministry of Agriculture and Cooperatives 1977.

Rice farmers in rainfed areas of the northeast still grow more of the traditional rice varieties which are photoperiod sensitive. The most popular varieties in the region are the glutinous rice Niaw Sanpatong and the nonglutinous rice Khao Dawk Mali. The two are not resistant to many major diseases and insects. The government has released two new varieties of glutinous rice that have shown superior yield capacity but their use in the northeast is not yet widespread. Their unacceptability is partly due to the poor quality of the soils in the area. In contrast, practically all of the land in the Central Plain uses the new varieties for off-season or dry season rice cropping. Glutinous rice is the cereal staple in the northeast, and nonglutinous rice, in the Central Plain.

COST AND RETURNS

The cost of rice production per rai in the northeast is the lowest among the regions because of the low level of inputs applied. Human and animal labor is largely used and costs are relatively low. Average cost of producing rainfed rice in the northeast was about US$131/ha and US$98/t in 1976. In the Central Plain, it was about US$191/ha and US$110/t (Table 6). In the same year, the average cost of producing dry season rice in the northeast was about US$179/ha and US$135/t; in the Central Plain, it was US$274/ha and US$85/t (Table 7). The cost per ton of rice in the northeast in both seasons is relatively high compared to that in the Central Plain. That is explained by the lower yield per hectare in the northeast. Besides, the price of paddy in the northeast is lower than that of the Central Plain, which is closer to the Bangkok market. The average cash income from rice production in 1977 was US$33 in the Northeast and US$178 in the Central Plain.

TENURE AND CREDIT

Most farmland in the whole country is owned by farmers. In 1976, farmers owned an estimated 84% of farmland; only 12% was rented. In the Central Plain about 65% of the farmland was owned and about 31% was rented; in the northeast, about 91% was owned and 3% rented. The number of farmers who rented land in the Central Plain was relatively greater than that in the northeast -- about 41% vs 9%. Because many farmers still do not own land, the government has just launched a land reform scheme. The scheme aims to improve the tenure arrangement for landless farmers, small-scale farmers who have inadequate land for cultivation, and farm tenants.

Although farmers in the northeast are mostly owner-operators, they are still poor. Most are small-scale operators and are in

Table 6. Cost of production and yield of rainfed rice by region, 1974-75 and 1975-76.

Region	Cost of production US$/ha	Cost of production US$/t	Yield (t/ha)
		1974-75	
North	176	76	2.3
Northeast	132	11[illegible]	1.1
Central Plain	202	10[illegible]	1.9
South	183	127	1.3
Kingdom	164	127	1.6
		1975-76	
North	184	97	2.2
Northeast	131	98	1.3
Central Plain	191	110	1.7
South	193	82	1.8
Kingdom	161	95	1.7

Source: Division of Agricultural Economics, Ministry of Agriculture and Cooperatives 1976.

Table 7. Cost of production and yield of dry season rice by regions, 1974-75 and 1975-76.

Region	Cost of production US$/ha	Cost of production US$/t	Yield (t/ha)
		1974-75	
North	244	89	2.7
Northeast	219	75	2.9
Central Plain	271	94	2.9
South	189	84	2.2
Kingdom	266	94	2.8
		1975-76	
North	272	78	3.5
Northeast	179	135	1.3
Central Plain	274	85	3.2
South	225	123	1.8
Kingdom	273	85	3.2

Source: Division of Agricultural Economics, Ministry of Agriculture and Cooperatives 1976.

debt. On the average, they had debts of US$110/farm in 1973. The problem of indebtedness is more serious in the northeast than in the Central Plain. The government has maintained a credit program for the farmers through private banks and the Bank for Agriculture and Agricultural Cooperatives since 1966. However,

the scheme is not of much help to small farmers -- especially in the northeast -- who do not have collateral for loans. Farmers in the northeast need increased capital for new inputs.

EMPLOYMENT

The number of farm family members in the northeast and the Central Plain is about the same -- average of 6-7 per family. Of that number, 3-4 are usually active farm laborers. The family member in the northeast is usually fully employed during May to November, the rice-growing season. After rice harvest, some farmers grow upland crops such as groundnut, kenaf, tobacco, and watermelon. Some do small-scale trading or provide hired labor in town. However, many have nothing to do and are unemployed during the dry season. Unemployment is more serious in the northeast than it is in the Central Plain where a second-crop rice is possible and job opportunities in Bangkok are available. Double-cropping systems in the northeast might be one means of minimizing the problems of unemployment.

