UPLAND RICE
A Global Perspective

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Foreword

Nearly 20 million hectares of the world's rice growing area are planted to upland rice. About 60% is in Asia, 30% in Latin America, and 10% in Africa. Upland or dryland rice yields are quite low, accounting for only 5% of world production. The increases in world rice production over the past two decades resulted from successes in research and the transfer of modern technology. However, these successes had virtually no effect on upland rice production. This rice sector, separated hydrologically from the major lowland-flooded cultural system, has received little attention from both national and international research programs.

Upland rice growers, mostly subsistence farmers with few alternative sources of food, may soon share in the benefits of increased upland rice research. Before 1975, upland rice research was conducted at a few scattered locations in Asia, Africa, and Latin America. Since then, many national programs have targeted upland rice as a neglected agricultural commodity and have begun to establish experiment stations in upland rice areas where none previously existed.

Because research on upland rice has been limited, the Consultative Group on International Agricultural Research (CGIAR) recently requested all international agricultural research centers (IARCs) with rice programs to increase their upland rice activities and develop a global strategy for upland rice improvement. As a component of this strategy, the International Rice Research Institute initiated an Upland Rice Training Course. Dr. John C. O'Toole of IRRI was the course coordinator. He was assisted by Dr. Phool C. Gupta, on leave from G. B. Pant University in India. Both scientists soon realized that scientific literature on the subject was scarce and often difficult to obtain. This book in part is the result of their efforts to collect information on every facet of upland rice; their own extensive experience with the crop forms the remainder of the work. Student and scientist alike will find the book a comprehensive digest of upland rice research and production.

This volume was edited by Edwin A. Tout, associate editor. Gloria S. Argosino was the assistant editor.

M. S. Swaminathan
Director General

Preface

The inception of this volume was a charge given the authors in 1982. In preparation for the first Upland Rice Training Course at IRRI, we attempted to collect, organize, and integrate all available information from any location and in any language that dealt with any aspect of upland rice. In the resulting book, we have tried to balance the treatments of Asia, Africa, and Latin America. We acknowledge a bias toward our Asian experience, but we believe this is adequately offset by the excellent cooperation among national and international organizations in holding conferences and workshops on various aspects of upland rice research during the past four years. These exchanges between scientists and institutions have contributed greatly to our effort. In addition, the enthusiastic cooperation of upland rice workers around the world has contributed greatly to the information base we relied on to provide balance in our treatment of various upland rice producing regions.

Research on upland rice is in its infancy. Much of the information is unpublished and difficult to evaluate. We regret that many references in this volume are unpublished. We feel, however, that the compilation of this information is necessary, even though much of the content has not passed through the normal process of scientific review. We are indebted to those scientists and institutions who provided their unpublished information for this purpose.

We are acutely aware of the difficulty in defining the subject of this book - upland rice. The reader will encounter this problem frequently throughout the book, and many will disagree with our terminology in light of their local or provincial reference points. The problem is aggravated by our obligation to assume a global perspective, which requires some degree of generalization. We ask the reader to appreciate fully the heterogeneous array of physiographic, edaphic, climatic, biotic, and socioeconomic conditions in which upland rice is grown. With this in mind, each of the book's 12 chapters provides a synopsis of the most relevant topics concerning upland rice research and production.

Chapter 1 presents the geographic range and estimates of upland rice area in Asia, West Africa, and Latin America.

Chapter 2 illustrates the range of climatic variables such as precipitation, solar radiation, temperature, relative humidity, and wind in many upland rice growing regions. Interactions with upland rice growth and yield as well as other physical and biological factors are discussed.

Chapter 3 describes the basic physiography and soil taxonomy of upland rice regions. The physical, chemical, and biological properties of soils are discussed in relation to upland rice growth.

Chapter 4 discusses the role of upland rice in various types of cropping systems, i.e., shifting cultivation, monoculture, and intercropping. Global variations in the role of rice are compared and contrasted.

Chapter 5 deals with varietal improvement through sections on evolution, anatomy, genetics, and principles and procedures of plant breeding. Breeding for specific pests and environmental stresses are dealt with separately.

Chapter 6 emphasizes the principles of upland soil management, including soil and water conservation and erosion control. Soil fertility and nutritional disorders are covered as is the management of problem soils on which upland rice is grown.

Chapters 7 and 8 cover the wide variety of methods and equipment used for land preparation, seeding, weed control, harvesting, and threshing.

Chapters 9, 10, and 11 deal with pests such as weeds, diseases, insects, birds, and rats. Major upland rice pests and their control are discussed. Because of the regional specificity of pest species, principles that apply in Asia, Africa, and Latin America are emphasized.

Chapter 12 provides an introduction to the economics of upland rice production in the realistic context of its role in a cropping system.

We sincerely hope that this synthesis of multidisciplinary reports and experiences will be a useful reference for students and scientists. We gained much from this experience and appreciate the opportunity and support afforded by the International Rice Research Institute and the study leave granted to Dr. P. C. Gupta by G. B. Pant University of Agriculture and Technology, Uttar Pradesh, India.

P. C. Gupta
J. C. O'Toole

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FAO. 1976. Mechanization of rice production: India-Nigeria-Senegal. An International Coordinated Research Project, 1970-76. (Table 8.4, 8.5, 8.6, 8.7; Fig. 8.1, 8.11)

Grim, R.E. 1968. Clay mineralogy. McGraw-Hill Book Co., New York. (Table 3.5)

Hillel, D. 1980. Fundamentals of soil physics. Academic Press, New York. (Fig. 3.4)

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Oldeman, L.R., and M. Frere. 1982. A study of the agroclimatology of the humid tropics of Southeast Asia: technical report. FAO/UNESCO/WMO Interagency Project on Agroclimatology. Food and Agriculture Organization of the United Nations, Rome. (Fig. 2.7, 2.15)

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Sanchez, P.A. 1981. Soil management in the savannah and jungles of South America. In Characterization of soils in relation to their classification and management for crop production: examples from some areas of

humid tropics. D.J. Greenland, ed. Oxford University Press, England. (Fig. 3.3)
Young, A. 1976. Tropical soils and soil survey. Cambridge University Press, Cambridge, England. (Table 3.7).

UNPUBLISHED REFERENCES

We utilized several unpublished materials in preparing this upland rice book because published information was not sufficient in many areas. We sincerely acknowledge these scientists who allowed the use of their unpublished information in our book. We list their names below. The bibliographic details are given in References Cited at the end of each chapter.

A. O. Abifarin, A. A. Agboola, N. R. Alemania, K. Alluri, J. T. Amoloza, E. L. Aragon, M. Arraudeau, A. Azim, L. A. Barrios, I. Basa,. A. de Beauville, J. M. Bonman, S. W. Buol, R. Brinkman, A. J. Carpenter, E. M. Castin, R. Chabrolin, C. Chandaratat, T. T. Chang, C. Charreau, A. Chinchest, M. A. Choudhury, S. L. Choudhury, G. S. Chung, M. G. Cline, W. R. Coffman, V. P. Coronel, I. Cosico, J. P. Crill, R. T. Cruz.

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CHAPTER 1

Upland Rice Distribution

Upland rice has been described in many ways in different parts of the world. This book follows the definition adopted for the 1982 upland rice research workshop in Bouake, Ivory Coast. “Upland rice is grown in rainfed, naturally well drained soils without surface water accumulation, normally without phreatic water supply, and normally not bunded” (13). Huke (9) used dryland rice instead of upland rice and defined it as “rice grown in fields that are not bunded, are prepared and seeded under dry conditions, and depend on rainfall for moisture.” Upland rice thus resembles dryland rice as used by Huke (9) and IITA (15). The French *pluvial rice* also equates with upland rice.

The true extent of upland rice distribution is unclear. In many countries, land where upland rice is grown is not described separately from land for other rice culture. The quantification of upland rice is further complicated because it is intercropped or relay cropped with maize, sorghum, soybean, cowpea, cassava, sugarcane, coconut, and spices. Often, intercropped upland rice area is not counted. Nevertheless, it is possible to broadly describe upland rice distribution.

GEOGRAPHICAL DISTRIBUTION

Upland rice is grown in Asia, Africa, and Latin America. Of 143.5 million ha of world rice area, about 19.1 million ha, 13.2%, is planted to upland rice. Of this, 10.7 million ha is in Asia, 6.1 million in Latin America, and 2.3 million in Africa (11) (Table 1). Although upland rice constitutes a relatively small proportion of total rice area, in Latin America and West Africa it is the dominant rice culture (Fig. 1). About 75% of rice area in Latin America and 50% in Africa is upland rice.

Except in Brazil, where more than 5 million ha of upland rice are under mechanized cultivation, it is a subsistence crop (11) planted by poor farmers who apply few purchased inputs. Yields average about 1 t/ha (2). In favorable areas of Latin America, however, yield may be 2.5 t/ha (4).

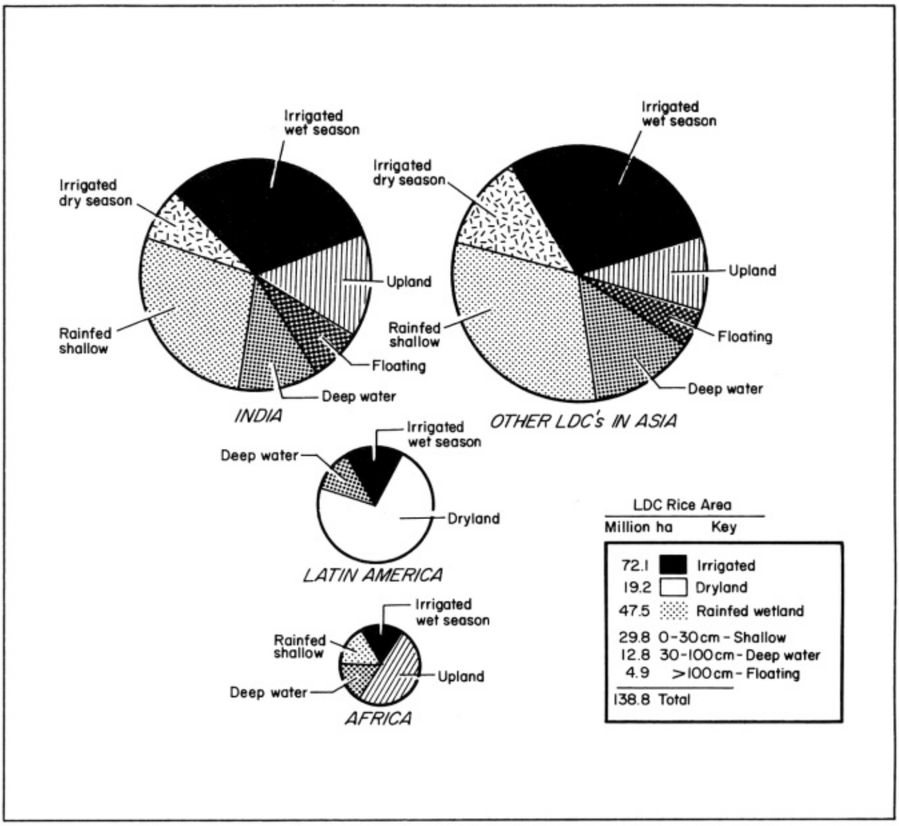
Southeast Asia

In Southeast Asia, upland rice is grown on 4.6 million ha, or about 13% of the rice area (Table 2). Indonesia plants 1.1 million ha, followed by Thailand with 0.96 million ha. Burma grows 0.79 million ha. Kampuchea, Vietnam, and the Philippines each have more than 0.4 million ha. Laos has 0.3 million ha and Malaysia 91,000 ha of upland rice. Upland rice distribution in Southeast Asia,

Table 1. Estimated rice area by dominant water regime (11).

Location	Total rice area (thousand ha) 1978-80	Rice area (thousand ha) by water control: Irrigated		Rainfed				% upland to total rice area
		Dry season	Wet season	Shallow[a]	Deep water[b]	Floating[c]	Upland	
India	39,500	2,700	12,700	11,100	4,500	2,500	6,000	15.2
China	35,300[d]	[e]	33,600	1,800	0	0	0	0
Bangladesh	10,100	1.000	200	4,300	2,600	1,100	900	8.9
Thailand	9,300	500	1,300	4,900	1,100	400	1,000	10.8
Indonesia	9,000	2,700	4,600	600	300	200	700	7.8
Vietnam	5,200	800	1,200	1,400	900	400	400	7.7
Burma	4,800	100	700	2,000	1,000	200	700	14.6
Philippines	3,400	600	900	1,200	400	0	400	11.7
Pakistan	2,000	0	2,000	0	0	0	0	0
Nepal	1,300	0	300	700	200	50	50	3.3
Korea	1,200	[e]	1,200	0	0	0	0	0
Sri Lanka	700	200	300	200	0	0	50	7.1
Malaysia	700	200	200	200	0	0	100	14.3
Lao People's Republic	700	0	50	300	0	0	300	42.8
Kampuchea	600	0	50	200	50	100	100	16.7
Developing Asia	126,000[f]	8,800	61,400	29,000	11,200	4,950	10,700	8.5
Latin America	8,200[g]	0	1,200	0	900	0	6,100	74.4
Africa	4,600	0	800	700	700	0	2,300	50.0
Other[h]	4,800	[i]	4,800	0	0	0	0	0
World	143,500	8,800	68,200	29,700	12,800	4,950	19,100	13.2

[a]0-30 cm. [b]30-100 cm. [c]More than 100 cm. [d]Allocation by estimation rather than data. [e]All rice grown during the summer months and shown under wet season. [f]Including 1,800,000 in countries not separately identified. [g]Brazil has 6,200,000 ha. [h]Japan has 2,500,000 ha, the USA has 1,250,000 ha. [i]Physically Included in the irrigated wet season area, but harvested in dry and wet season.



1. Areas of rice in developing countries by type of culture (adapted from IRRI 1982).

Table 2. Rice area in Southeast Asian countries.[a]

Country	Area (thousand ha)					
	Upland	Deep water	Irrigated		Rainfed	
			Wet season	Dry season	Shallow (0-30 cm)	Intermediate (30-100 cm)
Burma	793	173	780	115	2,291	1,165
Thailand	961	400	866	320	5,128	1,002
Vietnam	407	420	1,326	894	1,549	977
Kampuchea	499	435	214	-	713	170
Laos	342	-	67	9	277	-
Malaysia	91	-	266	220	147	11
Indonesia	1,134	258	3,274	1,920	1,084	534
Philippines	415	-	892	622	1,207	379
Total	4,642	1,686	7,685	4,100	12,396	4,238
% of total	13	5	22	12	36	12

[a]Total area (double-cropped areas counted twice) is 34,747,000 ha (g).

shown in Figure 2, is derived from the map, *Southeast Asia — rice area planted by culture type,* developed by Huke (9).

South Asia

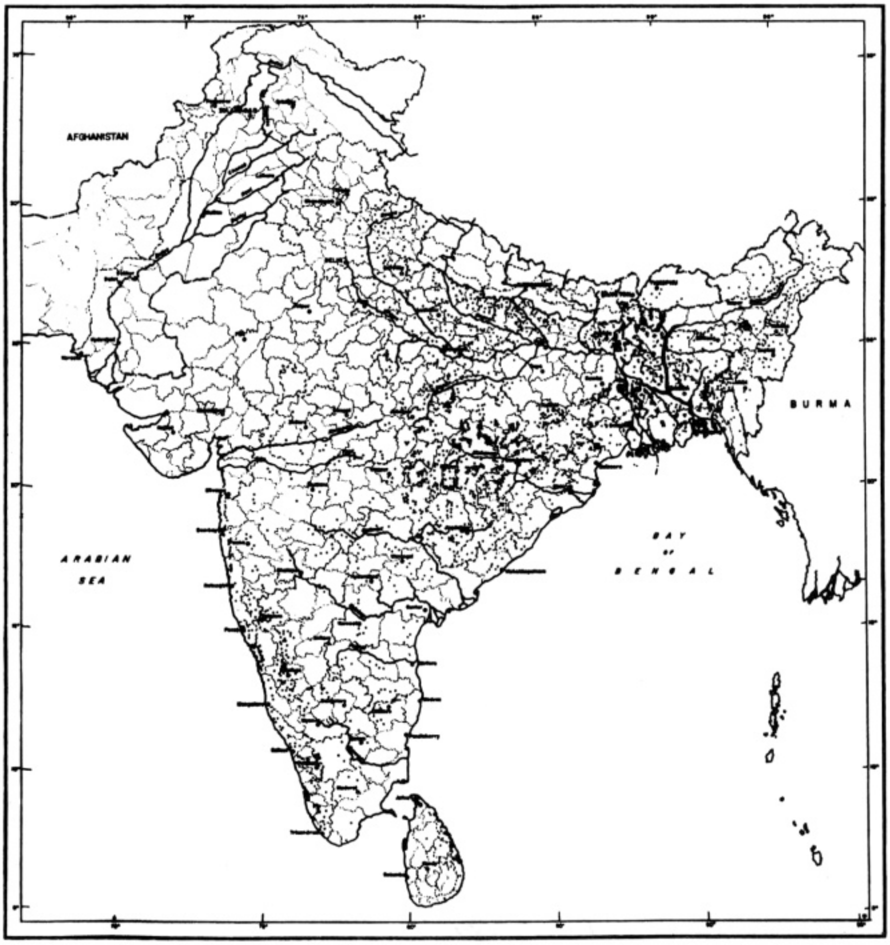
More than 50% of Asian upland rice is grown in South Asia, where it represents about 13.4% of total rice area. Most of the area (6 million ha) is in India. Another 0.85 million ha is grown in Bangladesh. Sri Lanka, Nepal, and Bhutan each have 50,000 ha or less (Table 3). Figure 3 (9) shows upland rice distribution in South Asian countries.

2. Dryland rice distribution in Southeast Asia. Each dot represents 3000 hectares (9).

Table 3. Rice area in South Asian countries[a] (9).

Country	Area (thousand ha)					
	Upland	Deep water	Irrigated		Rainfed	
			Wet season	Dry season	Shallow (0-30 cm)	Intermediate (30-100 cm)
India	5,973	2,434	11,134	2,344	12,677	4,470
Bangladesh	858	1,117	170	987	4,293	2,587
Pakistan	–	–	1,710	–	–	–
Sri Lanka	52	–	294	182	210	22
Nepal	40	53	261	–	678	230
Bhutan	28	–	–	–	121	40
Total	6,951	3,604	12,569	3,513	17,979	7,349

[a]Total area planted (double-cropped areas counted twice) is 52,965,000 ha.



3. Dryland rice distribution in South Asia. Each dot represents 3000 hectares (9).

In India, most upland rice is grown in the eastern and north central states and along the southwestern coast. Principal upland rice growing states are Madhya Pradesh (1.3 million ha), West Bengal (0.88 million ha). Uttar Pradesh(0.7 million ha), Orissa (0.7 million ha), and Bihar (0.53 million ha) (9). In Bangladesh, most upland rice is in Jessore, Rangpur, and Mymensingh. In Sri Lanka, Batticaloa, Trincomalee, and Ampara are the principal districts. Only small areas are planted in Nepal and Bhutan.

About 600,000 ha is grown in China and 100,000 ha in North Korea. Given the present yield and area planted, Huke (9) estimated that Asian upland ricelands may supply 46.2 million people 75% of their average daily needs (Table 4).

Africa

Earlier inventories of upland riceland in Africa included rice grown on welldrained soil and hydromorphic rice grown on soils where the water table may be near the surface during the growing season. These two rice culture types were separated in a 1977 conference at the International Institute of Tropical Agriculture (IITA) (10, 15).

Estimates of upland rice distribution in Africa vary greatly because of the diverse nature of its cultivation. Roughly 40-50% of the rice area is planted to upland rice (1, 11).

Table 4. Human support or carrying capacity of rice area in South and Southeast Asia, by cultural type or water regime in 1980 [a].

Land type	Area[b] (thousand ha)	Mean yield (t/ha)	Area (ha) needed to support 1 person [c]	Support capacity (no. of persons)
Deep water (> 1 m)	5,308	1.0	0.220	24,150,000
Irrigated (all)	28,984	3.8	0.058	497,720,000
Shallow rainfed (0-30 cm)	30,248	1.8	0.122	247,930,000
Intermediate rainfed (30 cm-1 m)	11,547	1.2	0.183	63,100,000
Upland	11,558	0.9	0.250	46,230,000
Total	87,645			879,130,000

[a]Includes all nations from Pakistan through the Philippines but China, Japan, and Korea. Population in 1980 was 1,233,900,000. Population data are from the 1978 World Population Reference Bureau, Washington, D. C., USA and were increased by 5% to account for 2 yr of growth. [b]Estimated by R. E. Huke, IRRI visiting scientist. [c]Assuming 220 kg rough rice/capita per year, which equals 140 kg cleaned rice or 1,380 cal/person per day, which is 75% of the daily requirement in southern Asia (no waste is considered).

Table 5. Rice production systems in West Africa (10).

System	Area (thousand ha)	% of total
Upland	1,437	62.5
Hydromorphic	58	2.5
Mangrove swamp	184	8.0
Lowland swamp	506	22.0
Irrigated	115	5.0
Total	2,300	100.0

Most African upland rice is grown in West Africa, where about 1.4 million ha (62.5%) of the rice is upland (Table 5). More than half of the rice grown in Ivory Coast, Liberia, Zaire, Sierra Leone, Guinea, and Nigeria is upland (1,5) (Table 6 and 7). There is some discrepancy in data because the West Africa Rice Development Association (WARDA) includes as upland rice areas lands which occasionally are submerged by runoff water and where groundwater level is in the root zone during the growing season. These areas are classified as hydromorphic by IITA and phreatic by the Institut de Recherches Agronomiques Tropicales (IRAT). Figure 4 shows upland rice distribution in West Africa.

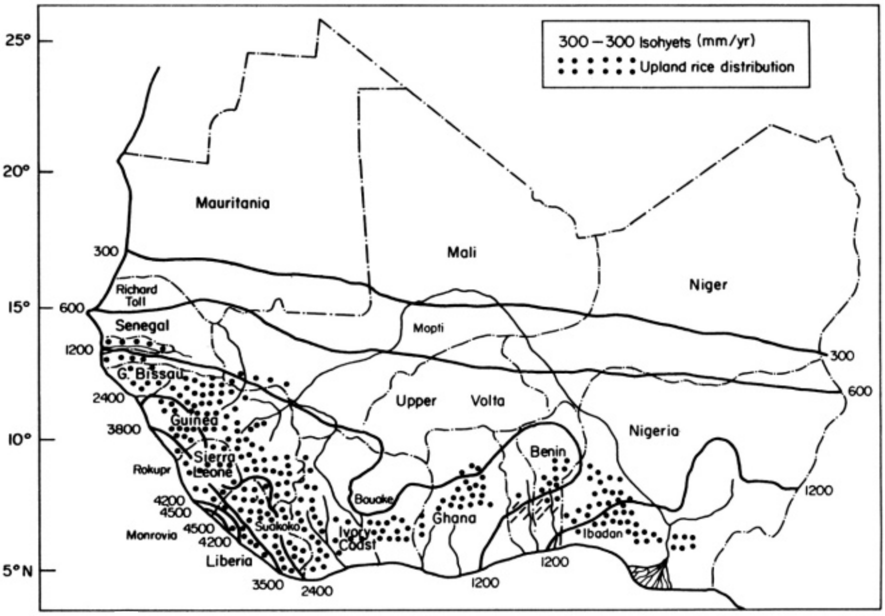
There also are large upland areas in Zaire, Madagascar, and Tanzania (1,10). In East Africa, upland rice cultivation on welldrained soil is limited by low rainfall and is less important than hydromorphic and swamp rice (10).

Table 6. Upland rice area in Africa in 1981 (1).

Country	Total rice area (thousand ha)	Upland rice area (thousand ha)	Upland as % of total
Ivory Coast	475	450	95
Liberia	180	170	95
Zaire	250	260	90
Sierra Leone	400	300	75
Guinea	380	230	60
Nigeria	450	240	55
Madagascar	1,175	310	26
Senegal	85	15	16
Mali	160	Negligible	Negligible
Tanzania	150	Negligible	Negligible
Egypt	400	0	0
Others	530	25	5
Total	4,675	2,000	43

Table 7. Upland rice area in the WARDA region in 1982 (5).

Country	Upland area (thousand ha)	% of rice area
Benin	5.3	54
Gambia	4.7	15
Ghana	59.0	97
Guinea	315.0	58
Guinea Bissau	16.8	40
Ivory Coast	430.0	93
Liberia	178.2	89
Mali	7.8	5
Mauritania	0.0	0
Niger	0.0	0
Nigeria	104.9	22
Senegal	52.0	71
Sierra Leone	241.0	65
Togo	17.8	72
Upper Volta	18.9	49
Total	1451.5	58



4. Categories of rice cultivation and rainfall distribution (preliminary) in West Africa.

Per hectare production in West Africa is low: about 1.2 t/ ha for all rice systems. According to Arraudeau (1), major upland rice growing countries produced about 0.9 t/ ha a year between 1970 and 1979.

Latin America

Upland rice in Latin America is substantially more important than in Asia and Africa. It is grown on 6.1 million ha. With yields of a little more than 1 t/ha, it gives a total production of about 7.5 million t (4). Brazil has the largest area, 5.4 million ha. Other countries with sizable upland rice areas are Colombia, Venezuela, Costa Rica, Panama, Mexico, Bolivia, and Ecuador (Table 8, Fig. 5).

Upland rice represents 77% of Brazil's rice area and about 66% of national rice production. It is grown in rainy season mainly in the central region. Shifting upland cultivation is practiced in the northeast Amazon basin (Fig. 6). Most irrigated rice is grown in the south.

In the last 12 yr, the irrigated rice area decreased 23%, but productivity increased 27%. The upland rice area nearly doubled in those years, but productivity (1.2 t/ha) did not increase (7) (Table 9).

ENVIRONMENTAL DISTRIBUTION

Upland rice environments vary widely, making it difficult to extend to other locations technologies and genetic material developed for one location. Environmental variability has encouraged classification of upland rice environments so

Table 8. Rice area planted in major production systems in tropical Latin America in 1980 (4).

Country	Area (thousand ha)			
	Irrigated	Favored upland[a]	Unfavored upland[b]	Total upland
Brazil	779	1558	3894	5452
Mexico	73	37	23	60
Tropical South America	577	231	136	367
Bolivia	0	17	38	55
Colombia	308	21	93	114
Ecuador	51	53	0	53
Paraguay	21	11	0	11
Peru	72	23	5	28
Venezuela	125	106	0	106
Central America	31	149	73	222
Costa Rica	2	77	3	80
El Salvador	4	10	0	10
Guatemala	0	9	3	12
Honduras	1	5	13	18
Nicaragua	22	5	0	5
Panama	2	43	54	97
Caribbean	442	45	3	48
Guyana	86	35	0	35
Cuba	206	0	0	0
Dominican Republic	108	0	0	0
Haiti	38	10	3	13
Jamaica	4	0	0	0
Tropical Latin America	1902	2020	4129	6149
Excluding Brazil	1123	462	235	697

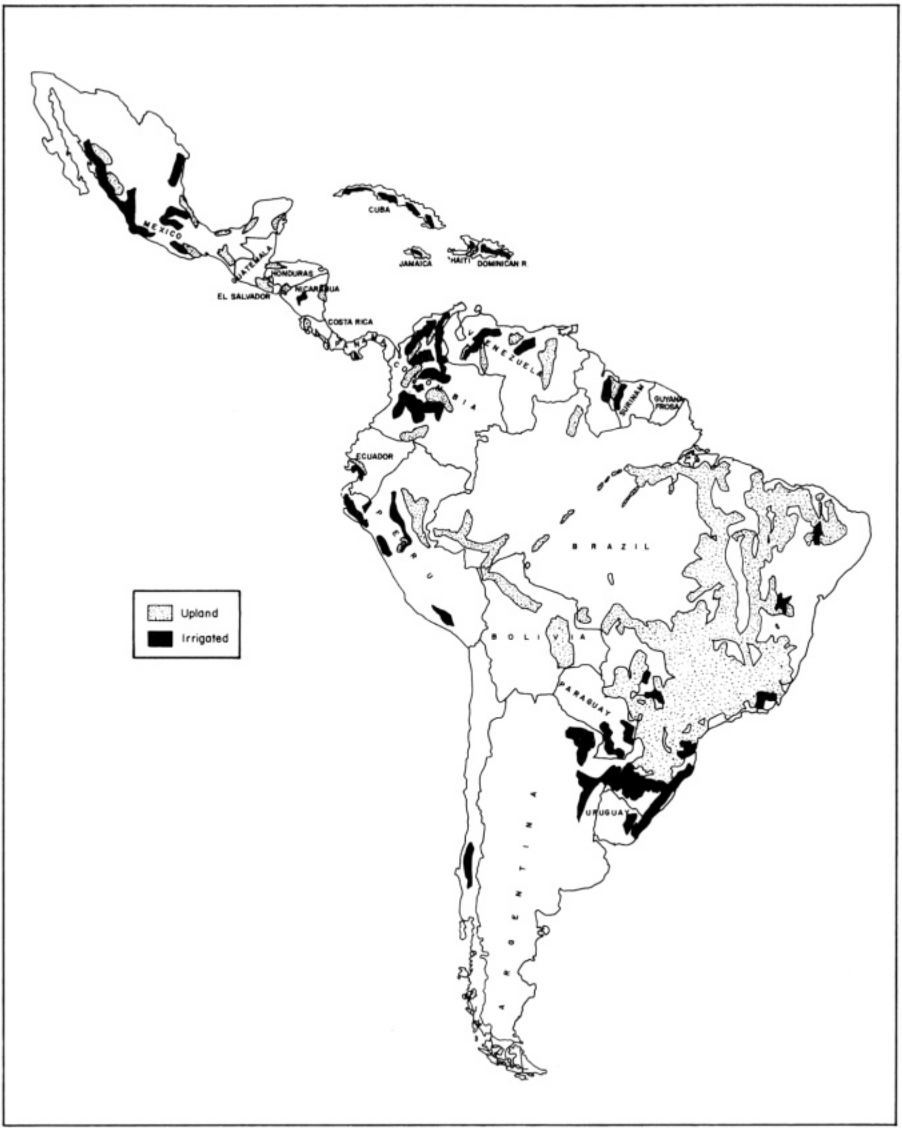
[a] Rainfed lowland rice data are included in favored upland. Estimate of area planted includes 520,000 ha in the Varzeas of Brazil, 20,000 ha in the Pozas of Ecuador, and a small area in the Dominican Republic. [b] Traditional (subsistence) upland is included In unfavored upland. Estimated area in tropical Latin America is 950,000 ha, mainly in Brazil, Colombia, Panama, Bolivia, and Costa Rica.

that technologies and genetic materials can be easily identified for analogous environments. Assessing upland rice distribution by environment also helps identify the constraints that limit productivity and therefore helps devise suitable management tactics to increase productivity.

Asia

Asian upland rice environments have been divided into four complexes based on climate and soil data. Sites are classified as having long (5-12 mo) or short growing seasons (1-4 mo) and fertile (inherent fertility 1-5) or infertile soils (6-9).

About 15% (1.72 million ha) of upland rice is in the most favorable environments, those with 5 mo rainy season and relatively good soil. Those areas are in eastern and southwestern India, Bangladesh, Indonesia, and the Philippines. Most upland rice, 33% is grown where rainy season is long but soils are poor: southwestern and northeastern India, Indonesia, Burma, Vietnam, Thailand, Laos, Kampuchea, and the Philippines. About 27% of upland rice is grown where rainy season is short but soils are good (central India and Bangladesh), and 25% is



5. Latin America irrigated and upland rice regions.

in areas where rainy season is short and soils are poor (eastern India, Kampuchea, and Thailand) (8, 12).

Africa

There is no classification of African upland environments because it is difficult to assess their distribution. Upland rice is grown in the savanna and forest regions in West Africa. Short-duration (100 d) varieties are grown in the savanna and

6. Upland rice in Brazil (6).

long-duration (150 d) ones in the forest. The Sudanese savanna has fewer wet months than the Guinea savanna and the woodland fewer than the forest. In the forest, farmers practice shifting, slash-and-burn cultivation (3). Generally, however, upland rice is grown in the humid forest zone where it is intercropped with other upland crops (10).

Latin America

In Latin America, upland rice is grown in a variety of ecosystems that range from extremely low (cerrado, Brazil) to high levels of productivity (llanos, Colombia). Jennings et al (14) divided Latin American ecosystems into favored, moderately favored, unfavored, and subsistence environments. They also have been classified as favored and unfavored. Steinmetz et al (16) used the term favorable for upland rice where there is at least 66% probability of more than 50 mm rainfall/ 10 d in the growing season.

CIAT (4) described upland rice distribution:

- *Favored upland rice* is grown on flat land where more than 2000 mm of rainfall falls during a 6-8 mo rainy season. Yields average 2.5 t/ha, but better

Table 9. Rice production in Brazil *by* area and yield (7).

Year	Southern Brazil (irrigated)			Rest of Brazil (upland)			Total		
	Area (thousand ha)	Yield (t/ha)	Production (thousand t)	Area (thousand ha)	Yield (t/ha)	Production (thousand t)	Area (thousand ha)	Yield (t/ha)	Production (thousand t)
1970	2617	1.8	4647	2362	1.2	2906	4979	1.5	7553
1971	2422	1.6	3797	2342	1.1	2596	4764	1.3	6393
1972	2390	1.9	4545	2431	1.4	3379	4821	1.6	7924
1973	2365	1.6	3841	2430	1.4	3326	4795	1.5	7167
1974	2306	1.7	3936	2359	1.2	2828	4665	1.4	6764
1975	2509	1.7	4372	2798	1.2	3410	5307	1.5	7782
1976	2882	1.8	5312	3774	1.2	4445	6656	1.5	9757
1977	2429	1.8	4490	3563	1.3	4504	5992	1.5	8994
1978	2117	1.7	3567	3506	1.1	3729	5623	1.3	7296
1979	1846	1.8	3324	3593	1.2	4265	5439	1.4	7589
1980	2146	2.2	4764	4325	1.1	4874	6471	1.5	9638
1981	2134	2.2	4746	4492	0.9	3892	6626	1.3	8638
1982	2014	2.6	4550	4120	1.2	5041	6134	1.6	9591

farmers harvest 4–5 t/ha. Favored uplands are in Venezuela, southern Brazil, Central America, and Colombia.

- *Moderately favored upland rice* is grown on less fertile soils, receives less rainfall than that in favored areas, and has 2-3 wk of drought during crop growth. It is grown in parts of Bolivia, Ecuador, Mexico, Venezuela, in most of Central America, and in much of sub-Amazonian Brazil. Average yield is 1.5 to 2.0 t/ha.
- *Unfavorable upland rice* is grown where there is low, irregular rainfall, mostly in the central Brazilian cerrado (savanna). The crop may have a 20–to 30-d drought. Yield averages 1 t/ha.
- Subsistence upland rice is grown in remote areas of northeast Brazil where farmers plant rice for family consumption and practice shifting cultivation. Yield is low (6).

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CHAPTER 2

Climate

Rice (*Oryza sativa* L.) is a semiaquatic crop. Upland rice is therefore cultivated at the ecological limits of the species and thus climate, particularly rainfall, is a critical determinant of its productivity. Upland rice is grown in several tropical zones. In addition to rainfall, solar radiation and temperature strongly influence growth and yield. In this chapter we discuss these major climatic parameters and their interaction with upland rice growth. Examples from Asia, Africa, and Latin America illustrate the climatic variation within and among upland rice growing regions.

RAINFALL

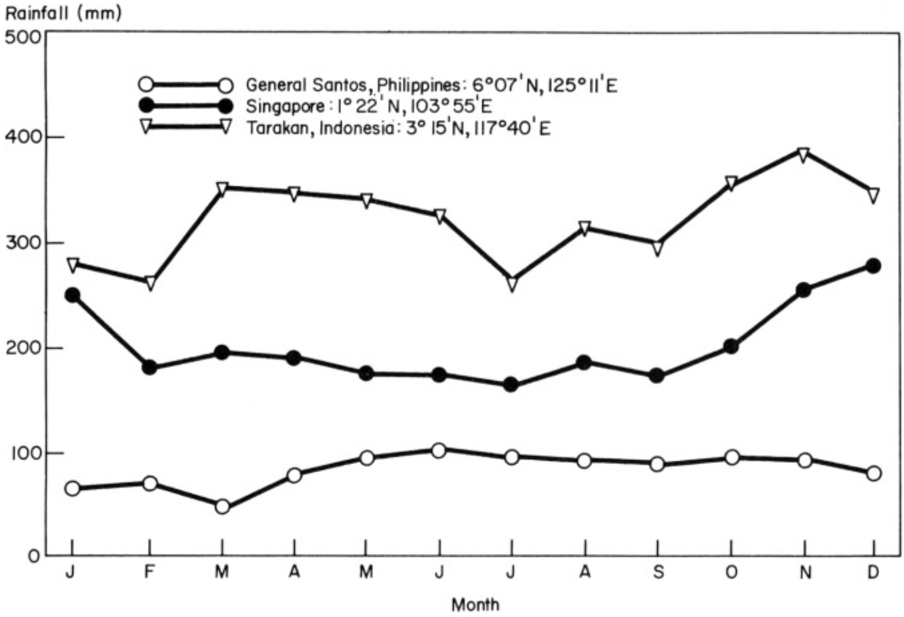
Rainfall is the most variable and least predictable agroclimatic element. Its amount and distribution determine the upland rice cropping season. Because rice is so sensitive to water stress, rainfall distribution is more important than seasonal total. Jana and De Datta (17) showed that water deficits reduced yields in experiments in the Philippines even when annual rainfall was more than 2,000 mm.

Three basic tropical rainfall regimes affect upland rice culture: generally even rainfall throughout the year, a monomodal annual peak, and bimodal annual peaks. Most seasonal and spatial rainfall variation is associated with movement of the intertropical convergence zone (ITCZ). The ITCZ is a function of the displacement and intensities of semipermanent temperate high pressure systems (16). Asian monsoons represent the moving path of the ITCZ.

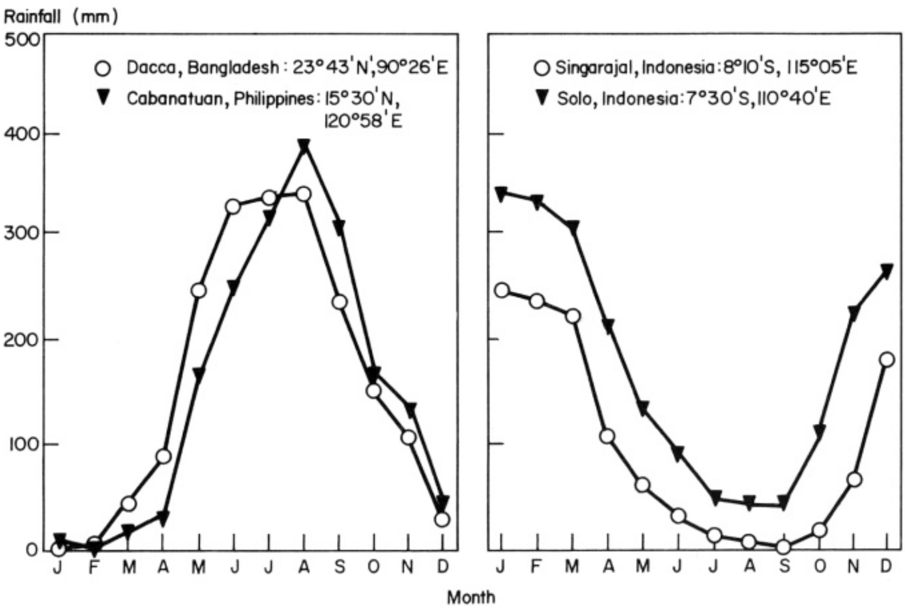
The movement of these systems and their interaction with land and sea produce moist and dry air masses. Sharp discontinuities in humidity may occur within the ITCZ. The proximity of an area to a source of moist air, such as oceans, and the localized effects of mountain ranges modify ITCZ effects. Mountain ranges increase monsoon rainfall on the windward side or reduce it on the leeward.

The beginning and end of the monsoon varies each year. Therefore, rainfall regimes can be established only if long-term records are available for analysis. Fortunately, extensive records are available for much of the world.

In some tropical locations, monthly rainfall varies little and there is no distinct wet or dry season. This rainfall pattern occurs near the equator, where the ITCZ has less influence. Figure 1 gives three examples: General Santos, Philippines, has an average 100 mm rain/mo; Singapore, about 200 mm/mo; and Tarakan, Indonesia, about 300 mm/mo. Figure 2 shows the monomodal rainfall regime



1. Mean monthly rainfall regimes with minimal seasonal variation (27).



2. Mean monthly rainfall regimes with monomodal distribution north (a) and south (b) of the equator (27).

most characteristic of monsoon Asia. The pattern north of the equator contrasts with that south of it. Bimodal peaks are characteristic only of Asia north of the equator (Fig. 3) and in a relatively limited zone in West Africa (20).

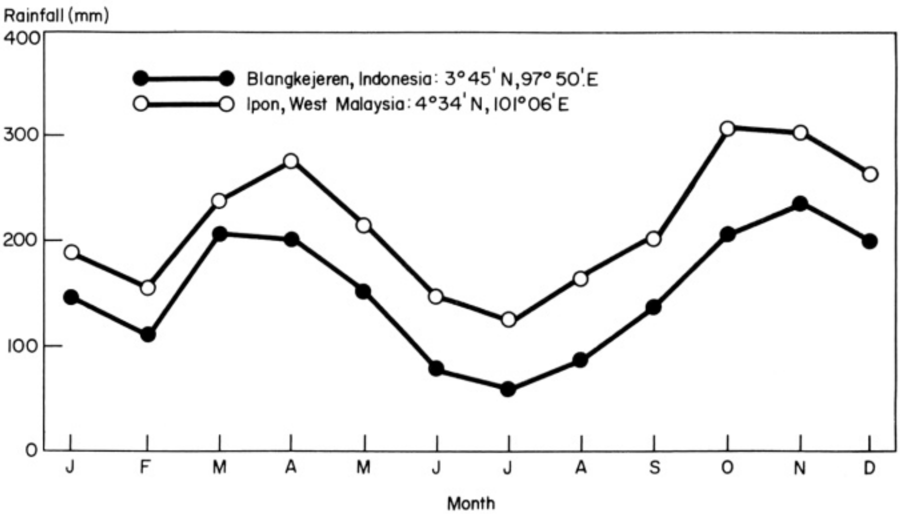
The intensity of bimodal peaks varies and the degree of dryness between the peaks determines the suitability of cropping patterns. Often, upland rice varieties are chosen for duration or photoperiod sensitivity to match critical growth stages to a bimodal pattern.

Rainfall variability within the cropping season is extremely important to upland rice production and is a key to developing genetic and agronomic technology for an area. Unfortunately, rainfall records are usually published as monthly means, which is inadequate for agricultural planning. Weekly or 104 rainfall totals for ³ 25 yr are desirable and allow probability analysis.

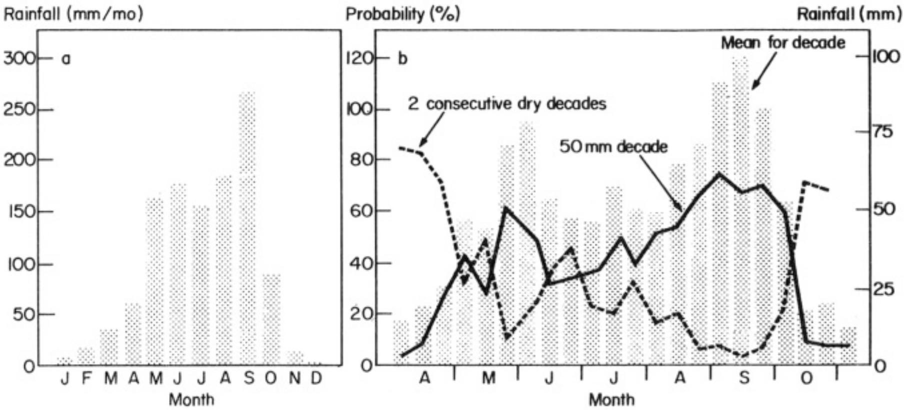
Oldeman and Frere (28) showed how 10-d (decade) analysis of rainfall records provides more relevant information than monthly means. Figure 4 shows both types of information for Khon Kaen, Thailand. The decade information base illustrates a slight bimodal seasonal trend that is not discernible in the monthly means. Contrary to the monthly May mean of more than 150 mm, the decade information shows that the probability of getting at least 50 mm/ decade is less than 50% during the first 2 decades of May.

The monthly mean indicates slightly more rainfall may be expected in June. Examining the decade analysis shows that the probability of receiving 50 mm/ decade drops significantly in the last 2 decades of June. The most assured rainfall period, when there is 60% or greater probability of at least 50 mm/decade, is from the third decade of August to the third decade of September.

Figure 4b also illustrates the probabilities throughout the season of 2 consecutive decades occurring with less than 50 mm of rainfall. The probability decreases gradually through April and May but is more than 40% in the second and



3. Mean monthly rainfall regimes with distinct bimodal variations (27).



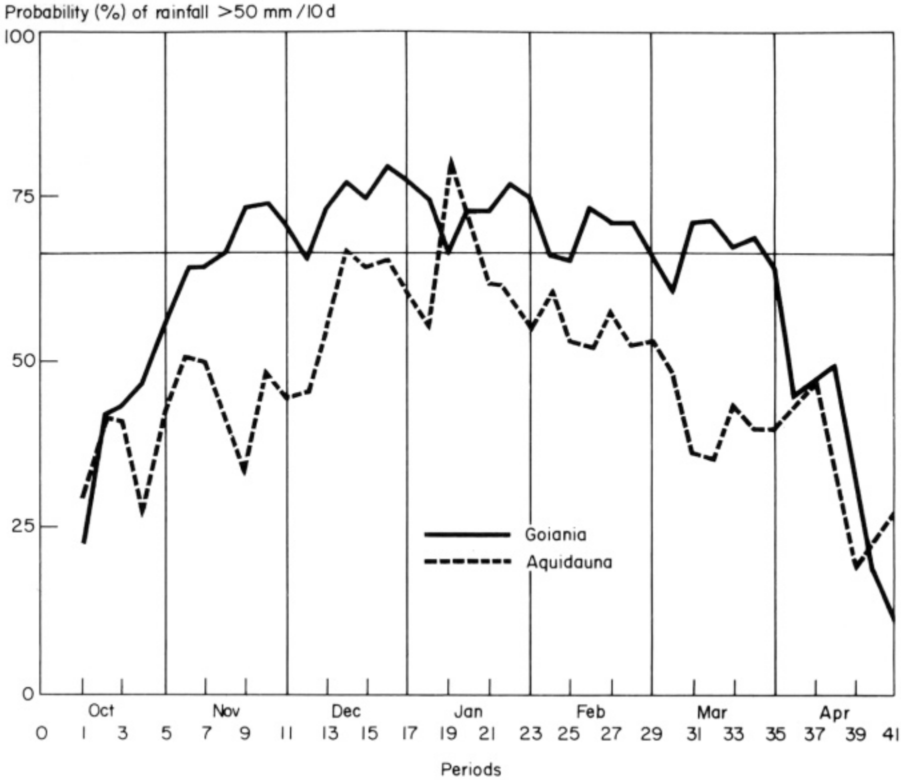
4. a) Mean monthly rainfall at Khon Kaen; b) The probability of receiving at least 50 mm rain in 10 d, the probability of having at least 2 consecutive decades with less than 50 mm. and mean 10-d rainfall at Khon Kaen, Thailand (27).

third decades of June. Depending on water balance and growth stage interactions, this might be catastrophic for crop establishment. The end of the season is very clear in the decade analysis. Upland rice-based cropping systems would have to be planned around the abrupt change in rainfall.

Rainfall probability analysis is currently used in upland rice research and planning in West Africa (21) and Brazil (35). In Brazil, recent efforts to identify favorable and unfavorable regions for upland rice culture are based on probability of dry periods, called *Veranicos,* which, coinciding with reproductive stage, can cause significant yield losses. Steinmetz et al (35) used 10-d mean rainfall records to set a 66% probability of receiving 50 mm of rainfall 10 d as essential for a favorable area (Fig. 5). Their preliminary results are being used to plan national research and production programs based on the risk of regional Veranicos. The analysis also has been used to devise plant breeding strategies. Results emphasize the need for new varieties with 100-d maturity for certain high risk areas.

Drought is a nebulous term generally relating to a time of below normal rainfall in a particular locale. Although it often is used, a specific definition is difficult to find. The World Meteorological Organization commissioned a working group to address drought and agriculture. The group's report (13) is a good example of the complexity of the term. It summarized 57 different definitions devised since 1896: 14 dealt with rainfall alone, 13 with rainfall and mean temperature, 15 with soil-water and crop parameters, 10 with climatic indices and estimates of evapotranspiration, and 5 were of a general nature.

Many recent efforts to define and analyze agricultural drought have been based on water balance. When the interaction between crop roots and the soil water reservoir can no longer supply water for evapotranspiration at the climatically determined potential rate, crop water stress exists. Thus, crop water stress, or drought, exists when the ratio of actual evapotranspiration (ET_a) to potential evapotranspiration (ET_P) falls below 1.0. Meteorologists, hydrologists, physiologists, soil physicists, and economists all have developed discipline-oriented



5. Probability of 50 mm rainfall/ 10 d for 41 10-d periods, in 5-d increments, during the rainy season for Goiania (Goias) and Aquidauana ([Mato] Grosso do Sul) for 27 and 28 yr (10).

definitions, but we believe the above is the most realistic for agriculture. The ratio ET_a:ET_p integrates the soil-plant and atmosphere continuum of the hydrological cycle.