Many irrigation projects are under construction. Some have been completed in the northeast, e.g. projects in Khon Kaen, Kalasin, and Ubon Rachathani. The projects will help expand the rice area within a year and will increase the employment opportunities for farmers in the region.

EDUCATION, COMMUNICATION, AND EXTENSION

Most farmers in both the northeast and Central Plain have received formal education at least through the fourth grade level. Very few have gone beyond this level, particularly in the northeast. The opportunity for farmers to learn to read and write after completing their formal education varies from region to region, depending on the state of mass communication and transportation development. Generally speaking, the communication system is more developed in the Central Plain than in the northeast. It is generally believed that because of their somewhat higher level of formal education and the improved communication system, farmers in the Central Plain tend to accept new technology faster than those in the northeast. However, the rapid adoption of kenaf production several years ago and the recent rapid spread of cassava production in the area indicate that northeastern farmers can adopt new crops and practices under the right conditions. Information and news relating to farming have become more

available through the newspapers, published materials of both private companies and various government agencies, and through the radio. It is interesting to note that a transistor radio is usually found with the farmer working in the rice fields. The radio is assuming an increasingly important role in transmitting agricultural news and information to farmers. However, local and feeder roads are still a major need in the northeast.

Agricultural extension services are not well distributed throughout the northeast. Only where there are special projects -- irrigation, development projects, and Accelerated Rural Development special crop production projects -- are extension workers able to work closely with farmers. However, there is still lack of coordination between researchers and extension workers. Researchers lack adequate information on the problems that should be investigated, and the extension system is not clear on what extension workers should extend to farmers. It is generally felt that the research and extension programs should be integrated. Because of the lack of an efficient agricultural extension system and manpower, the Ministry of Agriculture is undertaking a World Bank-assisted project to improve the extension system and train additional manpower. The program is now under way in some parts of Thailand.

One point that should be made is that at least one extension worker should be assigned to every rice experiment station or crop experiment station. Very often farmers come to the experiment station rather than to the extension office located in the city or town.

FARMERS' INSTITUTIONS

Farmers' groups or associations patterned after those of Taiwan were introduced in Thailand many years ago. The groups are rather loosely organized. Recognizing their importance, the government has encouraged and supported the setting up of better organized farmer institutions throughout the country. The final form is the agricultural cooperative association with multiple objectives. Many have been formed in the Northeast. They are encouraged to make more efficient use of government services such as extension and marketing facilities. In addition, the farmers are to increase their bargaining power in relation to their purchase of inputs and selling of products. Improved transportation, storing, processing and other marketing facilities have already benefited farmers in the marketing of some crops. The facilities are expected to continue benefiting farmers by increasing their net income.

CONCLUSIONS

This paper has focused on the conditions in the northeast region of Thailand where the total land area relative to the population is greater than that in the north. The erratic nature of the rainfall of the northeast, both between years and within years, and the poor water-holding capacity of the soil, make much of the land marginal for rice production with the current technology. The rapid rate of growth in the production of off-season rice in the Central Plain and the expansion of irrigation facilities along the major river systems of the northeast may enable Thailand to produce less-water-demanding crops in the shallow rainfed rice-producing areas of the northeast in the future.

The fact that the northeastern region has traditionally supplied the buffalo and cattle for the rest of the country may indicate that large areas of the region could be used to produce beef as the demand for meat in the Asian regions increases.

Although a large proportion of the farmers in the northeast own land, both micro and macro economic data indicate that the farmers of the region are the poorest in the country.

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Strategies for Future Research

Future research for rainfed lowland rice[1]

Following discussion of papers and reports given during the conference, a committee considered future research strategies and took the first step toward

- defining and characterizing rainfed lowland rice,
- suggesting a general strategy,
- establishing research priorities, and
- recommending possible mechanisms for implementing or improving research efforts.

DEFINITION AND CHARACTERIZATION

Rainfed lowland was defined to include all rice-growing systems where:

- there is no artificial water supply or the supply is undependable and limited to local impoundment,
- there is intent to obtain soil saturation, and
- the water depth usually does not exceed 1 m.

For research purposes the rainfed lowland area was subdivided into three categories based on expected maximum sustained water depth:

1.	Shallow	0-20 cm
2.	Intermediate	21-50 cm
3.	Semideep	51-100 cm

GENERAL RESEARCH STRATEGY

It must be understood that rainfed lowland rice grows as a part of a cropping system, all of which conditions the specific research needs. This implies the necessity for on-farm research

[1]The following served as the Committee to develop Future Research Strategies: M. S. Ahmad (Bangladesh), S. Biswas (India), W. R. Coffman (IRRI), S. Effendi (Indonesia), F. B. Escuro (Burma), T. Eugenio (Philippines), M. V. Rao (India), and Boriboon Somrith (Thailand).

and, ultimately, a more definite characterization of the areas with special emphasis on water (all parameters), which would permit identification and development of appropriate component technology. For the present we should recognize rainfed lowland systems as being bound by time of rainfall distribution and by great uncertainty with regard to water quantity at a given time. These two factors strongly influence possible cropping systems and the establishment of research priorities.

RESEARCH PRIORITIES

The shallow category is by far the largest area, followed by the intermediate and, finally, semideep areas. Research priorities should be established accordingly.

Crop improvement

Yield stability is the most important consideration in developing varieties for rainfed lowland areas. We should utilize methods of breeding and testing geared toward selection of varieties with high yield stability. In addition to the characteristics of presently available improved varieties, other characteristics should be emphasized.

- *Drought tolerance* is a major characteristic needed for improved rainfed lowland rice varieties. It is extremely important for yield stability and is a major consideration of most farmers in the selection of a variety. Most farmers cannot afford the complete loss of a crop, and they will choose varieties that minimize drought risk, regardless of yield potential.

- *Intermediate stature and suitable seedling height* are usually necessary for rainfed lowland areas. Stresses, such as drought or adverse soils, are common to rainfed areas and tend to reduce plant height. Taller types are desirable because of undependable water depths and competition from weeds. In waterlogged areas, tall seedlings are often required for stand establishment.

- *Submergence tolerance* is clearly important in areas of uncontrollable water. Short duration floods are common in rainfed lowland areas. In such situations elongation capacity is probably a liability because the elongated plants will lodge when the water recedes. Submergence tolerance should be preferable if it can be incorporated to an adequate degree.

- *Photoperiod sensitivity* is probably required for varieties in many rainfed lowland areas. The fact that the most traditional varieties are photoperiod sensitive is not adequate evidence that the characteristic is required. Mahsuri and IR5 are relatively photoperiod insensitive, but they occupy vast rainfed lowland areas. We need more knowledge of the role of photoperiod sensitivity and a better understanding of its breeding behavior.

- *Early maturity* is clearly advantageous in many rainfed lowland areas, particularly where direct seeding is practiced. It provides for the possibility of double-cropping and minimizes risk by shortening exposure to adverse environmental conditions.

- *Tolerance for adverse soils* is particularly important in the case of rainfed lowland varieties. Flooding is seldom continuous and, depending on the particular soil, may result in a wide fluctuation of mineral concentrations in the soil solution during the cropping season.

Crop management

Crop management research should focus on stand establishment, with emphasis on direct seeding. Fertilizer management, with emphasis on nitrogen, should also be a priority.

Pest management

At present, weed control, with emphasis on direct-seeded situations, is the only priority research need in pest management for rainfed lowland areas. Disease and insect pests should not be a serious problem in the relatively less intense cropping patterns of rainfed lowland systems.

RESEARCH MECHANISMS

The recently initiated collaborative research programs, the International Rice Testing Program, and the international networks should be fully utilized in approaching the complex problem of rainfed lowland rice. Other avenues of cooperative research should be explored.

Finally, we strongly reiterate the need for research in situations that are valid representations of rainfed lowland conditions.

International Collaboration

PRELIMINARY FINDINGS FROM THE FIRST INTERNATIONAL RAINFED LOWLAND RICE OBSERVATIONAL NURSERY

D. V. SESHU and H. E. KAUFFMAN

The first International Rainfed Lowland Rice Observational Nursery (IRLRON) was initiated in 1978 following discussions at the International Rice Research Conference at IRRI, which focused on rainfed lowland rice. Twenty-eight countries in Asia, Africa, and Latin America participated in the testing of IRLRON.

IRLRON was formed with 261 entries originating from different countries (primarily Bangladesh, India, Indonesia, and IRRI). Entries included semidwarfs, intermediates, and talls, and ranged widely in maturity. Mahsuri, Pelita I-1, IR5, IR34, and BKN6986-147-2 were included as checks.