With this reference point, it is impractical for researchers to use the number of rainless days or the percentage below mean rainfall to describe drought duration or severity. In practice, however, this is the only way to communicate with nonscientific audiences on such a complex phenomenon.

Crop water stress often is used to explain variations in upland rice yield. However, Table 1 from O'Toole and Chang (30) illustrates the large number of environmental factors that are affected by drought and cautions against simplistic use of the term in research.

TEMPERATURE

Diurnal and seasonal variations in air temperature are relatively small in the equatorial belt. Elevation above sea level is the major determinant of temperature.

Table 1. General description of environmental factors that directly or indirectly interact with a rainfall-deficit condition to create an array of complexes referred to as drought. The factors are considered in relation to their variability across location and through time and to the principal cultural systems in which rainfed rice is grown (30).

Variability[a]	Factor	Cultural system: Upland	Cultural system: Lowland	Cultural system: Deep water
	Edaphic			
	Physical			
I	Depth (potential root zone)	Often deep	Averaging 10-30 cm	Usually deep
*	Texture	Light (sandy to clay loam)	Heavy (clays, few loams)	Heavy (clays)
*	Physical obstruction (plow or hard pan)	Uncommon	Present	Absent
*o	Hydraulic conductivity	High	Low	Low
	Chemical			
*+0	Biochemical	Aerobic	Anaerobic (possibly alternately aerobic)	Aerobic - anaerobic
*o	Deficiencies or toxicities			
	e.g., Fe deficiency	Yes	No	No
	Zn deficiency	No	Yes	Yes
	Al toxicity	Yes (at pH <5.0)	No	No
*	Native fertility	Low	Wide range	High
	Climatic			
*+0	Rainfall			
	Totals (crop season)	500-1 500 mm	700-2000 mm	Not relevant; influx is from surface flow
	Distribution (crop season)	34 mo > 200mm	3-7 mo > 200 m	Deficits in early stage associated with erratic onset of monsoon
*+0	Temperature			
	Air	----Variable by geographic location - longitude, latitude, elevation---- and hydrological conditions		
	Soil			

*+o	Atmospheric evaporative demand		----Determined primarily by macroclimatic conditions but respond----- significantly to microclimatic modifiers	
*+o	Wind			
*+o	Solar radiation (crop season)		-----Generalization on quantity or photoperiod not possible------	
	Hydrologic			
*+o	Water depth			
	(surface)	Rarely >O	0-50 cm	1-6 m
	(subsurface)	Low	High (often perched)	Positive
*+o	Occurrence of water excess (flood)	Rare	Rare to annual flooding	Annually
	Biotic			
*+o	Competitive	Severe	May be severe	Severe during establishment
	Plants (weeds)		-------- Drought accentuates the problem in all systems-----	
	Agronomic			
*+	Land preparation	Dry	Wet	Dry
*+	Crop establishment	Direct sown (dry)	Direct sown or trans-planted (wet)	Direct sown (dry)
*+	Use of agrochemicals	Negligible	Wide range related to water control	Negligible

[a] Across locations (*), across seasons (+), and within seasons (o).

At higher latitudes, especially when influenced by varying rainfall regime and solar radiation, seasonal temperature fluctuations are more distinct.

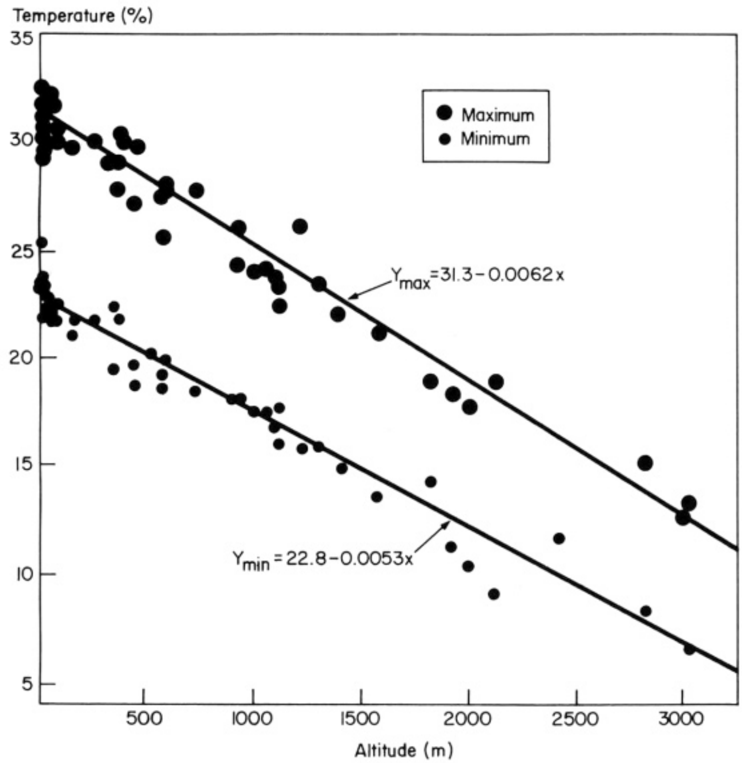
In equatorial Indonesia and Malaysia, Oldeman and Frere (28) calculated the linear regression between altitude and monthly mean maximum and minimum air temperature. Maximum temperature declined 0.6° C/100 m increase in altitude in July when it was 31.1° C at sea level. Minimum temperature fell 0.5° C/100 m increase in altitude with a July sea level temperature of 21.6° C. In October the regression equations were:

$$Y\ max = 32.2°\ C - 0.64X \text{ and } Y\ min = 22.8°\ C - 0.55X$$

(X is in 100 m). Figure 6 relates annual maximum and minimum temperatures and altitude for locations in Indonesia.

Although seasonal variations are small in the equatorial belt, local effects may produce more pronounced variations. On coastal plains, temperature variations are small throughout the year. Further inland, daytime dry season temperatures may be considerably higher, and night temperatures will be lower than on the coast.

In the humid equatorial region, seasonal maximum and minimum temperatures generally vary 2-3° C. Variations are more important at latitudes of 12° or higher. At 12°, maximum temperature at low elevations varies from about 30° C in



6. Relation between altitude and mean annual maximum and minimum temperatures for locations in Indonesia (28).

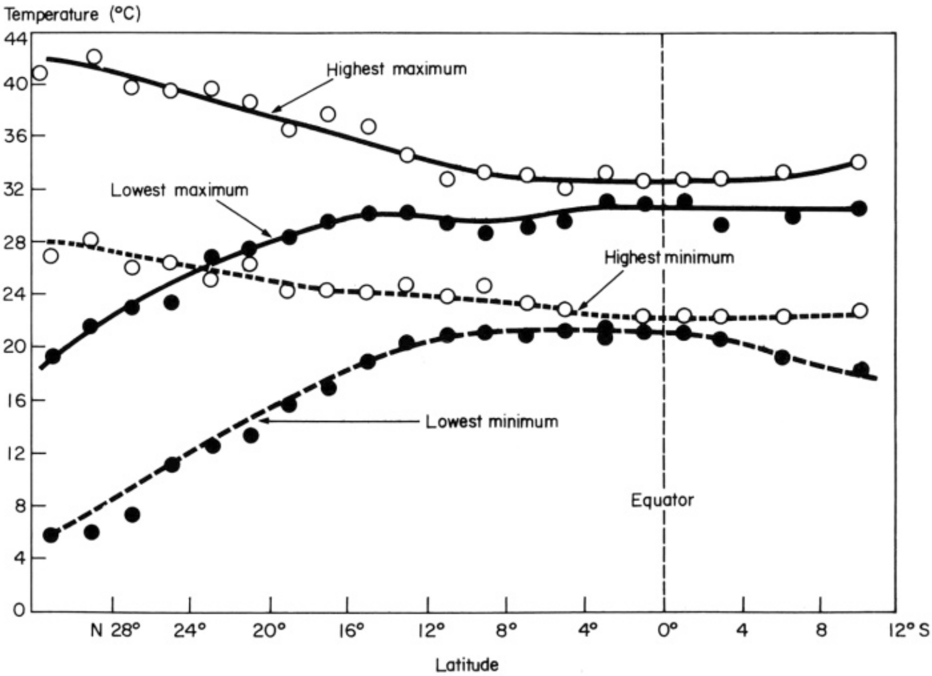
the coolest month to 35°C in the hottest. Minimum temperatures vary from 21 to 24°C. At latitude 20° north, maximum temperatures vary from 28 to 37°C, and minimum temperatures are 16-25°C. At 25° north, maximum and minimum temperatures are 25-40°C and 11-26°C (Fig. 7, 8).

Low air temperature is very important to upland rice where latitude or elevation, or both, cause night temperatures to fall below the limits in Table 2. Low air temperature effects vary with crop growth stage, but a common problem in uplands is low temperature (14-18°C) during panicle initiation, meiosis, and pollen development. Developing cold tolerance is an integral part of many upland rice breeding programs in Asia (15).

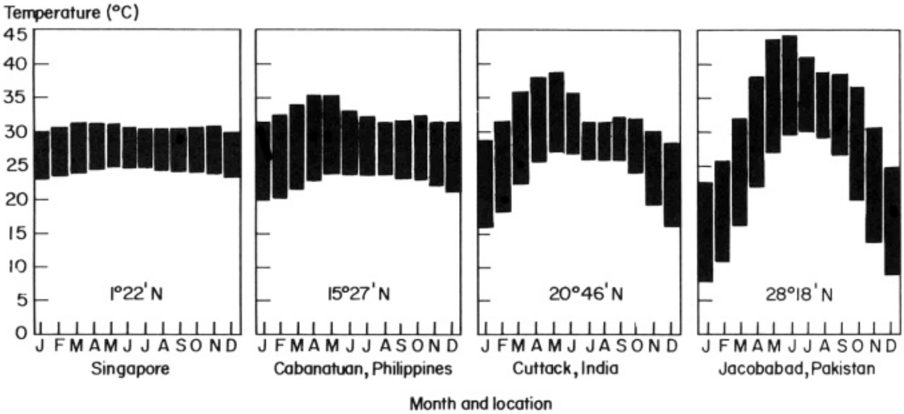
Upland rice also may suffer from high temperatures, especially in combination with drought stress. Yoshida et al (41) reviewed the effect of high temperature on yield. High temperature effects are growth stage specific (Table 2). The reproductive period 15 d before flowering is very sensitive. Genotypic variation exists for both low (15) and high (23, 41) temperature tolerance and may be important in breeding for local conditions.

RADIATION

Solar radiation is the primary energy source for crop growth and profoundly affects temperature and evaporation. Reliable information on radiation in upland rice regions seldom is available, mainly because reliable equipment to measure



7. Effect of latitude on the annual variations of maximum and minimum temperature (27).



8. Mean monthly maximum and minimum temperature regimes at various latitudes (27).

solar radiation only recently became available and is relatively expensive compared to instruments for measuring rainfall and temperature. Also, sunshine duration must be measured more frequently and sunshine hours must be mathematically converted to radiation intensity (12, 28).

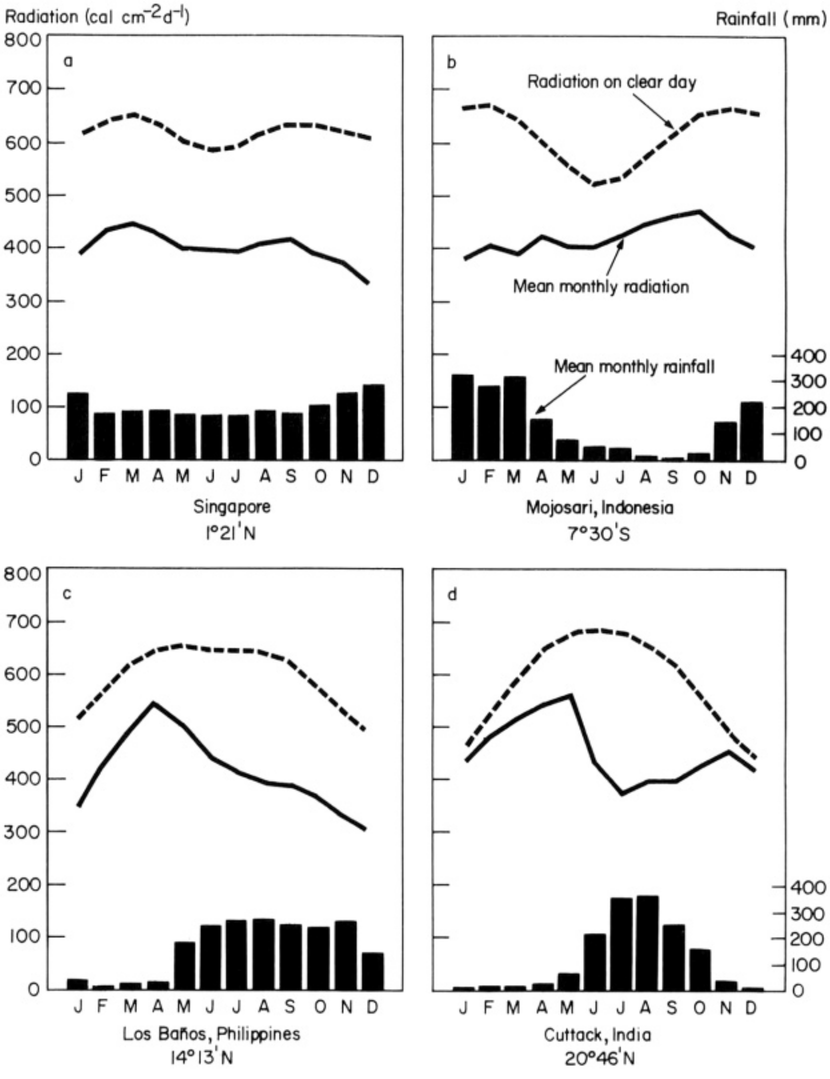
The relevance of solar radiation levels to upland rice production has not been studied. In irrigated rice, radiation during the last 45 d of the crop is strongly related to yield. Upland rice, however, may react differently, perhaps negatively, to increased radiation depending on water balance components such as soil water holding capacity and evaporation.

Oldeman and Frere (28) analyzed radiation levels in Southeast Asia. They emphasize that irrespective of cloud cover, as indicated by clear day radiation levels, solar radiation has less seasonal variation in the equatorial belt than at higher latitudes. When variation does occur in the equatorial belt, it is related to the rainfall regime and, therefore, cloud cover (Fig. 9).

In Indonesia, radiation is low, between 350 and 450 cal $cm^{-2} d^{-1}$. Singapore, at 1° north, has even less variability at about 400 cal cm^{-2} d^{-1}. In Los Baños, Philippines, seasonal radiation is more variable. There is relatively low radiation

Table 2. Rice response to temperature at different growth stages (40).

Growth stage	Critical temperatures (°c)		
	Low	High	Optimum
Seedling	10	45	20 - 35
Seedling emergence and establishment	12 - 13	35	25 - 30
Rooting	16	35	25 - 28
Leaf elongation	7 - 12	45	31
Tillering	9 - 16	33	25 - 31
Initiation of panicle primordia	15	-	—
Panicle differentiation	15 - 20	38	—
Anthesis	22	35	30 - 33
Ripening	12 - 18	30	20 - 25



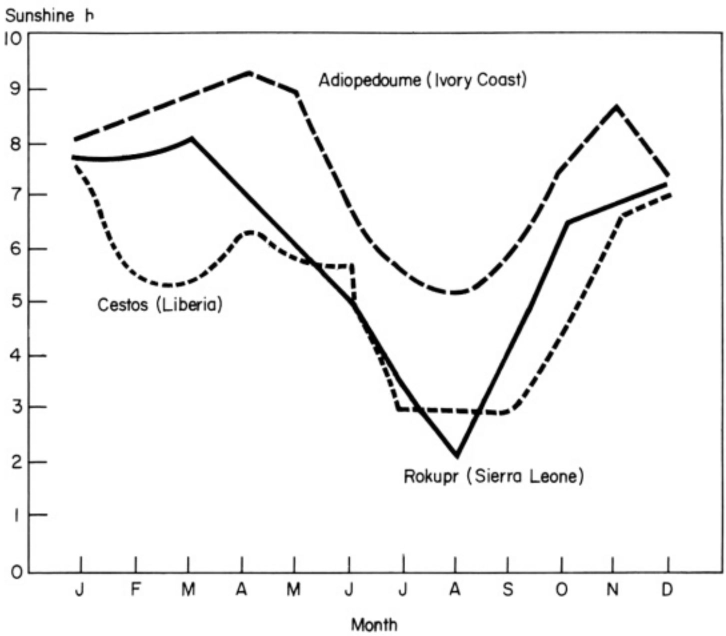
9. Mean monthly radiation, monthly radiation on perfectly clear days, and mean monthly rainfall for Singapore; Mojosari, Indonesia; Los Baños, Philippines; and Cuttack, India (27).

(300 cal cm^{-2} d^{-1}) in December and January, which corresponds with decreased extraterrestrial radiation shown by clear day radiation levels. Radiation increases sharply late in dry season, March-April, parallel with higher extraterrestrial radiation up to 550 cal cm^{-2}d^{-1}. Radiation values drop in rainy season, although clear day radiation remains high until September.

The sharp drop in radiation is even more pronounced in Cuttack, India. From November to March, skies are clear and radiation approaches maximum. Highest radiation is in May (560 cal cm^{-2} d^{-1}). By July, at peak rainy season, radiation drops to below 400 cal cm^{-2} d^{-1}. Figure 9 shows that radiation intensity is related to both extraterrestrial radiation and rainfall patterns.

Lawson (20, 21) found similar patterns in West African upland rice areas. July mean solar radiation decreases from 550 cal cm^{-2} d^{-1} at about 18° north to 300-325 cal cm^{-2} d^{-1} in coastal areas at 5° north. The bimodal rainfall regime at Ibadan, Nigeria, causes an inverse radiation pattern. Das Gupta (5) described radiation, based on average sunshine hours per day, in Ivory Coast, Liberia, and Sierra Leone (Fig. 10). The June-September radiation decrease coincides with the rice season. Das Gupta noted that low solar radiation does not appear to limit rice yield and that in adjacent savanna zones with greater radiation, the crop suffers from water stress. He concluded that, for upland rice production in West Africa, soil moisture is more limiting than solar radiation and that high solar radiation is undesirable in the lower rainfall zones.

At the equator, photoperiod or day length during the cropping season is an almost constant 12 h. At 20° north, photoperiod varies about 1.4 h. Lawson (21) noted that despite the trend toward developing photoperiod-insensitive rices, photoperiod-sensitive varieties may be useful in West Africa where bimodal rainfall causes midseason water deficits. Photoperiod sensitivity could time reproductive stages to coincide with the highest probabilities of adequate rainfall. Table 3 shows the photoperiod response of traditional upland varieties grown in Asia, Africa, and South America.



10. Average sunshine hours at selected sites m West Africa (5).

Table 3. Response of some upland rice varieties to different photoperiods.[a]

Variety	Country	Time to flowering (d) 10 h	Time to flowering (d) 14 h[c]	Basic vegetative phase (d)	Photoperiod sensitive phase (d)
				Photoperiod insensitive	
Pate Blanc MN3	Ivory Coast	113	113	78	0
Colombia 1	Colombia	98	101	63	3
IAC1246	Brazil	85	91	50	6
Seratus Molan	Indonesia	93	99	58	6
E-425	West Africa	93	100	58	7
Perola	Brazil	82	89	47	7
Azmil	Philippines	90	98	55	8
Miltex	Philippines	95	104	60	9
Moroberekan	Guinea	94	104	59	10
Yassi	Ivory Coast	99	110	64	11
OS4	Zaire	88	100	53	12
Palawan	Philippines	99	112	64	13
63-83	Ivory Coast	84	98	49	14
LAC5	Liberia	96	111	61	15
Cartuna	Indonesia	72	89	37	17
LAC23	Liberia	98	119	63	21
IR442-58	Philippines	84	108	49	24
				Weakly sensitive	
MI-18	Philippines	78	112	43	34
IR5	Philippines	93	128	58	35
Ku 70-1	Thailand	58	106	23	48
Khao Lo	Laos	54	130	19	76
Ku 104	Thailand	55	205	20	150
				Strongly sensitive	
Khao Phe	Laos	59	-	24	
Ku 113-1	Thailand	64	-	29	
Moddai Karuppan	Sri Lanka	84	-	49	
TD47	Thailand	75	-	40	
TD48	Thailand	71	-	36	
TD51	Thailand	70	-	35	
Thiorno	Senegal	77	-	42	
Vanam Villai	Sri Lanka	84	-	49	

[a] Unpublished data of K. Alluri, IRRI. [b] At 2 photoperiods. [c] A dash (—) means no panicle primordia after 200 d of growth (6).

INTERACTIONS OF AGROCLIMATIC FACTORS

Evaporation and evapotranspiration

Evaporation changes water from liquid to vapor. It depends on a water vapor pressure gradient between the evaporating surface and the atmosphere and an energy source. For upland rice, principal evaporation surfaces are the soil-atmosphere interface and the mesophyll cell wall surfaces of rice leaves.

The diffusion of water from leaves via stomata is called transpiration and combined soil and plant evaporation is termed evapotranspiration (ET). Solar radiation is the main source of energy for ET although sensible heat from the air may be important during rainless periods. Soil and canopy temperature, air temperature, dry air, and wind also influence ET.

High solar radiation and air temperature, which are common in the tropics, cause high potential evaporation. This is contrary to the impression given by climatic classifications such as humid or subhumid tropics. When an upland rice crop cannot take up, conduct, and transpire water at the atmospherically determined potential ET, a crop water deficit exists. ET_a of upland rice has rarely been measured although several methods of estimating ET_a and ET_p have been used. Doorenbos and Pruitt (7) summarized many of these methods.

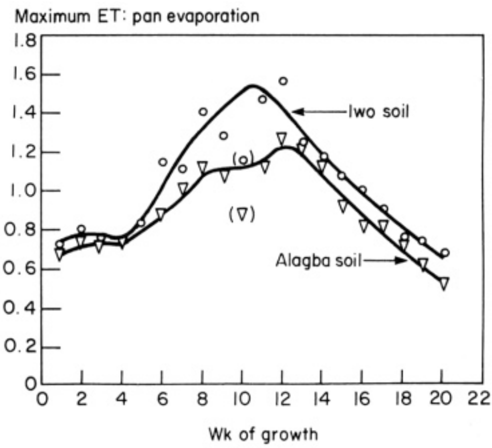
Lawson and Alluri (22) measured ET_a of upland rice OS6 and related it to growth of the crop's transpiring surface at different stages and to climatic changes during the season that could be referenced to pan evaporation. Figure 11 illustrates the ratio of maximum ET to pan evaporation for two soils in Nigeria. ET ranged from 2.9 to 6.1 mm d^{-1} . Table 4 shows the average meteorological conditions during their study and the daily mean rates of ET from well-irrigated upland rice grown on two Nigerian soils.

Water balance

Rainfall, air temperature, and solar radiation interact with topography, soil physical properties, and upland rice root and shoot systems to produce the dynamic water balance. Evaporation from soil and plants is a principal transfer process.

There are few water balance studies of upland rice fields. Kalms and Imbernon (1 8, 19) provide a rare look at the water balance of upland rice in Bouaké, Ivory Coast. They used a neutron probe, a tensiometer stack, and root sampling to determine water use in various soil layers and to estimate other parameters such as soil evaporation and drainage below the root zone. They critique the *balance sheet, no transfer level,* and *in-depth flow* methods and illustrate their results with different varieties and on soils with varying water-holding capacity. The methods were most useful during water deficit. Determining differences between varieties also was most successful during stress.

O'Toole and Moya (31) measured soil matric potential and daily mean vapor pressure deficit of the air in an upland rice field in the Philippines. These indicators



11. Ratio of weekly mean maximum ET in rice to class A pan evaporation (22).

Table 4. Weekly mean values of solar radiation (Ra), saturation vapor pressure deficit (Ae), windspeed at 2 m (V), pan evaporation (Eo), and maximum evapotranspiration (ETm) for 2 soil types (22).

Wk	Period (1978-79)	Ra (cal cm^{-2} d^{-1})	Ae (mb)	V (km h^{-1})	EO (mm)	ET (mm) Iwo	ET (mm) Alagba
1	20-26 Oct	443.3	6.96	4.0	4.48	3.28	3.05
2	27 Oct-2 Nov	460.2	5.98	3.5	4.06	3.19	2.94
3	3-9 Nov	411.4	6.84	3.0	4.06	3.08	2.89
4	10-16 Nov	493.7	8.95	2.4	3.93	2.88	2.85
5	17-23 Nov	496.1	10.36	2.9	4.21	3.45	3.47
6	24-30 Nov	447.7	10.02	2.9	3.98	4.55	3.47
7	1-7 Dec	445.3	10.65	3.4	4.11	4.55	4.11
8	8-14 Dec	396.9	9.30	2.9	3.69	5.16	4.02
9	15-21 Dec	377.5	8.19	2.9	3.24	4.10	3.54
10	22-28 Dec	416.3	11.09	4.3	4.27	4.89	3.70
11	29 Dec-4 Jan	392.1	10.20	9.3	3.70	5.42	4.13
12	5-11 Jan	355.8	6.06	3.2	3.21	5.02	3.98
13	12-18 Jan	346.1	9.71	3.7	3.75	4.64	4.49
14	19-25 Jan	367.9	12.10	3.4	3.96	4.65	4.23
15	26 Jan-1 Feb	445.3	13.86	4.8	5.74	5.40	4.77
16	2-8 Feb	493.7	15.17	5.1	6.15	6.14	5.11
17	9-15 Feb	469.5	14.77	5.1	5.86	5.35	4.56
18	16-22 Feb	452.6	13.20	4.8	5.87	4.41	4.20
19	23 Feb-1 Mar	474.4	14.84	5.0	6.28	4.55	3.91
20	2-8 Mar	386.5	13.62	4.6	6.14	4.19	3.23

of soil and atmospheric water status were used to predict the crop canopy water potential for each day of the crop season. Estimates of soil and plant water status were used to explain changes in yield and yield components over two crop seasons.

However, few research stations are equipped for detailed studies of crop water balance and many use only simple techniques to estimate seasonal trends of soil water content and hence crop water use or status. To estimate the length of a dry period or the growing season, a cumulative water balance must be calculated. Dry periods can then be identified as occurring when soil moisture drops below a particular value, where water is not directly available to the plant or crop. or when ET_a, falls below ET_p and crop water stress develops. Hounam et al (13) wrote:

> Drought in the agricultural sense does not begin with the cessation of rain but rather when the available stored water in the soil will support actual evapotranspiration at only a fraction of the potential evapotranspiration.

Rijks (34) established a simple relationship between actual soil water content (S_i), total available soil water content or water holding capacity (Sa). actual ET (ETA_i), and potential ET (PET_i) as

$$\frac{ETA_i}{PET_i} = 1.03 - e^{(-3.5 \times \frac{S_i}{Sa})}$$

Thornthwaite and Mather (36) developed a water budget concept and tables to estimate soil moisture storage after various PET for different soil water-holding capacities. The method is successful in temperate climates.

Frere and Popov (12) developed a cumulative water balance concept for the growing season of a given crop for successive 10-d periods. They considered water balance to be the difference between precipitation and crop and soil water loss, taking into account the water retained by the soil. Crop water requirement is determined by multiplying PET by the crop coefficient for the particular decade, which is related to the phenological crop stage. Water accumulation (8) in the topsoil is described as

$$S_i = S_{i-1} + P_i - fE \times E_i$$

S_i is soil water content at the end of time interval i, S_{i-1} is soil water content at the start of a time interval i, P_i is rainfall during i, E_i is evaporation from a free water surface, and fE is the water that evaporates from the soil relative to open water evaporation. This fraction is the average of the fraction at the beginning and the end of the time interval

$$fE = 0.5\ (fE_{i-1} + fE_i).$$

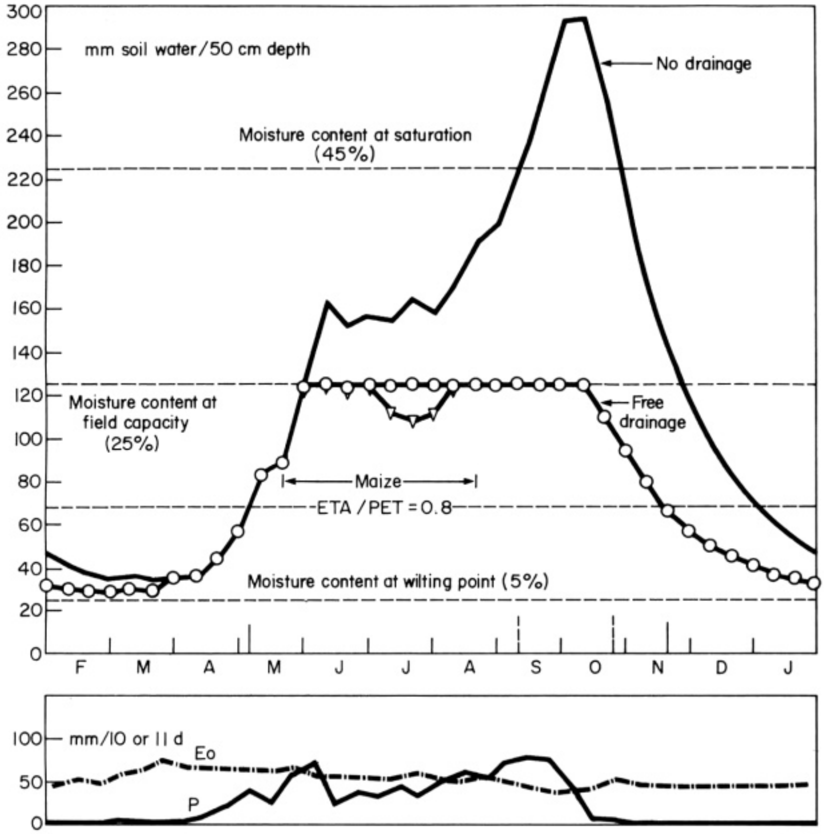
To determine these fractions, one must know the soil moisture contents (S_{i-1} and S_i), and soil moisture content at wilting point (Sw) and saturation (Ss). The formula is

$$fE_{i-1} = \frac{S_{i-1} - Sw}{Ss - Sw}$$

Because S_i is unknown, a value is estimated and the calculation performed. If the estimated S_i and the calculated S_i values differ more than a certain percentage, a new S_i is estimated until the difference is smaller than a certain percentage (iterative approach). Through this process, the moment when soil water reaches a certain level, for example, 50% of soil moisture-holding capacity, can be determined. This could be defined as the beginning, or the end, of the growing season (Fig. 12). This method, repeated for several years, can be used to estimate the beginning and end of growing season. Few such studies have been done for upland rice, however.

Monthly rainfall data are highly variable and have the greatest impact on the dry period, particularly where precipitation is fully effective, where there is free drainage, and where rainfall is the only water source. Is it possible to identify the probable dry period based only on mean monthly rainfall?

Let us assume a soil moisture holding capacity of 100 mm for the first 50 cm soil profile, assume the crop will be affected by drought when the ratio ET_a:ET_p is less than 0.8 or when there is a soil water storage of 40 mm (see Rijks formula). This implies a 60 mm water reserve directly available to the crop. The crop will be



12. Cumulative water balance based on 10-d rainfall and evaporation data, and soil moisture characteristics for free drainage on bare soil, no drainage on bare soil, and free drainage with a maize crop (7).

affected when atmospheric balance (PET-P) is greater than 60 mm. Oldeman (26) showed a significant relationship between monthly rainfall and P-PET. For tropical conditions he found that P-PET= 1.014 P-120.55. Substituting 60 mm for PET-P shows that at least 60 mm water/ mo is necessary to satisfy crop water needs.

To identify periods with monthly precipitation of at least 60 mm in 3 of 4 yr, we must use estimated rainfall probabilities. Oldeman and Frere (28) established the following estimates: P_{75} = 0.76 P mean - 20. If P_{75} is 60 mm, mean monthly precipitation is 105 mm. A dry month would therefore be one with less than 105 mm precipitation, an average value useful for upland rice areas where the soil moisture-holding capacity is about 20% and mean air temperatures are 23-28° C. In cooler climates or on soils with higher moisture holding capacities, necessary mean monthly rainfall will decrease (Table 5).

Planting deeper rooted rice varieties will reduce required monthly mean precipitation because they have access to larger soil water reservoirs. Conversely, young crops with shallow, developing root systems cannot use water throughout

Table 5. Mean monthly precipitation required to satisfy crop water demands at full canopy stage at 3 air temperatures and 3 moisture-holding capacities (27).

Soil waterholding capacity (volume %)	Precipitation (mm) at		
	<23°C	23-28° C	>28° C
10	85	145	195
20	45	105	160
30	20	65	130

the assumed 0.5 m profile, and need higher monthly precipitation. Generally, water balance methods do not include changing root depth because little is known about upland rice root systems and in situ water extraction.

AGROCLIMATIC CLASSIFICATION SYSTEMS AND CROP SEASON

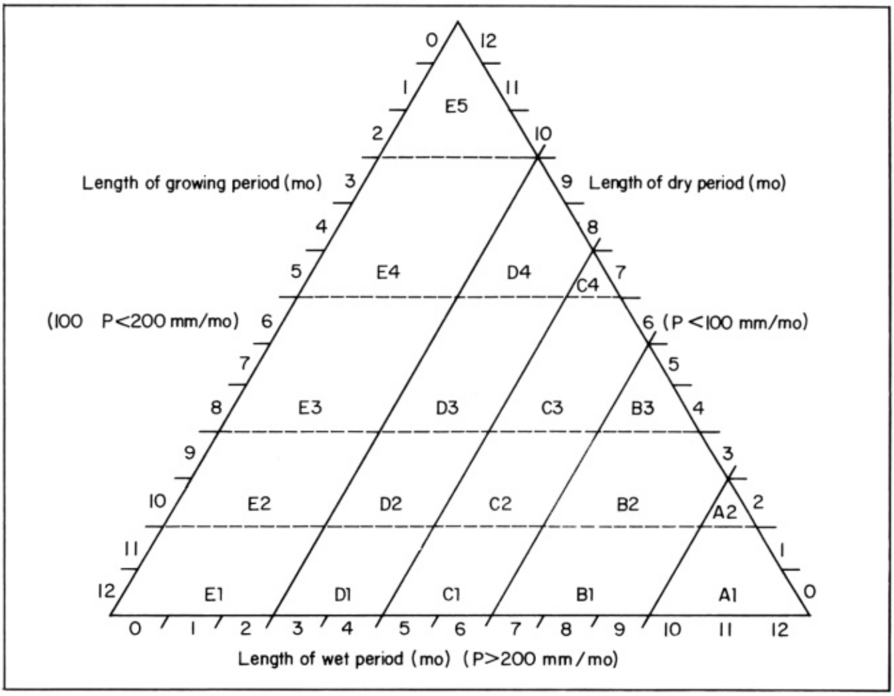
Rainfall and soil water balance information are most commonly used in relation to crop establishment, critical growth stages, and harvest of upland rice or rice-based cropping systems (Chapter 4). Water balance and monthly mean rainfall studies in Southeast Asia established that upland crops need about 92 mm and wetland rice 174 mm rainfall/mo. The criteria for dry(1ess than 100 mm) and wet months (more than 200 mm) proposed at IRRI in 1974 (14) were widely used and were adopted by FAO (11). Many studies used the criteria to determine dry and wet season length.

The criteria are particularly suited for mapping agricultural land. In Indonesia, Oldeman (26) devised a simple but functional way of using mean monthly rainfall statistics for mapping. Later, with the same wet and dry month criteria, Oldeman and Frere (28) refined the system to define 18 agroclimatic units (Fig. 13). It relates the length (consecutive months) of wet and dry seasons to potential rice-based cropping patterns. The minimum wet season for rainfed rice is 3 mo. The minimum wet season for 2 transplanted rice crops is 7 mo, and 10 wet mo are needed to grow rainfed rice throughout the year. The major agroclimatic ones are

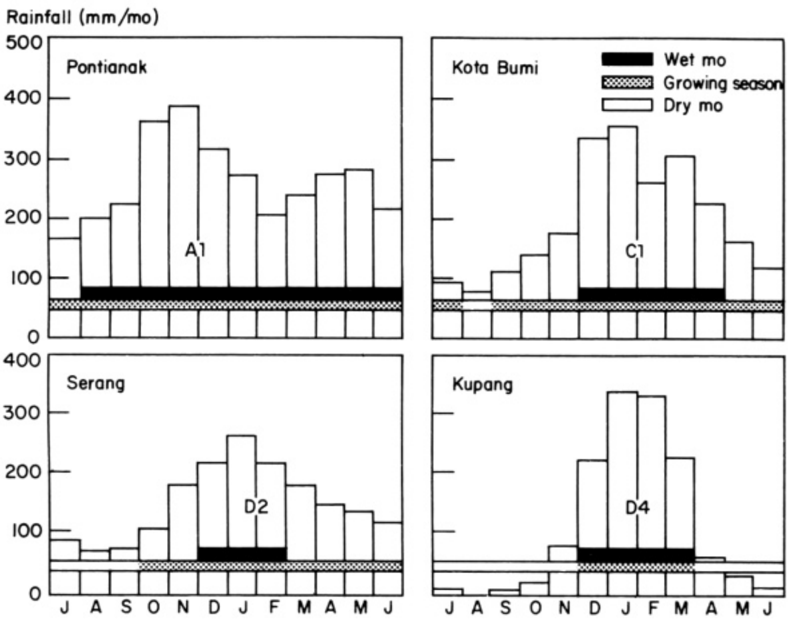
A. more than 9 consecutive wet mo,
B. 9 consecutive wet mo,
C. 5-6 consecutive wet mo,
D. 3-4 consecutive wet mo, and
E. less .than 3 consecutive wet mo.

The agroclimatic zones are subdivided according to the number of consecutive dry months. If less than 2 mo, year-round cultivation of food crops is possible. A 2-3 mo dry period requires careful planning for year-round cultivation; 4-6 mo makes a fallow period unavoidable but 2 sequential crops are possible; 7-9 dry months (3-5 mo growing season) allows only 1 food crop. If the dry period exceeds 9 consecutive months, food crops cannot be grown without irrigation.

Several specific zones were identified in addition to the major agroclimatic zones. Large parts of Indonesia north of the equator have bimodal rainfall. If wet



13. System proposed by Oldeman (26) lor agroclimatic classification of rice-based cropping patterns.

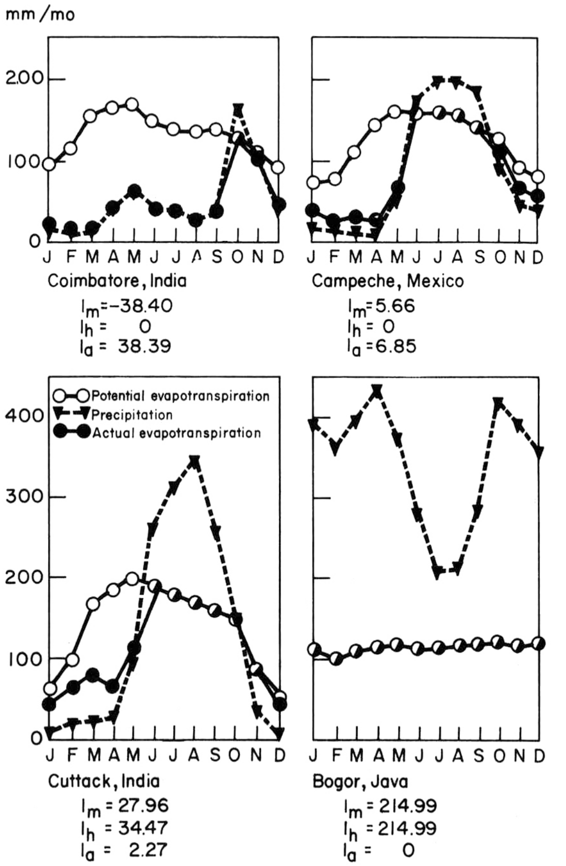


14. Classification of rainfall regimes by the agroclimatic classification of rice-based cropping patterns (28).

season is interrupted by 2 or more months with 100-200 mm monthly rainfall, the zone is classified according to the length of the longest wet period. To indicate bimodal rainfall distribution, a dot-pattern is superimposed on the map over the main zone. A second distinction is made for areas where monthly rainfall exceeds 400 mm for 2 consecutive months. Such excessive precipitation may cause severe floods. Figure 14 shows how delineation of wet and dry months from long-term mean monthly rainfall records is used to identify the growing season for rice-based systems.

Although this classification system is specific to Southeast Asia, it is based on extensive research on climatic, edaphic, and other ecological factors and may be applicable in other upland rice regions.

A major use of water balance studies has been to identify cropping seasons from long-term simulations or synthesis of climate information. Thornthwaite Associates (37, 38, 39) estimated water balance components for locations around the world. Where little or no climate data are available, which is frequent for upland rice areas, extrapolation from the nearest meteorological station may be useful. Figure 15 uses upland rice areas in India, Indonesia, and Mexico to illustrate how to estimate the growing season from long-term climatic records.

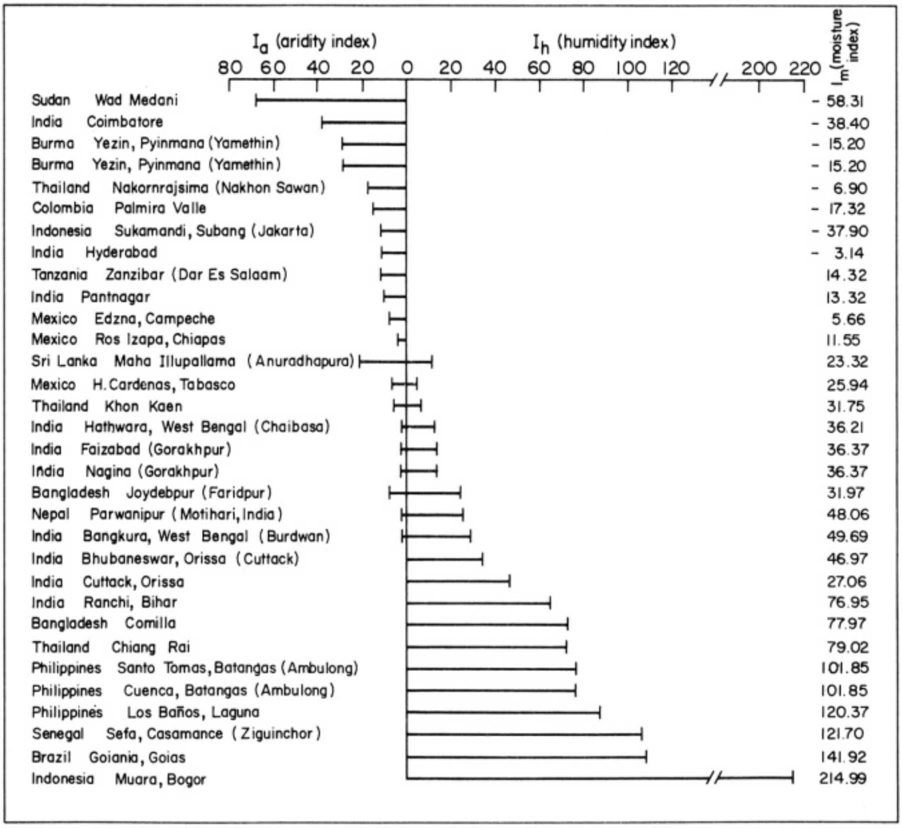


15. Annual trends in precipitation, ET_a. and ET_p at locations ranging from and to very humid. Moisture index (I_m), humidity index (I_h), and aridity index(I_a) aid in illustrating the climatic type with regard to both the magnitude of annual precipitation and seasonal adequacy for upland crop production (2, 36).

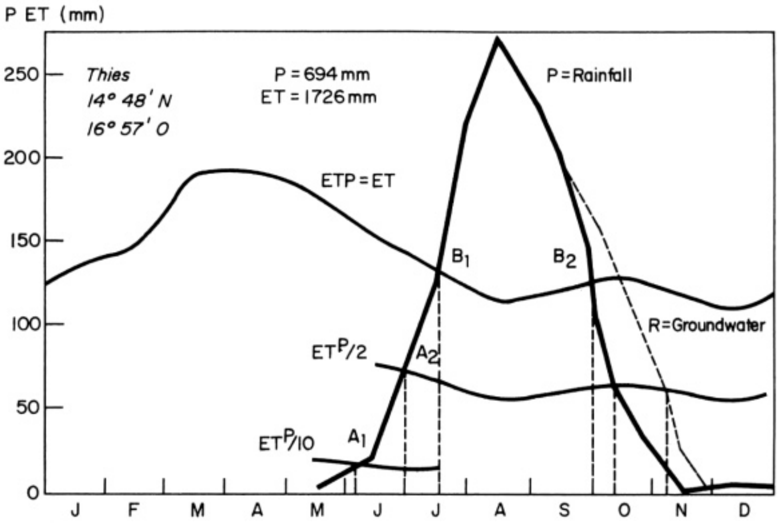
Figure 15 also shows three water-related climatic indices: moisture index (I_m) humidity index (I_h), and aridity index (I_a) These indices, devised by Thornthwaite and Associates, help classify and compare upland rice regions. In Figure 16, I_a, I_h, and I_m are used to show the range of hydrological conditions for upland rice and the range of upland rice water regimes. Locations in Burma, South India, and Sudan represent some of the driest upland zones and sites in Indonesia, the Philippines, and Senegal are some of the most humid.

In parts of India, West Africa, and South America, total rainfall is less than 1,000 mm in the rice season. In such areas crop establishment and sensitive growth stages like panicle initiation and flowering are rigidly controlled by the beginning and end of rains. The role of photoperiod-sensitive cultivars is obvious.

Charreau and Nicou(4) and Charreau(3) show how to use climatic records to estimate the growing season for upland crops in Senegal (Fig. 17), and identify the close association between climate-water balance intersections and the phenological significance for crops. Intersection of rainfall (P) curves with ET, ET/2, and ET/10 curves correspond with points of phenological significance for most crops. The



16. Climatic classification of 32 sites where the 1976 International Upland Rice Observational Nursery was grown. Values are for rice growing months only.



17. The seasonal trends of precipitation (P) and ET, and groundwater storage (R) at Thies, Senegal, West Africa (4).

intersection of the rainfall curve with ET/10, called Al, is the beginning of land preparation. The first intersection of the curves for rainfall and ET/2, called A2, represents the mean sowing date of most crops. The first intermediate period begins there and ends where P = ET.

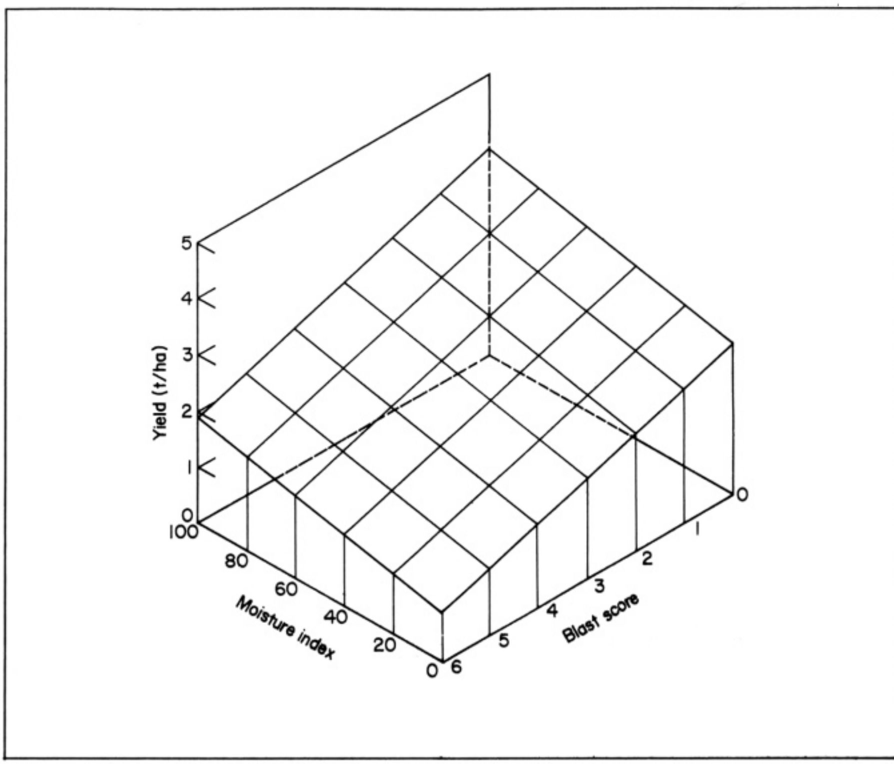
Two points where P= ET, called B1 and B2, are the limits of the humid period during which rainfall is higher than PET_i. Water surplus goes to ground storage, deep drainage, and runoff during this period. B2 generally corresponds to flowering for photoperiod-sensitive crops. The second intermediate period without groundwater storage extends from B2 to the second point where P = ET/2. With groundwater storage, this period extends to a point where the dashed line intersects ET/2 (P + R = ET/2). Groundwater storage extends this period. The first and second intermediate periods and the humid period constitute the moist period, with or without water storage.

CLIMATE AND INSECT AND DISEASE INCIDENCE

Lawson (21) lamented the lack of factual cause and effect relationships between climatic variables and pest population dynamics for upland rice. Although empirical evidence is available, no research reports could be identified.

Water deficits seem to increase blast (Bl) according to Buddenhagen (1), Ou (32), and results of the 1975-77 International Upland Rice Yield Nursery of the International Rice Testing Program (Fig. 18). The slope of yield reduction with decreasing moisture index values is actually less than for leaf B1 score. The figure shows the interaction between moisture regime and B1 incidence for 17 sites by year.

Water deficits decrease water and nutrient uptake (29). A decline in mineral



18. Relationship between upland rice yield, moisture index (I_m) for the crop season, and Bl score from 17 locations by year combinations where Bl occurred at International Upland Rice Yield Nursery sites in 1975, 1976, and 1977. The response surface is described: Yield=2.67+0.01 1_m -0.30 Blast Score, n= 17, R = 0.66**.

nutrition may reduce crop resistance to the B1 pathogen as was illustrated for other crops (33). Water deficits also affect the upland rice microclimate (25), which may effect dew formation on leaves. El Rafaei (9) related B1 infection and sporulation of the B1 fungus to the duration of water film on the leaf as a consequence of dew formation.

Unfortunately, we must base this scenario on synthesis of indirect observations because neither the mineral nutrition nor microclimatic aspects of B1 epidemiology or the effects on occurrence and behavior of the insects that attack upland rice have been studied.

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CHAPTER 3

Landscape and Soils

Upland rice soils range from erodable, badly leached Alfisols in West Africa to fertile volcanic soils in Southeast Asia. Their texture, water-holding capacity, cation exchange capacity (CEC), nutrient status, and soil-related problems vary greatly. Landscapes also vary. Upland rice is grown on flat plains in South Asia and Brazil and on 30% or greater slopes in parts of Southeast Asia. In many countries it grows on rolling hills.

LANDSCAPE

In South and Southeast Asia, 38% of upland rice (about 4 million ha) is on level to gently rolling (0-8% slope) land (14, 17, 25) (Fig. 1). In Southeast Asia, most upland rice is grown on rolling and mountainous land, with slope varying from 0 to more than 30% (Fig. 1). Two million ha are on slopes greater than 30% (14).

In West Africa, upland rice grows on hills in the humid zone and flat land in the drought-prone and moist forest zones. Most of the area is in the moist forest zone, although actual hectarage has not been determined (12). Rolling topography may have slopes up to 15% (17).

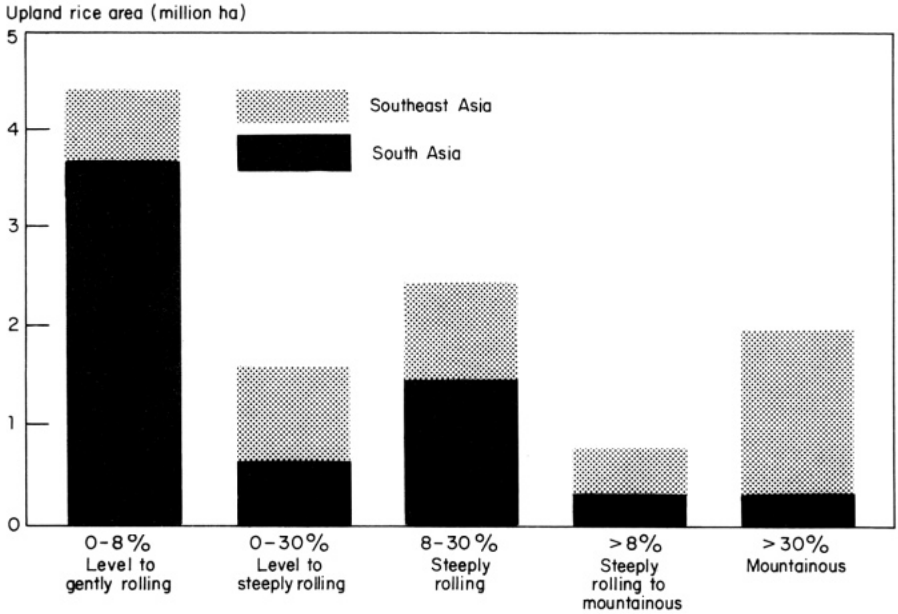
Most upland rice in Brazil is on level to gently rolling (0-8% slope) land under mechanized cultivation (5). In north and northeast Brazil, some upland rice is grown on rolling topography under shifting cultivation (11). In Peru, upland rice is grown in the Amazon Basin at 300-1000 m elevation (44).

CLASSIFICATION OF UPLAND RICE SOILS

The definition of upland rice limits the range of soils on which it can be cultivated. Soils with groundwater tables within the rice root zone and semiarid and arid soils where rice cannot be grown without irrigation are not discussed.

Moormann and van Breemen (37) contend that soils used for rice should be placed in a general classification system and not treated as an exclusive soil group. The soil classification systems used in upland rice areas include:

- *United States soil taxonomy*
- *Legend of FAO/UNESCO soil map of the world*
- *Brazilian Soil Classification System*
- *French System (ORSTOM)*



1. Distribution of upland rice area by slope class, South and Southeast Asia (14, 25).

Soil taxonomy was published in 1975 by the United States Department of Agriculture(USDA)(47). It is widely used in many rice growing areas, and has five categories: order, suborder, great group, family, and series.

Order includes 10 taxa that represent all known soils of the world (Table 1). Orders, suborders, and great groups are differentiated by combinations of diagnostic horizons and soil properties. Families and series are distinguished by properties to create taxa which are successively more homogenous for soil uses. Tropical soils are in all 10 orders and several suborders and great groups (41).

In 1961, FAO and UNESCO began to prepare a soil map of the world at a 1:5,000,000 scale. It was intended to include a universal legend of soil units and become a worldwide inventory of soil resources.

The soil classification system developed by the Office de la Recherche Scientifique et Technique d'Outre-Mer(ORSTOM) is widely used in French West Africa (41). The soils are separated by climate and vaguely defined criteria such as slightly weathered (Sols peu evolues). Brazilian pedologists modified the USDA system by dividing the Latosols and retaining the other units found in tropical America. At lower categorical levels, the Brazilian system emphasizes color, base saturation, and vegetation. Table 2 summarizes the taxa used in Soil taxonomy, FAO/ UNESCO, the French System, and the Brazilian System of soil classification (17, 41).

We use *Soil taxonomy,* with parallel FAO/UNESCO references where possible, to classify upland rice soils. Because there are so many lower taxa, our broad discussion of soil conditions and plant growth is at soil order level. Often, however, soil data are unavailable for upland rice areas.

Most upland rice is grown on the following orders:

- *Alfisol* (Luvisols, Eutric Nitosols). Alfisols have silicate clays translocated to the subsoil without excessive depletion of bases and without a mollic epiped on (a dark-colored, well-structured, deep surface horizon). Alfisols have more clay in the B than in the A horizons and base saturation is high. Alfisols are most common where there is a pronounced dry season (Ustic moisture regime).

  The suborder Ustalfs is most important for upland rice. The prefix *ust* indicates that unirrigated soil is too dry for most annual crops for 3 mo of the year, but that there is adequate soil moisture for 6 mo of plant growth (8, 37).

  Ustalfs are common in tropical and subtropical areas with seasonal rainfall. They are the dominant upland rice soils in India and in the dry zones of Sri Lanka. They were earlier called laterites (41). In Southeast Asia, they occur on small areas. In Africa, they are in the savanna and dry forest zones where annual rainfall is 600-1500 mm. On well-drained upland Ustalfs, upland rice is grown in shifting cultivation. Deeper, medium-to-fine textured soils with good water-holding capacity are preferred (37).

- *Ultisols* (Acrisols, Dystric Nitosols, some Planosols). Ultisols have clay translocation and accumulation in subsoil horizons. They have lower subsoil base saturation than Alfisols. They also have low subsoil pH. They lack readily weatherable mineral, but have low activity clays (kaolinite, sesquioxides) that dominate the clay complex more often than they do in Alfisols. Ultisols are further developed than Alfisols (37).

  Ultisols are common to high rainfall tropical areas and represent 31% (3 million ha) of upland rice area in South and Southeast Asia (Fig. 2) (14, 25). More than 50% of upland rice in tropical Asia is grown on Alfisols and Ultisols. Ultisols are common in Sumatra and Kalimantan (Indonesia) and in Thailand (8). Ultisols also occur in Africa and tropical America (Fig. 3) (41).

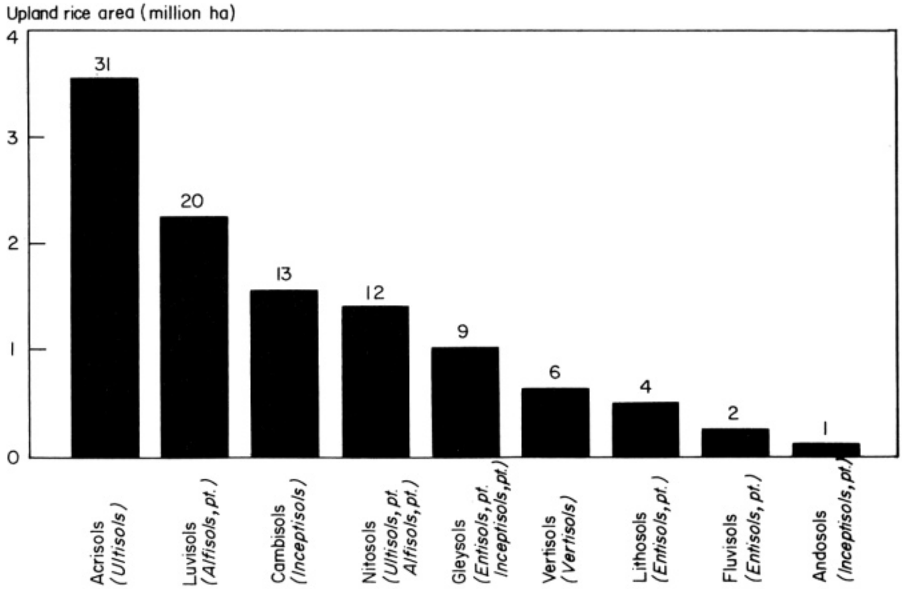
Table 1. Soil orders: comprehensive classification system (47).

Order	Key profile characteristics
Entisols	Recent soils; little or no change from parent material.
Inceptisols	Light-colored subsoils; weak soil development.
Mollisols	Soft, deep, dark soils; high base status of surface horizon.
Alfisols	Subsoil, horizon of accumulated clay; high base saturation; high in weatherable minerals.
Ultisols	Subsoil horizon of accumulated clay; low base saturation; few or no weatherable minerals.
Oxisols	Uniform textured; friable profile high in oxides Fe and Al with kaolinite clay; no weatherable minerals, low CEC.
Vertisols	Dark soils; high in montmorillonitic clay, prone to shrink and swell; high CEC.
Aridisols	Mineral soils of dry regions with either calcium carbonate or salt accumulation.
Spodosols	Strong brown subsoil underlying a gray to brown surface horizon; strongly acid.
Histosols	Soils with more than 30% organic matter to 40 cm depth.

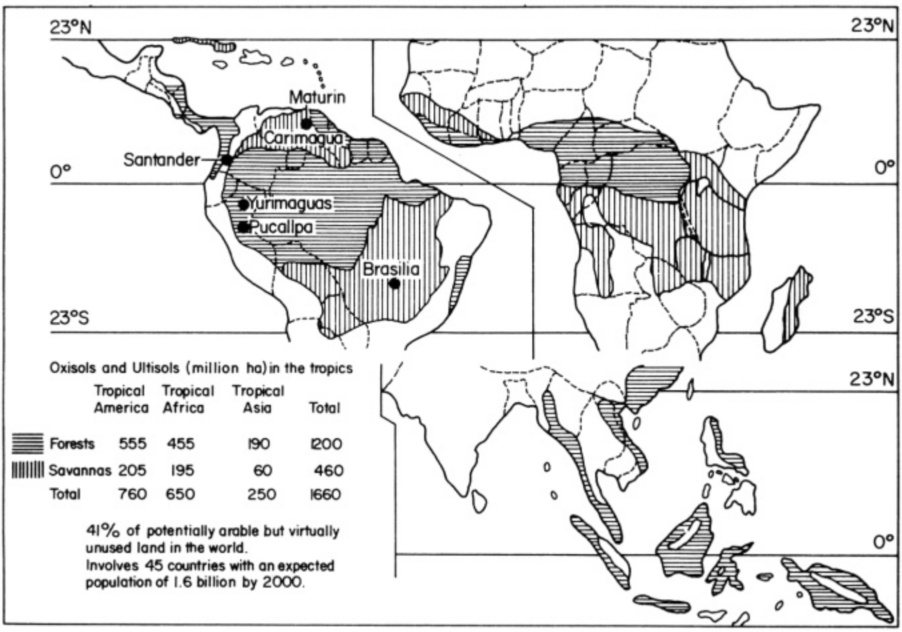
Table 2. Approximate correlation of the Brazilian soil classification system with *Soil taxonomy,* the French system, and the FAO legend (41, 46).

Brazilian system	Soil taxonomy	French system	FAO legend
Latosols (soils with latosolic B horizon with CEC 6.5 meq/100 g of clay)	Oxisols	Sols ferralitiques fortement desatures typiques ou humiferes	Ferralsols
Latosol Vermelho Escuro (dark red Latosol)	Ustox or Orthox	Sols ferralitiques fortement desatures typiques ou humiferes	Orthic or Acric Ferralsols
Latosol Vermelho Amarelo (red-yellow Latosol)	Ustox or Orthox	Sols ferralitiques fortement desatures typiques ou humiferes	Orthic or Acric Ferralsols
Latosol Amarelo (yellow Latosol)	Ustox or Orthox	Sols ferralitiques fortement desatures typiques ou humiferes	Xanthic Ferralsols
Latosol Roxo or Terra Roxa Legitima (dusky red Latosol)	Eutrustox or Eutrorthox	Sols ferralitiques fortement desatures typiques ou humiferes derives de basalte	Rhodic Ferralsols
Podzolico Vermelho Amarelo (red-yellow Podzolic)	Ultisols	Sols ferralitiques moyennement desatures eluvies	Acrisols Dystric Nitosols
Podzolico Vermelho Amarelo equivalente eutrofico (Eutrophic red-yellow Podzolic)	Alfisols	Sols ferrugineux tropicaux lessives	Luvisols Eutric Nitosols
Terra Roxa Estruturada	Alfisol	Sols ferrugineux tropicaux lessives	Luvisols Eutric Nitosols
Red and yellow sands	Psamments	Sols ferralitiques moyennement ou forte-ment desatures de texture sableuse	Ferralic Arenosols
Podzols	Spodosols	Podzols	Podzols
Grumusols	Vertisols	Vertisols	Vertisols
Soils with incipient B horizon	Inceptisols	(Several)	Cambisols
Soils with natric B horizon	Aridisols	Sols halornorphes	Solonchaks
Regosols	Entisols	Regosols	Regosols
Soils with hardpan	Various	Planosols	Planosols
Other hydromorphic soils	Various	Sols hydromorphes	Gleysols

Among Ultisols suborders, Udults (some Acrisols, Dystric Nitosols) are most common for upland rice. Udults are Ultisols with a udic (wet) soil moisture regime. They occur where subsurface soil profiles do not completely dry for long periods. They are common on undulating-to-steep upland positions on a wide variety of parent materials that tend to be



2. Distribution of Asian upland rice area by soil mapping unit (14, 25). Figures on the bars indicate percentages of upland rice area belonging to each soil mapping type.



3. Geographical distribution of Oxisols and Ultisols in the tropics under forest and savanna vegetation (42).

medium acid or acid. Much upland rice is on these soils, and it often is grown in shifting cultivation (37). Shallow subsurface clay layers and steep slopes make them prone to erosion (8).

- *Oxisols* (Ferralsols, some Gleysols). Oxisols are highly weathered, mainly reddish and yellowish soils. They are old and developed on stable landscapes that are not or only slightly influenced by soil erosion. Oxisols are highly acid, with very low CEC, and high Al saturation and phosphate sorption. They usually have a deep profile with moderately favorable water holding capacity and low erodability. Typical characteristics of Brazilian Oxisols and Nigerian Alfisols are in Table 3 (21).

  Oxisols occupy about 22% of the tropics (41). They are common in the Amazon Basin and in the Latin American cerrado. In South America, 45.3% of the soils are Oxisols and 19.1% are Ultisols (42). In Brazil, most upland rice soils are Oxisols; mechanized upland rice is grown on newly cleared Oxisols for 2-3 yr and then other crops are planted (6, 37).

  Oxisols are deep and well-drained and present no physical barriers to root growth. Their granular structure permits tractor traffic shortly after rain and they are resistant or immune to erosion. Oxisols have extremely low pH and low CEC. Al toxicity inhibits root growth (42). For detailed discussion of chemical and physical properties of Brazilian Oxisols, read Cline and Buol (6) and Sanchez (43).
- *Entisols* (some Fluvisols, some Gleysols, some Arenosols, some Regosols). Entisols have no or only weak profiles because of inert parent material, youth, manual terracing, or because they are in floodplains (37). At most, only a thin horizon has formed. Little upland rice is grown on these soils except in northeastern Thailand, where upland rice is grown on Psamments in sandy terrace deposits.
- *Inceptisols* (some Gleysols, Andosols, Cambisols). Inceptisols are immature soils with weakly developed profiles. Andepts (Andosols) are most important for upland rice. They usually are dark-colored with a clay fraction dominated by amorphous material (allophane, a noncrystalline Al silicate)

Table 3. Savanna (or cerrado) soils derived from pre-Cambrian basement complex rocks from Brazil and Nigeria (21).

Horizon	Depth (cm)	Clay (%)	Gravel (%)	pH H_2O	Exchangeable cations (meq/100 g) Ca	Mg	K	Al	Free Fe_2O_3 (%)	Bulk density (mg m^{-3})
			Oxisol (Haplorthox), near Brasilia, Brazil							
A_1	0-15	40	0	4.7	0.64	0.16	0.12	1.68	12.5	1.05
B_1	30-70	48	0	4.6	0.20	0.03	0.04	1.28	15.6	1.14
			Alfisol (Haplustalf) Sepeteri Nigeria[a]							
A_1	0-10	7	10	6.2	8.36	2.57	0.44	0	4.5	1.55
B_1	25-36	16	60	5.6	0.67	0.38	0.1 2	0.25	5.7	1.77

[a] Clay and chemical data are based on fine earth (< 2 mm). Gravel and bulk density are on whole-soil basis (21).

and with less than 0.85 bulk density and high topsoil organic matter content. About 1 % of Asian upland rice area is on Andepts (25). Upland rice is grown on Andepts of volcanic origin in Indonesia and the Philippines (37) and in Central and Andean Latin America. Andepts are very porous and provide an excellent rooting medium; have high organic matter and N contents, high phosphate sorption capacity, and highly pH-dependent CEC. With proper management they are highly productive (17).

- *Mollisols* (Mollic Gleysols). Mollisols are thought to have developed under grasslands. They have a thick, dark-colored, well-structured surface horizon with high humus content (mollic epipedon) and high base saturation throughout the profile. Very little upland rice is grown on Mollisols. The single major area is in Southwestern Luzon, Philippines, around Lake Taal (37) where the Mollisols are on pyroclastic sediments.

SOIL PROPERTIES

Several physical and chemical properties make upland rice soils different from lowland rice soils. Upland soils are welldrained and rice depends on rain and moisture stored within soil. Information on effects of physical and chemical soil properties on upland rice is scarce.

Physical properties

Soil physical properties are important to upland rice because they influence soil moisture retention, root growth, and ease of cultivation after rainfall. Associated physical properties are texture, water-holding capacity, penetration resistance, and structure.

Texture. Texture is the distribution of particle sizes in soils. A soil may be coarse-, medium-, or fine-textured. Texture is used to evaluate soil suitability for upland rice because it includes all inorganic particles and directly or indirectly relates to plant growth. Texture influences water transmission and storage, air flow, and the capacity of soils to supply nutrients.

Table 4 shows USDA and international classifications of soil particle size.

Table 4. Particle classes and size ranges (49).

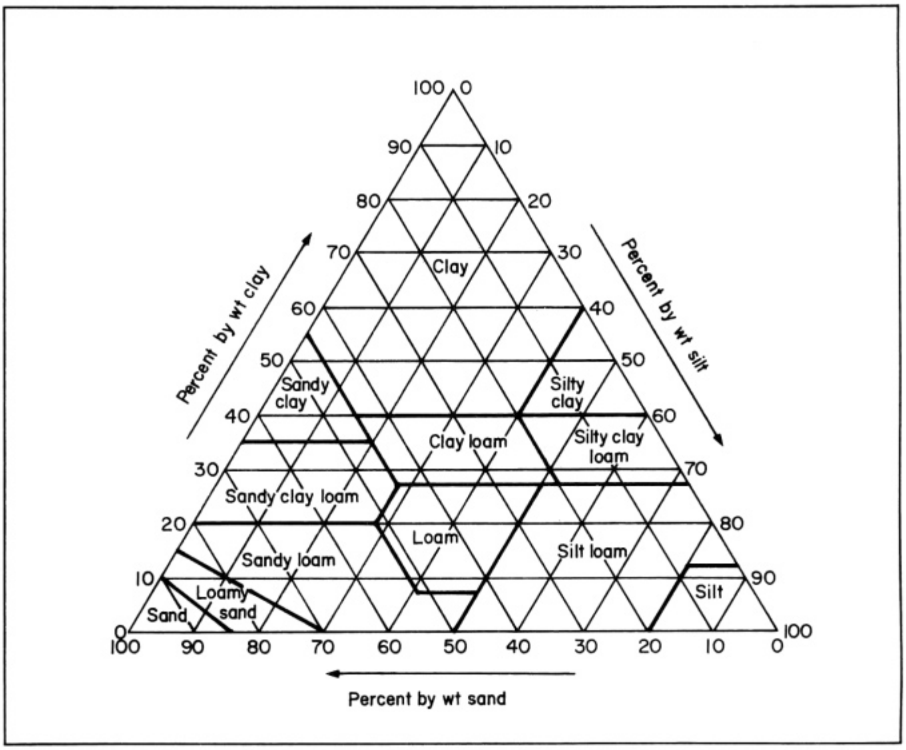
Class	Diameter (mm)	
	USDA	International
Sand	2-0.05	2-0.02
VCS - very coarse sand	2-1.0	-
CS - coarse sand	1-0.5	2.0 -0.2
MS - medium sand	0.5 -0.25	2-0.2
FS - fine sand	0.25-0.10	0.2 -0.02
VFS —very fine sand	0.10-0.05	-
Silt	0.05-0.002	0.02-0.002
Clay	0.002	0.002

When the proportion of coarse, medium, and fine particles is determined, soil texture can be identified using Figure 4 (20).

The major rice soils have less than 35% (by volume) of particles coarser than 2 mm. There are four such soil classes (all percentages are mass fraction of the fine earth) (37):

- Sandy -The fine earth portion is in sand or loamy sand but not loamy very fine sand or very fine sand.
- Loamy - The fine earth fraction is loamy very fine sand, very fine sand (dominant fraction between 0.05 and 1 mm), or finer, with less than 35% clay. Coarse loamy is defined as having less than 18% clay, and fine loamy has 18-35% clay.
- Silty - This has less than 35% clay, less than 15% fine or coarse sand, or both. Coarse silty material has less than 18% clay and fine silty has 18-35% clay.
- Clayey - The fine earth fraction has more than 35% clay. Fine clayey has 35-60% clay and very fine clayey 60% or more clay.

Upland riceland soil texture varies widely depending upon parent material and degree of soil development. Soils from basic rocks are mostly clayey, while soils from intermediate rocks are mainly coarse loamy near the surface and fine loamy to fine clayey in the subsoil (37).



4. Textural triangle, showing the percentage of clay (below 0.002 mm), silt (0.002-0.05 mm), and sand (0.05-2.0 mm) in the basic soil texture classes (20):

Texture may be the most important property of rice soil with equal moisture regimes and comparable mineral compositions (36). Texture affects soil moisture status more than any other property except topography and is particularly important in unbunded upland rice (10).

Fine-textured soil is best for upland rice because it holds more water. Riquier (40) recommended that rainfed rice be planted on fine-textured African soils because of hydromorphy. He classified the following African soils and areas as suitable for upland rice:

- In Senegal, south of the Casamance River, with satisfactory rainfall, upland rice can be grown on Ferric and Gleyic Luvisols.
- In Guinea Bissau, upland rice is grown on low fertility Ferralsols and in some mangrove soils.
- In Guinea, upland rice is grown on humid Ferralsols on hills.
- Many poorly drained areas in Sierra Leone are suitable for upland rice.
- In Liberia, upland rice is grown mostly on rapidly degrading Oxisols.
- North of Upper Volta, soils are dry and fine textured, similar to sodic soils, and difficult to cultivate.
- The valleys of northern Niger are too sandy for upland rice.
- Nigeria has large areas well suited to upland rice.
- Good areas for upland rice are found in Ivory Coast.

Moormann and Veldkamp (38) suggest that the abundant, sandy, coarse-textured soils in West African upland rice areas limit production because of low water retention capacity. Sandy soils also are infertile and applied N may quickly leach out of the root zone (34).

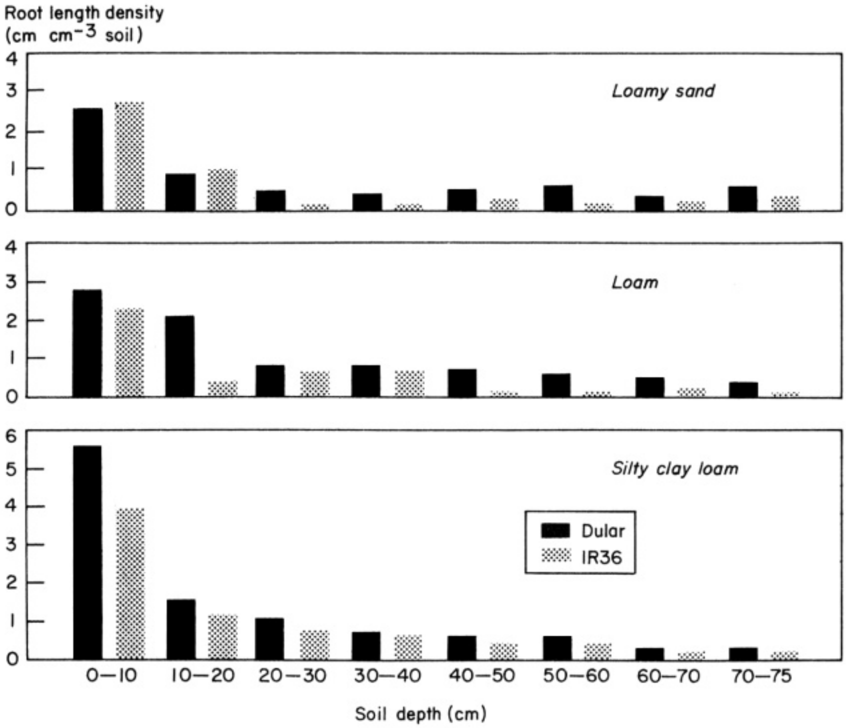
High clay content, as in Vertisols, also may have several disadvantages. With sufficient water supply they can produce good rice yields, but land preparation often requires advanced mechanization. Drought on fine clay soil can reduce yields because of restricted hydraulic conductivity (38).

In a laboratory study with 15-x 30-cm steel cylinders, Kar et al (27) found that roots grew best in silty clay loam > sandy loam > silt > sand > loam> clay loam > clay > silty clay. A high percentage of silt or sand with a moderate clay content (20-35%) provided a favorable environment for root growth and penetration.

Tomar and O'Toole (45) grew IR36 and Dular in deep containers (75 cm deep soil, 200 litre capacity) in silty clay loam, loam, and loamy sand. Root length density of both varieties decreased with soil depth (Fig. 5). In loam and loamy sand, Dular had relatively higher density than IR36 at shallower depths. IR36 rooting density was less than that of Dular below 20 cm in loamy sand and below 40 cm in loam.

Subsoil texture is as important as topsoil texture. The adverse effect of coarse soil diminishes if the subsoil has sufficient clay content (10, 37). Such soil can be tilled by machines without adversely affecting water storage capacity.

Water-holding capacity. Soil physical properties affect the amount of water held in a soil, the energy with which it is held, and ease of its movement through the soil. Water-holding capacity and energy are functions of soil pore size and texture. Larger pores hold more water but with less energy, thus they drain first. Conversely, smaller pores hold less water but hold it more tightly because of



5. Root length density patterns of IR36 and Dular in different layers of 3 soils (45).

molecular forces between water molecules and soil particles. These same kinds of surface forces hold the exchangeable ions of plant nutrients. Water flows more slowly through smaller pores.

In upland rice growing areas such as those on savanna soils in West Africa, cerrado soils in central Brazil, and lateritic soils of South Asia, water supply is the major constraint to yields. Even in humid areas, drought, especially at reproductive stage, may seriously reduce yields. In general, clay soils have more water storage capacity than sandy soils, making sandy soils more drought prone except where rainfall is well distributed throughout the crop season. Organic matter content also influences water-holding capacity. Some Philippine and Indonesian volcanic soils have high organic matter content and good water storage capacity.

Penetration resistance. Penetration resistance often is used to predict the resistance of a soil to shear or compression forces. High penetration resistance requires substantial energy to establish seedbeds and may impede root growth. When roots cannot extend normally, nutrient and water uptake and, therefore, yield decline. High soil resistance limits the depth of tillage by animal-drawn implements.

Soil moisture content also influences penetration resistance. At low moisture content, soil moisture suction is a compressive force that also increases particle-to-particle friction and overall soil resistance.

Ghildyal and Tomar (15) described the effect of soil strength on rice root and shoot growth. There was a close relationship between penetration resistance and root and shoot length in a lateritic sandy clay loam. Higher penetration resistance reduced seedling emergence. The effect was more pronounced on plumule than on radicle growth. Increasing penetration resistance from 1.03 J cm^{-2} to 6.12 J cm^{-2} decreased maximum root length from 10.8 cm to 1.7 cm.

Soil structure. Soil particles, particularly clays and finer silts, seldom occur individually when allowed to dry. They form clusters or secondary units called peds or aggregates that are held together by cementing agents. These are the building blocks of soil structure. Soil structure is the pattern of spatial arrangement of soil particles in a soil mass, which indicates the size, shape, durability, and stability of peds. Structure also reflects the nature (extent, size distribution, shape, and stability) of pore space. A complete description of structure is impossible. Instead, indices of structure are used to describe a part of structural quality.

For a soil to have structure, aggregates or peds must form and they should form a pattern within the soil mass. If either quality is lacking, the soil has a single-grain or massive structure. In sandy soils, few aggregates form and particles exist individually, creating single-grain structure. Massive structure results when binding strength is equal between any two adjacent particles, and no observable aggregation or definite orderly arrangement occurs. Dried lowland paddies often have massive structure, particularly the hardpan or plow layer that impedes water movement and helps keep water ponded. Fine-textured upland subsoils also can have massive structure.

Soil structure usually is evaluated quantitatively using several indices: bulk density, porosity, pore-size distribution, and soil aggregation, which includes stability and size distribution of aggregates. These indices directly or indirectly measure the pore space affecting plant growth which is determined by the arrangement of solids in the soil mass.

Favorable soil structure is essential for upland rice growth and productivity. Soil structure influences root growth and soil water retention. In Senegal, Charreau and Nicou (4) found an inverse relationship between bulk density and maize and sorghum rooting. Moormann (34) wrote that improved soil structure could increase upland rice yield from West African soils.

Subsurface soil structure determines drainage and permeability and, for upland rice, affects water supply and root growth. Open structure increases root growth, but low water retention capacity increases the risk of drought. Slow permeability due to a rather massive structure 20-30 cm below the surface often favors upland rice growth (34).

Chemical properties

Soil mineralogy and parent materials, organic matter, reaction, and CEC determine the nutrient supplying potential of upland rice soils. Inherent fertility is most important where upland rice is grown in shifting cultivation and no fertilizer is added to replace nutrients removed by the crops. Gradual loss in nutrients causes farmers to abandon fields after 2-3 crop cycles and move to newly cleared bush/forest land.

Soil mineralogy and parent material. Nutrient availability in nonfertilized rice soils depends on the parent material and degree of weathering or soil formation. For upland rice, soils from basic rocks are better than those from acidic rocks. If soils with similar parent materials are compared, the degree of weathering and mineralogical composition are an important determinant of inherent fertility (37).

Clay minerals consist of crystalline and amorphous or noncrystailine units. The silicon oxygen tetrahedron unit and the Al oxygen octahedron unit are two basic structures of crystalline silicate clays. These clays include

- kaolinite and halloysite 1:1 (the proportion of the structural components),
- illite 2:1 nonexpanding type,
- vermiculite 2:1 limited expanding type, and
- montmorillonite 2:1 expanding type.

Amorphous silicate clay is represented by allophane, which develops from amorphous minerals from volcanic eruptions. Besides silicate clays, soils also contain hydrous oxide clays. Most hydrous oxides contain Fe and Al with general formulas of $Fe_2O_3 \times H_2O$, and $Al_2O_3 \times H_2O$. They often dominate tropical and semitropical soils. The dominant oxides are

- gibbsite ($Al_2O_3 \cdot 3H_2O$) or boehmite,
- goethite ($Fe_2O_3 \cdot H_2O$) or hematite,
- limonite ($Fe_2O_3 \cdot H_2O$) or magnetite.

The CEC of various clay minerals is given in Table 5.2:1 type clay minerals with expanding lattices have the highest CEC and water absorption properties (33).

The total effect of clay minerals on upland rice growth is difficult to determine because clay minerals are not an independent growth-determining factor, but act with texture and organic matter. Nevertheless, soils that are entirely kaolinitic are less productive than those with 2:1 lattice clay minerals such as smectites, illites, and vermiculites (38).

Clay mineralogycreates different water-holding capacity and cation retention in surface soils. The clay mineralogy of some upland rice soils with ammonia fixation capacity is in Table 6 (1). Clays with dominant vermiculite and montmorillonite fix the greatest proportion of applied ammonia (94 and 91%), followed by beidellite (72%) and X-ray amorphous (45-64%) clay. Fixation was negligible (10%) in clays with hydrous mica, halloysite, and chlorite.

Most upland rice soils in West Africa are kaolinitic (3, 38). Most soil clays in central Brazil are lattice 1:1 clays such as kaolinite and halloysite, and have oxides

Table 5. Cation exchange capacity (CEC) of various clay minerals (18).

Mineral	CEC (meq/100 g)
Kaolinite	3-15
Halloysite $2H_2O$	5-10
Halloysite $4H_2O$	40-50
Illite	10-40
Chlorite	10-40
Smectite	80-150
Vermiculite	100-150

Table 6. Mineralogical composition of clays and proportion of ammonium fixed under upland conditions (1).

Sampling site	Mineral composition[a]								Ammonium fixed (%)
	XA	M	B	V	HM	H	K	C	
Los Baños	4	1							64
San Pedro		5							60
Bani			5						72
Natividad				4		2			94
Cabanatuan				5					88
Vietnam				2	4		3		54
Siclang				4	3		3		12
Santana			3	2		4			82
Luisiana				3		4			52
Guillermo				3		4			56
Tagaytay		2		3			4		64
Sampaguita					4	3		3	10
Budhuran		4			3	3			91
Los Baños	5								45

[a]XA = x-ray amorphous material, M = montmorillonite, B = beidellite, V = vermiculite, HM = hydrous mica, H = halloysite, K = kaolinite, C = chlorite. 5 = monomineralic (> 90%), 4 = dominant (50-90%), 3 = major (20-50%), 2 = minor (5-20%), and 1 = trace (< 5%).

of Fe, Al, or Ti, and insoluble minerals such as quartz. Gibbsite, hematite, and goethite are sometimes present. Advanced weathering has formed resistant microaggregates gathered by A1 and Fe oxides that cause clay soils to have permeability equal to that of medium-textured soils, which encourages root development (11).

The weathered soils on old basalts of the Pleiku area in Vietnam, which do not contain appreciable weatherable minerals and have a clay fraction dominated by Fe oxides and kaolinite, are poor rice soils, but are planted to rice in shifting cultivation. Yields are low even with good management. In the same area, however, rice yields are higher on soils from younger basalts. With fertilizer, these soils can grow regular upland rice crops (37).

Another example of clay mineralogy’s influence on upland rice cultivation can be taken from two volcanic soils in the Philippines. The soils have similar topography, are fine-clayey, and have similar rainfall patterns (37).

The relatively young pyroclastic sediments (water-transported volcanic ash) in southwestern Luzon (Batangas and Cavite) contain considerable weathered minerals in the coarse fractions and 2:1 lattice clay (mainly smectite) and varying amounts of allophane in the clay fraction (37). They are very productive upland rice soils. With good management, yields have been 7 t/ha (9).

In contrast, older volcanic formations in Luzon, including pyroclastic sediments and lavas, are less productive. They are mainly Udults, with fewer weatherable minerals in silt and sand fractions, a predominantly kaolinitic clay fraction, and much lower base saturation. Upland rice is grown in shifting cultivation. Forest/bush land is cleared, planted with rice for 1-2 yr, then abandoned.

Soils on basic rocks and where young alluvial sediments are of mixed origin and without exclusively kaolinitic clay mineralogy are best for rice production. They are in river plains and are used for wetland rice production. Most upland soils of West Africa developed either from intermediate-to-acid crystalline rocks (basement complex), or from mostly arenaceous sedimentary rocks. These parent rocks generally produce soils with poor inherent fertility for upland rice (38).

Organic mutter. The direct effect on upland rice of organic matter has not been systematically studied. However, some general relationships have been established for organic matter behavior in upland soils. Organic matter usually improves upland soils, but an excess can be harmful.

Generally, organic matter improves soil structure and increases water-holding capacity, CEC, and nutrient supply (19, 28, 34, 37, 38). Humus, the most stable part of soil organic matter, increases water retention and transmission. Organic matter content is most important where a slight decrease in water retention capacity reduces upland rice yields. This is particularly true for sandy- or coarse-textured soils with kaolinitic clay mineralogy and marginal rainfall. In such soils, rice grown where there is high organic matter content will be less affected by drought. Where clay mineralogy is more favorable, the beneficial effect of organic matter on water-holding capacity diminishes.

Organic matter stabilizes soil aggregates, increases porosity, and reduces bulk density (19), thus improving the rooting environment for upland rice. A good rooting environment is important because upland rice often is intercropped with maize, cassava, beans, and other upland crops that need to have good root growth to utilize moisture from lower soil layers.

Humus retains cations and influences soil nutrient status. CEC varies from 1-3 meq g^{-1} of organic C. In clay soils with low CEC. cation retention depends primarily on humus-content. This is particularly important on upland rice soils with sandy texture and kaolinitic clay mineralogy (37).

Organic matter can provide large amounts of N and P to rice. Farmers who practice shifting cultivation in West Africa, Latin America, and Southeast Asia plant upland rice after slash-and-burn clearing of forest land. These soils initially have favorable organic matter content, but after 1-2 yr of cultivation, organic matter diminishes to 0.5-0.8% because of erosion losses (38). The resulting low organic matter content reduces soil fertility and rice yields, and farmers abandon the land and clear new land for rice.

Organic matter can increase P availability in several ways. Organic P is more available to plants afer mineralization. Organic matter can complex Al and Fe from their phosphates and, through CO_2 formation, can liberate Ca-bound P (19). Organic matter is a good source of micronutrients, or can fix large quantities of micronutrients. Cu absorption by peaty material is a well known example (19). However, little upland rice is grown on peat soils.

Soil reaction. Upland rice is grown with a wide range of pH, but most upland soils have pH 4.5-6.5, which is quite suitable for rice production (34). Very little upland rice is grown on saline and sodic soils. Oxisols have generally lower pH (4.7) than the Alfisols (6.2) (21). Although pH is not directly related to upland rice growth and yield, it is a valuable indication of soil suitability for rice because it reflects soil fertility status. Elements such as A1 and Mn become toxic if soil pH is low. For example, many cerrado soils in Brazil have a pH 4.8-5.2; extremely low effective CEC and extractable Ca, Mg, P, and Zn; high Fe and high Al saturation (11, 32). Such soils require careful management for upland rice.

SOIL-RELATED CONSTRAINTS

There are both chemical and physical soil-related constraints. Their nature and severity differ among soils in upland environments.

Physical constraints

Soil moisture retention is important because upland rice depends primarily on rainwater. For a shallow-rooted crop like rice, the volume of soil from which moisture is available is limited (30). Most soils in West Africa and some in Brazil have low water-holding capacity(11, 29, 30, 34, 48). In West Africa, soils have low water-holding capacity because they are coarse or medium- to coarse-textured.

Although Brazilian soils are fine-textured, kaolinitic clay mineralogy gives them moisture retention properties like coarse-textured soil. Low water retention capacity causes moisture stress soon after rains stop. Moisture stress reduces nutrient availability (24).

Erosion is a major constraint in some West African and Southeast Asian upland rice areas. Soils in those areas are mostly Ultisols or Alfisols with coarse-textured topsoils. Heavy rainfall on rolling topography greatly speeds erosion (8, 35, 48). Erosion is a particularly serious problem where shifting cultivation is practiced. When the protective forest groundcover is cleared, soil erosion removes topsoil and many nutrients, and farmers must clear new fields after 1-2 crop years. This is one reason capital-intensive food crop farming systems used in temperate regions have not been adopted in those areas (35).

Chemical constraints

Most upland rice soils are N deficient. Brazilian soils, in general, and cerrado soils, in particular, also are deficient in P, K, S, Zn, Ca, and Mg. They also suffer from high phosphate fixation, which increases P deficiency (11, 31). West African soils are deficient in P, Fe, Ca, Zn, and S. They have generally low nutrient status (7, 12, 48).

Heavy rainfall leaches bases from soil and can cause soil acidity. Most upland rice soils are acidic. Acidity is more severe in Oxisols of the Brazilian cerrado than in West African and Asian Alfisols and Ultisols (7, 13, 21). Acid soils have A1 and Mn toxicities. A1 toxicity is a serious growth inhibitor if soil pH approaches 4.0 (39). Fe deficiency normally occurs in neutral and alkaline soils (24), but little upland rice is grown on alkaline soils.

SOIL FERTILITY CLASSIFICATION

Inherent or potential soil fertility refers to a soil's capacity to produce crops on a sustained basis (50). Fertility is not a soil property alone but of the total environment of a site. Climate, soil, and slope all are important to potential productivity. Soil properties vary with climate.

Each crop has specific soil requirements, but there are many soil properties that are important for most crops. Table 7 gives a general framework for assessing soil fertility in terms of conditions affecting fertility and the morphological and analytical properties that affect them (50).

Greenland (16) advocated including physical and chemical soil properties as criteria for determining potential productivity of soils in lowland humid tropics. The most important soil physical properties are those that determine the extent of root proliferation and air and water movement, and those that control water storage and water availability to crops.

Soils need a well-distributed system of pores larger than about 0.05 mm to allow root entry, and other easily deformed pores that can accommodate root growth. Soils should be free of compacted horizons and gravel layers. For good air and water transmission, more than 10% of a soil's volume should be pores larger than 0.05 mm and for adequate water storage a further 10% of pores should be 0.01-0.0005 mm in diameter. Transmission pores should be continuous and both transmission and storage pores should be stable against stress. Erodability also is important in assessing soil potential for crop production.

Chemical properties that determine potential soil productivity include nutrient reserves in weatherable minerals, organic matter, phosphate fixation, CEC, and soil reaction (16). In low pH soils, A1 and Mn toxicities are important

Table 7. A framework for assessing soil fertility (50).

Fertility condition	Relevant soil properties
Physical condition	
Rooting condition:	
effective depth	Depth to weathered rock, laterite, stone lines, fragipans
root penetration	Texture, structure, consistence
Moisture condition:	
drainage	Depth of water table, permeability
Moisture retention	Field capacity, wilting point, available water capacity; indirectly, texture
Erosion resistance	Permeability, structure; indirectly; organic matter content
Plant nutrient	
Present nutrient status, available and reserve	N content, C: N, exchangeable K, available P, content of other nutrients; weatherable minerals, total PK; indirectly, organic matter content.
Capacity to retain and make available added nutrients	CEC, reaction; indirectly, texture, organic matter content
Chemical conditions	
Properties of the exchange complex	Reaction, base saturation, proportions of exchangeable bases
Salinity or other forms of toxicity	Soluble salts, exchangeable sodium percentage, calcrete
Organic matter	Organic C content, C:N

criteria for assessing productivity. In neutral and alkaline soils, Fe deficiency may limit growth under aerobic conditions (39).

Buol et al (2) developed the Soil Fertility Capability Classification System (FCC) to bridge the gap between the subdisciplines of soil classification and soil fertility. The FCC is a technical system for grouping soils according to the problems they present for agronomic management of their chemical and physical properties. It includes quantifiable topsoil parameters and subsoil properties directly related to plant growth. FCC classes indicate major fertility-related soil constraints that can be interpreted in relation to specific farming systems or land utilization types. The system consists of three levels: *type* (topsoil structure), *substrata type* (subsoil structure), and 15 modifiers. Several modifiers have been changed since 1975 (43). For details, see Buol et al (2) and Sanchez et al (43).

The FCC has been tested, evaluated, and used in many countries. The studies showed that

- soil individuals in one FCC unit may belong to different orders, suborders, great groups, subgroups or families in *Soil taxonomy* or other natural systems;
- the number of FCC units in a given area or data set is much smaller than *Soil taxonomy* units, thereby simplifying interpretations;
- making fertilizer recommendations based on FCC units was more profitable than making general recommendations (43).

These concepts were verified with fertilizer response data from 542 sites of the FAO/ ANDA/ ABCAR simple fertilizer trials conducted in Minas Gerais, Brazil, from 1969 to 1973. These included 248 upland rice trials. Yields were 77% higher for C type soil (low infiltration rates, good water-holding capacity, potentially high runoff, sloping difficult to till) compared to SL soils (medium to high infiltration and low to good water-holding capacity). The a (Al toxic) modifier reduced grain yield. Despite some limitations, the system performed satisfactorily (43).

IITA also is developing a soil evaluation system using mineralogical characteristics as main criteria. Its primary objective is to provide agricultural planners with simple guidelines for agricultural soil utilization in the tropics (23). For further details see the IITA annual reports (22, 23).

Because upland rice soils are well drained, some of these criteria can be used to evaluate inherent soil fertility for upland rice production. However, no systematic effort has been made to evaluate and classify long-term inherent potential of upland rice growing soils.

IRRI attempted classification of upland soil fertility status for South and Southeast Asia (13, 14, 26). The effort was to encourage more effective communication among upland rice growing countries and regions with analogous environments and to facilitate the exchange of genetic material and management technologies. Fifty-one soil units were rated from 1 to 9 (high to low fertility) based on subjective judgment, and using FAO world soil map publications 1977 and 1979 and personal observations regarding acidity, CEC, organic matter content, natural NPK status, and possible micronutrient toxicities and deficiencies (13).

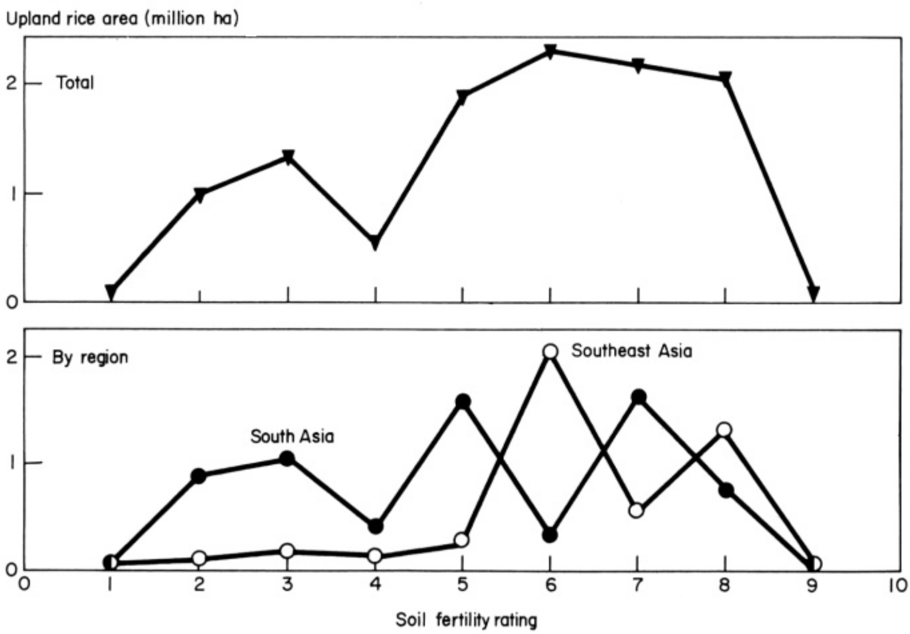
Soils with low inherent fertility are generally poorly adapted to upland rice in South and Southeast Asia. They have low productivity, likely micronutrient imbalances, and returns to cash inputs may be poor. For such soils, shifting cultivation may be the only viable management system.

Fifty-eight percent of South and Southeast Asian soils are classified as infertile (rating 6-9) (Fig. 6). However, South Asia grows more upland rice on fertile soils than Southeast Asia. Table 8 shows the inherent fertility of dominant soils in each region. In Southeast Asia, favorable soils are Ochric Andosols (Andepts). In South Asia they are Eutric Cambisols (Tropepts, Tropaquepts) and Chromic Vertisols (Vertisols) (13, 26).