This report summarizes results from 17 tests conducted in 9 countries in Asia and Latin America (Table 1). Because of differences in growing seasons, results from all participating locations were not available at the time of preparation of this paper. Most trials were transplanted but some were direct seeded. Rainfall during the crop season varied from 492 mm at Joydebpur, Bangladesh, to 2,998 mm at Karjat, India. The nursery data included observations on plant height, days to flowering, phenotypic acceptability, and tolerance for drought, for submergence, and for diseases and insects.

Twenty-seven of the 261 entries were generally rated good for phenotypic acceptability on the basis of average scores for the trait in 14 locations (Table 2). The entries with good ratings included the check varieties Mahsuri, Pelita I-1, and IR34. Mahsuri is tall and the two others are of intermediate stature. Because the rainfed lowland situation varies from region to region, the preference for plant type and maturity varies accordingly, as reflected by the acceptability scores in Table 2. However, the intermediate-statured varieties seem to hold promise in different situations.

The entries rated good for tolerance for drought and submergence are listed in Tables 3 and 4. The other stresses that prevailed at

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Table 1. Particulars of locations where the first International Rainfed Lowland Rice Observational Nursery (1978) tests were conducted.

Test no.	Region and country	Station and location	Latitude	Longitude	Elevation (m)	Cooperator
	SOUTHEAST ASIA					
1	Burma	Agric. Res. Inst., Yezin, Pyinmana	19°N	96°E	98	Rice Division
2	Philippines	Expt. Stn., Ilagan, Isabela	17°N	121°E	45	R. J. Lara
3		IRRI, Los Baños	14°N	121°E	39	Plant Breeding, Pathology, Physiology and Entomology Deps.
4		BANCOM Farm, Tacloban, Leyte	11°N	125°E	-	F. L. Andres
5		Guimba, Nueva Ecija	14°N	120°E	-	J. C. O'Toole and M. A. Maguiling
6	Thailand	Chumpae Rice Expt. Stn., Khonkaen	16°N	102°E	215	B. Chaiwatana and S. Rajatasereekul
7	Vietnam	Agric. Stn.-1, Gialam, Hanoi	21°N	105°E	5	Dao The Tuan and Nguyen Dinh Giao
	SOUTH ASIA					
8	Bangladesh	BRRI Sub-Stn., Comilla	23°N	91°E	8	S. B. Siddique and S. K. Zaman
9		BRRI, Joydebpur	24°N	90°E	8	T. Das and M. A. Hamid
10	India	Dryland Agric. Res. Stn., Ranchi, Bihar	23°N	85°E	625	S. C. Prasad
11		Rice Res. Stn., Pattambi, Kerala	10°N	76°E	25	K. I. James and P. A. Varkey
12		Agric. Res. Stn., Karjat, Maharashtra	18°N	71°E	52	V. H. Patil, Y. S. Jadhavya, M. Madokhot, and G. Baburao
13		VVKN. Lab. Hill Agric. Hawalbagh, Almora, U.P.	29°N	79°E	1300	V. S. Chauhan and J. P. Tandon
14	Nepal	Parwanipur Agric. Stn., Parwanipur	27°N	85°E	75	B. B. Shahi and S. P. Singh
15		Kankai Agric. Stn., Chandradangi	26°N	87°E	100	S. K. Shakya and K. P. Dhungana
	LATIN AMERICA					
16	Colombia	CIAT, Palmira, Valle	3°N	76°E	1000	M. J. Rosero
17	Costa Rica	Enrique Jimenez Nunez, Canas	10°N	85°E	12	J. Murillo and J. Morera

Table 2. Entries in the first International Rainfed Lowland Rice Observational Nursery (1978) with good phenotypic acceptability ratings based on averages in 14 locations (av sc re of less than 5.0 in the 1-9 scale, where 1 is highly acceptable and 9 is highly unacceptable).