Inherent fertility rating was combined with length of growing season to identify upland rice environmental complexes to assist in varietal improvement and management technology development (13, 26). Length of growing season was expressed as the number of months in the year in which rainfall exceeded potential evaporation by 20%. Each site was categorized as having either a long growing season (5-12 mo) or a short growing season (14 mo), and as having either fertile (inherent fertility 1-5) or infertile soils (rating 6-9). There are four environment complexes (Fig. 7):

1. long growing season with fertile soils (LF),
2. long growing season with infertile soils (LI),
3. short growing season with fertile soils (SF), and
4. short growing season with infertile soils (SI).

About 15% of Asian upland rice is in LF. Yields are high and adaptation of modern technology with purchased inputs is feasible. Semidwarf varieties can be developed for these areas.

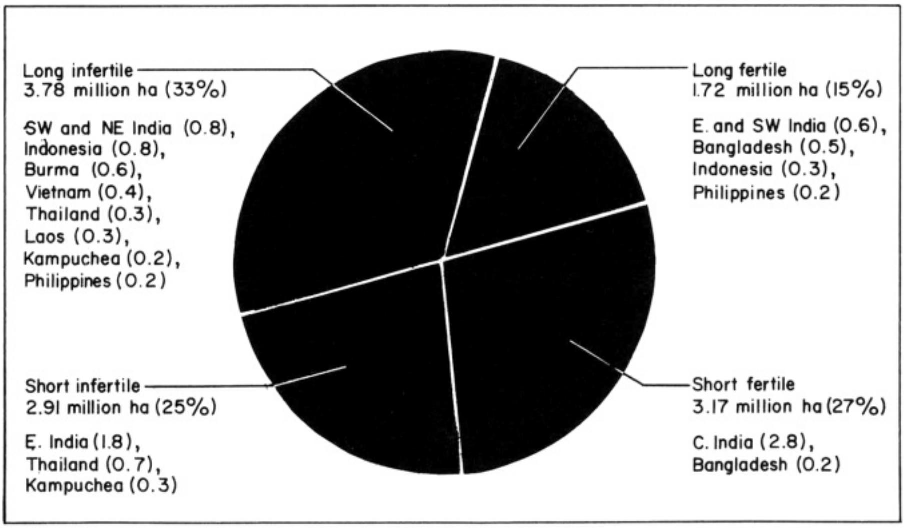


6. Distribution of upland rice soils by inherent fertility status rating: both regions combined and by region. Rating scale: 1 = highly favorable, 9 = highly unfavorable (25).

Table 8. Soil mapping units of dominant importance for upland rice, by region (25).

Soil unit	Upland rice area (million ha)	Upland rice (%) within the region	Soil fertility rating[a]
Southeast Asia	4.7		
Orthic Acrisols (Tropodults)	2.0	42	6
Ferric Acrisols (Tropodults)	0.6	13	8
Gleyic Acrisols (Aquults)	0.5	10	8
Oystric Nitosols (Rhodudults)	0.4	9	7
Ochric Andosols (Andepts)	0.1	2	4
South Asia	6.9		
Ferric Luvisols (Ustalfs)	1.1	16	7
Eutric Cambisols (Tropepts, Tropaquepts)	0.9	13	2
Chromic Luvisols (Alfisols)	0.7	10	5
Eutric Gleysols (Tropaquepts)	0.6	9	5
Chromic Vertisols (Vertisols)	0.5	7	3

[a]Stele: 1-2: highly favorable, 3-4: favorable, 5-7: unfavorable, 8-9; highly unfavorable.



7. Asian upland rice in 4 major ecosystems according to the length of the rainy season and soil fertility (25, 26).

About 33% of Asian upland rice is in LI. The environment is most important in Southeast Asia. Acidic, highly leached, or shallow soils are a serious constraint to adaptation and productivity of upland rices. Varieties with adverse soils tolerance, late maturity, and drought recovery ability are important. Moderate yields are possible with careful fertility and erosion management.

SF environments are mostly in South Asia — India, Bangladesh, and Burma. Extremely short growing season makes drought the overriding constraint. Early maturity is essential for varieties to escape severe reproductive drought stress when the monsoon fades. Drought avoidance characteristics and recovery ability are essential.

About 23% of Asian upland rice is grown in SI environments, which are marginal for rice production. India, Thailand, and Kampuchea contain most of the area. Severe climate and soil constraints make yield improvement unlikely. Early maturing varieties with drought tolerance and recoverability and careful soil management may slightly help yields.

Classification of upland rice environments is very important for developing improved varieties and management technologies. The experience gained in classifying Asian upland rice environments should be extended to tropical Africa and Latin America. A unified environmental classification system for upland rice would facilitate the exchange of genetic material and management technologies between analogous environments.

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CHAPTER 4

Cropping Systems

Upland rice is monocropped or intercropped. In favored environments with long growing seasons, it may be planted in sequence with other upland crops. There are few data indicating how much land is planted to different upland cropping systems.

TERMINOLOGY

Several terms are used to describe upland cropping systems.

Shifting cultivation is a primitive system where forest land is cleared, planted to rice 2-3 yr, and abandoned. After several fallow years, farmers may return and repeat the sequence.

Pioneer cultivation is shifting rice cultivation where fallow is replaced by perennial vegetation such as pasture or trees.

Alley cropping is intercropping rice with legume shrubs.

Monoculture is growing a single crop at one time.

Multiple cropping is growing more than one crop each year.

Intercropping is growing two or more simultaneous crops in alternating rows or sets of rows.

Mixed cropping is growing two or more simultaneous crops in the same field with no distinct row arrangement.

Mixed row-cropping is growing two or more simultaneous crops with a distinct row arrangement.

Relay cropping is growing two or more sequential crops. The succeeding crop is planted before the preceding crop is harvested but after it flowers. Relay cropping may be used to modify strip cropping, mixed-row cropping, mixed cropping, or intercropping.

Interplanting is planting short-term annual crops into long-term annual or biennial crops. Where interplanting is between rows of a long-term crop, it often is the same as intercropping, which is the better term.

The *cropping pattern* is the spatial and temporal combination of crops on a plot and their management.

The *cropping system* is the crop production activity of a farm. It comprises all components required for producing a combination of crops and relations between them and the environment. These include physical and biological factors, technology, labor, and management.

The *farming system* is the production and consumption activities the farmer uses to derive benefits from land and other inputs through crop growth and the use of technologies available under specific environments.

SHIFTING CULTIVATION

Shifting cultivation is common in West Africa; the forested areas of Latin America; the northeastern hill regions of Bangladesh; Assam, India; Sumatra, Kalimantan, and Sulawesi, Indonesia; Western Samar, Zamboanga del Sur, and Isabela Philippines; and northern Thailand (2, 5, 30, 69, 73).

Accurate data on the area of upland rice planted in shifting cultivation are rare, but IRRI estimated the area for some Asian countries (30). Shifting cultivation is practiced on 2-3% of the upland rice area in Bangladesh, 5-10% of the area in Indonesia, 25% of that in the Philippines, and about 80% of that in Thailand.

Shifting. cultivation occurs because poor management allows detrimental weed infestation and declining soil fertility within 2-3 yr after a field is cleared and planted with rice. Farmers move to new land because rice yield decreases to almost nothing. Sometimes, shifting cultivation is accompanied by population migration. If farmers stay in their villages, it is semifixed cultivation (2).

Shifting cultivation follows a definite pattern. The forest is cleared in dry season. Cut trees and brush are left to dry and are burned just before rainy season. Hand tools usually are used. Mechanical clearing often increases soil erosion (34). Generally, there is no land preparation, but sometimes the soil is lightly hoed.

Rice seeds may be planted over 2-3 wk. They are planted in widely spaced holes made by pointed sticks, or sometimes broadcast. In West Africa, it is common to mix seeds of several varieties with different maturity (120-160 d). This reduces the risk of total crop loss if there is erratic rainfall. Weeds usually are not controlled and infestation rapidly increases. Little or no fertilizer is applied.

After 1 yr, increasing weed population and declining soil fertility reduce yields. Leaving the soil fallow for 4-10 yr is the only practice used to restore fertility. Adding fertilizer will improve grain yields of rice planted in shifting cultivation. Das Gupta (6) found that 20-40 kg N/ha was needed to obtain 2-3 t grain/ ha the first year of shifting cultivation. For the second and third rice crops, more than 40 kg N/ha was needed to obtain 1.5 to 2.0 t grain/ha.

Harvesting takes several weeks and depends on family, mostly women’s, labor. Individual panicles are harvested with sharp knives, which makes tall varieties with big panicles popular. Straw remains in the field and is later burned.

Fallow is an essential component of shifting cultivation. It permits regrowth of forest species and restores soil fertility. Forest regrowth is slow in the savanna and fast in the humid forest. The fallow period once lasted 10-40 yr but now is 3-10 yr, largely because of increasing population pressure.

Deegan (7) studied the effect of shortened fallow on declining yield in Sarawak, Malaysia. Optimum fallow was 15 yr, but 48% of the fields were fallow for 5 yr or less, 34% were fallow for 6-11 yr, and 17% were fallow for 12 yr or longer. The average was 7.7 yr. The increasing food demand of an expanding population was the main cause of shorter fallowing..

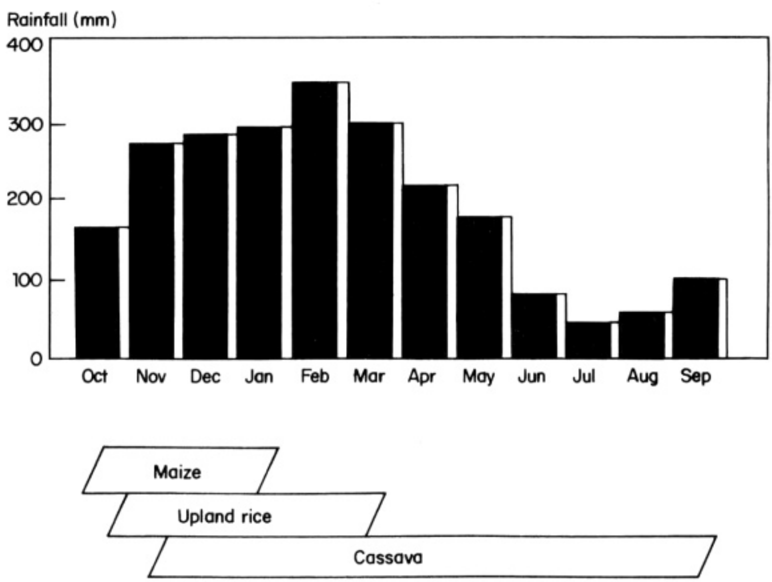
Shifting cultivation has advantages and disadvantages. With proper fallowing, soil fertility returns, and the traditional varieties commonly planted are tolerant of disease and drought. Cultivation practices are simple and involve mostly hand tools. Rocks, stumps, etc. do not affect cultivation.

To be practiced without disturbing the ecosystem, shifting cultivation to feed a large population requires a large area because yields are low. The accompanying deforestation increases erosion, which prevents forest regrowth and allows land to be taken over by *Imperata cylindrica,* a difficult to control perennial weed (2).

Cropping patterns for shifting cultivation

In West African shifting cultivation, one or more crops may be mixed with upland rice. Growing a diversity of food for the farm family, not yield maximization, is the goal. The mixture may differ each year. Common crops include maize, cassava, yam, sorghum, and pearl millet, and may include beans, chili, groundnut, sesame, spices, and banana (2).

In Indonesia, the common cropping pattern in shifting cultivation is maize + upland rice + cassava + legume (Fig. 1). Upland rice + maize is especially common. Variations in the mixture usually are determined by the maize population. Cassava interplanting depends on local food habits. In cooler subtropical regions, cassava may not grow well and may be replaced by other crops (37, 38). In Brazil, rice and maize are intercropped and followed by cowpea (57).



1. Monthly rainfall distribution and cropping pattern commonly used on red-yellow Podzolic soils in Indonesia (38).

Improving shifting cultivation

Productivity of shifting cultivation can be increased by

- improving cultural practices, or
- converting from shifting to permanent cultivation.

Improvements should be suited to local socioeconomic conditions. The resources of shifting cultivators are limited. There seldom is money to buy fertilizer, machinery, and pesticides. Engineering tools and methods to control erosion probably are unavailable. It is difficult to convince shifting cultivators that modern varieties and cultural practices are superior to traditional rices and practices.

Greenland (17) suggested the following steps to improve the productivity of land used for shifting cultivation.

- Keep the land for forestry — tree crops such as cocoa, oil palm, or rubber — or for livestock pasture. Food crops can be interplanted or underplanted. This system reduces erosion by maintaining permanent vegetation cover.
- Use minimum or zero tillage with crop residue management.
- Use mixed or relay cropping to keep a plant cover over the soil for most or all of the year.
- Apply fertilizers to replace nutrients used by crops.
- Plant legumes such as cowpea, lima bean, and winged bean as a mixed crop with upland rice.
- Add plant ash instead of expensive lime to lessen soil acidity. Trees with deep root systems like *Acioa barteri* can be grown with cereals. They bring cations from the subsoil to the topsoil through leaf litter. Fallow tree crops with similar properties should be selected.

With proper management and inputs, yield of upland rice grown in shifting cultivation can be substantially increased. In Thailand, a carefully chosen, locally adapted, modern variety yielded 5.3 t/ha in a 1-yr trial. Inputs were 187.5 kg triple superphosphate/ ha and 62.5 kg urea/ha applied at field preparation and at planting (16).

After 4 yr of experiment station research (1978-81) and 2 yr on farmers' fields, Seguy (57) found rice + maize + cassava followed by cowpea and grown under improved management produced more food than the traditional shifting cultivation system (Table 1). Planting new varieties and using herbicides and fertilizers almost doubled production, net profit/ha, and return/labor-day.

Rotations such as rice - cassava - rice and cassava - rice - cassava are very attractive, with and without fertilizer, for small farms in Brazil.

PIONEER CULTIVATION

Pioneer cultivation is shifting rice cultivation where fallow is replaced by perennial vegetation such as pasture or trees. Upland rice is a cover crop that uses inherent soil fertility before pasture is planted. Pioneer cultivation is common in Brazil and Nicaragua (2).

In Ivory Coast, Nigeria, Ghana, Liberia, and Sierra Leone, rice is intercropped with young fruit and forest trees for 2-3 yr (intercalary cultivation). As the

Table 1. Three-year agroeconomic comparison of traditional and improved cropping systems (57).

System	Cumulative 3-yr production (t/ha)				3-yr production cost ($)	3-yr return ($)	Labor-days (3 yr)	Mean return/d ($)
	Rice	Maize	Cowpea	Cassava				
Low inputs 0.5 ha with herbicide + fertilizer; 0.5 ha with no input; and 1.0 ha with herbicide (total 2.0 ha)	11.8	1.5	0.42	33.8	502	2596	581	4.5
High inputs 1.75 ha with associated cultures with herbicides, fertilizers, and new varieties	18.5	2.6	0.91	13.9	1057	2814	610	4.7
Traditional system (1.5 ha)	6.9	1.1	0.23	0.0	150	1069	520	1.8

trees grow, they shade more area and less rice is planted. After a few years the rice crop will be shifted to a new tree plantation. Intercalary cultivation is more efficient than traditional shifting cultivation (2). Planting rice produces food and income while young trees are growing to bearing age, improves land utilization, diversifies farm income, provides small farm security, controls erosion, and lessens weed infestations. Important trees are coffee, cacao, banana, and sometimes rubber.

In forestry projects, new trees sometimes are planted after old, unproductive vegetation is cleared. Farmers may be given a small plot of new seedlings to care for and are allowed to grow rice or other crops for 2-4 yr, after which they move to another new plot. This system was developed for timber production by the British colonial service in India and Burma (16), and is being used in Ivory Coast, where it is called *Aaungya* (2).

ALLEY CROPPING

Alley cropping is intercropping upland rice with legume shrubs. Legume hedges are planted 24 m apart, between which rice is planted. The hedges are pruned to 60 cm height and the prunings are incorporated in the soil. Alley cropping helps control soil erosion and the prunings, used as green manure, increase soil fertility. *Leucaena leucocephala* is the most popular legume shrub for alley cropping, but *Calliandra caolophyrus* and *Sesbania grandiflora* are being tested at the International Institute of Tropical Agriculture in Ibadan, Nigeria (23).

MONOCULTURE

On highly mechanized farms in Brazil, and in West Africa, India, and the Philippines, one crop of short-season upland rice often is planted on the same land each year (46).

Effect of monocropping on yield

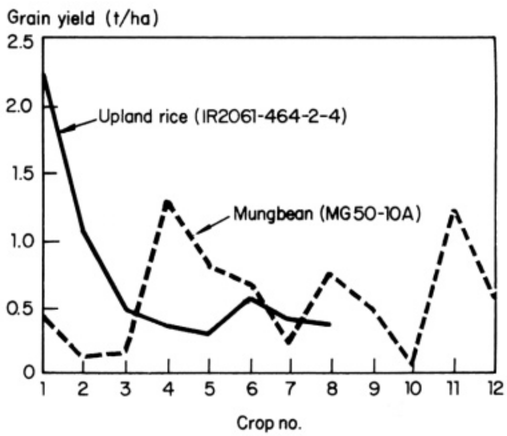
The effect on yield of monocropping upland rice has not been fully documented. Mahapatra et a1 (40) did not find adverse effects on soil properties after 5 yr continuous upland rice cropping at Rokupr Rice Research Station in Sierra Leone. Continuous cropping slightly improved organic C content, available P, and cation exchange capacity (CEC), and decreased pH from 5.8 to 4.8. For northeastern Brazil, Seguy (57) recommended 3 yr continuous upland rice cropping for small farms and 5 yr for experiment stations. Yields were 5 t ha with continuous cropping of improved varieties.

Often, continuous upland rice cropping reduces yields (2, 25, 26, 27, 64, 72). Grain yield may begin to decline with the second rice crop and be very low by the third successive crop (Fig. 2). The main effect of continuous cropping is postheading growth inhibition. At IRRI, similar effects on grain yield of continuously cropped mungbean have been observed. Mungbean had poor germination and seedling growth, but the effect was less than for upland rice (27).

IRRI research suggests that the harmful effects of continuous cropping are persistent (27, 64). Planting rice for 3 to 6 successive seasons substantially reduced plant height and grain yield (Table 2). Alternating upland rice with fallow, mungbean, cowpea, or sorghum may give better yields.

Keeping a continuously cropped rice field fallow for 5 mo in dry season considerably improved growth and yield of the next rice crop, but the following crop again had low yields (Tab1e 3). Rice yield was better when cowpea or sorghum was planted between rice crops (64).

Repeatedly growing the same crop on the same land can develop *soil sickness,* which is thought to be caused by a combination of soil pathogens, mineral



2. Grain yields in continuous cropping sequences (27).

Table 2. Effect of previous cropping on growth and yield of rice, mungbean, cowpea, maize, and sorghum at IRRI (64).[a]

Crop	Previous crops	Plant ht (cm)	Grain yield (t/ha)
Rice			
IR2061-464-2	3 rice (IR2061-464-24)	56 b	0.4 b
	15 mo fallow	82 a	1.7 a
	5 mungbean	82 a	1.3 a
IR2061-464-24	6 rice (IR2061-464-24)	45 b	0.7 b
	7 cowpea	88 a	3.0 a
IR747-B2-6-3	4 rice (IR747-82-6-3)	62 a	0.9 b
	4 sorghum	74 a	1.5 a
Mungbean			
MG50-10A	5 mungbean	57 b	0.66 a
	3 rice	72 a	0.68 a
MG50-10A	8 mungbean	39 b	0.53 b
	6 sorghum	81 a	1.21 a
Cowpea			
EG green pod #2	5 cowpea	35 b	0.60 b
	5 maize	137 a	1.64 a
Maize			
DMR 2	5 maize	211 a	3.6 b
	5 cowpea	223 a	4.7 a
Sorghum			
Cosor 2	4 sorghum	142 a	3.4 a
	4 rice	135 b	3.7 a

[a] Separation of means for a crop by Duncan's multiple range test at the 5% level.

Table 3. Effect of previous cropping on upland rice growth and yield at IRRI (64).[a]

Cropping period and rice variety	Previous crops	Plant ht (cm)	Dry matter wt (g/m^2)	Grain wt (g/m^2)
Jun-Sep 1976, IR2061-464-24	5 rice	54 b	585 c	165 c
	5 mo fallow in a continuous rice pattern	61 b	772 b	214 b
	7 cowpea	88 a	1265 a	446 a
Oct 1976-Feb 1977, IR2061-464-24	6 rice	57 c	554 b	149 bc
	1 rice crop after 5 mo fallow in a continuous rice pattern	59 c	742 b	117 c
	1 rice after 7 cowpea	68 b	1046 a	308 b
	8 cowpea	81 a	1205 a	385 a
Jan-Jun 1977, IR5	7 rice	47 b		0 b
	2-1/2 yr fallow	63 a		127 a
	1 rice after 5 mo fallow in a continuous rice pattern	44 b		0 b

[a] For each column in every period. means are separated by Duncan's multiple range test at the 5% level. Dry matter and grain weight were determined from 4 20- × 20-cm blocks within a plot. Heavy rat damage in the Oct crop prevented yield determination from larger areas.

depletion, changes in soil structure during tillage, and accumulation of toxic substances (allelopathy) (64).

After 8 upland crops of IR8, the nutrient status of a continuously cropped soil was not much different from that of soil that was fallow for 2.5 yr or from that planted to rice with short fallow periods. This may indicate that nutrient status is not a factor in soil sickness (27, 64).

In another study, Ventura and Watanabe (64) found that sterilizing soil improved growth and yield of continuously cropped rice and of rice planted after fallow (Table 4). Flooding the soil also improved yields. Adding sterilized rice roots to fallow soil decreased rice yield, indicating that root residues are related to the harmful effects of continuous cropping.

Yamada (72) found that soil sickness existed in the top 0-30 cm of soil in continuously cropped upland rice plots. Replacing surface soil with subsoil did not improve yields. Disinfecting the soil around seeds sown in continuously cropped soil was only partially effective. Because soil sterilization by irradiation improved rice yield in continuous cropping, Arraudeau (2) suggested that the harmful effect may be due to microorganisms.

Dark culture is a fast, simple way of identifying soil sickness. Normal plants grown in complete darkness die from autolysis in 2-4 wk. Infected plants die much earlier. Using this technique, Ventura and Watanabe (64) found that partially sterilizing infected soil slowed autolysis, indicating the influence of microorganisms on soil sickness (Table 5). More research is needed to determine the exact cause of yield decline in continuously cropped rice.

MIXED CROPPING

Mixed cropping is growing two or more crops at the same time in the same field with no distinct row arrangement. It is most common on small farms in West Africa. Mixed cropping is practiced to avoid total crop failure, to maximize productivity, and to supply the needs of the farm family. Crops commonly planted with upland rice are maize, sorghum, millet, cassava. sweet potato, eggplant, yam,

Table 4. Effect of soil sterilization, flooding, and incorporated rice root residue on IR2061-464-2-4 growth and yield (64). IRRI greenhouse, May-Oct 1976.

Soil source	Soil treatment	Root residue	Plant ht (cm)	Straw wt (g/pot)	Grain wt (g/pot)
Continuous rice field (7th crop)	Unsterilized	With	66 d	19.4 bc	6.9 b
	Sterilized	With	70 b	30.2 a	16.5 a
	Unsterilized, flooded	With	101 a	22.2 b	15.5a
Fallow field	Unsterilized	Added	70 d	15.5 c	5.6 b
	Unsterilized	Not added	71 cd	21.5 b	8.0 b
	Unsterilized	Sterile roots added	73 bc	21.3 b	7.2 b
	Sterilized	Not added	70 b	30.2a	15.2a

[a]Separation of means in a column by Duncan's multiple range test at the 5% level.

Table 5. Number of autolyzed IR2061-464-2-4 rice plants in dark culture grown in continuously cropped soils at IRRI (64).

Field soil condition	Treatment	Plants (no.) at indicated days after sowing										
		16	18	20	22	24	26	28	30	32	34	36
						Feb 1976 dark culture						
4 rice crops	Unsterilized	0	3	8	27	37[a]						
	10% acetone	0	0	5	22	26	36	37	37	39[a]		
	Steam	0	0	0	5	7	14	25	25	36	39[a]	
1 rice crop	Unsterilized	0	0	1	14	22	31	33	35[a]			
	10% acetone	0	1	5	13	16	18	18	32	34	37	39[a]
	Steam	0	0	0	3	13	17	23	27	30[a]		
						Feb 1977 dark culture						
7 rice crops	Unsterilized	0	3	14	16	22	25	30[a]				
	10% acetone	0	0	0	3	10	12	18	23	28	28	30[a]
	Steam	0	0	0	3	13	17	23	27	30[a]		
30 mo fallow	Unsterilized	0	0	6	19	23	24	30[a]				
	Unsterilized (with root residues)	6	17	24	28	30[a]						
	10% acetone	0	0	0	7	13	20	24	26	26	28	30[a]
	Steam	0	0	0	12	19	23	27	29	30[a]		
10 mungbean crops	Unsterilized	0	1	2	10	20	24	29	30[a]			
	10% acetone	0	0	0	5	14	20	21	24	24	28	30
	Steam	0	0	3	8	16	17	27	28	28	30	

[a]All seedlings autolyzed (64).

pigeonpea, groundnut, beniseed, cowpea, okra, hot pepper, tomato, and cocoyam (6, 43) (Plate 4.1).

In Sierra Leone, farmers broadcast a mixture of rice seed and small quantities of other seed. In Rokupr, Sierra Leone, 2 yr after clearing bush from the fields, Mahapatra and Abu (39) compared the farmers' practice of mixed cropping upland rice, maize, beniseed, and cowpea without fertilizer, with line sowing with the same crops and applied fertilizer and pest control. They also compared pure-stand plantings of maize, rice, beniseed, and cowpea. Line sowing was better than the farmers' practice (Table 6).

Rice+ maize intercropping was most economical, followed by rice + maize + cowpea + beniseed. However, rice + maize + cowpea + beniseed was best under farmer management. Cowpea and maize are short- and medium-duration crops and are little competition to rice. However, beniseed is a long-duration crop and competes adversely with upland rice.

INTERCROPPING

Intercropping is growing of two or more crops simultaneously in the same field. Crops need not be sown at the same time and their harvest time may differ, but they

Table 6. Effect of management on grain yield and crop value of different upland rice-based cropping systems in Rokupr, Sierra Leone, 1975 (39).

Crops	Farmer practice Yield (t/ha)	Farmer practice Values ($)	Improved practice Yield (t/ha)	Improved practice Value[a] ($)
Rice	0.4	62	0.8	134
Maize	1.7	372	2.5	568
Beniseed	0.007	2	0.014	5
Cowpea	0.14	106	0.29	221
Rice	0.3	56	0.4	59
+ maize	0.9	175	3.5	786
		231		845
Rice	0.3	55	0.4	66
+ beniseed	0.008	3	0.01 1	19
		58		a5
Rice	0.5	75	0.6	93
+ cowpea	0.1 3	101	0.24	184
		176		277
Rice	0.3	42	0.5	78
+ maize	0.70	156	1.63	363
+ cowpea	0.06	43	0.06	46
+ beniseed	0.006	2	0.010	4
		243		491

[a]Converted at Le 1.00 = US$1.07. Prices at harvest: $0.16/kg rice, $0.22/kg maize, $0.36/kg beniseed, $0.76/kg cowpea.

usually are simultaneous for most of their growing period. Generally, it is difficult to distinguish intercropping from mixed cropping. Willey (70) uses intercropping to describe both situations.

Certain terms are used to denote crop combination characters for intercropping. *Component crops* are individual crops within the intercropping system. *Intercrop yield* is the yield of a component crop and is expressed over the area occupied by both crops. Adding both intercrop yields gives a *combined intercrop yield.* A *sole crop* is a component crop grown alone and is assumed to be grown at optimum population and spacing. *Combined sole* crop yield is the combined yield when unit area is divided between the two sole crops in some given proportion. For a detailed discussion on general aspects of intercropping, see Willey (70, 71).

Benefits of intercropping

There are several benefits of intercropping upland rice (4, 33, 56, 63, 70, 71). Kass (33) summarized the following advantages of intercropping, which he described as simultaneous polyculture:

- reduces insect pest and disease incidence,
- is adapted to local environmental variability,
- is adapted to crop-specific light requirements,
- provides a continuous and varied supply of fresh food,
- provides good soil cover,
- reduces labor for land preparation and generally provides for more economic labor use,
- provides agronomic benefits like reduced lodging and improved stand establishment,
- associated crops may tolerate drought better than pure stands,
- uses land more effectively than single cropping,
- reduces intraplant competition, and
- increases yield stability.

Additionally, if animals are used in the system, intercropping may provide a more balanced and uniform source of feed (63).

Yield stability across seasons is the most important reason for the wide popularity of intercropping in subsistence or near-subsistence agriculture (70): if one crop fails or grows poorly, the component crop or crops compensate for lost yield. With a stable intercrop, yield in a given season, field, and with a certain level of management can be reliably predicted.

Another advantage of intercropping is increased productivity of complementary component crops. Well designed intercropping combines component crops that use growth resources more fully than would single crops. Intercrop competition is less than intracrop competition (70).

There are two kinds of intercrop complementarity.

- *Temporal complementarity* is when growth patterns of component crops differ so that component crops have high resource demands at different times. Rice + maize have temporal complementarity. Early maize matures in 75-90 d and rice takes 120-150 d.

- *Spatial complementarity* is when a combined leaf canopy makes the best use of water and nutrients. This complementarity is less understood than and may be impossible to differentiate from temporal complementarity (70).

Willey (70) reviewed the reasons for yield advantages in intercropping and found that intercropping maximized use of natural resources such as light, water, and nutrients. Sometimes, component crops may benefit from the N fixed by a companion legume crop. It has been suggested that intercropping reduces weed infestation (33, 70), but Moody and Shetty (42) feel that data do not support the claim.

Problems of intercropping

Intercropping may have the following disadvantages (33, 44, 70).

- Adverse competition and allelopathy may reduce intercrop productivity.
- Mechanization is difficult.
- Crop-specific management operations are difficult to perform.
- Research is complex and difficult to manage.
- Without careful management, intercropping can rapidly deplete soil nutrients.

These difficulties tend to be associated with more developed agriculture. More primitive farmers seem well adapted to manage intercropping and seem to prefer it to single-cropping (70).

Evaluating intercropping

The productivity of intercropping can be evaluated by biological yield, economic yield, land equivalent ratio (LER), cash return/input, or labor and cash return/ unit area. Willey (70) gave three basic criteria for assessing yield advantages in intercropping.

- Intercropping must give full yield of a main crop and some second crop yield.
- Yields of intercropped component crops must exceed the sole crop yield.
- The combined intercrop yield must exceed the combined sole crop yield.

The first and third criteria are most important for intercropping with upland rice. The first is applicable where upland rice is the secondary crop, as when it is grown between sugarcane rows or between rubber or other plantation crops. The third situation is more common where the farmer's interest is in all the component crops, which may include maize + rice, rice + peanut, or rice + maize + cassava.

There are several ways of evaluating intercropping efficiency (9, 33, 70, 71), but LER is preferred because it is simple, easy to compute, and not affected by market value of crops and inputs. Moreover, all the component crops, irrespective of type and yield, are considered on a relative and directly comparable basis (4, 70).

LER is the relative land area under sole crops that is necessary to produce at an equal management level the yields achieved from intercropping. LER is expressed as:

$$\text{LER} = \frac{X_I}{X_m} + \frac{Y_I}{Y_m}$$

where X_l and Y_l are the yields of intercropped component crops and X_m and Y_m are yields of the crops in monoculture.

LER was designed for intercropping, but it can be used to assess the performance of component crops in intercropping. LER for intercropping is the sum of LER of the component crops. LER below 1 indicates a harmful effect of intercropping. If LER is higher than 1, there is a positive benefit to the crop combinations. LER of 1.2 indicates a 20% yield advantage in intercropping over monoculture.

Because LER is independent of crop yields and does not indicate the economic benefit of yield levels, it may not always be meaningful (4, 9). In practice, farmers never compare pure stands of sole crops and mixtures of component crops. Therefore, LER is theoretical and unrelated to practical field conditions. Nevertheless, it provides relative comparisons of different crop combinations in intercropping systems.

Economic analyses such as cash return per unit area or per unit input also are used to compare intercropping systems. However, economic analysis has two drawbacks. It is highly dependent on price fluctuations of inputs and outputs, and intercropping is practiced by farmers who farm for family consumption and have little surplus for markets. Economic analysis of input-output relationships may not be very useful for subsistence farms.

Intercropping upland rice

Intercropping upland rice is most common on subsistence farms in Southeast Asia.

Many crops are intercropped with upland rice, depending on length of growing period and farmer preference. Common systems include rice + maize, rice + maize + cassava, rice + cowpea, rice + peanut, rice + sesamum, rice + beniseed, rice + soybean, rice + mungbean, rice + pigeonpea, sugarcane + rice, rice *Capsicum* sp. + *Solanum* sp. + beans + maize + banana + cassava, and rice + cassava + maize + okra + pepper (1, 4, 9, 11, 18, 19, 21, 24, 25, 27, 28, 31, 32, 33, 35, 36, 39, 44, 47, 48, 50, 59, 60, 61, 68). Among them, upland rice + maize and upland rice + maize + cassava have been widely studied.

Rice + maize is the most popular system for Asian uplands, particularly in Southeast Asia. Their growth patterns are complementary. Rice and maize are planted at the same time; the seeding rate of maize depends on farmer needs (3, 37, 38). Maize grows more rapidly than rice and is harvested before rice heads. The maize canopy does not develop until after rice tillers. Farmers plant early maturing (75-90 d) local maize varieties. The rices are tall, local varieties that mature in about 150 d.

In Indonesia, Sierra Leone, Brazil, and Peru, cassava is an important component with upland rice + maize (33, 37, 38, 44, 68). Cassava is generally planted after rice and maize are established, and may be relay-planted in maize rows so that when maize is harvested it occupies the same space (31, 68). After rice is harvested, peanut can be planted in its place, and when peanut is harvested, cowpea can be grown, thus allowing 5 crops in 1 yr (38, 68). In West Africa, spices and beans are grown in the main intercrop of upland rice + maize + cassava (6, 44).

Rice is a cereal, and thus supplies primarily carbohydrates to human diets. Often, legumes are preferred food crops because they have high protein content and enrich the soil by fixing N. Two or three rows of rice at 20-25 cm spacing are planted between 2 rows of mungbean, cowpea, peanut, pigeonpea, and soybean in many parts of India, Indonesia, Philippines, Brazil, and West Africa (4, 6, 9, 19, 31, 50).

A sugarcane crop (planted or ratoon) does not develop a complete ground cover for several months, which allows growing a short duration upland rice crop. Two to four rows of rice can be planted between two rows of sugarcane. This has been used in Mauritius and the Philippines (1, 48).

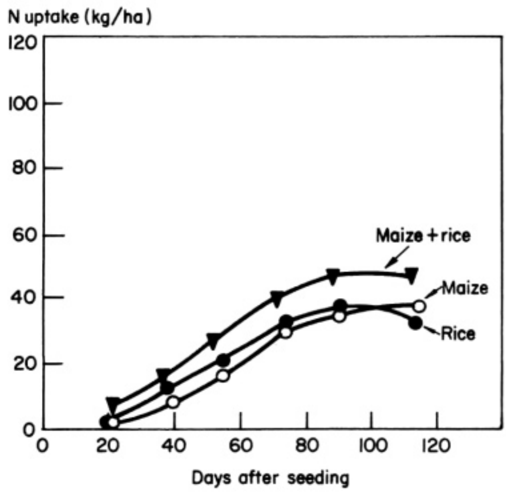
Intercropping productivity

Generally, individual crops yield slightly less when intercropped, but total productivity is higher than in monoculture. Total dry matter production is closely related to leaf area and the dry matter accumulation per unit leaf area of intercropped maize and rice.

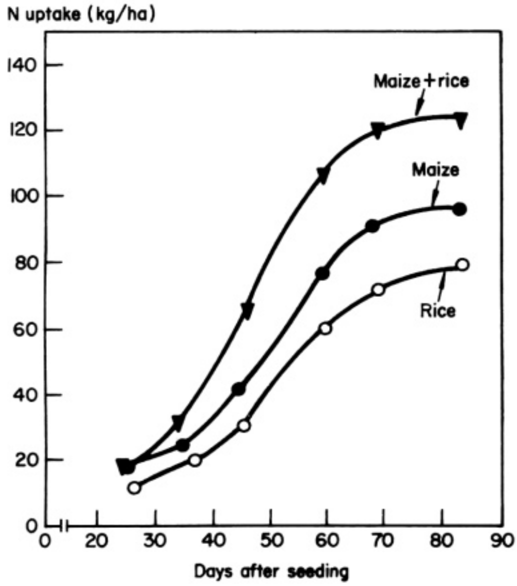
Maize + rice is a highly efficient combination because of the increased leaf area duration (LAD) of the intercrop during the assimilation period. Maize + rice accumulated more N than either maize or rice in monoculture with zero or 180 kg N/ha (Fig. 3, 4).

Elemo and Mabbayad (10) found that upland rice and peanut yielded less when intercropped 1:1 than in monoculture (based on a hectare of intercrop), but that absolute yield (based on a hectare of the component crop in the intercrop) of component rice and peanut was higher than yields of the sole crops. LER was highest (1.21) when both were planted on 21 Jun in the Philippines (Fig. 5).

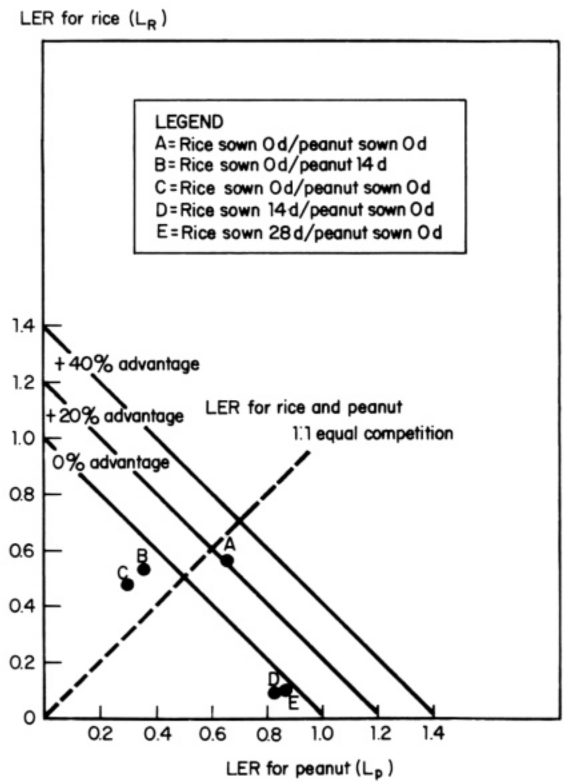
Intercropping mungbean and groundnut with rice at Cuttack, India, improved grain yield and LER when compared with monocropped rice (Table 7). Higher grain yields were attributed to the symbiotic association of legumes with rice (50). Intercropping upland rice with redgram or pigeonpea was studied at



3. N accumulation at various crop growth stages with no applied N (adapted from 25).



4. N accumulation at various crop growth stages with 180 kg applied N/ha (adapted from 25).



5. LER diagram for rice and peanut at different sowing dates (10).

Table 7. Grain yield and LER for upland rice-based intercrops (50).

Crops	Yield[a] (t/ha)					
	1975-76	1976-77	1977-78	1978-79	1979-80	Mean
Rice	2.8	3.0	1.6	1.7	0.0	1.8
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
Groundnut	0.4	1.0	0.2	0.1	0.8	0.5
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
Green gram	0.52	0.77	0.36	0.78	0.45	0.58
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
Rice + groundnut	2.3 + 0.2	2.0 + 0.7	1.0 + 0.1	1.6 + 0.1	0.0 + 0.6	1.4 + 0.3
	(1.40)	(1.35)	(1.15)	(1.81)	(1.18)	(1.38)
Rice + green gram	2.4 + 0.38	2.3 + 0.32	1.6 + 0 .38	1.5 + 0.40	0.0 + 0.37	1.6 + 0.36
	(1.82)	(1.19)	(2.00)	(1.39)	(1.42)	(1.56)

[a] LER values are in parentheses.

Ranchi, India. Two to three rows of upland rice were intercropped with pigeonpea. The intercrop yielded more than monocropped pigeonpea or rice. LER was 1.41-1.64, indicating that intercropping was 41-64% more productive than monocropping (4) (Table 8).

Growing upland rice between rows of newly planted or ratooned sugarcane is quite productive. Sugarcane takes about 4 mo to shade the soil. During this time, 24 rows of rice at 20 cm spacing can be grown. With rice + sugarcane, upland rice yield was 0.8 t/ha in Mauritius and 1.5 t/ ha in the Philippines. Rice did not decrease sugarcane yield (1, 48).

Food quality characteristics vary among intercropped varieties. Cereals are generally rich in carbohydrates, legumes are rich in proteins, and root and tuber

Table 8. Performance of a wet season upland rice intercropping system, Ranchi, India (4).

Year	System	Yield (t/ha)		LER	Expected monetary value ($/ha)
		Sole crop	Intercrop		
1973-74	Rice	3.1	-		285
	Pigeonpea	0.43	-		98
	Rice +	-	2.1	0.67)	
				)1.64	286
	pigeonpea	-	0.4	0.97)	
1974-75	Rice	1.6	-		149
	Pigeonpea	1.4	-		311
	Rice +	-	1.4	084)	
				)1.64	374
	pigeonpea	-	1.1	0.80)	
1975-76	Rice	2.3	-		208
	Pigeonpea	0.68	-		118
	Rice +	-	1.0	0.43)	
				)1.41	240
	pigeonpea	-	0.8	0.98)	

crops are rich in starch but have high water content. Because intercropping generally serves family consumption, the food components of the intercrop are important. Effendi et al (11) found that introduced intercropping patterns that included maize + upland rice + cassava + peanut - rice bean and maize + mungbean + upland rice + cassava + mungbean + cassava produced more than twice the calories and protein of the traditional maize + upland rice + cassava pattern (Table 9).

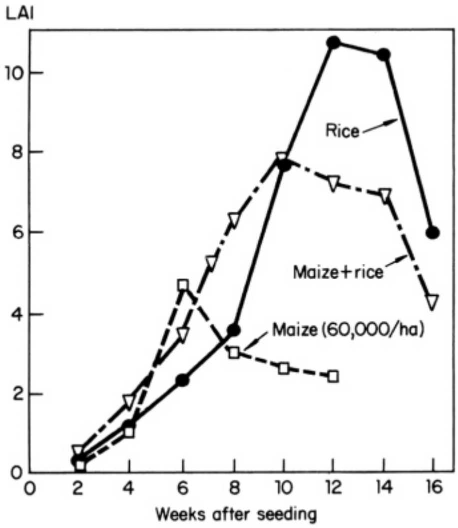
There have been some studies on physiological competition in upland rice + maize intercropping (25, 35, 36, 59). The compatibility of rice + maize depends on avoiding overlapping reproductive growth stages. Yields of intercropped rice are positively correlated with the number of days when rice can grow after maize is harvested (36). If rice can grow more than 45 d after maize is harvested, yield can be similar to that of a sole rice crop.

The early rapid growth of maize and the high productivity of rice late in the season make rice + maize compatible for high yields. Maize reaches maximum leaf area index (LAI) 6 wk after planting, whereas rice reaches maximum LAI 12 wk after seeding and after maize is harvested (25) (Fig. 6).

Photosynthetic efficiency, measured by net assimilation rate 6 through 8 wk after planting, was higher (44 $g \cdot m^{-2} \cdot wk^{-1}$) for maize (1-m row, 40,000 plants/ha) than for rice (26 $g \cdot m^{-2} \cdot wk^{-1}$). The net assimilation rate for maize + rice (maize at 1-m row, 40,000 plants/ ha) was 43 $g \cdot m^{-2} \cdot wk^{-1}$. Maize had relatively low LAD (leaf area integrated over time) and accumulated little dry matter. Maize + rice had high

Table 9. Yield, calories, and protein from different year-round cropping patterns, Way Abung, Indonesia, 1977-78 (11).

Cropping pattern	Yield (t/ha)	Calorie (Kcal/ha)	Protein (kg/ha)
Introduced pattern			
Maize +	2.5	9,060	235
upland rice +	3.7	8830	250
cassava +	19.9	23870	139
peanut -	0.6	2,270	148
rice bean	0.3	1,270	70
		45,290	842
Introduced pattern			
Maize +	1.8	6,443	167
mungbean +	0.32	1,104	71
upland rice +	3.5	1.104	235
cassava +	28.7	34,470	201
mungbean +	0.28	966	62
cassava	2.4	2,848	17
		46,935	753
Farmer pattern			
Maize +	0.6	2,251	58
upland rice +	2.4	5,822	165
cassava	10.9	13,087	76
		21,160	299



6. LAI of rice and maize during the growing period. IRRI, 1975 dry season (25).

LAD and high dry matter accumulation. Rice alone had considerably higher LAD than maize + rice, but produced less dry matter (25).

Sooksathan (59) found that rice + maize had high productivity per unit of leaf area. Findings were similar at IRRI, primarily because of increased LAD of the intercrop during assimilation (25). Comparative efficiency of rice + maize was greater under favorable conditions.

Selecting component crops

For efficient, highly productive intercropping, it is important to choose complementary component crops. IRRI research in this area has concentrated on upland rice + maize (26, 35, 36). Ideally, the rice should be a long duration variety and the maize should have short duration.

Four maize and three rice varieties with different duration were evaluated in intercrops for relative changes in yield caused by varying maturity (26). Maize varieties were Penjalinan (78-d maturity), Thai Composite (95 d), DMR 2 (102 d), and UPCA-2 (106 d). Rices were IR28 (107 d), C-22 (124 d), and IR34 (134 d).

Five rows of rice were intercropped with 2 rows of maize spaced at 1.5 m. Yields of intercropped rice tended to be lower than those of rice in monoculture. Tall C-22 and long-duration IR34 yielded slightly lower when planted with Penjalinan, the earliest maize (Table 10). Yield depression was greatest for all rices when planted with a late-maturing maize. Yields were positively correlated with the number of days rice had to grow after maize was harvested (Fig. 7).

Maize yields also differed, tending to be higher in the intercrop than in monoculture. However, maize yielded significantly less when intercropped with early maturing IR28 than when planted with late maturing IR34 (Table 10).

To identify proper maize plant type for intercropping with upland rice, Lohani and Zandstra (35) compared yields with normal maize canopies and those modified by manipulating leaf angle, half clipping leaves, and detasselling. The modified

Table 10. Grain yield and LER for rice + maize[a] (26).

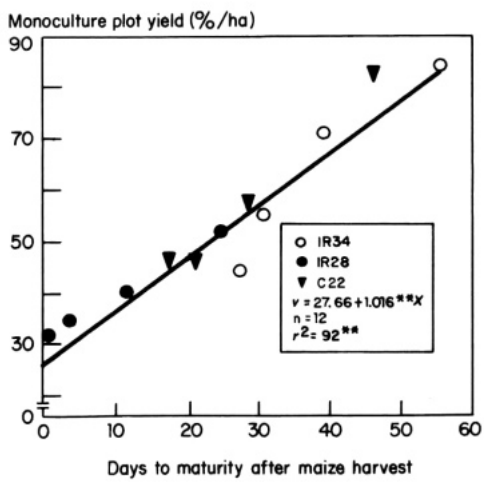
Maize	Grain yield[b] (t/ha) and LER									Main plot mean yield[c] (t/ha)
	IR28 (3.31)			C22 (3.25)			IR34 (2.41)			
	Maize	Rice	LER	Maize	Rice	LER	Maize	Rice	LER	
Penjalinan (3.181	1.9	1.7	1.12	1.7	2.1	1.34	2.2	2.0	1.52	2.0 a
Thai Composite (4.73)	2.7	1.3	0.98	2.8	1.9	1.17	3.4	1.7	1.43	1.7 b
DMR 2 (5.40)	3.3	1.1	0.95	3.6	1.5	1.14	3.7	1.3	124	1.3 c
UPCA-2 (5.28)	3.5	1.2	0.98	3.2	1.6	1.09	4.0	1.1	1.21	1.2 c
Subplot mean yield[c]		2.9 b			2.8 b			3.3 a		

[a]Maize as main plot, rice as subplot. [b]Values in parentheses are monoculture yields (t/ha). Crops and days to maturity were IR28,107; C22, 124; IR34, 134; Penjalinan, 78; Thai Composite, 95; DMR 2, 103; and UPCA-2, 106. [c]Means followed by different letters are significantly different at the 5% level.

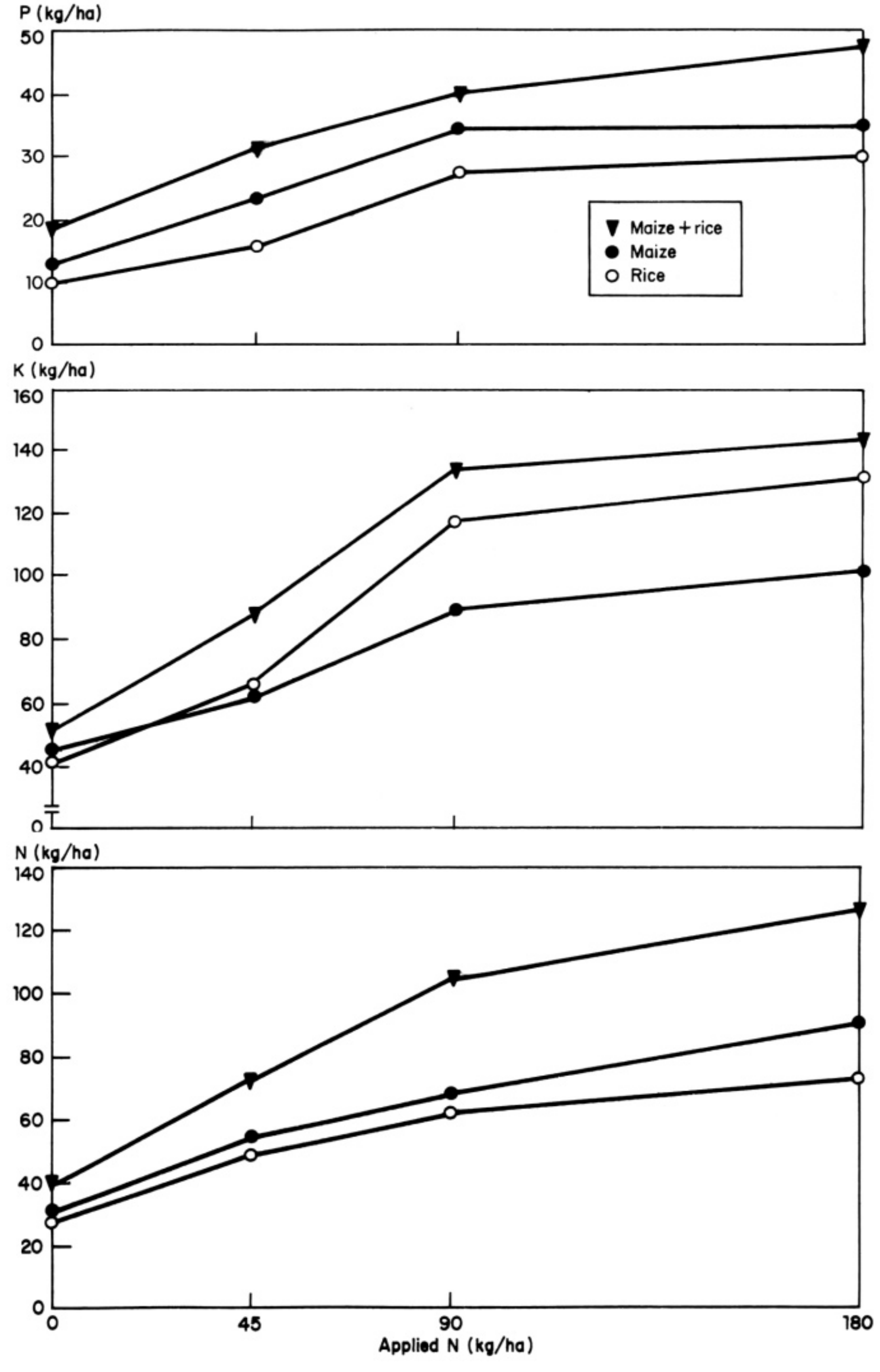
canopies were evaluated with rice + maize intercrop of 32,000, 40,000, and 50,000 plants/ ha. Maize rows were 1.25 m apart, between which 4 rows of rice were drilled. Increasing plant density from 32,000 to 40,000 increased maize yield but reduced rice yield. Artificially manipulating leaf angle and clipping the leaves decreased maize yield but increased rice yield. Detasselling increased both yields. For upland rice + maize, maize should have low foliage, erect leaves, and small tassels.

Fertilizer and crop management

The fertilizer and management requirements of component crops affect intercrop management. Research at IRRI compared nutrient uptake by rice + maize with that of rice and maize in monoculture (25, 45, 61). Increasing applied N from 0 to



7. Relation between intercrop rice yields and days to maturity after maize harvest (26).



8. Total nutrient accumulation at 85 d after seeding (adapted from 61).

180 kg/ ha increased NPK uptake of the intercrop. Nutrient uptake was higher than for the crops in monoculture (Fig. 8). Increasing N from 180 to 240 kg/ ha did not increase N uptake of rice + maize (Table 11).

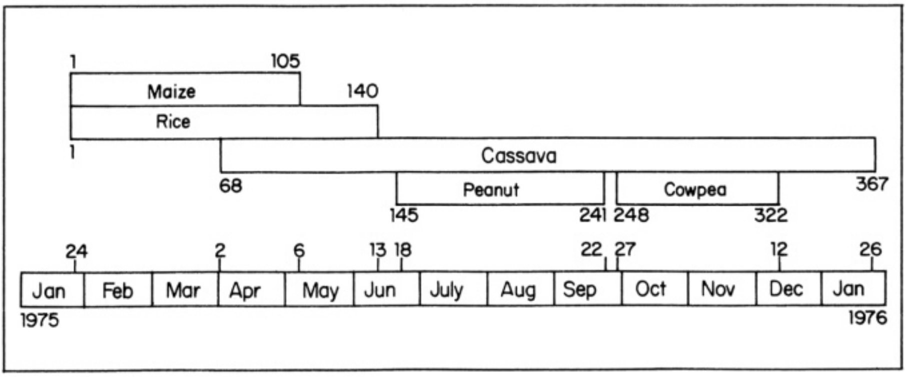
Increasing applied N from 0 to 180 kg/ ha increased intercrop yield from 2.0 to 6.2 t/ ha (Table 12). However, LER dropped from 1.60 to 1.45, indicating that

Table 11. N uptake of maize, rice, and maize + rice with different applied N, in a rainfed farmer's field, Laguna, Philippines, 1973 (45).

Crop	N uptake (kg/ha)		
	Maize	Rice	Maize + rice
		60 kg applied N/ha	
Maize	104		
Rice		95	
Maize + rice	52	61	113
		120 kg applied N/ha	
Maize	81		
Rice		62	
Maize + rice	47	54	101
		180 kg applied N/ha	
Maize	95		
Rice		68	
Maize + rice	85	56	141
		240 kg applied N/ha	
Maize	99		
Rice		91	
Maize + rice	73	67	140

Table 12. Grain yield of maize + rice, maize, and rice at different levels of applied N at IRRI, Feb-May 1975 (25).

Crop	Yield (t/ha)			LER
	Maize	Rice	Maize + rice	
		0 kg applied N/ha		
Maize	1.4			
Rice		1.2		
Maize + rice	1.0	1.0	2.0	1.60
		45 kg applied N/ha		
Maize	2.5			
Rice		2.5		
Maize + rice	1.9	1.5	3.4	1.34
		90 kg applied N/ha		
Maize	3.8			
Rice		3.5		
Maize + rice	2.8	2.1	4.9	1.34
		180 kg applied N/ha		
Maize	4.0			
Rice		4.5		
Maize + rice	3.2	3.1	6.2	1.45



9. The intercropping system used for the N and row-spacing study. Numbers at the corner of boxes are the number of days between the start of the experiment and crop planting or harvest. Yurimaguas, Peru (68).

intercropping was 60% more productive at 0 applied N and 45% more productive at 180 kg N/ ha than rice or maize in monoculture (25). In another study, LER was not increased by increasing fertilizer from 180 to 240 kg N/ ha. LER was maximum (1.50) with 180 kg N applied to rice + maize (45).

Wade and Sanchez (68) studied a maize + rice + cassava + peanut + cowpea system at Yurimaguas, Peru. Tall crops were planted at 1, 2, or 3 m spacing and with 0, 45, 90, or 180 kg N/ha per yr in equal splits at planting and 60 d after planting. N was not applied to legumes or to later growth stages of cassava. Before maize and rice were planted, fields received 1 t lime, 49 kg P and 40 kg K/ha (Fig. 9). Rice in monoculture responded up to 45 kg applied N/ha and maize in monoculture responded up to 180 kg N/ha. Cassava, peanut, and cowpea did not respond to applied N (Table 13).

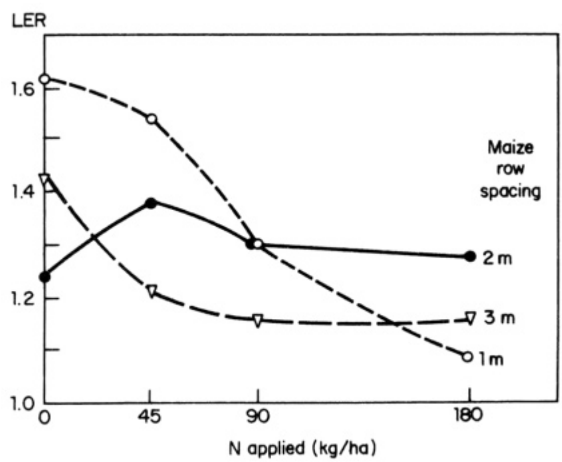
Maize + rice yielded 30-60% more than when planted in monoculture. LER was highest at 0 N (Fig. 10). At 0 N, 1-m maize row spacing was most efficient (LER 1.62), but yield was only 2.4 t/ha. At 180 kg N/ha 2-m spacing yielded 3 t/ha and LER was 1.48. Cassava yielded poorly because of the wet year. No cowpea was grown at 1-m spacing because of the dense cassava canopy. Peanut yields were 50% of those in monoculture (Table 14). The intercrop yielded 300% more than the crops planted in monoculture.

Comparing intercrop yield with monoculture yield is not always meaningful. Wade and Sanchez (68) found that comparing 1 ha of maize + rice + cassava + peanut + cowpea with 0.2 ha of each crop in monoculture is agronomically absurd. In the experiment, intercrop yield was compared to a system where 1/3 ha was sown to rice - peanut -cowpea, 1/3 to maize, and 1/3 to cassava (Fig. 11). However, this did not include the area that normally is left fallow. In a theoretical comparison they divided a 1-ha field into 20.5-ha plots. One plot was planted to rice - peanut - cowpea and one was used for maize - cassava. They harvested 250% of the relative yield of monoculture compared to 299, 309, and 318% relative yields of intercropping. On the average, the 5-intercrop system produced 23% more food than when the same crops were grown in 2 intensive monoculture sequences.

Table 13. Effect of N rate and row spacing of tall crops on yield of intercrops as compared with monoculture yields, Yurimaguas, Peru, 1975 (68).

Cropping system	Total N applied (kg/ha)	Yield (t/ha)				
		Rice	Maize	Cassava	Peanut	Cowpea
Intercropped,	0	1.7	0.7	17.8	2.0	-
1 m rows of	45	1.8	0.8	7.9	2.4	-
tall crops	90	1.4	1.5	17.3	1.8	-
	180	1.4	1.1	15.1	1.7	-
Mean		1.6	1.0	14.5	2.0	-
Intercropped,	0	2.3	0.1	39	2.5	0.24
2 m rows of	45	2.0	0.5	8.0	2.6	0.24
tall crops	90	2.2	0.6	6.0	2.9	0.16
	180	2.4	0.6	6.6	2.9	0.31
Mean		2.2	0.5	6.1	2.7	0.24
Intercropped,	0	2.4	0 2	2.8	3.5	0.21
3 m rows of	45	2.2	0.3	5.9	2.8	0.33
tall crops	90	2.1	0.5	6.3	2.6	0.27
	180	2.1	0.6	7.5	2.6	0.43
Mean		2.2	0.4	5.6	2.9	0.31
Monoculture,	0	2.2	0.9	20.4[a]	3.96	0.49[b]
0.75 m rows of	45	2.4	1.2	22.9	3.0	0.47
tall crops	90	2.4	1.7	17.4	3.1	0.51
	180	2.4	2.4	21.5	2.9	0.49
Mean		2.3	1.6	20.5	3.2	0.49
LSD .05		0.7	0.4	6.9	0.9	0.11
CV (%)		19.5	26.4	349	20.9	24.2

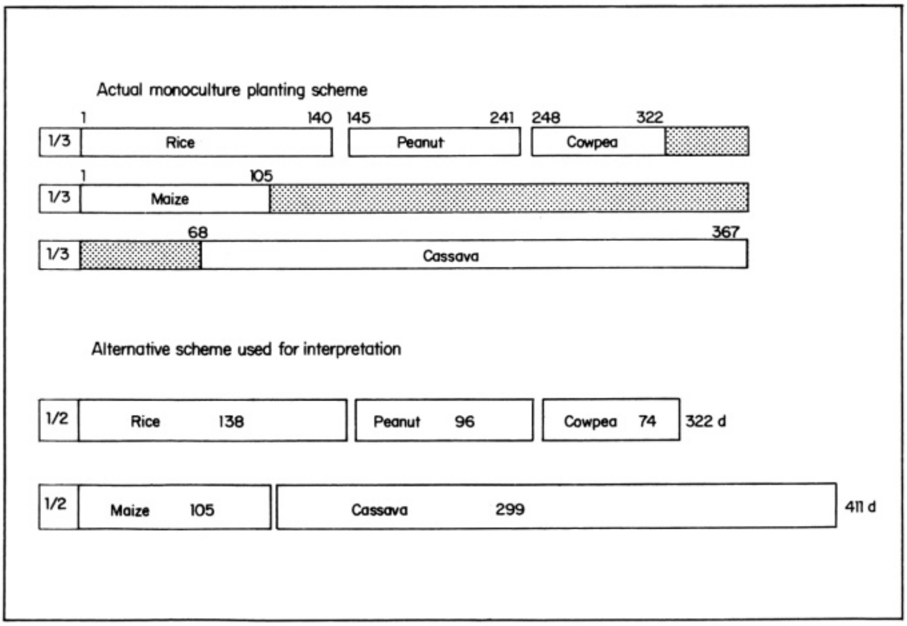
[a]Only half the fertilizer rate was applied to monoculture cassava. [b]Residual effect from fertilizer applied to rice monoculture.



10. Effect of N application and tall crop row spacing on LER (sum of relative yields) of maize + rice. Yurimaguas, Peru (68).

Table 14. Relative yields of 3 intercropped systems (monoculture yields = 1.0) (68).

Row spacing (m)	Total N applied (kg/ha)	Relative yield Rice	Maize	LER	Relative yield Cassava	Peanut	LER	Relative yield Cowpea	Total
1	0	.86	.76	1.62	.94	.53	1.47	-	3.09
	45	.81	.73	1.54	.34	.82	1.16	-	2.70
	90	.60	.90	1.30	1.04	.58	1.62	-	3.12
	180	.59	.50	1.09	.74	.62	1.36	-	2.45
	Mean	.72	.72	1.44	.76	.64	1.40	-	2.84
2	0	1.11	.16	1.27	.26	.65	0.91	.50	2.68
	45	.95	.43	1.38	.34	.86	1.20	.50	3.08
	90	.93	.37	1.30	.33	.92	1.25	.31	2.86
	180	1.01	.27	1.28	.30	1.05	1.35	.64	3.27
	Mean	1.00	.31	1.31	.31	.87	1.18	.49	2.98
3	0	1.15	.27	1.42	.18	.96	1.14	.46	3.02
	45	.95	.26	1.21	.26	.93	1.19	.69	3.09
	90	.88	28	1.16	.45	.83	1.28	.55	2.99
	180	.91	.25	1.16	.36	.91	1.87	.88	3.31
	Mean	.97	.26	1.23	.31	.91	1.22	.65	3.10
LSD .05		.37	.25		.35	.27		.25	
CV (%)		29	21		44	22		36	



11. Actual monoculture Scheme ana an alternative scheme which minimized bare spaces. Shaded areas represent bare soil (68). Numbers at the corner of the boxes indicate the beginning and end of a crop duration. Numbers inside bars indicate crop duration. Numbers 322 and 411 give the total duration of the cropping pattern.

Plant population and row spacing of the tall statured crop, such as maize, are important to the productivity of upland rice intercropping. If the maize population is increased and row spacing reduced, rice yield declines (21, 60). The highest total productivity (with a 55% advantage over monoculture) was obtained with rice interplanted with maize at 43,000 maize plants/ ha and 1.4-m row spacing (20).

Sooksathan and Harwood (60) considered 20,000-40,000 maize plants/ ha at 2-m row spacing optimal for intercropping with rice. Rice seeds were drilled at 20 cm spacing between maize rows. In dry season with high light intensity, intercropping with 40,000 maize plants/ha is possible with favorable water and nutrient supply. In wet season with low light intensity, intercropping with 20,000 maize plants/ ha is preferable.

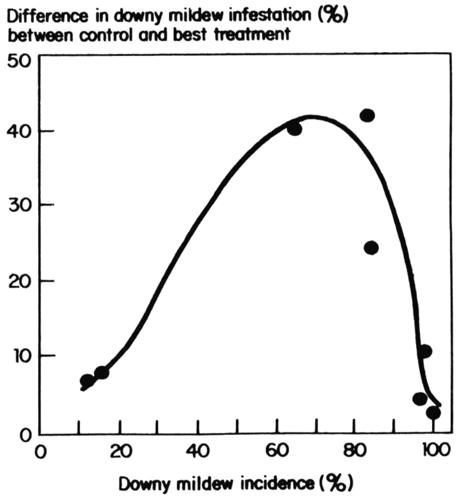
Insects and diseases

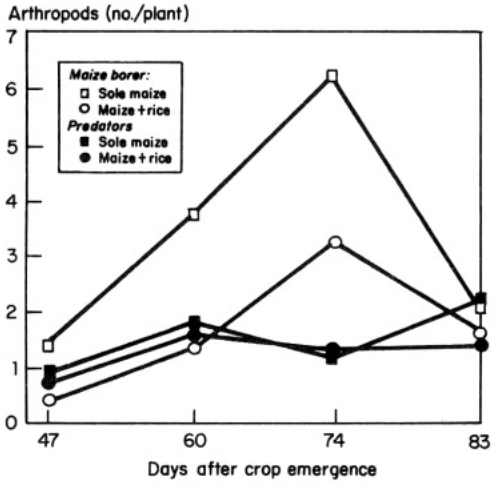
Sometimes, intercropping reduces pest problems because it provides less host area to pests of a specific crop, and component crop yield compensates for that lost from the pest-affected crop (62).

Maize borer and downy mildew incidence on rice + maize and monocropped rice and maize have been compared. Downy mildew incidence was lower in the intercrop than in monoculture only at intermediate infestation (Fig. 12). Infestation was less with 20,000 maize plants/ ha than with 30,000. At extremely low or high mildew incidence, intercropped and monocropped maize had similar infestation and row spacing had no effect (25).

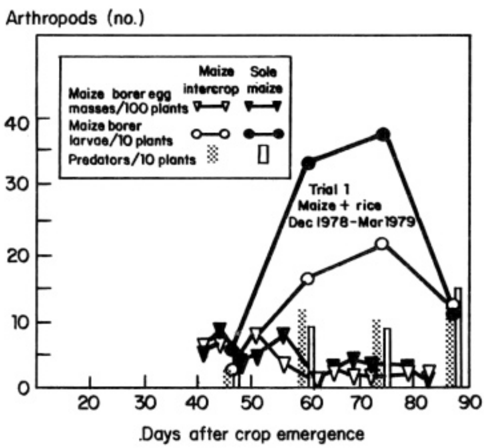
Oriental maize borer *Ostrinia furnacalis* populations were compared in rice+ maize and maize monoculture. There was no significant difference in egg mass per unit area or per plant for the two systems (29, 31). However, maize borer larvae and adults were fewer in the intercrop than in monoculture (Fig. 13, 14). Predator populations did not differ between systems.

12. Relation between downy mildew incidence on maize in monoculture (60,000 maize plants/ ha) in one season and the difference between the control and the best treatment (20,000 maize plants/ha intercropped with rice), Philippines (2.5).





13. Effect of intercropping on Asian maize borer, and a comparison of natural enemies sampled on maize plants intercropped with rice or as a sole crop (29).



14. Comparison of Asian maize borer predators and egg and larval numbers on intercropped and sole-cropped maize. Predators were collected using whole-plant enclosure traps (31).

Studies of the dispersal of maize borer larvae after hatching showed the larvae aggregated around the egg mass and then moved together to the upper leaves. A pioneer larva secreted a strand of silk, attached it to a leaf, and dangled from it. Then the suspended larva swung in the wind and secreted more silk (up to 1.5 m) until it touched an object or became airborne if the silk broke. A bridge was formed if the larva struck an adjacent plant with the silk still intact. The aggregating larvae crossed the bridge to adjoining plants. If the pioneer larva struck a non-maize plant, it returned over the bridge to the original plant.

This dispersal behavior may explain how intercropping reduces maize borer populations: widely spaced maize rows, or the greater distance between plants in intercropping than in sole cropping allows fewer larvae to reach new plants (29).

Economic advantages

For intercropping to be a viable production system it must be more profitable than sole cropping. Willey (70) suggested two ways of assessing the economics of intercropping. The first considers economy of land and can be calculated based on rental value. The second way is to calculate income gained from increased yield of the intercrop versus monoculture.

There is little economic information on upland rice intercropping because it usually is a subsistence system. In Yurimaguas, Peru, Wade and Sanchez (68) found that intercropping upland rice + maize + cassava + peanut + cowpea yielded \$500 (30%) more profit than growing them in 2 monoculture strips (Table 15). Choudhury (4) found that growing upland rice + pigeonpea was more profitable than growing them in monoculture. Similarly, maize + rice was found more profitable (35, 36) in the Philippines. In Lampung, Indonesia, maize + upland rice - cassava + peanut + rice bean was more profitable than the traditional maize + rice - cassava (37) (Table 16).

In northeastern Brazil, Seguy (57) found that rice + maize + cassava followed by cowpea was more profitable at low and high input levels than the traditional, small farm system (Table 1). Mean daily return was \$4.50 to \$4.70 for the new system versus \$1.80 for the traditional system. Rao et al (50) found that rice + mungbean returned 25% more than rice alone. However, rice + groundnut returned only 5% more than rice alone. In the Kumaon and Garhwall Hills of Uttar Pradesh, India, Jun-seeded upland rice followed by chickpea gave the highest return (\$711/ha) and 2.6 benefit-cost ratio, followed by upland rice - lentil and upland. rice - wheat (49) (Table 17).

RELAY CROPPING

Relay cropping is intercropping with minimum temporal overlapping of two or more crops, which lessens competition. Relay cropping saves farmers' time and separates harvesting of one crop from planting of the next. It may, however, create competition effects for both crops.

Table 15. Relative yield, gross income, and percent increase over monoculture of differently spaced five-crop intercrops, Yurimaguas, Peru, 1976 (68).

System	Sum of relative yields	Gross income less N cost[a] (\$/ha)	Increase over monoculture (%)
Monoculture in 2 strips	2.50	1558	-
Intercropping at 1-m spacing	2.99	2058	32
Intercropping at 2-m spacing	3.09	1996	28
Intercropping at 3-m spacing	3.18	2047	31
LSD .05	0.32	460	

[a] Maize: \$196/t; rice: \$219/t; peanut: \$416/t; cassava: \$60/t; cowpea: \$346/t. Urea: \$64/t; urea transportation: \$87/t.

Table 16. Second year's yields and economic returns from farmers' and introduced cropping patterns at different locations in Lampung, Indonesia, 1976-79 (37).

	Komering Putih 1976-77	Way Abung 1977-78	Bandar Agung 1976-77
Yield (t/ha) of farmers' cropping pattern			
Maize	0.3	0.9	0.8
+ upland rice	1.6	1.9	2.0
Cassava	18.3	9.8	-
Peanut	-	-	0.8
Net return ($)	384	303	267
Gabah rice equivalent[a] (t/ha per yr)	11.23	8.16	4.33
Yield (t/ha) of introduced cropping pattern			
Maize	2.1	2.5	2.0
+ upland rice	1.0	3.7	1.7
Cassava	26.1	19.9	21.1
Peanut -	0.4	0.6 (maize)	1.7
rice bean	-	0.28 (cowpea)	0.33
Net return ($)	486	987	523
Gabah rice equivalent[a] (t/ha per yr)	17.88	18.89	18.22

[a]Rough rice necessary to provide food calories equivalent to the total produced by all the crops in the pattern.

Table 17. Grain yield, costs, and returns for 1977-78 to 1980-81 for upland cropping systems in Uttar Pradesh, India (49).

Cropping pattern[a]	Wet season yield (t/ha)	Winter yield (t/ha)	Variable cost ($/ha)	Net return ($/ha)	Benefit-cost ratio
Rice -wheat	2.1	2.7	467	333	1.7
Rice -lentil	1.7	1.8	423	464	2.1
Rice -chickpea	1.9	2.2	457	711	2.6
Rice -pea	1.9	1.5	439	386	1.9
Spring rice - rapeseed	2.4	0.8	435	210	1.5
Spring rice -wheat	1.5	2.8	344	202	1.6
Finger millet -fallow	2.7				

[a]Cultivars were VL206 (spring rice), experimental strains (June rice), VL421 (wheat), 136 (lentil), VL86 (chickpea), VL1 (pea), T9 (rapeseed), and VL101 (finger millet).

Herrera and Harwood (20) found that relay planting maize, sorghum, sweet potato, cowpea, mungbean, and radish 21-30 d before harvesting IR8 did not adversely affect rice yield (Table 18). When relay planted with rice, mungbean, maize, and soybean yield declined 81, 66, and 33% when grown in shade for 2 wk (Table 19). When cowpea and sorghum were relay planted, yields declined 13% when they were shaded by rice for 3 wk.

In rainy season in Thailand, rice yield decreased significantly when mungbean was relay planted 90 d after sowing rice (38 d before harvest). There was no

Table 18. Effect on rice yields of relay planting crops before rice harvest, IRRI, 1972 wet season (20).

	Length of overlap (d)	Rice yield (t/ha)
Rice		4.0
Rice + maize	21	4.3
Rice		4.1
Rice + sorghum	21	4.3
Rice		4.0
Rice +sweet potato	30	3.9
Rice		3.4
Rice + soybean	21	3.9
Rice		4.0
Rice + cowpea	21	3.6
Rice		3.8
Rice + mungbean	21	3.5
Rice		3.4
Rice + radish	21	3.2

Table 19. Yields of five crops relay planted into rice, IRRI, 1972 wet season (20).

Overlap (d)	Grain yield[a] (t/ha)				
	Maize	Mungbean	Soybean[b]	Cowpea	Sorghum
0	2.4	0.75	6.8	091	3.1
7	1.3	0.60	59	0.84	3.3
14	0.8	0.14	4.5	0.79	3.1
21	0.7	0.12	3.4	0.65	2.3

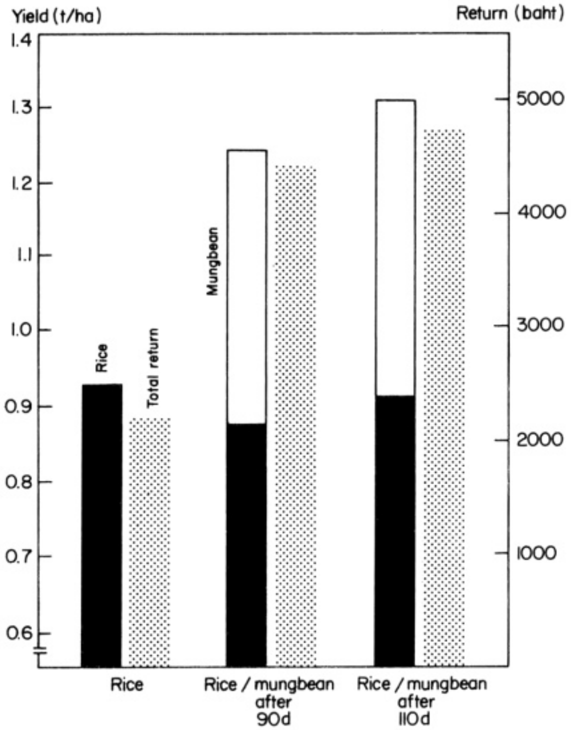
[a] Mean of 4 replications. [b] Harvested as green beans.

significant effect when mungbean was planted 110 d after rice (18 d before harvest). In dry season, planting mungbean 90, 110, and 130 d after rice (55, 35, and 15 d before harvest) did not significantly decrease rice yield. Relay planting mungbean in rice increased total return and grain yield of both crops over those crops in monoculture (65) (Fig. 15).

In Bandajaya, Indonesia, there is adequate rainfall to grow upland crops all year. In such conditions, the most promising pattern was maize + rice with cassava relay planted in maize rows. This yielded 36 t compared with 1.8 t from the traditional system (28). Cowpea can be intercropped in cassava rows after rice harvest (31).

CROP SEQUENCING AND MULTIPLE CROPPING

The possibility of growing crops after upland rice is determined primarily by soil moisture, which depends on rainfall pattern, soil texture, and length of rainy season. The upland rice season varies from less than 4 mo to almost 12 mo (12, 14). Growing seasons are short and erratic in eastern India, Thailand, and parts of Bangladesh. Burma, Indonesia, the Philippines, and parts of Bangladesh have long



15. Rice and mungbean yield and return from rice/mungbean relay planting (65). Baht 26 = US$l.

growing seasons (12). In addition to growing season, soil fertility, landscape, economics, and farmer needs influence crop sequencing.

The following factors should be considered when planning crop sequencing or a multiple cropping system.

- Timing of rice harvest and planting of the next crop is important. If rice harvest is in rainy season, is appropriate postharvest technology available? Is adequate land preparation possible for the following crop?
- What residue management is appropriate?
- What effect will nutrients applied to the first rice crop have on subsequent crops?
- Is there labor for harvesting and planting?
- Does the new sequence meet the needs and objectives of local farmers?

Multiple cropping with upland rice

Multiple cropping with upland rice varies from an annual two-crop pattern to a five-crop pattern. In the Philippines, one or two crops can be harvested after upland rice. Maize, sorghum, peanut, mungbean, and cowpea are possible second and third crops (14) (Table 20). In an open upland system in Zamboanga del Sur, about 30% of the land is planted to upland rice. Farmers plant rice in wet season and maize in dry season (8). Batangas upland rice farmers are commercially oriented. They grow maize after rice. Sorghum (13), garlic, eggplant, and other

Table 20. Philippine cropping pattern potential at different annual rainfall (14). Slope and soil fertility are assumed not to be limiting.

Months with 100 mm rainfall	Crops (no.) following Upland rice: Assured	Crops (no.) following Upland rice: Possible	Possible cropping patterns
0-3	0	0	Upland rice unlikely
4-5	0	1-2	Upland rice - mungbean
			Upland rice - sorghum
6-7	1	2-3	Upland rice - maize
			Upland rice - legume
			Upland rice - sorghum - sorghum ratoon
8-10	2	3	Upland rice - maize - legume
			Upland rice - sorghum - sorghum ratoon
11-12	2	3	Upland rice - maize - maize
			Upland rice - maize - legume
			Upland rice - maize - sorghum

high value crops also are grown (30). In Cale, Batangas, several crop rotations tested upland rice with low inputs in 1974-75 and high inputs in 1975-76. Rice - maize and rice - sorghum - sorghum ratoon yielded higher than other rotations (26) (Table 21).

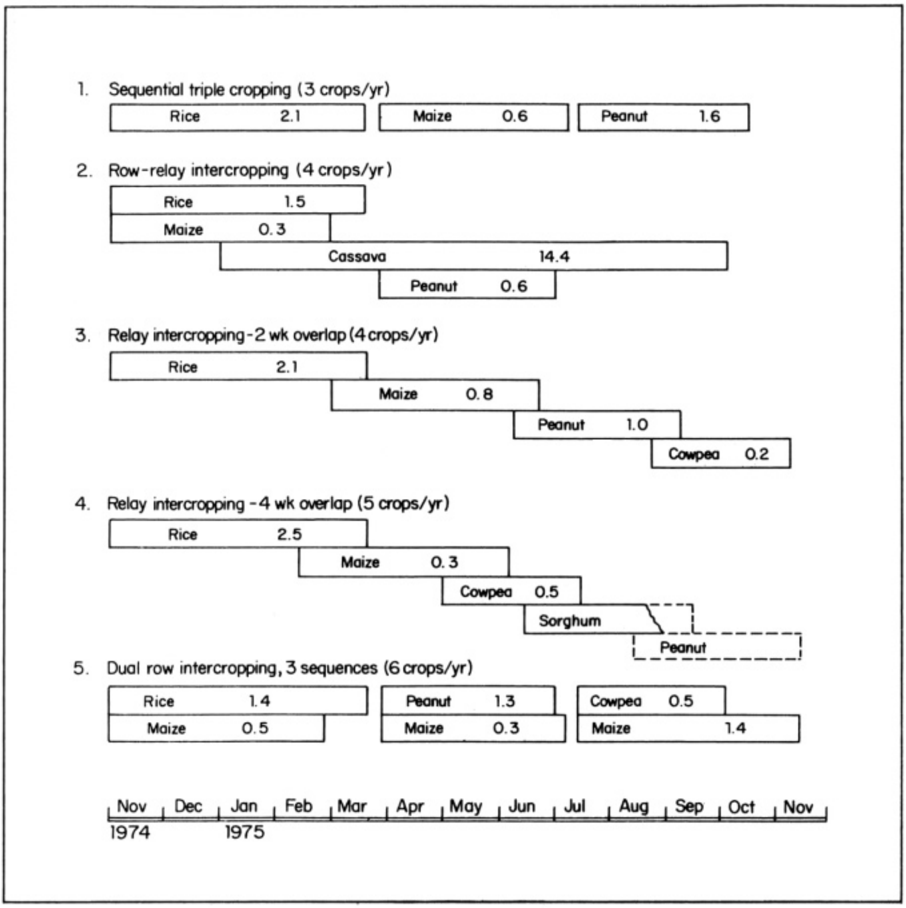
In Baturaja, Indonesia, and Yurimaguas, Peru, rainfall distribution permits year-around upland cultivation (3, 37, 38, 41, 68). At Baturaja, the most remunerative cropping pattern was maize - upland rice, relay cropped cassava, and intercropped peanut followed by rice bean. Farmers who grew rice - maize + peanut relayed with cassava lost money (3).

Wade and Sanchez (68) studied five intensive cropping systems with three to six annual crops at Yurimaguas (Fig. 16; Table 22, 23). Rice + maize with relayed cassava + peanut yielded the greatest biomass and the highest net income at all fertility levels. It produced particularly well with no added fertilizer, reduced weed infestation, and provided a good combination of family food. Highest fertilizer

Table 21. Yields of cropping patterns in Cale, Philippines, with low inputs in 1974-75 and high inputs in 1975-76 (25).

Cropping pattern	Yield (t/ha) 1974-75 Crop 1	1974-75 Crop 2	1974-75 Crop 3	1975-76 Crop 1	1975-76 Crop 2	1975-76 Crop 3
Rice - soybean	1.4	0.9	-	3.3	0.7	-
Rice - peanut	1.4	0.8	-	3.0	1.7	-
Rice - field maize	1.4	1.5	-	3.1	4.1	-
Rice - mungbean	1.4	0.35	-	3.1	0.60	-
Rice - sorghum - sorghum ratoon	1.4	2.5	0.98	3.0	39	0.6
Rice - green maize - mungbean	-	-	-	3.0	39[a]	0.77
Green maize - field maize - mungbean	-	-	-	35[a]	39	0.59

[a]In thousand marketable ears per ha.



16. Five alternative cropping systems. Numbers are the grain yield in tons per hectare. Yurimaguas, Peru, 1975 (68).

Table 22. Effect of fertilizer treatment in dry matter production of four multiple cropping systems, Yurimaguas, Peru, 1975 (68).

System[a]	Total dry matter production (t/ha)			
	Native fertility	Low input NPK-lime	High input NPK-lime	Mean
1	8.14	10.67	12.87	10.j6
2	15.80	18.23	20.35	18.12
3	9.29	10.54	13.48	11.10
4	9.59	13.99	16.35	13.31
Mean	10.71	13.36	15.76	

LSD .05 for systems = 1.60; LSD .05 for fertilizer levels = 1.35; CV (%) 8.2

[a] See Figure 17 for representation of the systems.

Table 23. Gross income from four multiple cropping systems and net income after deducting fertilizer costs, Yurimaguas, Peru, 1975 (68).

System[a]	Income ($/ha)						
	Native fertility	Low inputs NPK + lime		High inputs NPK + lime		Mean	
	Net	Gross	Net	Gross	Net	Gross	Net
1	1057	1309	1018	1215	632	1192	901
2	1263	1467	1252	1601	1170	1419	1204
3	954	1026	702	1228	580	1069	742
5	1133	1464	1155	1688	1069	1431	1121
MW	1102	1316	3 032	1433	863	1278	992

LSD .05 for system = $209; LSD .05 for fertilizer treatments = $1.166.
CV (%) for gross = 12.5, CV (%) for net = 13.1.

[a] See Figure 17 for representation of the systems.

response was with dual row rice + maize, peanut + maize, and cowpea + maize, which gave the second highest net income at all fertility levels.

In parts of eastern India, it is common to grow a short-duration (90-95 d) upland rice in wet season followed by horse gram, chickpea, rapeseed, safflower, or linseed in winter (22, 66). Rice is sown by mid-Jun and harvested by mid-Sep. Winter crops are sown in Sep and Oct. Brown Gora, a tall, short duration upland rice from Ranchi, is good for this system. Semidwarf Bala, Kiran, and Akashi also mature in 95-1 05 d, but reach full potential only with application of 40-50 kg N, 13 kg P, and 16.5 kg K/ ha and weed control during early growth (66).

In northeastern Tripura, India, rainfed upland rice is grown in wet season on highlands with well-drained, coarse-textured soils. Total rainfall is 2,000 mm, and falls from Apr to Sep. Sisodia et al (58) found that two or three annual crops can be grown on these lands if very short duration upland rice is planted. They evaluated the following crop sequences: rice - fallow - fallow, rice - rice - pulse, rice - finger millet - pulse, and rice - sweet potato - fallow.

Rice - sweet potato -fallow yielded most and was most profitable. Very short duration CRM13-3241 was planted in mid-Apr and matured in late Jun. Sweet potato (cross 4) was planted on ridges in mid-Jul and harvested in Nov. Rice yielded 2.0 t/ ha and sweet potato 20 t. Net profit was about $370/ha.

Influence of multiple cropping on soil properties

Crops included in a cropping system influence soil physical and chemical properties because of their different rates of nutrient uptake and root growth. Sadanandan and Mahapatra (51, 53, 54, 55) studied the effect of different cropping sequences on upland rice soils at the Central Rice Research Institute, Cuttack, India. The rotations included potato - rice - rice, maize - rice - rice, peanut - jute - rice, rice - jute rice, and rice - rice.

After 2 cycles, soil pH (initially 5.5 to 5.7) decreased in all the rotations. The maximum decrease, to pH 4.9, was for rice - jute - rice and rice - rice. This followed a maximum increase in exchangeable H in the topsoil for rice - jute - rice. Rice - rice and rice - jute - rice caused soil structure to deteriorate. Including groundnut in the sequence slightly improved soil structure. Exchangeable P at the 0-15 cm layer also was lowest in the last 2 rotations.

CHOOSING A SUPERIOR CROPPING PATTERN

The IRRI Cropping Systems Working Group proposed the following methodology for cropping systems research (24):

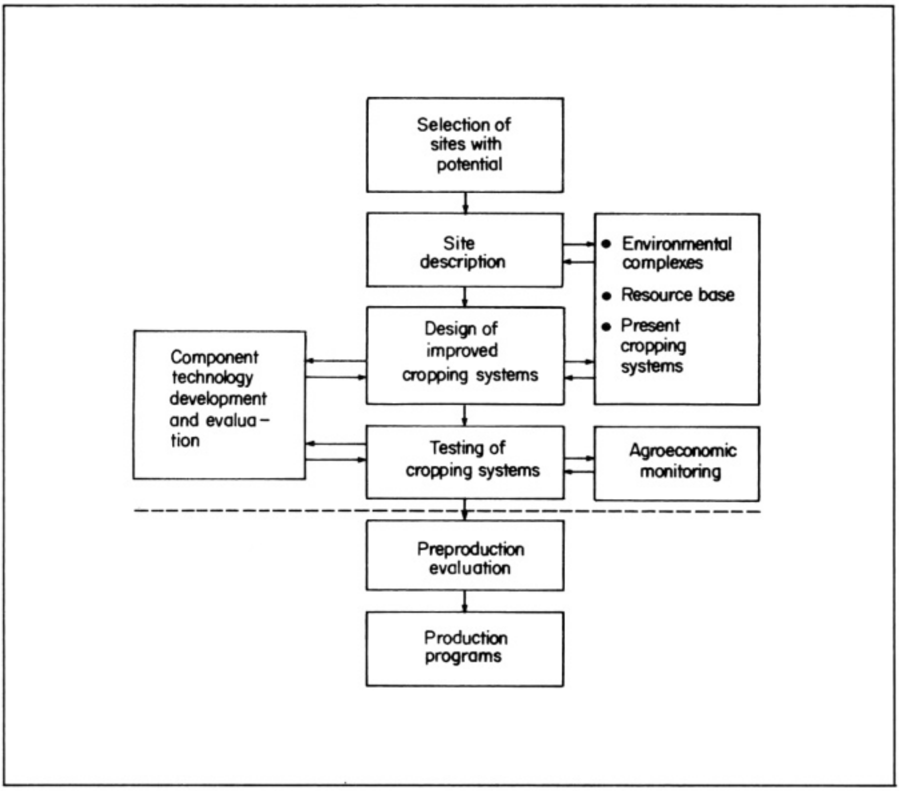
- select target areas,
- describe target areas,
- design cropping patterns,
- test cropping patterns,
- carry out applied research and preproduction testing,
- introduce production programs, and
- evaluate change.

The last three steps are for extending research results to national programs (13). Zandstra et al (74) emphasized that for research on rice-based farming systems, an overall framework and specific on-farm research methods should be developed. They suggested that the research framework should satisfy the following requirements.

- Research must be related to the specific production environment.
- Farmers must participate in designing and testing multiple cropping technologies.
- Research must include several commodities and crop-to-crop interactions, and be multidisciplinary.
- The methodology must clearly identify tasks and the responsibilities of team members for each task.
- Research must emphasize the formulation of cropping patterns that increase cropping intensity and are acceptable to farmers.

The methodology is primarily for small farms and considers agricultural research to be site dependent. Research involves environmental description and classification, design of improved cropping systems and their testing on individual farms, and methods for designing production programs (Fig. 17).

Garrity et al (13) evaluated an upland rice-based cropping pattern in eastern Batangas, Philippines. The farmers on whose land the research was conducted actively participated in managing and evaluating the test patterns. Farmers in the region generally grew upland rice followed by maize. Three new patterns were tested: rice followed by field crops other than the normal orange flint maize, intercropping, and a three-crop-per-year pattern. Cooperating farmers planted the new pattern on 1,000-m^2 plots adjacent to their rice - maize pattern. Results showed there were several ways of improving the traditional system. Better maize varieties increased productivity and soybean and sorghum performed well after rice. Godilano and Carangal (15) also found that sorghum after rice yielded higher than maize. If labor is available and inexpensive, rice + maize also can be productive.



17. Components of the on-farm cropping systems research methodology (74).

Table 24. Mean yields of crops in tho first year of a 3-yr rotation.[a]

Rotational pattern	Mean yield (t/ha)	
	Rice	Other crops
Rice - rice - rice	1.2	-
Rice + pigeonpea - rice + cassava - rice	0.3	11.4
Rice + cassava - rice + pigeonpea - rice	1.2	14.8
Rice + pigeonpea - rice + cassava - rice	0.3	10.8
Rice + cassava - rice + pigeonpea - rice	0.7	14
Rice + cassava - rice + pigeonpea - rice	15	12.3
Rice + pigeonpea - cassava - rice	0.9	13.3
Rice - pearl millet - rice	1.4	1.7

[a]Mahapatra et al 1978, cited in (69).

In the northern hills of Uttar Pradesh, India. the most popular 2-yr crop rainfed sequence is rice (Mar/Apr planting) - wheat - finger millet - fallow. Experiments at Vivekananda Laboratory for Hill Agriculture in Almora, Uttar Pradesh, showed that planting a short-duration rice cultivar like VL 206 in rainy season would allow a successful winter crop of wheat, pea, lentil, or chickpea. A rice - wheat rotation performed better than other rotations (67).

The economics of five upland rice-based multiple cropping systems suitable for eastern India were studied at the Central Rice Research Institute, Cuttack, in 1967-69 (52). Maximum net profit/ ha was from potato - rice - rice. The next most profitable rotation was rice -jute - rice in 1967 and maize - rice - rice in 1968. Rice - rice was least economic in both years.

In high-rainfall areas of Sierra Leone, upland rice-based cropping systems have been evaluated for economics and efficiency (69). When rice and cassava were grown together, 1.2-1.5 t rice and 12-1 5 t cassava ha were harvested. Rice alone yielded 1.2-1.4 t/ha (Table 24). Rice grown after 2 yr of cassava yielded highest, 2.3 t/ha. Rice planted after cocoyam or pigeonpea yielded 1.5 and 1.4 t/ha (69).

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CHAPTER 5

Varietal Improvement

Most farmers in upland areas grow land races which are generally tolerant of environmental stresses but whose yield potential is lower than that of modern varieties. Until recently, little effort was made to improve upland rice varieties. Modern semidwarf varieties bred for irrigated land generally have not been adopted in traditional upland areas.

EVOLUTION OF UPLAND RICES

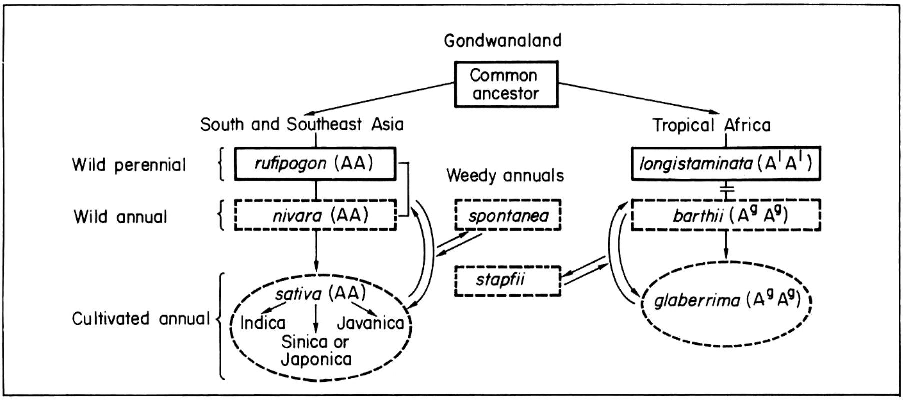
Most upland rices belong to *Oryza sativa* L. (Asia) and *O. glaberrima* Steud (Africa). Based on information from several disciplines, Chang (27) theorized that *Oryza* originated on the Gondwanaland supercontinent. As the supercontinent fractured and drifted, rice became widely distributed in the humid tropics of Africa, South America, Asia, and Oceania (Fig. 1).

O. glaberrima was selected and established in parts of West Africa more than 3,000 yr ago (20, 94, 165). It probably developed independently of Asian rice and was domesticated from a different wild progenitor, *O. barthii* (syn *O. breviligulata*) (165). *O. glaberrima* may have originated in the central Niger River Delta. South Senegal and Guinea were secondary centers of genetic diversification (3, 94).

O. glaberrima has weak stems, red grains that shatter easily, and long dormancy. It is susceptible to disease, and is low yielding. It can grow in deep water, swamps, and on uplands. In general, upland *glaberrimas* yield less than the best *sativa;*. (20). *O. glaberrima* rices have excellent vegetative growth. Thus they compete well with weeds, which are major constraints to upland rice production. They also tend to have resistance to blast (Bl) caused by *Pyricularia oryzae* and drought tolerance (4). Despite these good qualities, *O. glaberrima* has been largely replaced by *O. sativa* in West Africa (3).

The distribution of *O. sativa* from the Himalayas to the Mekong Delta suggests its diffuse origin. Domestication of a crop is not necessarily confined to the center of diversity of its wild relatives; therefore the area of greatest diversity of cultivated forms may provide a clue to the center of domestication (28). Northeastern India, northern Bangladesh, and the triangle formed by Burma, Thailand, Laos, Vietnam, and southern China appear to be the center of *O. sativa* domestication. From there, *O. sativa* spread eastward to China, Korea, and Japan.

Ecological selections created three varietal types — indica, japonica or sinica, and javanica — in different areas of South, Southeast, and East Asia. The tall,



1. Evolutionary pathway of the two cultivated species of rice. Taxa boxed with solid lines are wild perennials. Taxa boxed with broken lines are annuals. An arrow wit h a wild line indicates direct descent; that with a broken line indicates indirect descent. Double arrows indicate introgressive hybridization(27).

large, and bold-grained, bulu javanicas of Indonesia are more recent derivatives of tropical continental rices (28). Indonesian bulu varieties spread to the Philippines, Taiwan, and Japan.

O. sativa was introduced to Africa a little more than 2,000 yr ago (94). Travelers from Malaysia-Polynesia brought *O. sativa* to East Africa and Madagascar from where it reached West Africa. Also, traders traveling from India and Sri Lanka to South Arabia exchanged surplus rice at East African ports and in Madagascar (20,94).

O. sativa also moved along the slave trading routes from Zanzibar to Zaire. More than 450 yr ago, Portuguese traders introduced Asian rice into Senegal, Guinea-Bissau, and Sierra Leone on their return from expeditions to India. Whether this rice fame directly from India or was collected in East Africa is unclear (20). In 450 yr, Asian rices have adapted so well to West African conditions that the region has become a new center of genetic diversity (165).