		Phenotypic acceptability ratings at														
Entry no.	Designation	Yezin, Burma	Isabela, Philippines	IRRI, Philippines	N. Ecija, Philippines	Khonkaen, Thailand	Hanoi, Vietnam	Comilla, Bangladesh	Joydebpur, Bangladesh	Karjat, India	Almora, India	Parwanipur, Nepal	Kankai, Nepal	Palmira, Colombia	Canas, Costa Rica	Av
1	BR51-91-6	3	3	5	7	5	3	5	5	8	*	3	2	6	7	4.8
18	IET4488 (CR75-93) (Mut. 11-5)	4	3	5	3	5	5	6	7	5	*	5	5	5	5	4.8
19	IET4507 (CR167-7)	4	3	5	3	5	5	6	7	4	5	3	5	5	5	4.6
34	B241C-Sm-38-1	3	3	7	3	6	1	6	7	6	*	3	3	6	7	4.7
36	B441B-126-3-2-1	4	3	7	3	5	3	5	4	7	*	5	1	7	9	4.8
52	B1050C-Mr-26-1	4	5	5	3	5	1	*	6	5	*	5	5	6	5	4.6
81	MR10	3	3	*	3	6	5	9	7	6	*	3	5	5	3	4.8
90	IR8	4	3	7	5	4	3	9	7	3	*	3	4	6	1	4.5
91	IR20	4	3	7	3	6	3	*	6	7	*	3	2	6	5	4.6
92	IR26	5	5	7	3	4	5	*	5	3	9	4	4	5	5	4.9
95	IR32	4	3	5	7	6	3	7	5	4	*	3	2	6	3	4.5
97	IR38	3	3	7	3	6	3	9	5	9	*	3	2	6	3	4.8
99	IR42	3	3	5	3	5	3	9	5	8	*	3	5	6	3	4.7
115	IR2070-199-3-6-6-2	5	5	5	3	4	3	9	4	8	*	3	2	5	7	4.8
119	IR2071-588-6-2-6-4	4	3	7	3	6	1	9	4	8	*	3	5	6	5	4.9
120	Mahsuri (check)	3	3	7	3	3	1	9	5	7	*	5	1	6	9	4.8
133	IR3464-96-3-3-1-1	3	5	7	7	6	1	9	5	6	*	3	4	5	3	4.9
134	IR3464-96-3-3-1-3	3	5	5	7	6	3	9	5	4	*	3	3	5	3	4.7
144	IR3518-106-2-2-2	4	5	5	7	6	3	*	5	3	*	3	1	5	5	4.8
176	IR4442-46-3-3-3	3	3	7	3	6	5	9	5	6	*	3	2	5	5	4.8
178	IR4568-86-1-3-2	5	5	5	3	5	3	7	5	7	*	5	2	5	3	4.6
180	IR34 (check)	4	3	5	3	6	3	7	6	8	*	3	5	4	5	4.8
197	IR5677-17-3-1	3	5	7	3	4	1	7	6	5	*	3	1	5	7	4.4
198	IR5677-17-3-1-1	3	5	5	3	6	5	7	7	3	*	3	2	6	7	4.8
201	IR5677-117-1-1-3	3	5	5	5	4	5	7	6	8	*	3	1	6	5	4.8
240	Pelita I-1 (check)	3	7	7	3	3	1	9	6	5	*	3	3	5	7	4.8
250	MRC505	4	5	7	5	5	1	5	7	8	9	3	1	5	3	4.9

[a] * indicates no observation reported.

Table 3. Entries in the first International Rainfed Lowland Rice Observational Nursery (1978) rated good for drought tolerance, based on observations at Gialam (Vietnam), Joydebpur (Bangladesh), and Ranchi (India).

Entry no.	Designation	Entry no.	Designation
12	Sein Ta Lay	115	IR2070-199-3-6-6-2
20	Mahsuri (check)	117	IR2071-485-9-2-6
34	B241c-Sm-38-1	119	IR2071-588-6-2-6-4
42	B922C-Mr-11	133	IR3464-96-3-3-1-1
59	B2039C-Kn-7-2-5-3-1	168	IR4227-109-1-3-3
68	Gogo Putih	178	IR4568-86-1-3-2
71	Lagos Sel.	179	IR4570-83-3-3-2
76	63-83	193	IR5537-20-1-3-2
77	14-M-69	240	Pelita I-1 (check)
107	IR1746-226-1-1-4	258	Nam Sagui
108	IR1746-226-1-2-3	260	IR5

Table 4. Entries in the first International Rainfed Lowland Rice Observational Nursery (1978) rated good for submergence tolerance, based on observations at IRRI (Philippines) and Parwanipur (Nepal).