Rice is a semiaquatic plant and probably was first cultivated in valley bottoms with abundant water. As population grew, steeper slopes and high plateaus with more porous soils were farmed and upland varieties developed. Upland varieties tend to be early maturing, with low tillering capacity and long, thick roots (35).

In many hilly areas of Southeast Asia, rice grew under upland culture and shifting cultivation before it was grown in the lowlands. Management progressed from shifting cultivation to direct sowing in permanent fields to transplanting in bunded fields (27).

Most upland rices grown in Asia are indicas. Southeast Asian upland rices form a distinct morphoecologic group. Indian varieties are intermediate between lowland and Southeast Asian upland varieties. Recent studies indicated that Southeast Asian upland varieties are more closely related to the javanicas of Indonesia than to the indicas (91).

IRAT studies indicate that most West African upland rices are more similar to javanica and japonica varieties than to indicas, which is why crosses between upland and indica varieties often result in a high degree of sterility (96). Barrios (13) suggested that sterility in crosses of upland and lowland rices is not from gross chromosomal differences but from complex genic interactions. Nevertheless, this does not preclude the possibility of cryptic structural differences resulting from some chromosomal differentiation between traditional upland rices and lowland varieties.

Glaszmann et al (53) studied the distribution of 7 enzymes in 252 rices from IRRI, IRAT, and Thailand by starch gel electrophoresis. The varieties were separated into two groups — indica types, and japonica and javanica types - based on allele distribution among 14 loci. All upland rices from Africa and South America and most from Southeast Asia were japonicas or javanicas (Fig. 2).

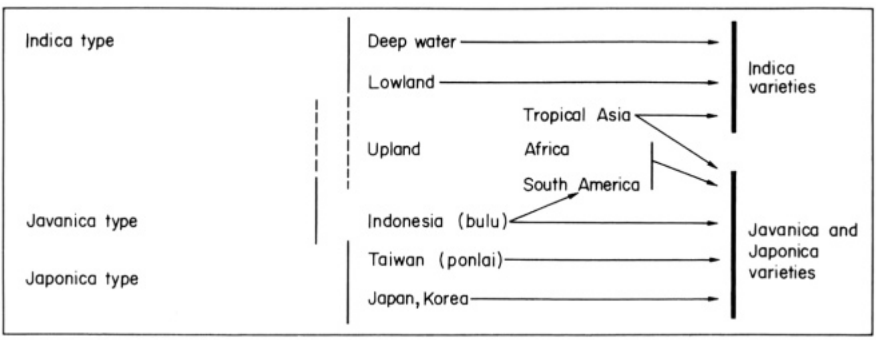
Ono (133) studied the origin of Japanese upland rices. He found that they are an ecotype of lowland rice differentiated by adaptability to drought and are similar to lowland japonicas. Some Japanese upland varieties, however, may have developed from indicas or javanicas. Because Japanese upland rices derive from several sources, they vary more than do local lowland varieties.

CHARACTERISTICS OF UPLAND RICES

Upland rice varieties have diverse characteristics. In favorable environments, they resemble irrigated semidwarfs. In Peru, where monthly rainfall exceeds 150 mm for more than 4 mo a year, IRRI-developed lowland rices perform well in upland areas. Several lowland selections yield 4-6 t ha^{-1} versus 1-3 t ha^{-1} for traditional varieties (102). At IRRI, De Datta et al (46) found that varieties bred for lowland culture consistently outyielded upland rices.

Japanese upland rices have distinctly different morphology and physiology than lowland varieties, probably due to their adaptation to aerobic soils and water deficits. Ono (132) described Japanese upland varieties as tall and low tillering with long, broad leaves, long panicles, stiff straw, lodging susceptibility, drought and Bl resistance, and poor response to heavy fertilizer application (Table 1).

In a seed mixture experiment, Japanese upland rices were more competitive than lowland varieties based on the number of seeds per plant. The competitive



2. Distribution of rice varieties by type (53).

Table 1. Characters of traditional Japanese upland and modern lowland rices (132).

Character	Upland rice	Lowland rice
Plant height	High	Low
Number of tillers	Few	Many
Panicle length	Long	Short
Stems	Thick and stiff	Slender and flexible
Grains	Large and long	Small and round
Leaves	Large and broad	Short and narrow
Root system	Deep	Shallow
Lodging resistance	Weak	Resistant
Drought resistance	Resistant	Low resistance
Bl resistance	Resistant	Susceptible
Grain quality	Inferior	Superior
Adaptability for heavy fertilization	Low	High

superiority of upland varieties was related to plant type, growing habits, and vigorous, deep roots (124).

In a study of 25 upland and lowland types, Chang et a1 (35) found that plant characteristics and growth features are at the same time similar and different. Many upland varieties had low tillering and constant leaf area. Under severe water stress, most of them were less damaged by drought and had lower panicle sterility than lowland types. However, lowland Dular and IR5 tolerated drought as well as upland varieties.

Chang et al (35) also found that drought resistance is associated with thick, long roots, a dense root system, and a high root-to-shoot ratio. Many upland varieties were responsive to water stress, and produced long, thick roots under dry growing conditions. Leaf characters such as moderate droopiness and the ability to fold when water stress occurs may also be associated with drought resistance.

Chang and Vergara (38) reviewed the varietal diversity and morphoagronomic characteristics of upland rice. They found no distinct morphological differences between tropical upland and lowland rices. Any rice variety will grow in upland and flooded culture, but its growth and yield may markedly differ.

Analysis of more than 4,000 upland rices in the IRRI germplasm collection indicates that Southeast Asian upland rices share the following morphologic and agronomic features (91):

1. tall stature;
2. deep, thick, branched roots;
3. low tiller number and rigid tillers;
4. pale green, long, broad, droopy, and sometimes glabrous leaves;
5. low leaf area index;
6. plastic leaf rolling and unrolling, frequently high cuticular resistance to transpiration;
7. poor recovery after water stress;
8. thick, brittle culms at maturity;
9. long, well-exserted panicles;
10. 95-140 d maturity and photoperiod insensitivity;
11. large, broad, thick, heavy grains;

12. low to intermediate (18-25%) amylose content, intermediate gelatinization temperature, and low to intermediate gel consistency;
13. high panicle fertility, even under drought;
14. high resistance to some races of B1 and susceptibility to leafhoppers, planthoppers, and virus diseases found in lowland areas;
15. tolerance for P deficiency, Al and Mn toxicity, and salinity;
16. low response to applied N;
17. low but stable yields (0.5-1.5 t ha^{-1}); and
18. low harvest index (below 0.4).

West African upland rices are 130 cm or taller, with moderate tillering capacity, and long, broad leaves. Varieties such as Moroberekan, OS6, and LAC23 tolerate some drought and are moderately resistant to fungus diseases, particularly B1. Grain is good by local standards, but yield potential is less than 5 t ha^{-1} and grain-to-straw ratio is low. They lodge badly and do not respond to applied N. A few *O. glaberrima* varieties have good seedling vigor and drought resistance but they are susceptible to B1, lodge easily and early, and grains shatter at maturity (3).

Few high yielding semidwarfs have potential for upland cultivation in Africa, where IITA research showed that semidwarf performance in upland conditions is cultivar-speclfic (66).

In Latin America, modern semidwarf rices perform well in favorable uplands in Colombia, Venezuela, and Central America. Tall improved and traditional varieties are planted in unfavorable uplands (23).

In Brazil, however, most of the varieties planted in favorable areas were developed for unfavorable environments. Most traditional Brazilian rices are tall, especially in favorable conditions. Height varies between 1.2 and 1.8 m. The rices have low tillering capacity and are planted at low density to minimize yield losses under limited rainfall. Most varieties have long broad leaves and substantial foliar area. Leaves are decumbent and glabrous. In favorable conditions, high leaf area causes shading of the lower canopy and promotes disease. Plants have long panicles with many glabrous spikelets, no aristae, and long hyaline grains. Some varieties have B1 resistance (49).

BREEDING OBJECTIVES

Upland rice grows in such diverse environments that a complete list of production constraints correctable by plant breeding is virtually impossible. However, a general list of desirable traits and problems is possible, and includes the following (1, 2, 5, 29, 37, 50, 95, 96, 114, 116, 118, 161):

- increased yield potential with yield stability;
- diverse plant types for cultivation in various cultural systems and environments;
- diverse grain quality characteristics;
- intermediate (110 cm) to tall (130 cm) height with low (3-5 tillers/hill) increasing to high (>20 tillers) tillering ability;
- panicle weight type varieties shifting to panicle number type in better environments;

- stiff straw and lodging resistance;
- good seedling vigor;
- deep, thick, dense roots;
- well exserted, fertile panicles;
- variable maturity;
- variable photoperiod sensitivity;
- responsiveness to moderate levels of applied N (30-40 kg N ha^{-1});
- drought resistance or tolerance;
- ability to compete with weeds;
- resistance to B1, sheath blight (ShB), narrow brown leafspot (NBLS) caused by *Cercosporu oryzae,* glume discoloration (GlD), stem borers (SB), leaf-hoppers, planthoppen, and grain feeding insects; and
- tolerance for low native fertility, low P, high Al, and acid soils.

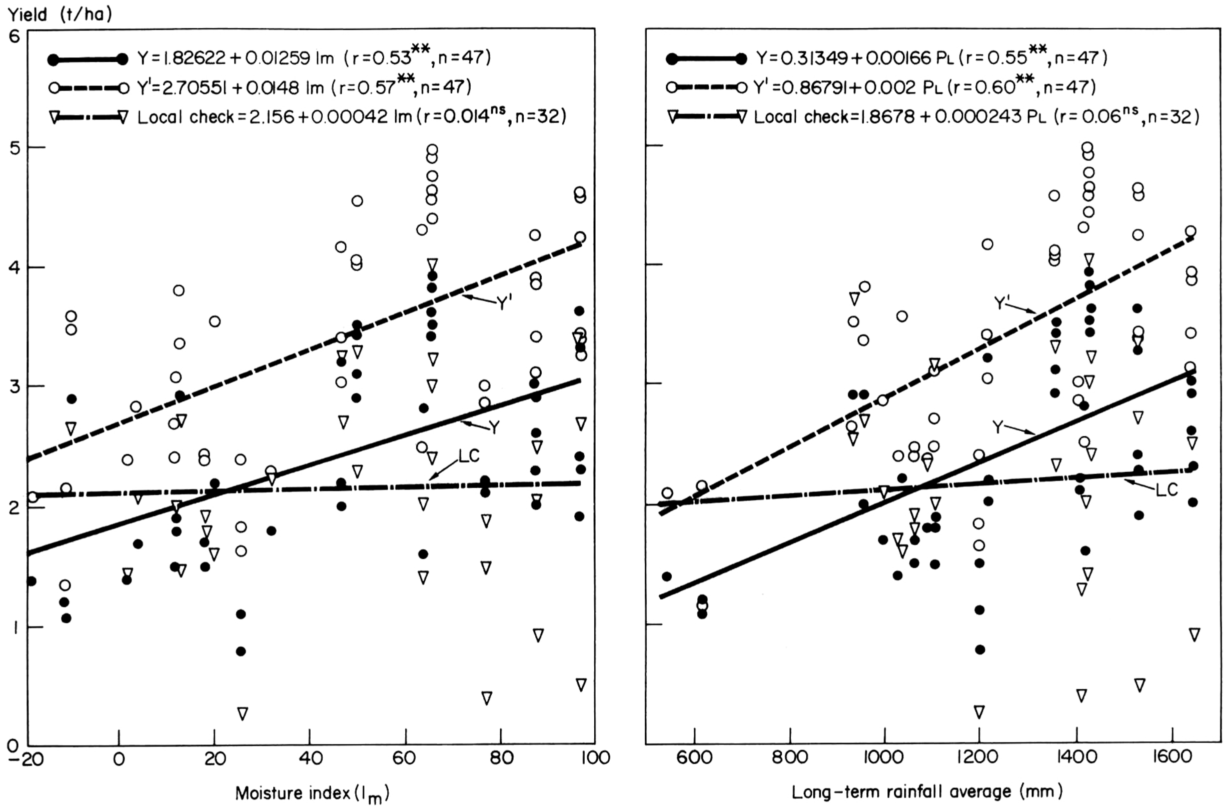
Upland rice environments vary greatly in potential productivity. To breed for *high yield* is an ambiguous and useless term unless some measure of environmental potential for yield is available.

Chapter 3 classifies upland rice environments by rainfall regime and soil fertility. Figure 3 (138) shows 1975-77 results of the International Upland Rice Yield Nursery (IURYN) at 47 locations. The yield of the 2 highest yielding entries in each location by year, the average of all entries (»25), and the yield of the local check or prevalent traditional cultivar are regressed on two climatic indicators; moisture index (I_m) and long-term average crop season rainfall. Figure 3 illustrates the scalar nature of current potential upland rice yield and allows estimation of what *high yield potential* might be, given the climatic constraints of a particular location and available germplasm.

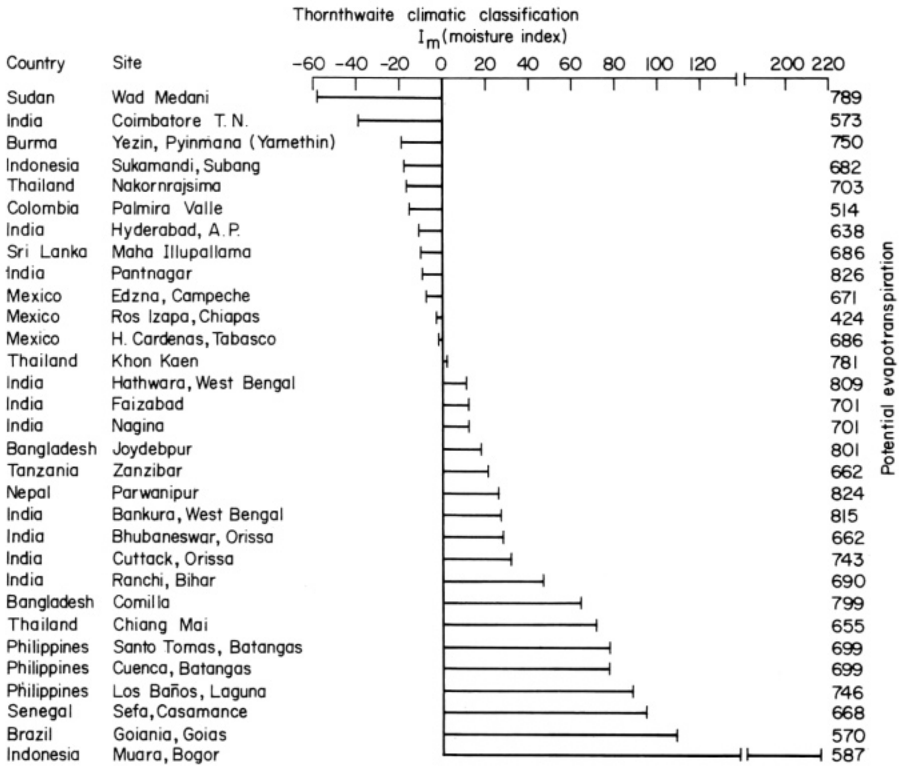
To use Figure 3 to estimate yield potential, it is necessary to know the I_m value or the long-term average rainfall for the rice growing season. Figure 4 shows I_m for several upland rice environments. To use I_m select a location homologous to the location of interest and based on the I_m value from Figure 4, read yield on the Y' line of Figure 3. Crop season long term (> 25 yr) average rainfall can be used similarly. The Y' represents potential yield with current genetic and agronomic technology associated with the 1975-77 IURYN. These values approximate what a breeder may set as a *realistic* goal for yield improvement, given the constraint of water availability.

Yield stability and adaptation of plant type to cultural systems also may be referenced to the scalar nature of water adequacy represented in Figure 3. Climatologists established that tropical rainfall variability can be represented as an inverse function of annual rainfall (129). Thus, production stability will decrease with decreasing crop season rainfall and I_m. Cultivars with long-term yield stability at a location will be best adapted to stresses such as drought and B1.

IURYN records from 1974 to 1983 show that the plant type of successful entries in Figure 3 also is a scalar parameter. Where seasonal rainfall is >1500 mm and I_m>80, the full advantage of genetic and agronomic inputs can be realized, and improved semidwarf entries often yield 4 to 5 t ha^{-1}. At sites with <900 mm rainfall or I_m <15 and, to a greater degree, <700 mm rainfall and I_m —10,traditional cultivars dominate.



3. Yield of 1975-77 IURYN entries as related to the Thornthwaite moisture index lor the growing season at 47 locations. Y = mean yield of all varieties (n = 25) at a location. Y= mean of 2 highest yielding varieties at a location; local checks = locally adapted variety grown with same agronomic practices as IURYN entries (138).



4. Climatic classification of 32 1976 IURON sites. Values are for rice growing months and calculations were adapted from Average Climatic Water Balance Data of the Continents, 1963. Publications in Climatology, Vol. XVI, No. 1. C. W. Thornthwaite Associates, Centerton, New Jersey (74).

The scalar nature of water and best plant type *cautions* idle use of the terms *plant type* and *yield potential* in relation to upland rice. Further refinement of climatic indicators and adding soil chemical and physical parameters to the classification system will allow more accurate estimates of potential production and the establishment of realistic goals for yield potential and stability.

It also must be kept in mind that other parameters change along with increased water availability in Figure 3. In general, a more favorable rainfall regime may allow cost-benefit ratios to change and encourage increased labor and agrichemical use. This presumably is not true for the IURYN trials on which Figure 3 is based, due to standardization of agronomic practices, but should be considered when determining potential yield targets, given farmer conditions. In contrast, upland farmers of a region may be unable to apply the inputs used in IURYN trials and, thus, may not realize varietal yield potential.

Although there are improvement criteria common to upland rice breeders around the world, each region has more specific breeding goals, especially in relation to diseases and insect pests (Chapters 10 and 11). The following section describes the objectives of upland rice breeding programs in South and Southeast

Asia, West Africa, and South America. In South America and, to some extent, in Southeast Asia, the objectives reflect environmental quality. *Favorable* and *unfavorable* environments require different breeding objectives.

Chang et al (37) suggested the following breeding objectives for upland rice breeding in Southeast Asia and at IRRI.

- Upgrading yield potential by developing intermediate-statured, moderate-tillering plant type.
- Retaining resistance or tolerance mechanisms that are related to yield stability, such as drought avoidance, B1 resistance, and recovery ability after water stress is relieved.
- Developing a range of maturities suited to different ecological niches; weak photoperiod sensitivity may be required for areas such as northeast Thailand.
- Retaining good agronomic characteristics (long, well-exserted panicles, high panicle fertility, nonshattering spikelets) and grain quality (low to intermediate amylose content, intermediate gelatinization temperature, and soft gel consistency; grain shape and size being less rigidly preferred).
- Incorporating high levels of pest resistance from improved materials (mainly semidwarfs) or outstanding donors. These include resistance to B1, ShB, brown spot (BS), stem borers, whitebacked planthopper (WBPH), leaffolders, root-knot nematodes, and others.
- Retaining or incorporating tolerance for adverse soil factors such as P deficiency, Al and Mn toxicity in acid soils, salinity, and Fe and Zn deficiency in alkaline soils.

Abifarin (1) listed the following objectives for upland rice improvement in West Africa.

- *Yield factors.* Medium to high panicle number, grains per panicle, and grain weight, with nonshattering panicles and easy threshing characteristics.
- *Morphology.* Medium height with stiff straw; tough, slowly senescent, moderate leaves; good tillering ability; well-exserted panicles; and superior root development and seedling vigor.
- *Physiology.* Medium to early maturity, N responsiveness, drought tolerance, high Fe absorption, and satisfactory embryo dormancy.
- *Grain quality.* Medium to long grains, high head recovery, and translucent grains with intermediate to high amylose, medium gelatinization temperature, high protein content, and favorable amino acid balance.
- *Disease and insect resistance.* Resistance to B1, NBLS, leaf scald (LSc) caused by *Rhynchosporium oryzae,* SB, and *Diopsis.*

IITA (4, 5) developed the following breeding objectives for upland rice in Africa: high, stable grain yield; improved plant type; early seedling vigor; resistance to drought, B1, GID, sheath rot (ShR), LSc, BS, SB, and acid soils; a range of maturity for different rainfall and cropping patterns; and acceptable grain quality.

Favorable environments

Favorable environments include areas with short and long growing seasons. There are no dry periods in the rainy season and soils are generally favorable. Rice varieties with 3-5 mo duration grow successfully. Breeding objectives for these environments may be similar to those for irrigated rice (114). Breeding for favorable environments should stress desirable morphological characteristics of high yielding lowland types, which include high tillering, erect leaves, and relatively short stature. Resistance to diseases, insect pests, and drought also is desirable (45).

Breeding objectives for favorable environments in Latin America are (114)

- vigorous dwarf or intermediate plant type;
- lodging resistance;
- 110-130 d duration;
- durable Bl resistance, either through gene pyramiding or crosses with slow blasting varieties;
- tolerance for foliage and panicle pathogens such as *Rhynchosporium, Helminthosporium,* and *Thanatephorus;*
- resistance to *Sogatodes oryzicola* and hoja blanca;
- tolerance for upland soil nutrient deficiencies, toxicities, and drought; and
- long, heavy grains (26-30 g/l00), with translucent endosperm, and intermediate amylose content and gelatinization temperature.

Escuro (50) listed the following breeding objectives for the Philippines:

- earliness and photoperiod insensitivity (Vigorous varieties that mature in 90-105 d help the crop to escape water stress.);
- strong seedling vigor;
- medium plant stature;
- lodging resistance;
- responsiveness to medium soil fertility;
- tolerance for moisture stress;
- disease and insect pest resistance, especially to B1, planthoppers, and SB. (Escuro said that selections must have natural pest resistance because of the increasing cost of pesticides.)

In India, most upland rice is grown at high and medium elevations. For high elevations, varieties should be of intermediate height (110-125 cm) with moderate tillering ability and high panicle weight. Taller (85-105 cm) semidwarfs with moderate to high tillering ability are appropriate for medium elevations. The varieties also should have drought avoidance and tolerance mechanisms and good recovery ability after moisture stress. Genes for resistance to B1, bacterial leaf blight (BB), and bacterial leaf streak should be introduced into upland varieties (118).

Unfavorable environments

Drought is a major constraint in unfavorable environments, where it may occur throughout the growth period and considerably reduce rice yields. P deficiency and A1 and Mn toxicity also may limit rice growth. In West Africa and Southeast Asia, erosion of soil nutrients also is a production constraint.

Weeds also reduce upland rice yields in unfavorable environments, and rice varieties should be moderately tall with long, droopy leaves to compete with them (37). Varieties also should be drought tolerant, B1 and insect resistant, and tolerant of P deficiency and A1 toxicity (161).

The savannas of Colombia and Venezuela, the jungles of Peru, and northern Brazil have vast areas where there is excellent rainfall for upland rice but strongly acid, infertile soils. Tall land races predominate. B1 and *Helminthosporium* leaf spot are the most serious diseases of rice in Peru (102). Breeding objectives for these environments include (114)

- vigorous, intermediate plant type;
- lodging resistance;
- thick, deep roots;
- 100-130 d maturity;
- moderate yield potential (24 t ha^{-1});
- durable BI resistance and tolerance for foliar and panicle pathogens such as *Rhynchosporium, Helminthosporium,* and *Thantephorus;*
- resistance to *Sogatodes oryzicola* and hoja blanca disease;
- tolerance for Al toxicity; and
- long, heavy grains (26-30 g/ 1000) with translucent endosperm, and intermediate amylose content and gelatinization temperature.

There are two ecological zones in West Africa: the moist forest zone and the dry savanna zone. In the moist forest zone, changing from shifting to permanent cultivation will require sustained breeding efforts. For the moist zone, varieties need moderate to good drought tolerance, medium maturity, good tillering ability, disease resistance, and high yield potential. For the dry zone, varieties need excellent drought tolerance, earliness, disease resistance, and high yield potential. Rices also should have erect terminal and flag leaves and flag leaves taller than panicles to limit bird damage. Nematode resistance also is desirable (67).

BREEDING METHODS AND PROCEDURES

Breeding methods

Breeding methods depend upon the objectives of varietal improvement. Methods used for varietal improvement of upland rice include genotype introduction, selection, hybridization, pedigree breeding, modified bulk breeding, backcrossing, recurrent selection, and mutation breeding. Haplomethod and tissue culture also are being used (96).

Breeding approaches for favorable and unfavorable environments differ. Breeding for favorable conditions allows greater use of elite lowland semidwarfs. Varietal improvement for unfavorable environments tends to rely more on traditional varieties and land races (154), with some inputs from improved semidwarfs.

Promising upland rice lines or varieties developed in one region can be directly introduced for cultivation in another region. It may be wise, however, to compare the new genotype with local races before recommending it for cultivation. For example, between 1976 and 1981 about 2000 new cultivars from IRRI, IITA, and WARDA were introduced and tested in Nigeria (128). Promising cultivars were tested in several yield trials before they were released for cultivation to farmers.

Selection. Selection probably is the oldest method of plant improvement. Two types of selection commonly are used.

In *pureline selection,* many individual plants are selected from a genetically diverse variety or population. Progeny rows from individual plants are grown for initial evaluation. Then, progeny selections are compared with each other in replicated yield trials and the parent variety and the highest yielding lines are released as pureline varieties.

In *mass selection,* several plants are selected to make a new variety. Varieties developed by mass selection include fewer genotypes in the improved population than in the parent population, but more than the single genotype of varieties developed by pureline selection. The number and variability of types depend upon variability within the original population and the intensity of selection.

Many West African upland varieties have been developed through selection from farmers' material. Varieties such as OS6, LAC23, ROK3, and Faya yield well and are popular (178). Agbede 15/56 (FARA3) was released in Nigeria in 1958 as a pureline selection from a heterogeneous population (128). In India, improved tall upland rices have been developed by pureline selection from land races (118).

Hybridization. Hybridization produces new variability by crossing two or more lines. As plant breeding capabilities have improved, hybridization has encouraged full exploitation of locally available genotypes. Desired new recombinants are created by outcrossing one line with another. Crosses may be

- single crosses — crossing one variety with another variety or line;
- double crosses — crossing two F_1 hybrids; or
- topcrosses — crossing an F_1 with a third variety or line.

Because rice is autogamous, hybrids are allowed to self-pollinate and the resulting populations are handled by the bulk, backcross, or pedigree method.

Hybridization is a widely used technique for varietal improvement in upland rice (4, 32, 37, 50, 60, 61, 62, 63, 64, 83, 87, 88, 93, 95, 96, 114, 128, 151, 170, 178). Crosses have been made of tall and semidwarf *indicas, indicas* and *japonicas,* and of *O. sativa* and *O. glaberrima.* Work is continuing to cross distant types to obtain suitable recombinant genes for resistance to pests and environmental stresses.

Bulk breeding. In the bulk breeding method, segregating generations from a hybrid of a self-pollinated crop are grown in a plot, with or without mass selection. Planting dates and cultural practices are usually the normal agronomic practices in the target area. At maturity, the entire plot is harvested in bulk and the seeds used to plant a similar plot the following season. This process is repeated as many times as desired. Usually, selection is at the F_5 or F_6 when traits have become fixed. Further evaluation is done in the same manner as the pedigree breeding method. Bulk breeding generally is suitable for quantitative characters, but not for concurrent selection for disease and insect pest resistance (103). The modified bulk method, which permits selection for pest resistance during early generations, may be more useful for upland rice than pedigree selection (37). Early generation (F_2 to F_5) selection was recommended by Mohanty (118) and Martinez (114).

Pedigree breeding. Pedigree breeding has been the most widely used method for upland rice improvement (32, 50, 96, 114, 118). It consists of three steps: crossing, selection of desirable lines or plants, and fixing superior lines followed by yield trials. Pedigree breeding is particularly good for monogenic traits that can be identified in early generations, such as insect pest and disease resistance. Individual plant selection for desirable traits begins in F_2 and continues through F_5. Combinations with poor resistance to disease, insects, and environmental stresses are discarded at F_2.

Recurrent selection. Recurrent selection is used primarily to increase the frequency of favorable genes in the plant population for quantitatively inherited traits. It is cyclic, and each cycle encompasses two phases: selecting a group of genotypes with favorable genes, and crossing them to obtain genetic recombinations. This gradually concentrates the frequency of desirable allele and modifies genes, thereby substituting time (generation) for space and population size. Recurrent selection also accelerates chromosomal reassortment and useful segmental interchanges.

Rachie (154) gave several reasons for using recurrent selection for upland rice improvement. He held that the major problems of upland rice involve polygenic characters such as yield, and adaptation to and tolerance for stresses. These multiple traits must be incorporated simultaneously into elite high yielding semidwarfs, which can be achieved in the same population or in separate gene pools. Rachie suggested that pedigree breeding and recurrent selection should be combined to optimize short- and long-term breeding objectives.

Backcrossing. Backcrossing transfers an important trait to an ideal variety that lacks that character. Backcrossing has not been used extensively in upland rice improvement because a suitable recurrent parent is lacking. Chang et al (37), however, suggested that it may be useful. Nine backcrosses of Azucena, Black Gora, IAC47, Kao Lo, and Kinandang Patong were made at IRRI in 1982 dry season. The backcross populations (BC_1) were highly sterile, had spreading culms, and easily shattered grains, and were susceptible to virus diseases (88).

Mutation breeding. Induced mutation is valuable when seeking to improve one or two easily identifiable characters in an otherwise well adapted variety. X-rays, gamma rays, and neutrons are forms of effective ionizing radiation for inducing mutation. Ethyl methane sulfonate (EMS) is one of several chemical mutagens that have been used.

Mutation breeding for upland rice improvement has been widely used by ISAT. Gamma irradiation of 63-83 from Senegal produced short-strawed mutants that had increased lodging resistance and retained other characters desirable in upland rice. IRAT13, IRAT78, and IRAT79 were developed from mutations of 63-83 (95). Similar work is being done at IITA (4, 60).

Haplomethod breeding (androgeneis). In haplomethod breeding, anthers are isolated and the chromosomes are doubled by using colchicine solution. If this technique is perfected, fixed lines will be directly obtainable from hybrid progenies. IRAT has developed several diploids using haplomethod breeding (15, 95, 97). Drawbacks in haploid breeding include loss of fitness and virtual elimination of desirable chromosomal interchange (breaking of linkages) (154).

Tissue culture. Rice plants can be regenerated from cultured cells (10), and whole plants can be produced from single somatic cells, thus extending the techniques of microbial genetics to rice breeding (158). Anther and pollen culture can produce haploid or homozygous diploid plants from single gametes. When pollen from F_1 or F_2 plants from conventional crosses is cultured, homozygosity is obtained in one step. The population produced has the variations that would have been found in F_2 or F_3 but individual plants in the population have a fixed genotype with no further segregation. Characters controlled by recessive genes are immediately apparent in lines produced from tissue culture.

Rachie (154) identified four roles of tissue culture in upland rice improvement:

1. embryo rescue in wide crosses to make interspecific, intergeneric, and interfamily crosses successful;
2. eliminating systematic and seedborne diseases;
3. in vitro screening for stress and disease tolerance; and
4. other applications in genetic engineering.

Many problems must be solved before tissue culture can become useful on a large scale. Chalett (26) noted three major difficulties.

1. The morphogenetic capacity of callus cultures may decline rapidly during continued in-culture maintenance.
2. Only a few cultured anthers produce calli.
3. Some regenerated plants may be albino; callus-induced green plants vary from 5 to 90%.

IRAT is using tissue culture for upland rice improvement (96).

Breeding procedures

An effective breeding program depends upon the systematic organization of procedures to fulfill breeding objectives. Systematic organization encourages efficient screening and generation advances. Some general steps in the breeding process include (24)

1. wide introduction of cultivars and breeding lines,
2. screening and yield trials of materials in different environments,
3. crossing promising parents for pedigree selection and population improvement, and
4. growing mutiple-entry observation nurseries and yield trials of selected lines.

A systematic upland rice breeding program will include the following steps (30):

1. introducing or assembling breeding materials;
2. observing and evaluating;
3. pureline, pedigree, or mass selection;
4. crossing, selecting, and evaluating selected progenies;
5. evaluating selected progenies in a pedigree nursery;
6. evaluating selected progenies in an observational yield trial;
7. evaluating selected progenies in replicated multilocation and seasonal yield trials;
8. evaluating selected progenies in field plot tests;
9. evaluating selected progenies in cooperative tests across institutions and countries; and
10. producing seed.

Variation in upland rice environments causes extreme differences in varietal performance; therefore, selection and screening methods for upland varieties must differ from those used for lowland rices. Alluri (4) suggested three ways of evaluating upland rices for Africa.

1. *Multilocation testing.* More reliable knowledge of varietal performance can be collected if rices are evaluated at upland sites with different environmental conditions and at several planting dates.

   A study in Nigeria showed that for a performance evaluation to be useful, yield trials should continue at least 3 yr at 4 sites in a randomized complete block design with a minimum of 3 replications (131).
2. *Evaluating cultivars across a toposequence transect.* Naturally rolling landscapes of many African countries may include conditions ranging from free draining, sandy upland soils with drought stress to hydromorphic, relatively clayey soils with moist to flooded conditions, all within a few metres elevation. Such environments enable evaluation and selection of cultivars under different soil water conditions while most other conditions remain the same.
3. *Evaluation at different fertility levels and spacing.* Genotype × spacing × soil fertility interaction influences disease incidence and severity of drought stress. Cultivars should be evaluated at two levels of spacing and soil fertility. Similarly, evaluation should include high and low input levels to reflect conditions of marginal and advanced farmers.

PROGRESS IN VARIETAL IMPROVEMENT

Upland varietal improvement has progressed independently in Africa, tropical Asia, and Latin America and also in collaboration with international agricultural research centers.

Africa

Varietal improvement in Africa has been through national programs and international programs such as IRAT, IITA, and WARDA.

National programs. There were a few rice national improvement programs in Africa before the establishment of the international agricultural research centers (IARCs). Rice research began in a small way in Nigeria, Ghana, and Sierra Leone. Moor Plantation in Ibadan, Nigeria, was the center of rice research.

Research on flooded rice was the primary objective of the Rice Research Station at Rokupr, Sierra Leone, established in 1934, but some upland rice research was conducted. In 1953, the Rokupr station was expanded to serve all West African anglophone countries. The West African Rice Research Station became the Sierra Leone national station in 1962 when the association of these states was terminated by independence. Upland rice research also was done at the Food Research Institute in Kumasi, Ghana, and by the Agricultural Research Station, Kpong, Ghana (3).

In Nigeria, the National Cereals Research Institute, Ibadan, is doing pioneer work in upland rice breeding. A pureline selection from local Agbede 16/56 (FARO 3) was released for central Nigeria in 1958. It was moderately high yielding and moderately Bl resistant. In 1966, OS6 (FARO 11) from the Yangambi Research Station of the Institut d'Etudes Agronomiques du Congo in Congo Kinshasa was introduced. OS6 was high yielding, more Bl resistant, and more fertilizer responsive than Agbede 16/56 (128, 130, 178).

In 1966, just as OS6 was released, a Bl epidemic reduced upland rice yields by 15-100%. The epidemic emphasized the need for varieties with better Bl resistance, as well as other desirable characteristics. In 1977, FARO 25 (Farox 56/30) was released. It yielded better than FARO 11 and FARO 3 (128, 130).

IRRI, IITA, and WARDA began massive testing of new varieties in 1976. Several cultivars selected from IRRI and IRAT materials and TOx86-1-3-1, TOx356-1-1-1, TOx495-1-1-1, TOx718-1, and TOx718-2 performed well and seem to be broadly adaptable in Nigeria (128).

Rice improvement in Sierra Leone is at the National Rice Research Station in Rokupr. Early research emphasized mangrove swamp varieties, but equal importance has been given to upland varieties during the last 12 yr. Recently, upland rice research was strengthened by an IITA/FAO/UNDP project that stresses development of disease-resistant varieties (178). Several new varieties such as ROK1, ROK2, and ROK3 have outyielded local varieties in field trials with traditional and improved management (110). ROK1 and ROK2 were developed by hybridization and ROK3 was selected from local materials (181).

The first rice breeding in Liberia was on a small scale at the Firestone Rubber Plantation. Rice research was strengthened in 1973 when a UNDP/FAO agronomist was assigned to the Suakoko Experiment Station and also in 1974 through the IITA/IDA/Liberia project (105). In 1967-68, LAC23 was selected from a local variety. It is a tall, leafy, low tillering, 135-140 d, drought-tolerant variety that outyielded the local variety (178).

Upland rice research began in Casamance, Senegal, in the 1950s. Varieties such as 617A were developed from Malagasy materials, and varieties such as Iguape Cateto from Brazil were introduced and distributed. In Senegal, upland rice research is conducted by the Sepegalese Agronomic Research Institute at Sefa. IRAT has taken responsibility for rice research in Senegal since 1960 (95).

Before 1966, rice research in the Ivory Coast was conducted by the Ministry of Agricultural Research, which released several useful varieties, including Moroberekan. Subsequently, the work wasassigned to IRAT(95). In 1975, Palawan, an introduction from the Philippines, was found to resist drought better than Moroberekan (105). Later rice breeding was done in collaboration with IRAT.

The National Institute for the Development of Congo (INEAC, Zaire) began collecting rice ecotypes in 1933, and released varieties such as R66 and OS6, which originated from crosses of local varieties and introductions from India, Malagasy and other countries. The varieties remain widely distributed and are useful throughout tropical Africa (95).

International Institute of Tropical Agriculture. The IITA upland rice improvement program began in 1979. Its principal objective is to increase African rice production through research (64). The program develops and provides superior breeding materials to assist national programs to increase their rice production. IITA cooperates with IRRI, WARDA, and IRAT.

IITA has emphasized research to develop upland varieties with high yield potential, improved plant type, resistance or tolerance for stresses such as drought, B1, *Rhynchosporium,* and ShB and adaptability to different climatic conditions (4, 5, 60, 61, 62, 63, 64).

IITA researchers have made extensive use of adapted land races, both as parents in conventional hybridization, and for irradiation (4). More than 5,000 accessions of *O. glaberrima* and *O. sativa* have been collected from Africa and elsewhere (178). Performance of superior IITA varieties is shown in Table 2. ITA116, ITA117, ITA118, ITA120, ITA135, and ITA235 showed good levels of drought and B1 resistance in trials at Ibadan and Zaria. ITA116, ITA117, ITA118, ITA225, and ITA235 have superior tolerance for acid soils. ITA117 yielded an average 3.0 t ha^{-1} in a 1981 WARDA moist zone trial. Other IITA varieties have yielded well in WARDA trials (4). In tests of IITA materials in Nigeria, in collaboration with the National Cereals Research Institute and the National Accelerated Food Production Project in 1982, ITA116, ITA117, ITA135, and ITA235 were identified as superior upland rice cultivars (64).

Institut de Recherches Agronomiques Tropicales. IRAT was established in France in 1960 to provide cooperative scientific assistance for improving and developing food crops in developing countries. Most IRAT upland rice research is in Africa, where it has bilateral cooperation and an extensive research network in Cameroon, Ivory Coast, Upper Volta, Mali, Senegal, Togo, and Madagascar. Basic research is conducted in France (25, 97). IRAT also collaborates with IARCs such as IITA, WARDA, IRRI, and the International Board for Plant Genetic Resources (IBPGR) and with the Institut des Savanes (IDESSA) in Bouaké, Ivory Coast.

Most of IRAT's upland rice improvement research is done at Bouakè, where it has introduced more than 7,000 *O. sativa* collections.

The research takes an interdisciplinary approach. In 1974, IRAT and ORSTOM began collecting African rices — cultivated *O. glaberrima* and wild *O. barthii* and *O. longistaminata* — or use in varietal improvement. Most IRAT-developed varieties have been from hybridization of distant parents, but irradiation, mutagenesis, androgenesis, gynogenesis, and tissue culture also have been used (25, 95).

Table 3 lists important IRAT developed upland cultivars and their distinct characteristics. Many IRAT varieties have shown great promise in IITA and WARDA trials (42, 64). IRAT identified deep rooting as a varietal characteristic important to drought resistance and developed IRAT13, which has good resistance. IRAT is working on horizontal B1 resistance rather than vertical resistance. It also developed IRAT10, a cross of Senegalese 63-104 and Taiwanese Lung Sheng 1. IRAT10 yields well, has short stature (100 cm), lodging and disease resistance, and matures early (25).

West Africa Rice Development Association. WARDA was established in 1970 at Monrovia, Liberia, to promote rice development in member countries of West Africa. WARDA confines its varietal improvement activities to the introduction of varieties developed in other countries and selection. It works closely with IITA, IRAT, IRRI, and national programs in West Africa.

Promising upland lines identified by national and international centers are screened at 14 West African sites in the annual WARDA Initial Evaluation Test (IET). Varieties selected from the IET are tested in Coordinated Varietal Trials (CVT) in member countries. CVT trials are conducted at Sefa, Senegal;

Table 2. Characteristics of superior upland rices developed at IITA (4, 5).

Variety	Parentage	Grain yield[a] ($t\ ha^{-1}$)	Plant height (+10 cm)	Days to maturity (+ 10 d)	Resistance[b]		Grain characteristics
					Bl	Drought	
ITA116	63-83/IR773	5.2	140	115	R	MR	Long, bold, translucent
ITA117	13a-18-3-1-3/TOx 7	5.5	110	110	R	R	Medium-long, translucent
ITA118	TOx 7-4-2-5-1/63-83	5.3	120	110	R	MR	Long, bold, with specks of abdominal white
ITA141	LAC 23/(TOx 7, IET1444)	6.1	135	120	R	R	Long, slender, translucent
ITA162	Moroberekan/(ROK1, TOx 7)	6.2	130	120	R	MR	Medium-long, bold, trace of white specks
ITA225	63-83/(ROK1, Dourado Precoce, Se 363G)	5.0	115	120	R	MR	Medium-long, bold, abdominal white, highly resistant to shattering
ITA235	OS6 mutant/OS6	5.5	115	115	R	MR	Medium-long, translucent
ITA257	IRAT13/Dourado Precoce/TOx 490-B	3.7	90	95	R	MR	Medium–long, translucent

[a] Under experimental conditions. [b] R = resistant, M = moderately resistant, S = susceptible.

Table 3. Upland rices selected by IRAT (25).

Variety	Country of origin	Genetic origin	Duration (d)	Height (cm)	Shattering[a]	Grain length (mm)	1,000-grain weight (g)
IRAT2 = (6383)	Senegal	Natural hybrid of 560 A	125	140	S	10	38
IRAT10	Ivory Coast	Lung Sheng 1/63.104	100	100	M	8	27
IRAT13	Ivory Coast	Mutant of 63-83	125	115	S	10	38
IRAT79	Ivory Coast + Cameroon	Mutant of 63-83	125	140	S	10	35
IRAT106	Ivory Coast	2243 X mutant of CP231	125	125	R	9	28
IRAT110	Ivory Coast	IRATI3/IRAT10	115	80	M	8	28
IRAT112	Ivory Coast	IRAT13/Dourado Precoce	110	105	M	10	33
IRAT116	Ivory Coast	Mutant of Moroberekan	135	130	R	9	30
IRA1133	Ivory Coast	IRAT13/1RAT10	110	105	M	8	35
IRAT140	Ivory Coast	Line 13 d/Moroberekan	120	95	M	9	28
IRAT146	Upper Volta	IRAT13/Dourado Precoce	100	110	M	10	38

[a]R = very resistant, M = moderately resistant, S = rather resistant.

Sapu, Gambia; Contuboel, Guinea Bissau; Farakoba, Upper Volta; Rokupr, Sierra Leone; Suakoko, Liberia; Bouaké, Ivory Coast; Nyankpala, Ghana; Sotouboua, Togo; Ina, Benin; Moor Plantation and IITA, Nigeria; Geuckedu, Guinea; and Sikasso, Mali.

Varieties developed in the WARDA regions are listed in Table 4, and promising and recommended upland rice varieties identified through WARDA trials are in Table 5 (42, 179).

Das Gupta et al (43) studied the adaptability of upland rice cultivars in WARDA coordinated multilocation trials between 1973 and 1979 (Table 6).

1. Widely adapted varieties that yield above average in all environments and have a regression coefficient close or equal to one (b=1) i.e. little or no genotype-environment interaction.
2. Varieties that do well in adverse or low yield environments but poorly in favorable environments. These varieties give moderate mean yield and have a regression coefficient much lower than one or close to zero (b<1).
3. Varieties that do well in favorable environments but poorly in adverse environments. These varieties give moderate to high mean yield and have a regression coefficient much greater than one (b>l).

South and Southeast Asia

National programs and IRRI have upland rice varietal improvement projects in South and Southeast Asia.

National programs. There are upland rice breeding programs in Bangladesh, India, Indonesia, Thailand, and the Philippines. In India, coordinated rice breeding began when the Central Rice Research Institute (CRRI) was established at Cuttack in 1946. The All India Coordinated Rice Improvement Project (AICRIP) was organized in 1965. AICRIP organized a coordinated program of rice

Table 4. Upland rices developed in West Africa (42).

Station, country	Varieties developed
Djibelor, Senegal	I Kong Pao, SE302G, SE314G, SE319G, DJ12-539-2
Rokupr, Sierra Leone	ROKl, ROK2, ROK3, ROK16
Suakoko, Liberia	LAC23 (red), LAC23 (white)
Bouaké, Ivory Coast	Dourado Precoce, IRAT8, IRAT9, IRAT10, IRAT13, IRAT109, IRAT110, IRAT112, IRAT133, IRAT138, IRAT142, IRAT144, IRAT170
Moor Plantation, Nigeria	OS6, SEL IRAT194/1/2
Nyankpala, Ghana	IR 1820-2 10-2
IITA, Nigeria	ITA116, ITA117, ITA1 18, IRAT123, ITA141, ITA235, ITA162

Table 5. Promising and recommended upland rices, identified in WARDA trials in West Africa (42).

Country	Varieties
Gambia	SE302G[a], IRAT110[a], IRAT112[a]
Guinea Bissau	IRAT109[a], IRAT133[a]
Senegal	IRAT10[a]
Guinea	LAC23, IRAT109, IRAT110, IRAT112, IRAT136, IRAT138
Sierra Leone	LAC238
Liberia	IRAT110, IRAT112
Upper Volta	IRAT10[a], SE302G[a]. Dourado Precoce[a], IRAT144[a]
Ivory Coast	IRAT144
Mali	IRAT10[a], IRAT13[a], Dourado Precoce[a]
Ghana	IR442-2-58[a]. Dourado Precoce[a], 4418
Nigeria	IRAT13, IRATIO9, IRAT110, IRAT136, IRAT138, SEL IRAT194/1/2
Benin	Col 38[a], IRAT10[a], IRAT142, CR1002[a]
Togo	IRAT10[a], IRAT13[a], ADNY8[a]

[a]Recommended for production.

improvement in India involving state university breeding programs and those of CRRI, and encouraged an interdisciplinary approach to rice breeding. More than 195 varieties have been identified through AICRIP (163), but only a few are upland rices.

Tall, local land races are grown on 90% of the Indian upland rice area: the rest is planted to semidwarfs. Tall varieties include improved pureline selections such as N22, a selection from Rajbhog, grown in Uttar Pradesh, and land races (118) (Table 7). Tall varieties yield less than semidwarfs, but farmers prefer them because of their stable yields.

Most semidwarfs bred in India for upland rice are early maturing with bold to medium grains. Few have high levels of drought resistance. On high uplands, farmers plant tall varieties with 100 d maturity. They have low tillering capacity,

Table 6. Three types of upland rice varieties based on main season adaptability studies in West Africa, 1973-78 (43).

Variety	Yield (t ha^{-1})
Category 1 (0.85 < b < 1.25)	
IR528-1-32	2.1
BR34-11-2	2.0
ADNY8	2.0
SE319 G	1.9
ADNY7	1.9
ROKI	2.8
ROK2	2.7
OS6	2.6
IR2035-108-2	2.5
4418	2.4
IRAT9	2.3
MRC172-9	2.3
4455	2.2
Category 2 (b < 0.85)	
Dourado Precoce	2.1
Soavina	1.9
IRAT10	2.3
M55	2.1
M18	1.9
Iguape Cateto	2.6
IRAT13	2.4
IR2035-108-2	2.9
4418	2.5
Category 3 (b > 1.25)	
I Kong Pao	2.0
IR442-2-58	1.9-2.8
SE302 G	1.9
SE314 G	2.0
IR30	1.9
IR1529-680-3	2.2
IET2885	2.1

[a]Category 1 = regression coefficient close to one. No or very little genotype × environment interaction. Good for all environments. Category 2 = regression coefficient less then one, Good for poor environments. Category 3 = regression coefficient much greater than one. Good for favorable environments.

weak stems, long panicles, and coarse grain and lodge with high fertilizer applications (111).

Recent research at CRRI, AICRIP, and agricultural universities has identified promising lines with mechanisms for drought tolerance. Some lines also have good drought recovery and high temperature tolerance (163). Promising upland semidwarfs include Aradhana (IET2232) (174), Parijat (IET2684), DR42 (119, 162), CR146-224, CR146-225, CR156-207 (168), Bala, Jamuna, Pusa 2-21 (l00), UPR82-1-7, and UPR103 D–6–1 (167).

In Bangladesh, upland rice breeding is at the Bangladesh Rice Research Institute (BRRI) in Joydebpur. Upland rice in Bangladesh is direct seeded in aus (spring). Drought, diseases, and insects are common problems. Most improved varieties are from traditional parents, mature in 90–115 d, and yield about 2 t ha^{-1}

Table 7. Popular tall upland varieties grown in India (118).

State	Variety
Andra Pradesh	Mtu17, Mettasannavari
Assam	Dumai, N22
Bihar	BR16 (brown gora), BR17 (black gora), BR18
Gujarat	Eonly Kolam 161-162, Sathi 34-36
Haryana	Jhona 351 (BAM12), Ch988
Himachal Pradesh	Lalnakanda 41, Ch1039, Ch988
Jammu and Kashmir	Ch 988, Ch 1039
Karnataka	Ptb10, Early Dochinga 6-22, Mugad 161
Kerala	Ptb10, Ptb28, Ptb29, Ptb30, Cul356
Madhya Pradesh	Nagpur 22, Laloo 14
Maharastra	Early Kolam 161-162, N22
Manipur	Changlei, Dumai, Phougak
Meghalaya	Ch988
Nagaland	Yuraba, Tauzmoi, Lakokolak
Orissa	Kalakeri, Kulia, B76, Jl, BAM12, N22, N22, (N136), Ptb10
Rajasthan	N22, Sathi 34-36, Sutar, Pathria, Sagan
Tamil Nadu	TKM1, TKM2, TKM6, Co31, ASD1, ADT27
Uttar Pradesh	N22, Sudha, Ch10, T136
West Bengal	Dular, Charnock, NC1626
Punjab	Jhona 351, Lalnakanda 41

(155). They include Kataktara (DA2), Panbira (DA12), Dharial (DA14), Dular (DA22), Marichbati (DA24), and Hashikalmi (DA26).

BRRI collaborates with IRRI to evaluate new upland rices in observational and yield nurseries. In 1982, several promising breeding lines were identified through the IURYN and the IURON. They included IR5931-110-1, IR6023-10-1-1, Seratus Malan, UPL Ri-3, and UPL Ri-5. In regional yield trials at 10 sites, BR203-26-2 yielded highest, with 1.8 t ha^{-1} (12).

Until the middle 1970s, rice breeding in Indonesia consisted largely of purification and selection among local varieties and evaluation of introductions. Seratus Malan, Genjah Lampung, Pulut Nangka, and Leter were varieties selected by these method's. Kartuna and Bicol (BPI-76-1) were introduced from the Philippines, but BPI-76-1 was susceptible to B1.

Hybridization and selection at the Central Research Institute for Agriculture in Bogor produced Gata (Sigadis/Syntha), Gati (Sigadis/Basmati), and Gemar (Jerak/Pb 8). These varieties were adapted for favorable uplands. Gama 87 (Genjah Mataram/Genja Raci), which is drought resistant, was developed at Gadjah Mada University in Yogyakarta (37, 169). Promising varieties identified in yield trials included IET1444 (Taichung Native 1/Co 29) and IR36. B1 resistant varieties included IR2061-522-6-9 and Lagos (14).

Rice breeding in the Philippines began early in the century. Mass selection and comparison among farmers' varieties identified Pinulot, Kinandang Puti, and Apostol, which became important varieties. The Philippine Seed Board and its cooperative testing program was established in the early 1950s. The board recommended the pureline selections Palawan, Azucena, and Dinalaga. In the 1960s, the board released Milpal 4, HBDA-2, BPI-1-48 (M1-48), and Azmil 26, all of which were developed through hybridization. In the 1970s, the University of the

Philippines at Los Baños developed C22, UPL Ri-3, UPL Ri-5, and UPL Ri-7 which have intermediate height, moderate tillering ability, and good grain quality (37, 50, 107, 148). Some of these varieties were susceptible to B1, and although their drought recovery ability is generally excellent, they have intermediate root systems. They yield about 4 t ha^{-1}.

In Thailand, upland rice breeding from the 1950s to the middle 1970s was limited to collecting farmers' varieties, purification, and evaluation. After multiple-site evaluation, nonglutinous Goo Muang Luang and Dawk Payom were recommended for southern Thailand. They yield slightly less than 2 t ha^{-1}. Sew Mae Jan, a glutinous rice, was recommended for the north. It yields about 2.8 t ha^{-1}. Khi Chang is cold tolerant and performs well at high altitudes (172). All three are traditional types (34). Recent crosses by the Rice Division and Kasetsart University are being evaluated.

International Rice Research Institute. IRRI's upland rice improvement program includes research at IRRI in Los Baños and collaboration with national programs and IITA, WARDA, IRAT, and CIAT. On requests from national centers and IARCs, crosses are made at IRRI. In 1982. 35 crosses were made for Bangladesh, 35 for Brazil, 6 for IITA, 42 for India, and 47 for Thailand (88). Over 4,000 crosses have been made for local testing and selection or for collaborators (34). IRRI's International Rice Germplasm Center (IRGC) maintains more than 4,000 accessions of upland rices. They are freely available to rice breeders.

In a review of IRRI's progress in breeding for upland environments, Chang et al (37) emphasized the research that preceded breeding, which included evaluations of root and shoot characteristics of upland rices. Correlations between deep and thick roots and drought avoidance, between plasticity in leaf rolling and unrolling with retention of favorable water status in plant tissue, and between recovery ability and vegetative growth vigor were identified. A mass screening technique for reproductive and vegetative phases was developed in 1974. Still to be elucidated are the nature of tissue tolerance for desiccation and factors associated with drought resistance at reproductive stage.

Major progress is summarized.

1. Several rices with good drought resistance and moderate drought recovery ability have been identified.
2. Yield potential in favorable areas has been increased to 4 t ha^{-1}.
3. Resistance to some pests and desired grain quality have been incorporated.
4. Through multilocation testing, improved materials have been categorized as adapted to favorable, unfavorable, or all upland environments (Table 8).
5. Some of these materials also are useful in drought-prone, shallow, rainfed environments.
6. More than 100 crosses of IRRI's improved germplasm and traditional varieties from collaborators have been provided to national and regional centers for selection under local conditions.

Latin America

In Latin America, most research to improve upland rice is in Brazil at the Instituto Agronomico Campinas (IAC), São Paulo; at the Centro Nacional de Pesquisa de

Table 8. Performance of promising IRRI lines in upland trials at 3 rites, 1977-80 wet seasons (37).

Line	Adapted environment	Mean yield (t ha^{-1})	Range of yields (t ha^{-1})	Stability index	Mean maturity (d)	Drought rating	
						Vegetative stage	Reproductive stage
IR3839-1	Favorable	2.4	0.1-3.8	1.35	118	5	3-5
IR3880-10	All	2.4	0.4-3.5	1.08	129	3-4	5
IR3880-17	All	2.2	0.2-3.7	0.99	128	4	5-7
IR5178-1-14	Unfavorable	1.6	0.2-2.9	0.79	116	4	5
IR5929-12-3	All	2.0	0.1-3.4	1.04	119	4	3-5
IR5931-110-1	Favorable	2.5	0.1-3.9	1.37	121	5	5-7
IR6023-10-1-1	All	2.1	0.6-3.4	1.11	132	3	5
IR6115-1-1-1	Favorable	3.0	0.2-4.3	1.42	130	4-5	7
IR9669 sel.	Favorable	2.9	0.4-4.5	1.34	132	5	7
IR43 (check)	Favorable	2.8	0.3-4.7	1.40	132	4	7-9
IR45 (check)	Favorable	2.4	0.3-4.0	1.17	135	5	7-9
Kinandana Patong (check)	Unfavorable	1.4	0.2-2.6	0.67	126	3	4

Arroz e Feijão (CNPAF), Goiania; and at CIAT in Cali, Colombia (22). Most research involves varietal selections at the advanced germplasm stage and finding solutions to solve national or regional problems.

In Brazil, upland breeding programs focus on drought, diseases (Bl, LSc, *Helminthosporium*), soil problems (P and Zn deficiency, A1 toxicity), insect pests (lesser corn stalk borer), and problems such as lodging, growth duration, and shattering (22, 160, 161). Most Brazilian upland varieties were developed at IAC and are well adapted to unfavorable environments. The most important of these are IAC25, IAC47, IAC164, and IAC165 (9, 23, 48, 166). Many medium duration varieties developed for unfavorable areas are planted in favorable areas because suitable rices for such areas are unavailable (49).

In addition to improved varieties, tall land races are grown in unfavored subsistence cropping areas. The CNPAF/EMBRAPA germplasm bank has collected more than 800 traditional Brazilian upland rice varieties.

Most improved upland varieties developed outside of Brazil are suited to favorable environments. They have various plant type, height, duration, grain quality, insect and disease resistance, drought and adverse soil tolerance, and yield potential (Table 9). Semidwarf rices dominate in favorable uplands, particularly in Colombia, Venezuela, and Central America. Some of the semidwarfs - Tapuripa, Magali, Bowani, Diwani, and Eloni — that grow well in upland areas were developed for irrigated conditions in Surinam. They produce well in favorable Central American environments, especially Panama, where they have high B1 resistance that has remained stable for 20 yr (23).

CIAT research on upland rice concentrates on varieties for favorable environments, defined as flat or gently sloping unbunded fields that receive 1,500 mm or more annual rainfall, averaging 250 mm mo^{-1} during growing months, and with not more than a 10-d rainless period during reproductive and ripening growth stages. Drought, acid soils, and B1 are major problems. Improved varieties for these conditions such as CICA7, CICA8, and CICA9 have been developed by CIAT and the Colombia Institute for Agriculture (ICA) (22).

CIAT has identified about 640 suitable varieties from IRRI, IITA, IRAT and national programs in Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Panama, and Peru (114). These entries are screened for grain quality and *Sogatodes,* and crosses are made of varieties with resistance to drought, B1, *Sogatodes,* and hoja blanca. The F_1 is grown at CIAT. For the F_2, nurseries are grown in different countries and environments. Promising lines are evaluated in the IRTP throughout Latin America.

For 10 yr, several national programs in Central America have used advanced breeding materials from CIAT and IRRI. In 1978, each national rice program began including the best locally adapted breeding lines in the Central American Upland Nursery (VICA). These lines provide good parental material for developing superior upland cultivars. They have high yield potential and Bl and LSc resistance in favorable environments but are susceptible in less unfavorable environments (23).

Table, 9. Agronomic characteristics of improved upland rice varieties grown in Latin America. Data are from two sites in Colombia[a] (23).

Variety	Duration (d)	Plant height (cm)	Disease reactions				Reaction to *Sogatodes oryzicola* (1-5)	Grain quality	
			Leaf BI	Neck BI	Hoja[b] blanca	LSc (1-9)		White belly	Grain length[c]
CICA4	135	89	5	22	MR	6	2.5	0.6	L
CICA6	136'	89	2.3 (4)	-	MR	-	1.5	0.6	L
CICA7	130	90	2	16	R	8	2.0	0.6	L
CICA8	143	94	4	75	S	5	2.0	0.8	L
CICA9	138	103	4	50	R	5	1.5	0.8	L
CR1113	141	94	1	51	S	5	5.0	0.2	L
Anayansi	145	86	3	40	-	5	3.0	1.6	L
Damaris	149	83	2	96	-	5	5.0	0.8	L
Bluebonnet 50	134	140	3	20	S	5	5.0	0.5	L
Eloni	141	90	2	-	-	3	2.0	0.8	EL
Pico Negro	133	109	-	-	-	-	-	1.0	L
IR1529 (IR43)	132	92	4	-	-	5	2.0	2.0	L
IAC25	135	130	3 (4)	0.1	S	7	5.0	1.4	L
IAC47	130	146	3 (4)	-	S	6	5.0	3.4	L
IAC164	110	114	1 (3.4)	-	S	5	5.0	3.6	L
IAC165	105	104	1 (3)	-	S	5	5.0	3.0	L
Diwani	131	94	1	-	MS	3	3.0	-	L
Ciwini	136	106	2.3	0	MS	3	2.5	0.2	EL
Carolino	147	144	-	-	S	-	-	2.2	L
CR201	139	103	-	-	-	3	4.0	0.4	L
Iniap 6	140	84	-	-	MR	5	2.5	0.8	L
Iniap 415	141	96	-	-	R	5	2.0	0.8	L
Iniap 7	142	100	4	-	R	6	2.0	0.4	L
Nilo 1	160	135	-	-	-	3	3.0	-	L
Tikal 2	131	94	4	98	-	5	3.0	0.6	L
Bamoa A75	136	90	-	-	-	-	-	-	L
Donato	150	109	-	-	R	-	-	-	L
Canilla	140	128	-	-	R	-	-	2.2	M
Dawn	124	90	1	86	S	5	5.0	0.6	L
Metica 1	124	75	1	0.5	R	5	3.0	0.2	L
Dourado	120	146	-	-	S	-	9.0	1.6	M

[a]Data are from CIAT-Palmira with disease evaluations at Villavicencio in Colombian llanos. A dash (—) indicates data not available. [b]S = susceptible, MS = moderately susceptible, R = resistant. [c]M = medium, L = long, EL = extra long.

INTERNATIONAL RICE TESTING PROGRAM

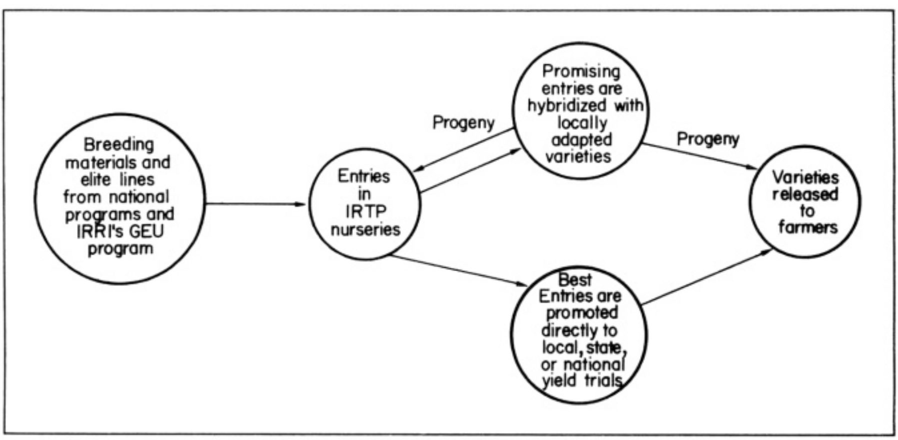
The IRTP is funded by the United Nations Development Program and coordinated by IRRI. More than 70 countries participate in the program. Its objectives are to

- make the world's elite rice germplasm available to rice scientists around the world for direct use or for crosses within their breeding programs;
- let cooperators assess the performance of their advanced breeding lines under many climatic, cultural, soil, disease, and insect conditions;
- identify varieties with broad-spectrum resistance to major diseases, insects, and stresses;
- monitor and evaluate the genetic variation of pathogens and insects;
- promote information exchange on the interaction of varietal characteristics in different rice growing environments; and
- promote interaction among rice scientists.

Scientists from around the world help plan the annual program and review results of the previous year's program by participating in monitoring tours, international rice research conferences, regional and subject matter workshops, and advisory group meetings. IRRI Genetic Evaluation and Utilization Program scientists participate in discussions with national scientists during feld visits and attend national workshops. Correspondence and questionnaires provide additional opportunities to enhance IRTP programs (78). The program is planned with IITA and WARDA in Africa and with CIAT in Latin America (Fig. 5).

The IRTP organizes IURYN and IURON. IURYN began in 1974 and IURON in 1975. Entries in those nurseries include improved and traditional varieties with different plant stature and growth duration. In 1982, upland nurseries were evaluated at 45 sites in Asia, Africa, and Latin America. Most nurseries are in favorable areas (164).

Table 10 summarizes IURON 1980-82 entries in terms of phenotypic acceptability, plant height, and flowering duration based on 25 sites in 1980, 22 in



5. IRTP's objective is to speed the development of improved varieties for rice farmers (78).

Table 10. Entries with phenotypic acceptability ratings less than or equal to five in the 1980-82 IURON (81, 84, 89).

Designation	Mean plant ht (cm)	Days to flowering
	1980[a]	
BG35-2		
CR156-5021-207		
IR3880-29		
KMP34		
ARC10372		
C924-9		
	1981	
IAC1246	103	94
I R 1004-3-1	94	92
IR10110-23-1	100	94
IR12979-24-1	96	91
IR5440-1-1-3	101	93
IR9256-59	77	88
IR9761-19-1	71	80
IR19793-25-2-2	71	79
IR3794-9-2-3	98	98
Jhum sonalichikon	105	83
IR6023-10-1-1	96	98
ITA235	89	88
UPL Ri-3	90	99
ITA175	81	89
	1982	
M18	90	94
Local check	94	98
UPL Ri-7	89	94
B2997C-TB-60-3-3	97	94
B3016B-TB-260-3-2-1-1-3	98	94
IRAT140	98	97
IRAT101	96	95
BG35-2	75	95
B2992B-TB-734-2-3-3-3-2	100	97
ITA139	107	94
TOx502-2SLR2-LS3-Bl	101	99

[a]No data on mean plant height and days to flowering were included before 1981.

1981, and 24 in 1982 (81, 84, 89). Promising 1976-81 IURYN entries are listed in Table 11. Mean yield ranged from 2.3 to 3.9 t ha^{-1}, and days to flowering from 77 to 131 (164).

In 1981, two Latin American upland nurseries, VIRAL-S (IURYN) and VIOAL-S (IURON), were organized in favorable upland rice environments. Grain yield and duration of the best entries are given in Tables 12 and 13. All VIRAL-S entries yielded more than 4 t ha^{-1} (157).

Seshu (164) listed IRTP evaluated entries that have been released as varieties in different countries. Upland rice C22, a Philippine variety, has been released in Burma as Yar 1. CICA8, developed by CIAT and ICA, has been released as CICA8 in Panama, Honduras, and Belize, as ICTA Virginia in Guatemala, and as Adelaide 1 in Paraguay.

Table 11. Performance of top entries in the 1976-81 IURYN (73, 75, 76, 79, 82, 85).

Entry	Yield (t ha^{1})	Days to maturity	Days to flowering	Entry	Yield (t ha^{1})	Days to flowering
		1976			1979	
IET1444 (India)	3.3		77	UPL Ri-5 (Philippines)	2.8	101
IR36 (IRRI)	3.1		83	IR9669 Sel. (IRRI)	2.8	106
IR1529-430-3 (IRRI)	3.1		93	BG35-2 (Sri Lanka)	- 2.7	91
IR2061-522-69 (IRRI)	3.1		78	IR2061-522-69 (IRRI)	2.7	88
B541b-Kn-19-34 (Indonesia)	3.0		89	IR45 (IRRI)	2.7	103
		1977			1980	
IET1444 (India)	3.0	116		IR5931-110-1 (IRRI)	3.9	91
IR36 (IRRI)	3.0	118		BG35-2 (Sri Lanka)	3.6	89
C22 (Philippines)	3.0	130		B733C-167-3-2 (Indonesia)	3.5	94
C4815/IR42^{2} (Philippines)	3.0	128		CR 156-5021 -207 (India)	3.5	95
KN361-1-8-6 (Indonesia)	2.9	118		IR5853-118-5 (IR52) (IRRI)	3.5	97
IR1529-430-3 (IRRI)	2.9	131		IR6115-1-1-1 (IRRI)	3.5	91
IR2061-522-69 (IRRI)	2.9	122		IR9560-26-3-1 (IRRI)	3.5	102
IR3839-1 (IRRI)	2.9	124		IR995-96-2 (IRRI)	3.5	101
		1978			1981	
IR1529-430-3 (IR43) (IRRI)	3.8		102	IR5931-110-1 (IRRI)	2.5	96
IR9669 Sel. (IRRI)	3.7		108	IR6115-1-1-1 (IRRI)	2.4	93
IET1444 (India)	3.6		86	UPL Ri-5 (Philippines)	2.5	100
IR36 (IRRI)	3.6		94	IR43 (IRRI)	2.4	100
B541b-Kn-19-34 (Indonesia)	3.5		107	BPI Ri-6 (Philippines)	2.3	101
Gama 318 (Indonesia)	3.5		107	CR156-5021-207 (India)	2.3	9
KN96 (Indonesia)	3.5		102	IR52 (IRRI)	2.3	100
IR2035-242-1 (IR45)	3.5		107			
IR3839-1 (IRRI)	3.5		94			
MRC172-9 (Philippines)	3.5		101			
IR9575 Sel. (IRRI)	3.5		98			

Table 12. Average yield and days to flowering of best entries of the 1981 IURYN (VIRAL-S) at 13 favorable upland locations in Latin America (157).

Designation	Origin	Days to flowering	Yield (t ha^{-1})
IET4094 (CR 156-5021-207)	India	88	4.4
P1377-1-15M-1-2M-3	CIAT-ICA	98	4.3
TOx728-2	Nigeria	94	4.3
B733 C-167-3-2	Indonesia	91	4.2
P1381-18M-2-18	CIAT-ICA	99	4.1
CICA8 (check)	Colombia	99	4.2
IR43 (check)	Philippines	94	4.4

Table 13. Average yield and days to flowering of best entries of the 1981 IURON (VIOAL-S) at 8 favorable sites in Latin America (157).

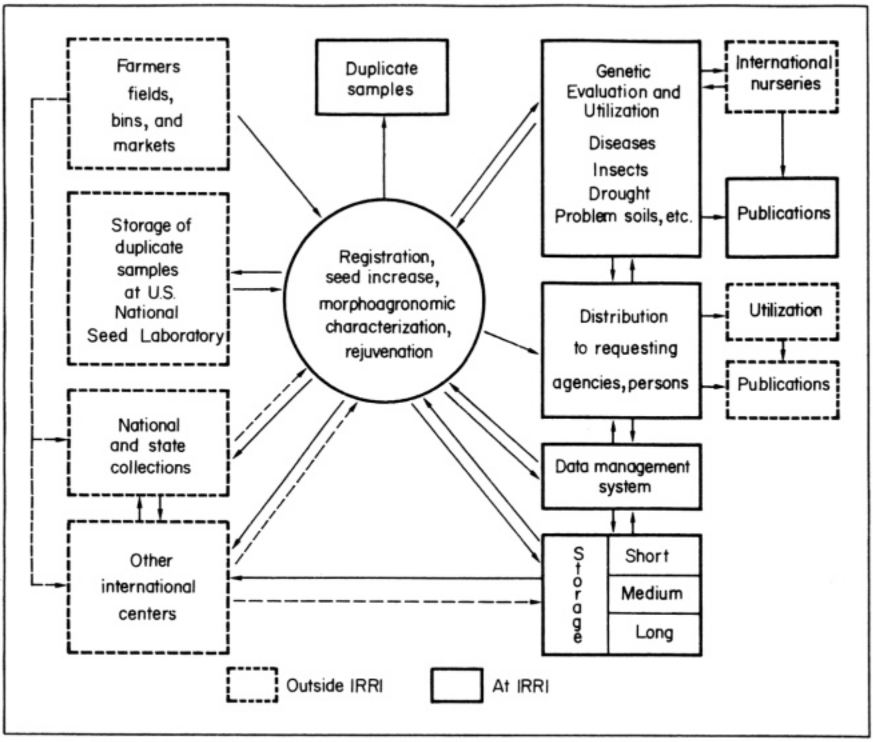
Designation	Flowering (d)	Yield (t ha^{-1})
IR13240-39-3	86	4.5
IR11248-148-3-2-3-3	94	4.4
IR10781-75-3-2-2	101	4.4
IR6115-1-1-1	98	4.0
IR7790-18-1-2	80	4.0
IR10198-66-2	80	4.0
BR51-46-5	96	4.0
IR10781-75-3-2	102	4.0
IR9846-261-33	84	3.9
IR13415-9-3	85	3.9
IR11248-83-3-2-14	92	3.8
IR10781-105-2-2	95	3.8
IR9761-19-1	81	3.8
IRAT127	95	3.7
IR9846-23-2	97	3.6
CICA8 (check)	98	3.8
IR42 (check)	104	3.8
IR43 (check)	91	4.0
CR1113 (check)	98	3 5

INTERNATIONAL COOPERATION TO CONSERVE GENETIC RESOURCES

IRRI's IRGC is responsible for

- acquisition, field collection, and coordination and consolidation of rice germplasm collections;
- characterization of cultivated and wild rices;
- rejuvenation and preservation of varieties and lines;
- seed distribution;
- standardization; and
- personnel development for germplasm collection and maintenance.

IRRI began the collection in 1981 with the assistance of rice researchers in Asia, the U.S. Department of Agriculture, and FAO. Today, collaborators include IARCs

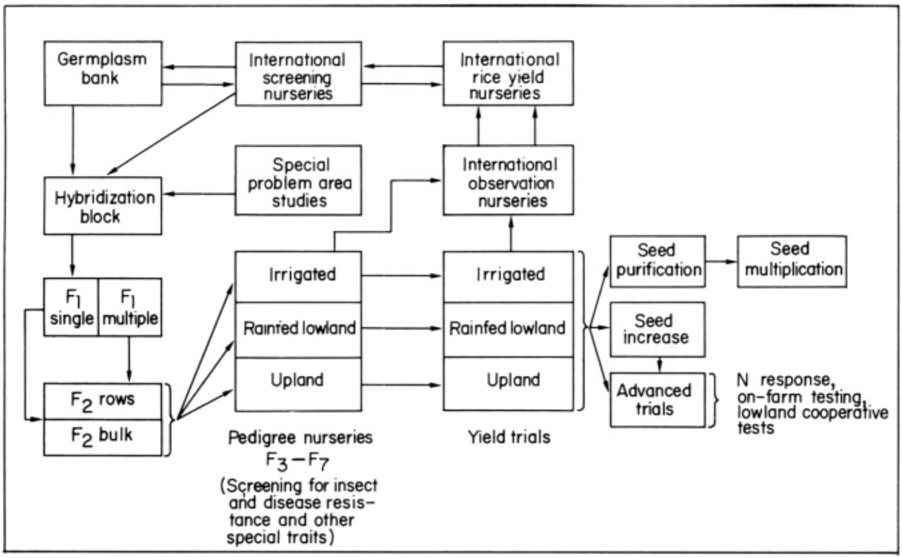


6. IRRI procedures and collaboration in collecting, multiplying, cataloging, preserving, evaluating, and utilizing rice germplasm (30).

such as IITA, IRAT, and WARDA. By 1 Jan 1983, the IRGC included 60,181 distinct accessions and ecostrains of *O. sativa,* and 5,042 newly received samples awaited sowing and registration. The collection also included 2,614 accessions of *O. glaberrima,* 1,100 populations of wild taxa, and 691 genetic testers and mutants (39). Figure 6 shows IRRI activities relating to germplasm collection and utilization.

The IRRI Rice Genetic Resources Laboratory opened in 1977. In its long-term storage facilities, seed samples are stored in vacuum-sealed cans at - 10° C. They are expected to remain viable for at least 50 and perhaps 100 yr. In medium-term storage (4°C), seed samples are expected to remain viable for about 25 yr; those in short-term storage (20°C), for 3-5 yr. The viability of seeds of control varieties is checked every 6 mo. A 15 g duplicate of each accession is sent to the U.S. National Seed Laboratory at Fort Collins, Colorado (44).

Evaluation and utilization of collected rice germplasm began at IRRI in 1962, and the GEU program was organized in 1973. The GEU program combines the efforts of a multidisciplinary team of plant breeders and problem area specialists to develop new rice varieties and procedures for producing and evaluating breeding materials (54). Figure 7 illustrates the flow of materials within the GEU program and from IRRI to national programs (104).



7. Flow of materials within the IRRI GEU program and to national programs through international nurseries, and back to the IRRI germplasm bank (104).

BREEDING FOR SPECIFIC TRAITS

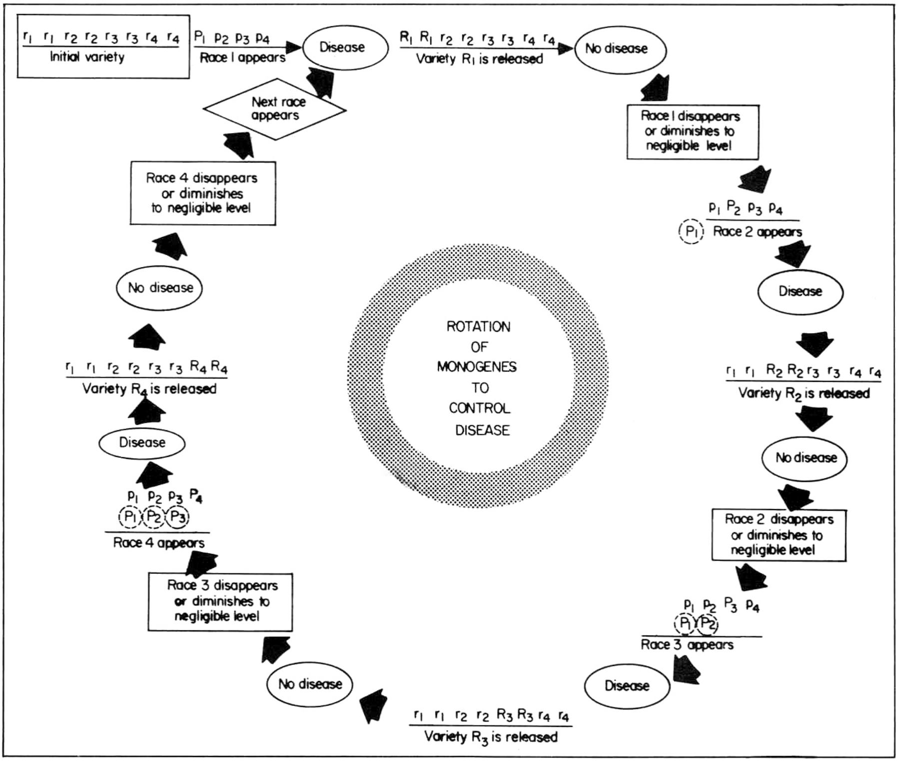
Considerable progress has been made in breeding for traits such as disease and insect pest resistance; tolerance for nutritional deficiencies, soil acidity, and Al and Mn toxicity; and drought resistance. All of them can be serious constraints to upland rice cultivation.

Blast resistance

Bl may be the most serious upland rice disease. The literature on breeding for Bl resistance is voluminous (146). Four breeding strategies are being used to develop rices with Bl resistance: single gene addition, gene pyramiding, horizontal resistance, and developing multiline varieties (98). Korean scientists are also working on gene rotation and race prediction for both Bl and bacterial blight (BB) (77) (Fig. 8).

Plants have two disease resistance mechanisms: vertical resistance and horizontal resistance (175). Vertical resistance usually involves a single gene, which may confer resistance to one or many races of a pathogen (122).

Horizontal resistance also is called slow blasting or field resistance (126). Van der Plank (175) described horizontal resistance as a uniform moderate reaction against all races of a pathogen. It checks, but does not stop, pathogen development, but usually defeats the disease (58). Horizontal resistance usually, if not always, is due to the action of several genes, which probably accounts for its relative stability over long periods. Several genetic changes probably are needed by the pathogen to overcome polygenic resistance, while a single genetic change often can overcome vertical resistance (122).



8. Proposed rotation of monogenes to control disease (77)

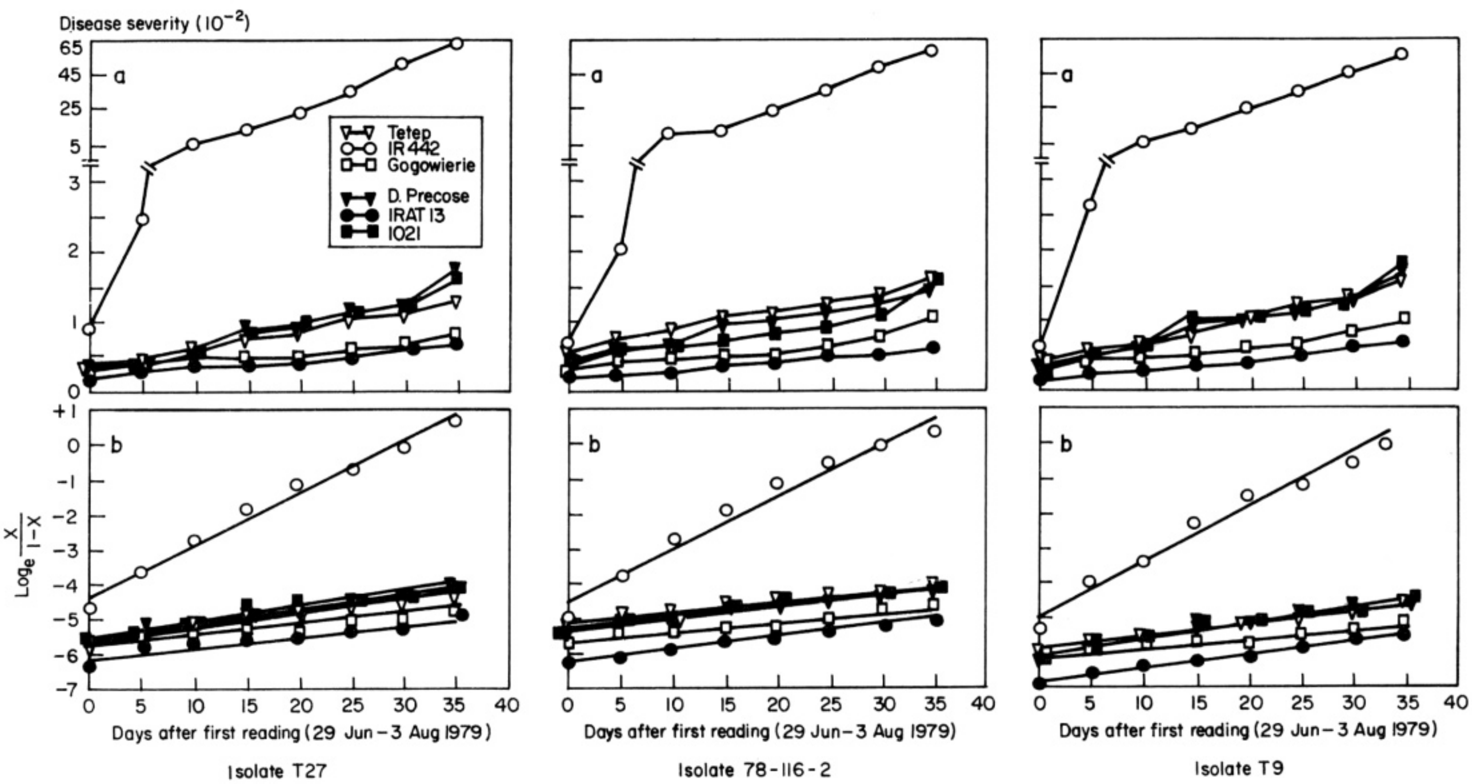
The major obstacle to developing Bl-resistant varieties is the pathogen's capacity to produce numerous races. Races in a single field will vary at different locations and seasons because different rices are planted and because the environment changes. Pathogen races also vary because there can be from 2 to 12 chromosomes within the nuclei (147).

Apparent infection rate (AIR), based on a formula developed by Van der Plank, has been used at IRRI to measure horizontal resistance. Rate (r) of disease increase (x) over time (t) corrected for decreasing amount of healthy tissue (1-x), is given in the equation:

$$r = \frac{1}{t_2 - t_1} \left(\log_e \frac{x_2}{1 - x_2} - \log_e \frac{x_1}{1 - x_1}\right)$$

where the subscripts are the beginning and end points of the time interval for which r is calculated (77).

Figure 9 shows disease development on six rices inoculated with three *P. oryzae* isolates. B1 developed more slowly on IRAT13, Gogowierie, Tetep, Dourado Precoce, and 1021 than on susceptible IR442-2-58. Gogowierie and IRAT13 consistently had the slowest rate of B1 increase and IR442-2-58 always had the most rapid increase, manifested by rapid disease development on lower and upper leaves and rapid movement of infection between plants (77).

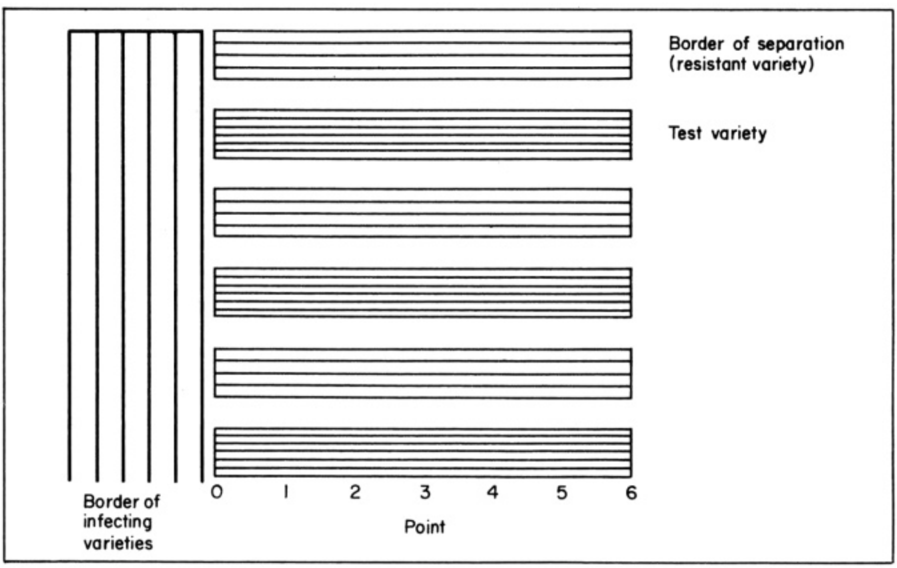


9. Disease progress curves (a) for 3 isolates of *P. oryzae* Cav. on 6 rice cultivars and their logit plots (b), 1979 (77).

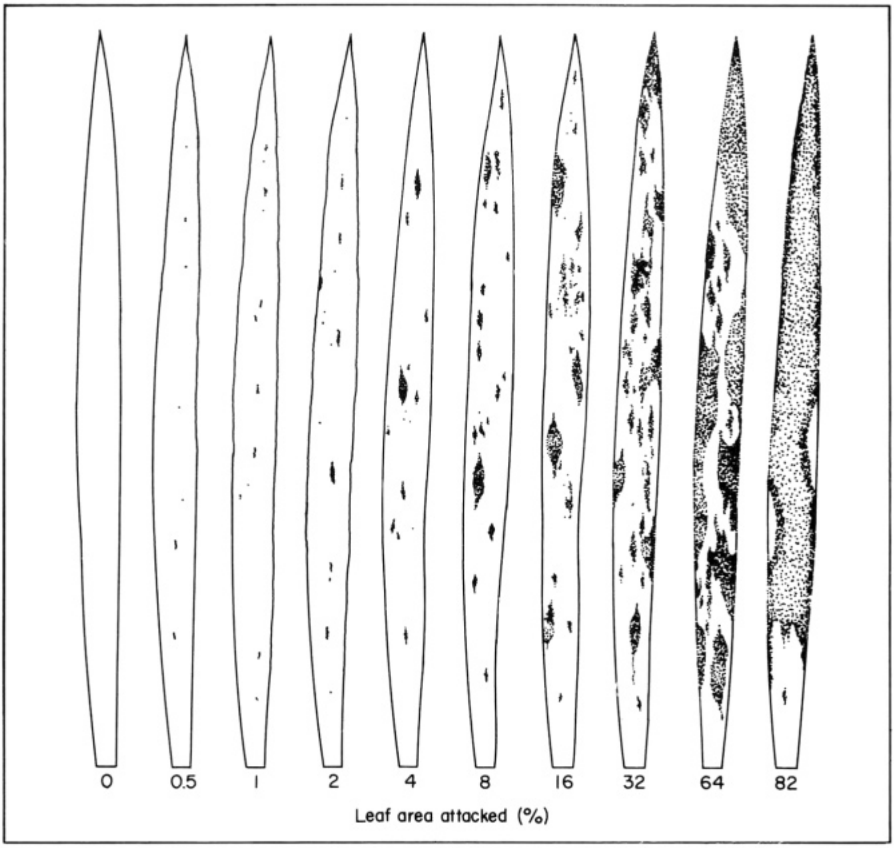
IRAT and IITA have emphasized horizontal B1 resistance in their upland rice breeding programs (4, 5, 17, 19, 58, 60, 126). Traditional African upland varieties such as Moroberekan, 63-104, R-75, RT1031-69, LAC21, and LAC23 have remained B1 resistant for more than 10 yr. Brazilian rices Dourado Precoce and Iguape Cateto, and IRAT rices IRAT13, IRAT104, IRAT109, and ITA112, developed by hybridization or by mutation from Brazilian varieties, also have stable B1 resistance (126).

IRAT uses two techniques to measure the varietal levels of horizontal B1 resistance. In the laboratory, conidia are regularly deposited on glass slides covered with agar. Touching the slides to leaves of selected varieties provides controlled inoculation. In the field, they use the decreasing inoculum trial for the evaluation of resistance (DITER) design, in which a gradient of *P. oryzae* spores is distributed from one susceptible spreader plot (Fig. 10). The test varieties are planted in 2- to 8-m-long parallel plots separated by a highly resistant variety. A plot of a susceptible variety is planted adjacent and perpendicular to the parallel rows. It is spray-inoculated with a local B1 strain, the races of which have been determined on a range of differential varieties. To establish a gradient of diminishing allo-inoculum, infection is measured at six distances from the spreader plot. B1 resistance is rated on a 10-point scale (Fig. 11) based on the leaf area destroyed.

The infection rating at point 0 indicates the susceptibility of a variety to allo-infection. At point 2, allo-infection is slight. If infection develops on any variety, auto-infectionis high and the variety is horizontally susceptible. A resistant variety produces no or little auto-inoculum. The score at point 2 thus expresses the ability of a variety to slow the progression of an epidemic (25, 59, 126). To confirm resistance, varieties should be tested for several years in farm fields with a mixture of virulent *P. oryzae* races (25, 126).



10. Plot design to test varieties for B1 resistance by the DITER system at IRAT (59).

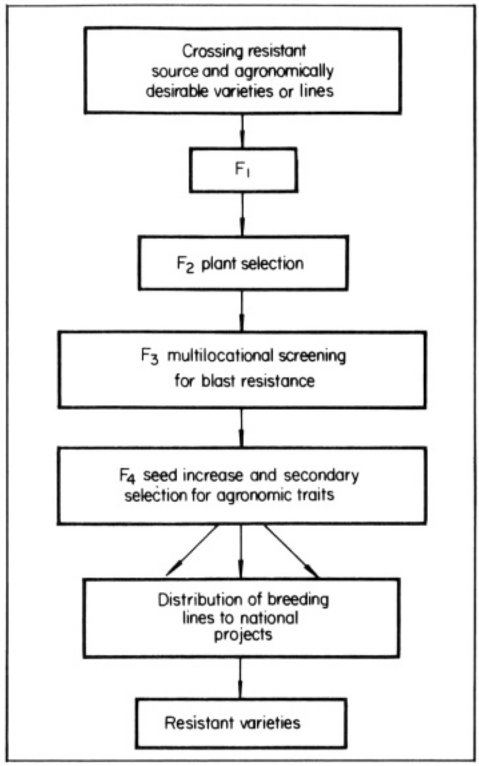


11. Scale for determining percent of BI-infected leaf area (59).

Land races that are believed to have high horizontal resistance have been utilized in the IITA breeding program. Several cultivars — including ITAl16, ITA117, ITA118, 1TA141, ITA162, ITA225, ITA235, and ITA257 — have been developed that have moderate to high horizontal B1 resistance (4, 5, 60, 61).

Varieties and lines with different sources of B1 resistance are tested every year in IRRI B1 nurseries. In 1982, 84, 565 entries, including several from IURON, were evaluated (88). Multilocation screening is in the F_3 in the IRRI B1 breeding program (Fig. 12), which emphasizes development of multiline varieties with resistance to several B1 races (18, 57).

Ikehashi and Khush (57) described how to develop a multiline variety. selecting resistant parents at several research centers and adapting a common recurrent parent in a backcrossing program to develop isogenic lines. After five or six backcrosses, isogenic lines would be available and their seeds are mixed to develop a multiline variety. Because the donor parents would be different and screening would be done at diverse locations affected by different *P. oryzae* races, different resistance genes presumably would be incorporated into the isogenic lines. Several IR8-parented isogenic lines were developed at IRRI (18). The 1981



12. Flow of materials in an IRRI breeding project for BI resistance (74).

International Rice Blast Nursery (IRBN) identified Fukunishiki, IR1905-PP-11-29-4-61, IRAT104, Tetep, CIAT-ICA5, and Camponi SML as B1 resistant (88).

CIAT's breeding strategy for B1 resistance (180) includes pyramiding major genes, concentrating of slow blasting components, combining of vertical resistance and slow blasting, backcrossing to tall donors characterized by slow blasting components, dwarfing tall slow blasting donors through irradiation, and developing multiline varieties. CICA7 and CICA8 maintain stable field resistance for several years. CICA7 has resistant genes from Colombia 1 and CICA8 from Tetep.

In WARDA varietal trials in West Africa, these rices were resistant to neck B1 (8): ROK16, DJIl-307-3-1-5, IR45, IR9669-Se1, IR8235-84, IR8235-194, IR9559-1-2-3, IR5931-81-1-1, IR6115-1-1-1, IR6023-10-1-1, IRAT13, IRAT133, IRAT142, IRAT144, IRAT146, IRAT160, IRAT161, IRAT162, IRAT165, IRAT166, IRAT169, IRAT184, ITA132, ITA135, ITA183, ITA208, ITA233, ITA234, TOx95-5-1-1-1, TOx728-1, SEL, IRAT 194/1/2, and M18.

Resistance to other diseases

Upland rice is also attacked by LSc caused by *Rhynchosporium oryzae;* BS caused by *Helminthosporium oryzae;* ShB caused by *Rhizoctonia oryzae,* imperfect state of the fungus, and *Thanatephorus cucumeris,* perfect state; false smut or green smut (FSm) caused by *Ustilaginoidea virens;* dirty panicles caused by several fungus species (5); and *hoja blanca* virus. IRRI. IITA, WARDA, CIAT, and several national centers have breeding programs to develop varieties with resistance to these diseases (8, 74, 77, 80, 87, 88, 114, 161, 179).

The IRRI GEU program screens all elite breeding lines for resistance to major diseases. IR8192-200-3-3-1-1, IR5853-18-2, IR5894-73-3, IR442-143-2-1, and IR4722-245-1-1 were found resistant to LSc, but no varieties have been identified as resistant to ShB (87, 88). In India, Athebu, Phourel, Chapaiber, Morangedo, Saibhum, Bhujan, ARC15762, ARC18119, ARC18275, and ARC10606 have been identified as ShB resistant (163).

GID is a serious problem in high rainfall areas in West Africa. IITA is screening varieties at Onne Station to identify those varieties with GlD resistance (4). At WARDA's IET and CVT, IR96-71-4-6-8, IRAT142, IRAT146, IRATl65, and ITA183 have shown resistance to LSc. IRAT146, IRAT162, IRAT166, and IRAT168 were found resistant to BS. Some varieties have multiple disease resistance. IRAT165 is resistant to B1 and LSc, and IRAT166 to B1, LSc, and BS (8).

Insect pest resistance

Insects seldom are major pests of upland rice because of the prolonged drought between harvesting one crop and planting the next. The most harmful lowland rice insects — brown planthopper (BPH), green leafhopper (GLH), yellow stem borer (YSB), and gall midge (GM) — are not upland rice pests. Sometimes, however, grasshoppers, armyworms, LF, and rice bugs seriously damage upland rice (91). In Africa, SB, including stalk-eyed fly, are major pests (5). Lesser corn stalk borer and SB are serious pests in Brazil (49, 52, 115).

Pathak and Khush (149) reviewed IRRI breeding programs for insect resistance in upland rice. They observed that TKM6 is a good donor of resistance to the striped stem borer (SSB) and GLH, and many rices have moderate SB resistance. To increase the level of resistance, they suggested a diallel selective crossing scheme, through which several lines with resistance to SSB and YSB were identified. IR13635-45, IR13641-20, IR13641-22, IR13641-23, IR13641-26, and IR13362-62 were resistant to SSB, and IR19362-92. IR19391-167, and IR19391-289 were resistant to YSB (77). IRRI has screened all elite lines for resistance to BPH (biotypes 1, 2, and 3), WBPH, GLH, zigzag leafhopper, YSB, SSB, whorl maggot (RWM), and LF (87, 88).

IITA began research on rice resistance to insect pests in 1973. Research has focused on African striped borer *Chilo zacconius,* African whiteborer *Maliarpha separatella,* African pink borer *Sesamia calamistis,* and stalk-eyed fly *Diopsis thoracica.* Field and screenhouse screening (except for white borer where screening was only in the field) identified several insect resistant varieties (Table 14) (5).

In 1982, 988 cultivars were evaluated in the screenhouse for resistance to stalk-eyed fly. Infestation ranged from 1.2 to 67% compared with a maximum of 15% under natural conditions. The 20 most resistant cultivars are shown in Table 15 (65). In Ivory Coast, screening of several hundred varieties for SB resistance showed Moroberekan, Madeba D, OS6, Kototouro S7, and S1 were resistant (8).

Table 14. Sources of resistance to insect pests of upland rice in Africa (5).