Entry no.	Designation	Entry no.	Designation
52	B1050C-Mr-26-1	191	IR4870-15-1-1
168	IR4227-109-1-3-3	197	IR5677-17-3-1
171	IR4417-179-1-5-2	198	IR5677-17-3-1-1
177	IR4442-81-2-2-1	203	IR5793-55-1-1-1
182	IR4683-54-2-2-3	209	IR5817-45-3

Table 5. Entries in the first International Rainfed Lowland Rice Observational Nursery (1978) rated good for blast resistance, based on observations at IRRI (Philippines), Tacloban (Philippines) and Palmira (Colombia).

Entry no.	Designation	Entry no.	Designation
3	Chanda Amon	74	IRAT8
4	Goda	75	IRAT13
8	Surjamukhi	76	63-83
9	IAC25	82	MR15
13	Cauvery	153	IR3858-6
30	N22	168	IR4227-109-1-3-3
67	G66-SI-39-3	184	IR4707-140-1-3

Table 6. Entries in the first International Rainfed Lowland Rice Observational Nursery (1978) rated good for tolerance for bacterial leaf blight, based on observations at Yezin (Burma), Parwanipur (Nepal), and Chandradangi (Nepal).

Entry no.	Designation	Entry no.	Designation
1	BR51-91-6	191	IR4870-15-1-1
34	B241C-Sm-38-1	193	IR5537-20-1-3-2
63	B2360-6-9-5	197	IR5677-17-3-1
94	IR30	198	IR5677-17-3-1-1
95	IR32	199	IR5677-35-4-2-3
98	IR40	201	IR5677-117-1-1-3
116	IR2071-176-1-2-1	206	IR5803-171-2-3-3
138	IR3483-109-3-2-3	211	IR5853-162-1-2-3
140	Pelita I-1 (check)	214	IR5914-21-3
145	IR3518-106-2-2-5-3	242	IR9209-262-3
160	IR5 (check)	245	IR9264-32103
174	IR4432-52-6-4	248	IR9995-65
182	IR4683-54-2-2-3	260	IR5

Table 7. Entries in the first International Rainfed Lowland Rice Observational Nursery (1978) rated good for tolerance for rice tungro virus, based on observations at IRRI (Philippines) and Joydebpur (Bangladesh).

Entry no.	Designation	Entry no.	Designation
1	BR51-91-6	145	IR3518-106-2-2-5-3
3	Chanda Amon	164	IR4215-301-2-2-6
59	B2039C-Kn-7-2-5-3-1	173	IR4432-28-5
133	IR3464-96-3-3-1-1	175	IR4432-103-6-4
134	IR3464-96-3-3-1-3	193	IR5537-20-1-3-2
137	IR3483-50-1-1-1-2	207	IR5803-305-1-3-3
142	IR3511-39-3-3	211	IR5853-162-1-2-3
143	IR3518-96-2-2-2	216	IR7141-18-3
144	IR3518-106-2-2-2	218	IR7545-27-3-2

Table 8. Entries in the first International Rainfed Lowland Rice Observational Nursery (1978) rated good for tolerance for whitebacked planthopper, based on observations at IRRI (Philippines).

Entry no.	Designation	Entry no.	Designation
6	BR166-2B-8	202	IR5793-8-3-3-2
12	Sein Ta Lay	233	IR9129-169-3
14	Holamaldiga	234	IR9129-192-2
30	N22	235	IR9129-457-1
110	IR2035-117-3	236	IR9168-13-1
139	IR5677-35-4-2-3	237	IR9209-26-2

one or more locations included blast, bacterial leaf blight, tungro virus, and whitebacked planthopper. The entries rated good for those stresses are listed in Tables 5 to 8.

It is evident that international collaboration facilitates identification of elite germplasm suitable for rainfed lowland rice situations for which appropriate high yielding varieties have not yet been identified. The screening tests may help identify varieties, or donors, that can be used in breeding for

specific traits that render each variety suitable as a rainfed lowland crop. These results are preliminary but with information from other test sites and with information from subsequent rainfed lowland rice nurseries it should be possible to identify varieties suited for the diverse situations in the rainfed lowland system. Future nurseries will be tested in more appropriate test sites. Information relative to various environmental parameters will be obtained and the performance of test entries correlated with those parameters. Such a systematic approach becomes possible only through sustained international collaboration.

In conclusion, we acknowledge the contributions of the cooperators in different national programs for the information in this report.

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