African striped borer	
Taichung 16	TOS2513
PR403	Ratna
ITA6-20-1-Bpl	Malagkit
IR503-1-91-3-2-1	Sung Song
PR325	SML 81B
H8	
African white borer	
ITA6-4-2	
IR1168-76[a]	
IR1561-38-6S[a]	
ITA7-7-2[a]	
TKM6[a]	
African pink borer	
W 1263	INJ171
Taichung 16	INJ146
SML 81B	Sikasso
Stalk-eyed fly	
IR579-160	ITA6-22-22Bp-1
Tx52-24	E. L. Gorpher
IR523-1-218	IR1561-38-6-5
Iguape Cateto	Huang-Sengoo
Leuang 28-1 -64	Td 10A
DNJ171	Magoti
Ctg 680	C5565
IR589-53-2	Saconodo Brazil
ITA6-16-7-Bp-3	

[a] Moderately resistant.

Table 15. The best varieties selected for resistance to stalk-eyed fly *D. thoracica* from 988 rices screened at IITA in 1982 (65).

Designation or IITA accession no.	Source	Infestation[a] (%)
TOs 5827	Liberia	1.2
321 3	Ivory Coast	1.8
285	USA	1.8
372	Indonesia	2.0
3212	Ivory coast	2.2
4791	Liberia	2.2
TOx916-6-1-101-2	IITA	2.4
TOg6390	Liberia	2.5
TOs 2 72	USA	2.8
TOs 567 7	Nigeria	2.9
ITA121	IITA	3.1
TOs5267	Ivory Coast	3.3
65 7	USA	3.3
37 3	Indonesia	3.3
x.2.D.T	Vietnam	3.4
TOx936-153-5-3-3	IITA	3.5
TOs 663	Nigeria	3.5
5734	Liberia	3.6
TOx891-212-2-102-1-1	IITA	3.6
Tog 6481	Liberia	3.8

[a] Infestation ranged from 1.2 to 66.7% in the mass screening test.

There have been preliminary field studies in Brazil to develop rices resistant to lesser corn stalk borer *Elasmopalpus lignosellus.* The line BKN6652-249-1-1 was the most resistant, with 14% dead plants. Susceptible Catetao had 33% dead plants (52).

SB *Diatraea saccharalis* is another serious insect pest in Brazil. Martins et al (115) studied the morphological relationships of SB resistance in rice and found that the percentage of attacked culm correlated with tillering capacity. Genotypes with hairy leaves tend to suffer less damage. Of the rices studied, the traditional upland varieties had less SB damage than introduced genotypes.

Resistance to soil acidity and Al and Mg toxicities

Upland rice often is grown in acidic soils with AI and Mg toxicities (see Chapter 6). Two techniques have been used in the considerable research to develop varieties tolerant of those conditions.

The acid soil technique has many limitations. It is difficult to control a soil system, describe and reproduce the Al content and isolate Al response from responses to Mn, Fe, Ca, and P. In the field, the technique is cumbersome and labor intensive, but it provides a relative scoring of varieties under actual conditions.

The nutrient solution technique for evaluating Al tolerance has been extensively employed and is considerably more precise than the acid soil technique because the important variables can be controlled. However, changes in pH may affect AI solubility and form.

In Colombia, Howelerand Cadavid (55) evaluated the performance of several upland rices in Oxisols with pH 4.3 and 3.2 meq Al/10 g soil. Tall Bluebonnet and Monolaya yielded more than semidwarf IR8 and CICA4, with and without modest lime additions (Fig. 13). Fageria and Barbosa Filho (51) screened 142 upland rices for field resistance to A1 toxicity in the Brazilian cerrado. Soil was an Oxisol with pH 5.2 and 0.55 meq exchangeable Al/100 g soil. Rices were evaluated with no lime and 3 t lime ha^{-1}. Grain yield and response to lime were plotted to classify varieties: A1 susceptible and responsive to lime, A1 susceptible and not responsive to lime, A1 tolerant and responsive to lime, and A1 tolerant and not responsive to lime (Fig. 14). Response to lime was calculated:

$$\text{Lime response} = \frac{\text{yield with lime - yield without lime}}{\text{Al saturation of limed plot - Al saturation of unlimed plot}}$$

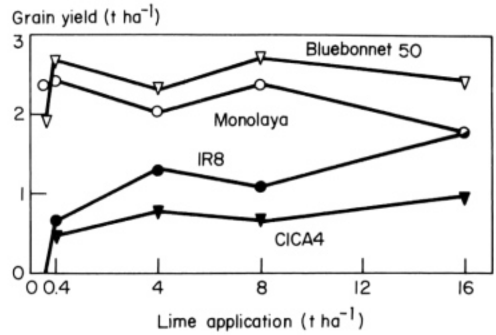
Tolerance for Al toxicity (Al_t) was calculated:

$$Al_t = \frac{\text{yield with lime - yield without lime}}{\text{difference of Al saturation with and without lime at flowering}}$$

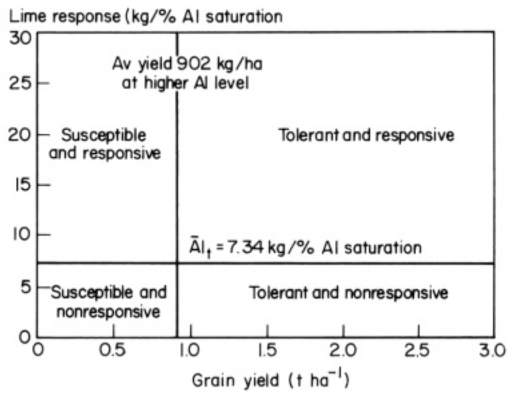
The diagram was divided into quadrants to represent the four groups of cultivars by lines of average yield on high A1 plots and average Al_t.

Cultivars that yielded well with high Al and responded well to lime were Fernandes, IAC46, Santa Amelia, IAC21, IAC1246, IAC1131, KN361-1-86, IR2070-199-3-6-6, IACIOI, IRAT104, Paulista, IR4727-217-3, IR4227-240-3-2, IAC165, CN770532, CN770527, CN770820, CN770167, CN770610, CN771204, Dular, Pinulot 330, Catao, and Chatao.

13. Response of four rice cultivars to lime application in Carimagua (55); average of three P levels.



14. Effect of high and low Al on rices, Goias, Brazil (51).



Cultivars that yielded well with high A1 but did not respond to lime were IRAT13, IAC120, 6 Meses, IAC12, IPSL 2060, Grao de Ouro, Rendimentos, Bicudo, Salumpikit, Mogi, Sequeiro de Parana, IAC5544, EEPG569, IR4829-2-1, IAC5100, Montanha Liso, Pratao Goiano, Selecao Amarelao, CN770867, CN770858, CN770643, CN770614, CN770893, CN770546, CN770602, CN770531, DJ29, AGIO-37, IAC5032, and Canta Galo.

Cultivars that yielded less with high Al but responded to lime were IAC47, Amarelao, IAC25, Taiwan, Tres Potes, Arcos Branco, Baixada, BKN6652-249-1-1, Dourado Precoce, IET6058, C22, Precoce Amarelo, Cana Roxa, Lageado, KN144, IR5793-54-2, C12, Serra Azul, B1293b-PN-24-2-1, H14, IR3483-180-2, IR4707-207-1, IR4227-9-1-6, Azucena, CTG1516, CN770530, CN770191, CN770447, Batatais, Catalao 101, Prata, Taquari, Rondon, Campineiro, and Milagres.

Ponnamperuma (152) screened 290 rices for performance with Al and Mn toxicities and Fe deficiency on the IRRI upland farm. Soils were Luisiana clay with pH 4.6 and 3.2% organic matter, Maahas clay with pH 6.6 and 2.0% organic matter, and Maahas clay limed to pH 7.6. IR24, IR661-1-170, IR1008-14-1, CAS209, and M1-48 were resistant to Fe deficiency and Al and Mn toxicities. In a dry season yield trial on a farmer's upland field with soil pH 3.9, in Laguna, Philippines, IR9995-76-2, IR8608-3-2, IR102060-29-2, IR9101-37-1, and IR6115-

1-1 yielded best with 4.5 to 5.1 t ha^{-1}. At pH 4.8, IR6115-1-1, IR9101-37-1, IR95604-3, and IR11297-170-3 performed best. In wet season, IR6115-1-1 and IR9995-76-2 yielded highest at both pH levels (88).

IITA is using analytical field screening to breed rices for acid soil tolerance at Onne Station in Nigeria. Acid (no lime or P application in soils with pH 3.8-4.0) and control (0.5 t lime and 60 kg P ha^{-1} to create pH 4.6-4.8) strip treatments are used to field-screen rices. ITA116, ITA117, ITA118, ITA225, and ITA235 have performed well in acid soils at Onne and also in Panama (4).

The nutrient solution method of screening rices for resistance to Al toxicity has been extensively employed. Relative root length, absolute root length, hematoxylin staining, and regrowth have been used to select resistant varieties (40, 55, 87, 88). Of these, relative root length can be used to screen many genotypes at once.

Using relative root length, Howeler and Cadavid (55) screened 240 cultivars for tolerance at 30 and 3 ppm A1 concentration in the greenhouse. Relative root length correlated with grain yields in a moderately limed field.

In 1981, IRRI used the same technique to screen 273 varieties at 30 ppm A1 concentration. Fifty-two varieties were tolerant of A1 toxicity (Table 16). Bluebonnet 50, a US lowland variety, also performed well (87). In 1982, A1 concentrations were varied (5, 10, and 30 ppm Al) to learn if a lower A1 concentration and a low salt content was as effective as screening at 30 ppm. varieties that showed tolerance at 5 ppm A1 were M1-48, OS4, Monolaya, Khaoto, Amarelao, and 20A. IR8, IR45, IR20), and CICA4 were susceptible (87, 88).

A1 tolerance is not necessarily correlated with Mn tolerance. Nelson (121) screened 20 rices for A1 and Mn toxicities in solution culture. The Mn solution contained 0.5 and 80 mg Mn cm^{-3}, and the A1 solution contained 3 and 30 mg A1 cm^{-3}. Results were correlated by relative root and shoot growth, and large varietal differences in Al and Mn tolerance were observed (Table 17).

Table 16. Al toxicity tolerance of 173 varieties, based on relative root growth at IRRI, 1981 (87).[a]

Tolerant	Intermediate	Susceptible
Agbede	Ardito	Arnbarikor 1
Agulha	Batataes	Belem
Amarelao	Bingala	Binato
Bengue	Blue Rose	Binundok
Bico Branco	Bosque Sel. 693	B 158 Bentoubala D.
Bico Preto	BPI 76	BD2
Binirhen	Canairo (acc. no. 3307)	Bombilia
Bluebonnet 50	Canairo (acc. no. 10753)	Buntot Kabayo
Cateto	Catetao Dourado	C4-63G
Cateto Branco	C1 5368-1	Catetao 24
Cateto Dourado	C1 5354-1	Chang Chang
Chokoto 14	C1 8900-1	C1 1428
C1 2011	Conquista	C1 5358
C1 2012	Criollo	C1 8898-2
C1 2013	Dalila	Cica 4
C1 5354-2	Dawk Mali	Congo

Continued on opposite page

Table 16 continued

Tolerant	Intermediate	Susceptible
Colombia 1	Elon-elon	Dawebyan (acc. no. 3445)
Come-cru Preludo	Fortuna	Dawebyan (acc. no. 3446)
Dinayang	Huk Do	Dinagat
Djaub	IR24	Djubuh
Djoweh	IR36	Ginwi G4
Dourado Agulha	IR48	IR5
Emata Y in	IR52	IR8
E425	IR442-2-58	IR20
Gualba	IR944-102-2-3-2	IR22
IAC1	IR1552-80-2-2-3	IR26
IAC3	Khao Lo	IR28
IAC9	Kinamay	IR29
IAC10	Larnpadan	IR30
IPEACO 162	Macan Binundok	IR32
IAC1131	Magsanaya (acc. no. 4019)	IR34
IAC5100	Mantoya	IR38
Iguape Cateto	Maranhao 2	IR40
Kanan	Miltex 125	IR42
Miga	Minoro	IR43
Miltex	Misuho	IR44
Magdatu	Moroberekan	IR45
Matao Liso	M23 Mugad	IR46
Milfor 6-2	Mutselu	IR50
Monolaya	Muzzlo 45	IR1416-131-5
MI-48	Palawan	IR 1561 -228-3-3
Norin 24	Perola	IR1813-494-2
OSA	P3-1	IR2068-653
OS6	P3 105	IR2071-588-2-5-1
Pratao	P3-111	IR2070-24-1
Pratao Precose	Perurutong NB	IR2076-67-3-5
Prolific	PI 190617-1	IR2851-42
Rexora	Secano	IR2852-8
Salak	Sikasso	Jappeni Tungkungo
Taal 2	Sinawit	Japones
TI 1	Sakotora S42	Lacross
Tres Meses	Sakotora S55	L1028
UVS	Sanakevelle Paddy	Magsanaya (acc. no. 725)
	Sornwari	Milagrosa
	Storbonnet	Mamoriaka
	Sueca	M. Bale
	Vencer	P3-93
	Wagwag	Sampaguita
	Yupul	Señorita
	20A	Sinaba

[a]The entries are available from the International Rice Germplasm Center of IRRI, P. O. Box 933, Manila, Philippines.

Salinity resistance

High salinity is not a major constraint to upland rice production (see Chapter 6).

Phulsundar and Desai (150) screened 10 rices for salinity tolerance in a calcareous, aerobic, upland soil with pH 8.3 and low available Fe in Maharastra, India. Local, tall Krishnasal and Dodga produced higher grain and straw yields than most semidwarfs. Their leaves remained healthy green and had high

Table 17. Responses of 20 rices to Mn and Al toxicity (121).

Variety	Excess Mn		Excess Al	
	Relative shoot weight	Rank	Relative root length	Rank
MI-48	0.61	14	0.61	3
IR127-80-1	0.80	5	0.45	9
CAS 209	0.65	12	0.32	17
IR22	0.48	16	0.40	13
IR24	0.55	15	0.37	16
IR712-23-2	0.66	11	0.42	12
E425	0.79	7	0.75	1
IR20	0.40	18	0.40	13
Peta	0.72	9	0.40	13
Palawan	0.80	5	0.43	11
Azucena	0.42	17	0.52	6
M1-329	0.82	4	0.27	20
C4-63G	1.07	1	0.31	18
IR5	0.72	9	0.58	4
Orig. Cent. Patna	0.86	3	0.63	2
IR442-2-58	0.64	13	0.47	8
IR1514A-E666	0.36	20	0.50	7
IR1561-228-3-3	0.40	18	0.56	5
C171	0.78	8	0.45	9
IR1721-11-68-3-2	0.87	2	0.28	19

chlorophyll content at tillering. Semidwarf RP1158-85-1 yielded and performed similarly. Semidwarf mutants of the Fe-resistant tall varieties (123) were evaluated. They were tolerant of Fe chlorosis, resisted lodging, and yielded well. PBN, one of the mutants, was recommended for upland cultivation as Prabhavani.

In the Philippines, Mercado and Malabayabas (117) evaluated six upland rices for NaCl tolerance at two leaf, four-leaf, and tillering stages. NaCl concentration in the .water culture solution varied from 2,000 to 8,000 ppm. Azmil and HB-Da were more NaCl tolerant than Azucena and M 1-48 at the same NaCl concentration. NaCl tolerance increased with growth irrespective of variety. At germination and seedling stage, Balakrishna and Iyengar (11) found upland IET5854 and IR825-41-1-3 to tolerate up to 10% dissolved NaC1.

Cold tolerance

Upland rice grows in tropical humid and savannah regions at different altitudes (Chapter 3). At high elevations in northeast India, Thailand, Burma, Indonesia, Vietnam, West Africa, and Brazil, rice growth is limited by low temperatures, which may occur at all crop stages. Damage is worst with low temperatures at seedling or reproductive stage (see Chapter 2).

There is very little published information on cold tolerance and screening methods for upland rice. We therefore describe general breeding strategies and screening techniques.

The extent of low temperature damage to rice depends on variety and growth stage. Common low temperature injuries include low germination, slow seedling growth, leaf discoloration, stunted vegetative growth characterized by reduced height and tillering, delayed heading, incomplete panicle exsertion, prolonged flowering due to irregular heading, spikelet degeneration, and abnormal grain formation (101). Cold damage at any stage reduces grain yield.

Breeding programs for cold tolerance use cold tolerant donor parents of diverse origin, appropriate breeding methods, suitable selection criteria, and reliable screening and testing techniques. Selection criteria should emphasize vigorous plants with short growth duration, intermediate stature, good panicle exsertion, high spikelet fertility, and moderate threshability (120).

Cold tolerance screening is done in laboratories, glasshouses, and fields. Genotypes entered in the International Rice Cold Tolerance Nursery (IRCTN) are evaluated in the field. In 1982, IRCTN nurseries were in 13 countries around the world. Plots included at least three 5-m-long unreplicated rows with 25- × 25-cm spacing and 1 seedling per hill. Inputs and cultural practices were location-appropriate. Plant height, flowering, phenotypic acceptability ratings, sterility scores, and disease and insect resistance were recorded (90). Eight promising entries were identified (92).

Rices at different growth stages have been screened for cold tolerance in the phytotron and in cold water tanks at IRRI and in Korea (106, 120, 177).

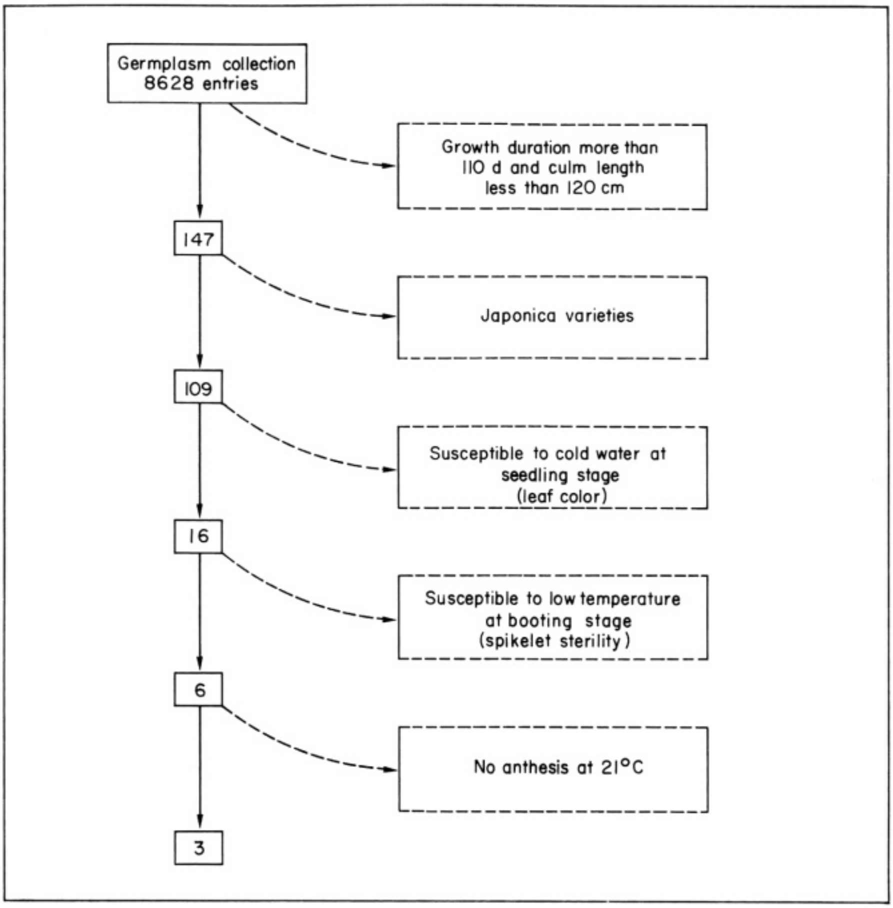
At IRRI, Vergara et al (177) used 110 d growth duration and 120 cm culm ,length as preliminary criteria for selecting cold resistant rices. Plants that mature later than 110 d at IRRI will mature at 150-200 d in cold areas. Similarly, plants with culms less than 120 cm will be very short and have greatly depressed yields when grown in cold areas. Based on these criteria, Vergara et a1 selected 147 indicas from 8,628 potential rices in the IRRI germplasm collection for screening (Fig. 15).

For seedling stage screening (159), seeds were soaked in water for 24 h and incubated for 24 h. The germinated seeds were sown 15 per row in porcelain trays, one row per cultivar. The trays were placed in a cold water tank (12° C) 10 d after seed soaking, and water depth was kept at 3 cm. After 12 d, seedlings were evaluated using the *Standard evaluation system for rice* (70). Sixteen of 109 cultivars were cold tolerant at seedling stage.

The 16 cultivars were screened for cold tolerance at panicle initiation. They were grown at 20/20° C day/night temperature until the collars of flag leaves appeared, and were grown for 5 d at 20/ 15° C. A darkroom was used for 15° C temperature. Plants grew at 29/21° C until harvest. Six of the 16 cultivars had less than 35% sterile spikelets, including upland Pratao (Brazil) and C21 and Azucena (Philippines).

The six cultivars were screened for low temperature tolerance at anthesis (176). They were grown in the field until panicle exsertion. Two-day-old panicles were collected at 0700 h and placed in test tubes with water to prevent drying. The test tubes were placed in growth cabinets with relative humidity of 70% and light intensity of 15 klux. Panicles were tapped against black paper to show pollen grains, and thus determine anthesis. Percent anthesis was calculated based on the number of panicles with open spikelets at 0700 h. At 21° C, C21, Pratao, and Leng Kwang had 70-100% anthesis.

Lee (106) described cold tolerance screening at germination, seedling, vegetative, panicle initiation, and ripening stages in the phytotron at Suweon, and



15. IRRI procedure for screening rices for low temperature tolerance (177).

with cold water irrigation in Chuncheon, Korea. In the phytotron, critical temperatures were 10° C for 9 d or 13/ 16° C day night for 3 d at germination, 10/5°C for 4-5 d at seedling stage, 18/10°C for 10 d at tillering, and 17°C for 10 d at meiotic and ripening stages. Most of the varieties Lee evaluated were japonica-indica crosses for irrigated conditions.

Of 17,689 entries from the world germplasm collection, Nanda and Seshu (120) identified 11 entries with cold tolerance at all growth stages (Table 18). Of them, Pratao and Dourado Aguillia from Brazil, C21 from the Philippines, Padi Sasahal and Padi Labou Alumbis from Malaysia, and Thangone from Laos are upland types.

Drought resistance

Several common terms are used to discuss drought resistance. Readers also may wish to refer to Chapter 2 for an interpretation of drought in climatic terms.

Table 18. Indica varieties with low temperature tolerance based on growth duration, plant height, spikelet sterility, leaf color, and anthesis (120).

Variety	Country of origin	Spikelet sterility (%)	Anthesis at 21°C (%)
Padi Sasahal	Malaysia	29	100
Lambayaque 1	Peru	14	90
Mitak	Indonesia	29	90
Padi Labou Alumbis	Malaysia	11	70
Jumali	Nepal	21	70
Pratao	Brazil	8	100
Lengkwang	China	27	70
Silewah	Indonesia	13	100
Thangone	Laos	9	80
Dourado Aguillia	Brazil	11	80
C21	Philippines	25	100

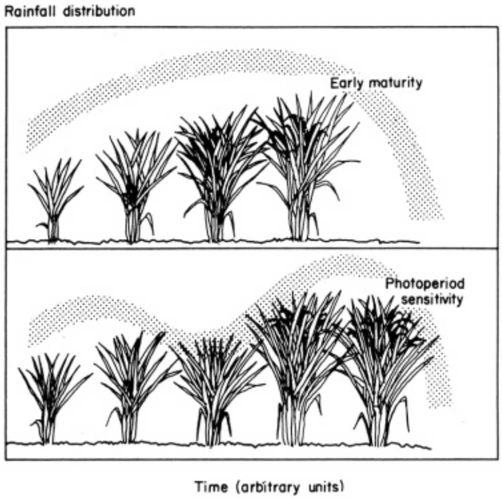
[a] Selected from 17,689 entries from the world germplasm collection.

- *Drought resistance* is the ability of plants to grow and yield satisfactorily where there are periodic water deficits, or the ability of a plant to live with limited water supply (173).
- *Drought escape* is the capacity of plants to mature before water stress becomes a serious limiting factor. Early maturity and photoperiod sensitivity are associated with drought escape (Fig. 16).
- *Drought avoidance* is the ability of plants to maintain high water status during a drought. Figure 17 shows root and shoot characteristics associated with drought avoidance.
- *Drought tolerance* is the ability of plants to withstand severe water deficit as measured by degree and duration of low plant water potential. Drought tolerance results from complex physiological changes.
- *Drought recovery* is the ability of plants to grow and yield after drought stress.

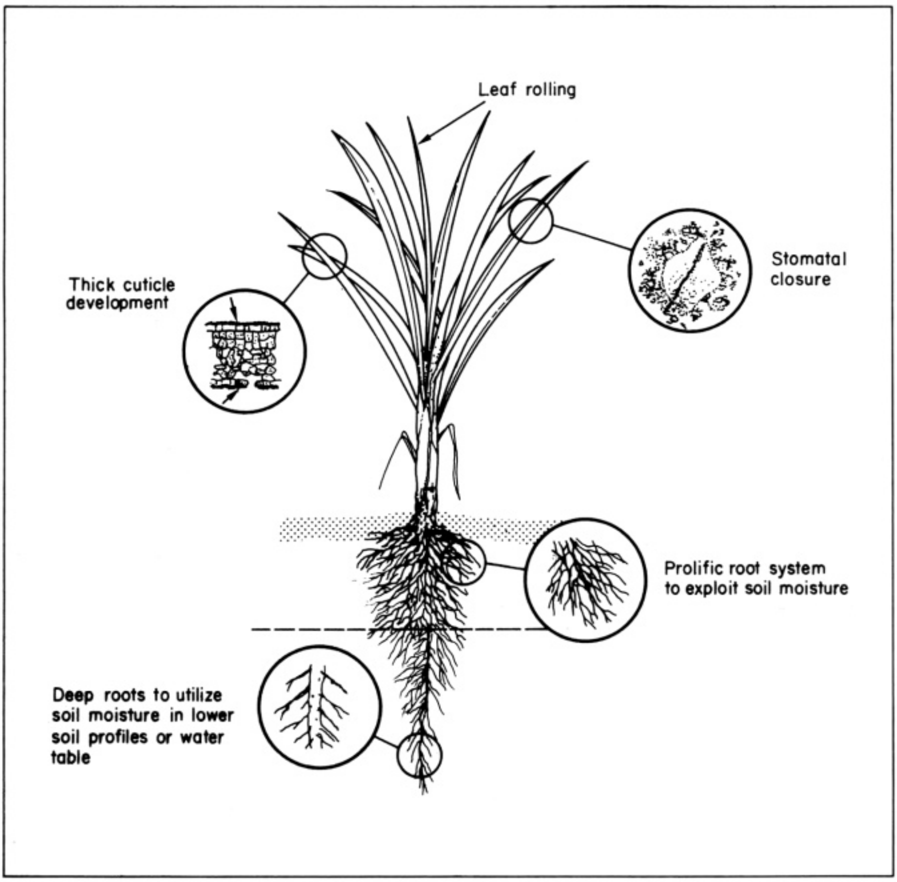
In this discussion, we use drought resistance in a general sense to include all the ways rice plants have adapted to survive water deficits.

In breeding for drought resistance, the first step is to diagnose the problem. It is necessary to identify the general soil physical and chemical characteristics of the target area and long term climatic pattern. With this information, necessary plant traits can be identified and appropriate selection criteria devised. For example, if deep roots are needed to reach soil water, greenhouse or field screening for deep rooting may be appropriate. However, if Al toxicity is causing truncated root growth, selection should not be for long roots but for tolerance for high A1 levels.

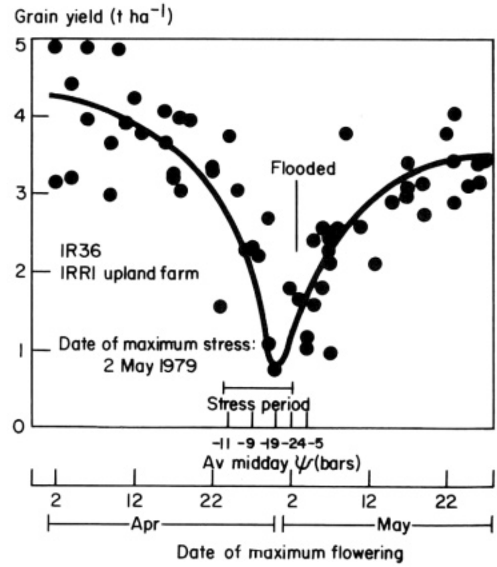
The diagnosis also may identify the growth stages that drought is most likely to affect, and thus prescribe how field screening or other trials should be conducted. The importance of diagnosis cannot be overemphasized. The time and effort spent learning more about local edaphic and climatic characteristics will pay dividends to plant breeders.



16. Drought escape mechanisms (136).



17. Drought avoidance mechanism (136).



18. Effect on grain yield of soil moisture stress during reproductive stage (77).

Growth stage sensitivity to water deficit. Drought-caused reductions in crop growth and yield depend on the degree and duration of water deficit and growth stage sensitivity (16). Upland rice is more sensitive to water stress at reproductive stage than at vegetative stage. O'Toole and Moya (143) found that decreased yield and grain weight and increased sterility were associated with degree and duration of water deficit at a particular growth stage. Recent IRRI research indicated that yield reduction or sensitivity to stress at reproductive stages (Fig. 18) may be ranked as flowering > gametogenesis ≥ panicle initiation > grain filling (77, 134).

Breeding objectives and approaches. The objective of breeding for drought resistance is to attain reasonable yields after the stress. Several authors have reviewed breeding for drought resistance in rainfed rice and the difficulty of separating drought resistance *per se* from agronomic yield (32, 34, 137, 156).

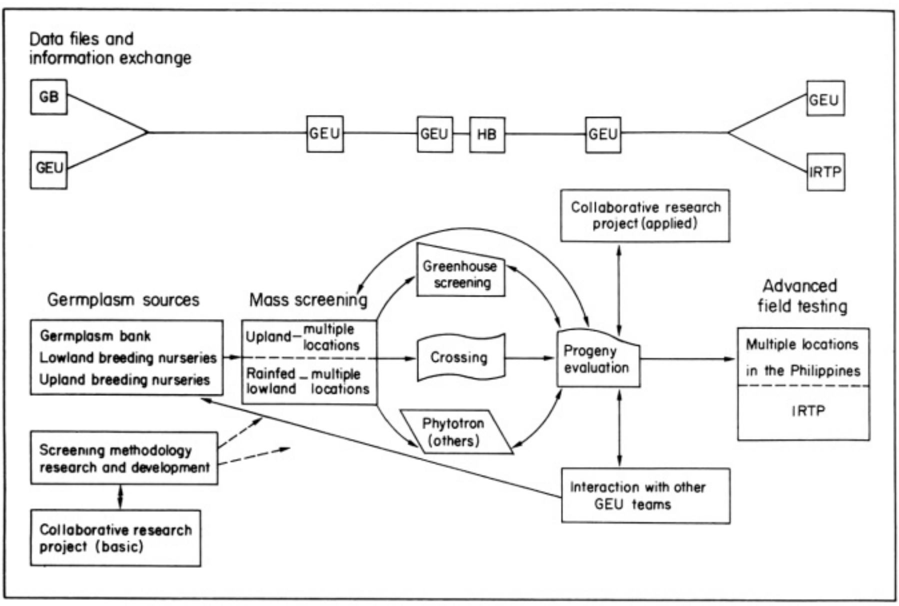
There has been little research to develop breeding methods or study heritability of drought resistance and the associated physiological or morphological traits. In plant breeding terms, however, separating drought resistance from yielding ability is impractical. In drought prone areas, yield stability is more important than high yields. The goal is not to harvest 5-6 t ha^{-1} but to harvest a realistic and stable 1.5-2.5 t ha^{-1}. Research programs to develop yield stability over locations and years and over water treatments within years were recommended by a working group charged with determining how to measure success in breeding for drought resistance (86). The group also discussed current and proposed methods to measure yield stability in multilocation trials.

Studies of drought resistance and recovery ability will help achieve this goal. If drought resistance is conferred primarily by deep and thick roots, maintaining favorable leaf water potential and early maturity will be the principal objectives of breeding programs (34). Other desirable considerations are moderately tall plants (>1 m), moderately long and droopy leaves, high seedling vigor, moderate and plastic tillering, moderate drought recovery ability, and high root-to-shoot ratio and harvest index (34, 36, 58, 109). Because most upland rice is grown for family consumption, breeding programs should consider the preference for long, well-exserted panicles; nonshattering, medium to bold grains; and 25% amylose content (31).

Drought-resistant genotypes should be selected from a diverse gene pool, selectively hybridized, and recombined to develop genotypes for vigorous screening in different drought-prone areas. Superior genotypes identified in multilocation testing should then be recommended as national varieties or used as parents in national breeding programs. The IRRI breeding strategy for drought resistance (Fig. 19) was reviewed by Chang et a1 (34).

Screening techniques for drought resistance. A suitable screening technique for drought resistance should accommodate many entries. Mass screening, line source sprinkler irrigation screening, toposequence screening, and greenhouse screening have been widely used to evaluate rices for drought resistance at different growth stages(6, 33, 36, 109, 112, 113, 127, 141, 153).

Mass screening techniques were developed at IRRI in dry season when the chances are less of rain interfering with imposed drought (36,109,113). Chang et a1 (36) and Loresto et a1 (109) developed techniques in which test varieties are grown under optimum irrigation until 40 d after seeding. Irrigation then is withheld for 20 d, when plants show distinct signs of internal water stress. Symptoms range from gentle leaf rolling (and unrolling at night) to leaf tip drying and death of lower leaves. Loresto and Chang (108) also developed visual scoring systems to record genotype response to drought at vegetative and reproductive stages (Table 19, 20).



19. Activities of the drought resistance component of the IRRI GEU program (34).

Table 19. Scoring[a] system for drought resistance screening at vegetative phases I and II[b] (108).

Decimal score	Plant type	Stress symptoms			
		Leaf rolling	Leaf drying	Plant color	Growth stunting
1	Tall traditional	Slight folding from early morning to late afternoon.	No drying.	Green	No stunting
	Semidwarf	No rolling.	Few leaf tips drying.	Green	No stunting
3	Tall traditional	Partial rolling from early morning to late afternoon.	Few tips drying more than 1 cm in length; 5-10% basal leaves dried.	Green	No stunting
	Semidwarf	No roiling.	75% leaf-tip drying extended to ¼ of leaf blade; 5-10% of lower leaves dried.	Green	No stunting
5	Tall traditional	Complete, tight rolling from early morning to late afternoon. Partial unrolling when temperature cools during day; complete unrolling at night.	Most younger leaf tips dried; 25-50% lower leaves dried.	Unusually dark green	No stunting
	Semidwarf	Complete, tight rolling; partial unrolling at night.	50% younger leaves with ½-1/3 area dried; 25-40% lower leaves dried.	Ashen gray or yellow	Slight
7	Tall traditional	Tube-like rolling; no unrolling at night,	Most upper leaves with 2/3-3/4 area dried; 60-80% lower leaves dried.	Ashen gray or yellow	Stunted
	Semidwarf	Same as tall traditional.			
9	Tall traditional	Tube-like rolling; no unrolling at night.	100% of all leaves dried; plants generally approach permanent wilting, some die.	Meristematic tissues show a slight green to light green tinge	Severe stunting
	Semidwarf	Same as tall traditional.			

[a] Scores were taken 15-20 d from the start of imposed stress or when susceptible checks showed symptoms of moisture stress. Preliminary scoring should be when plants show the first signs of stress. [b] Vegetative phase I refers to active tillering stage of both early and late-maturing varieties, and ranges from 50 to 60 d after seeding (DAS). Vegetative phase II applies only to the late-maturing varieties at about 80-100 DAS (108).

Table 20. Scoring system for drought resistance at reproductive phase, 12-15 d after start of stress (108).

Decimal score	Heading[a]	Panicle exsertion	Panicle size	Spikelet fertility (%)	Grain filling	Leaf rolling
1	No delay	Full	Normal	91-100	Mostly well-filled	Slight folding
3	Delayed by less than 1 wk	Full	Normal	76-90	Mostly well-filled	Half-rolling
5	Delayed by more than 1 wk	Partial[b]	Slightly reduced	51-75	Mostly half-filled	Full to tight
7	Delayed by more than 2 wk	Half-exserted	Reduced by half	11-50	Half-filled to empty	Tight
9	No heading until soil moisture is replenished	Half-exserted	Reduced by half	0-10	Mostly empty	Tight

[a]Late varieties usually recover and produce grains when rains begin before the end of the test. Reproductive scores usually are less reliable for the late-maturing varieties when rainfall is frequent before dry season ends. [b]Except for inherent agronomic traits.

The treatment and scoring usually last 15-20 d until soil moisture reaches 13% and no longer is differentiated by soil tensiometers (33). The field then is rewatered and drought recovery is recorded based on rate and degree of leaf unrolling, greening, and new leaf and tiller growth (Table 21).

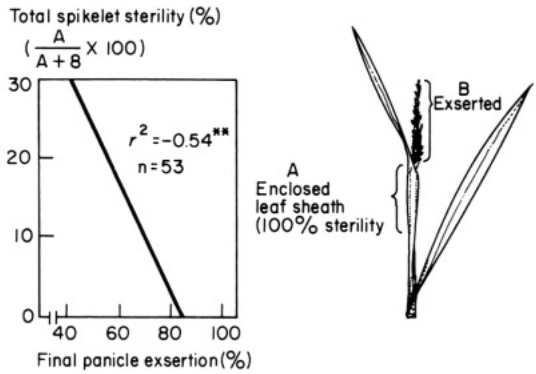
Two weeks later, the plants are again stressed to identify drought resistance at reproductive stage. In the most susceptible varieties, reproduction stops. Varieties also are scored based on heading time, leaf rolling and drying, panicle exsertion, and spikelet fertility (33) (Table 20). Cultivars with 100 d maturity often exsert panicles before reproductive stage stress affects expansive growth. When water stress coincides with panicle exsertion, unexserted panicles are 100% sterile (41, 144) (Fig. 20). Ten thousand entries can be field-screened at the same time using these techniques (34).

Malabuyoc et al (113) evaluated response of rices to drought at vegetative stage. Test entries were grown on the IRRI farm in dry season (Jan to Apr). They were irrigated until 30 d after seedling emergence; then irrigation stopped and soil began to dry. Soil water potential at 20-cm depth was measured daily, first with

Table 21. Scoring system for recovery (scoring 1 or 2 d after rewatering) (108).

Decimal scale	Description
1	90% of plants produce new leaves and tillers 1-2 d after watering (or a rain)
3	75% of plants produce new leaves and tillers 1-2 d after watering
5	75-90% of plants produce new leaves and tillers 3-4 d after watering
7	50-75% of plants produce new leaves and tillers 4-5 d after watering
9	Fewer than 50% of plants produce new leaves or tillers 1 wk after watering

20. Relation between panicle exsertion and spikelet sterility. A and B indicate panicles enclosed in or exserted from the flag leaf sheath at the end of the panicle exsertion phase (41).



tensiometers, and with gypsum blocks when water potential dropped below −0.08 MPa. To check these measurements, soil at 20-cm depth was sampled weekly and evaluated by gravimetric analysis.

Varietal reaction to drought was recorded, based on the *Standard evaluation system for rice* (SES) (70), at –0.2, –0.5, and –1.0 MPa soil water potential:

1 = slight leaf tip burning
3 = up to 25% of most leaf tips are dried
5 = 25 to 50% of all leaves are fully dried
7 = more than 60% of all leaves are fully dried
9 = all plants are dead.

After drought reaction at –1.0 MPa was recorded, the field was irrigated and drought recovery was scored, again by SES:

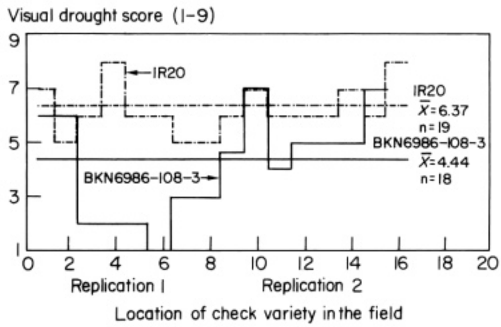
1 = 90–100% plants fully recovered
3 = 70-89% plants fully recovered
5 = 40-69% plants fully recovered
7 = 20-39% plants fully recovered
9 = 0-19% plants fully recovered.

Using this technique, 4,000 entries can be screened in one season (113).

Several drought resistant rices were deep water and lowland varieties, including deep water Leb Mue Nahng III from Thailand, and lowland ARC10372 from India and Carreon from the Philippines. De Datta and O'Toole (47) wrote that deep water rices often must survive drought at seedling stage, and thus have experienced natural selection for drought tolerance at vegetative stage.

Mass field screening often is difficult because of heterogeneous soil physical factors. Uneven water distribution, surface water impoundment, and runoff make visual scoring difficult. Researchers in Thailand solved this problem by planting resistant and susceptible checks at regular intervals. Entries were scaled up or down based on visual scoring of the check entries. Figure 21 shows how the mean scores of check entries varied across the field. Using this correction method increased the ratio of varietal to experimental variance, decreased the CV, and increased mean separation between entries (125).

Water stress is generally more damaging at reproductive stage than at vegetative stage. Relatively mild, short-duration water stress at or near flowering



21. Variation in soil drying across a field based on the response of susceptible IR20 and resistant BKN6986-108-3 at Klong Luang Rice Experiment Station, Thailand (125).

can drastically reduce the number of fertile spikelets, thus reducing grain yield to a fraction of its potential (87).

Whole-plot sprinkler irrigation was used at IRRI for mass screening to identify drought resistape at reproductive stage (87, 88, 92, 127). In 1983 dry season, 345 entries were evaluated for reproductive stage resistance.

For simultaneous flowering, the entries were planted on five different days, based on days to maturity. Sprinkler imgation was gradually increased from seedling to full canopy stage, and then applied to a depth equivalent to 1.2 × pan evaporation, except during the stress period.

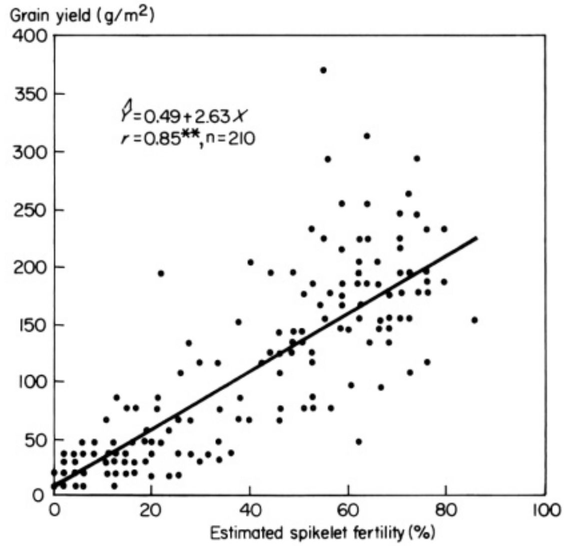
Entries that flowered too early (before 6 d of stress) or too late (after 12 d of stress) were discarded, leaving 187 entries that experienced 50% flowering between 6 and 12 d.

Percent fertility, grain yield, and relative grain yield were reliable criteria for reproductive stage screening. For mass screening several thousand entries, however, measuring grain yield is impractical. A visual estimate of spikelet fertility was an effective substitute. Grain yield was highly correlated with visually estimated spikelet fertility (Fig. 22) (92, 127). IRAT140 and IR9669 Sel. had outstanding grain yield, relative yield, and spikelet fertility.

A line source sprinkler irrigation system has been used in dry season to screen rices for drought resistance at many different water levels (77, 153). The system consists of full circle sprinklers at 6.2-m intervals (Fig. 23). The system maintains linearly decreasing water application rates across plots perpendicular to the sprinkler line and allows an assessment of the effect of different water levels on growth and yield of contiguous plots.

To assure uniform water distribution, sprinklers should be operated at low wind speeds, which often necessitates early morning or evening irrigation. Ponding and runoff can be minimized by intermittent irrigation (30 min on and 30 min off). Water application may be based on rainfall or pan evaporation from class A Standard Evaporation Pan (41). Catch cans at canopy height measure the water applied. The technique allows the sampling of leaf tissues and soil cores to obtain supplementary information on the internal status of the plant tissues in relation to soil moisture and evapotranspiration demands.

The sprinkler system can be operated for 15 d, beginning 15 d after panicle initiation, to evaluate drought response at flowering (41). Panicle exsertion was sensitive to changes in leaf water potential and was correlated with spikelet fertility.

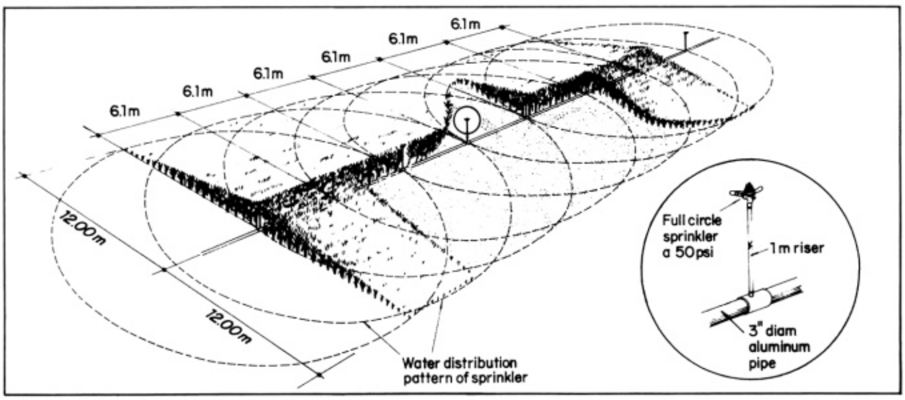


22. Relation between grain yield and visually estimated spikelet fertility in control and stress treatments (92). IRRI, 1983 dry season.

Spikelet sterility was highest in driest treatment (74%) and lowest in wettest treatment (17%). The degree of panicle exsertion was useful for visual selection at reproductive stage (92, 127, 144). The system also allowed an evaluation of root systems and water use efficiency (77).

A gently sloping toposequence provides a continuous moisture gradient ideal for evaluating varietal performance over a range of soil moistures. This technique has been used at IITA and IRRI (6, 71, 112). Test varieties and a check are grown along the toposequence, and soil water table depth and soil moisture regimes are monitored along the slope. Plants grown at different levels along the toposequence are evaluated for root characteristics, leaf water status, plant growth, and grain yield.

At IITA in 1978, 10 upland rices were evaluated for drought resistance on such a toposequence (112). Water table depth ranged from 15 to 100 cm (Fig. 24).

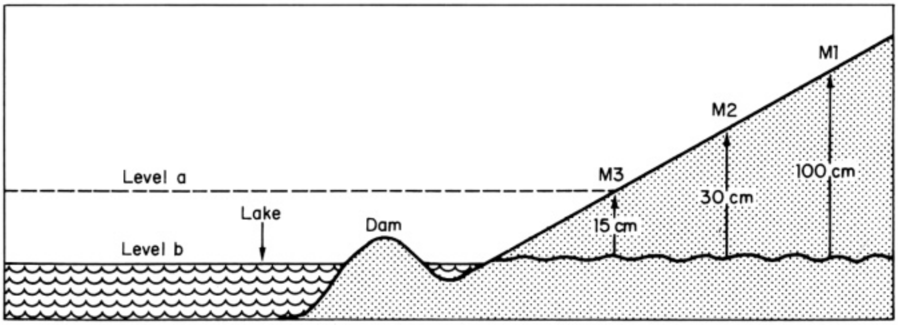


23. Arrangement of a line source sprinkler, with crop response to the variable water supply (77). IRRI, 1979.

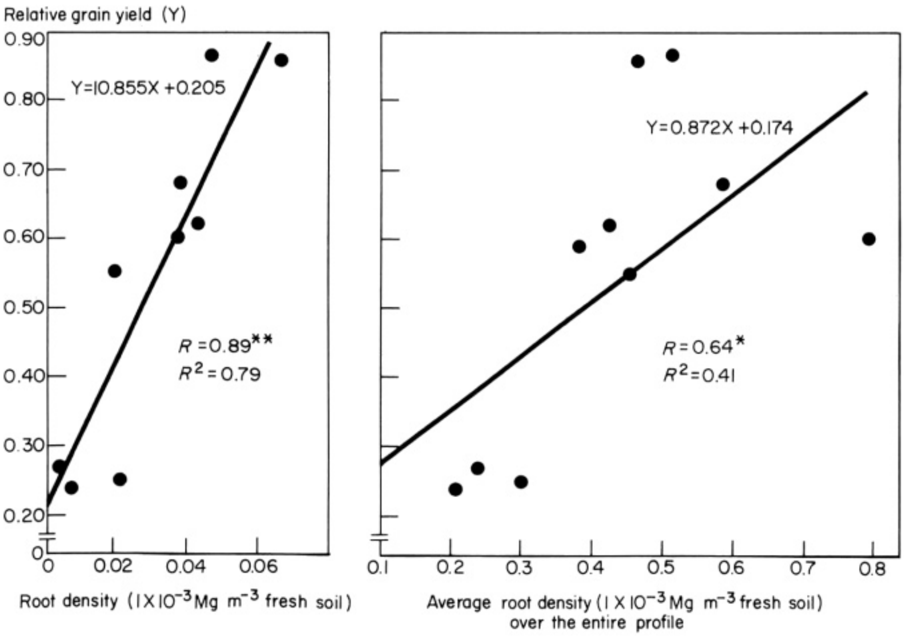
Relative grain yield was linearly related to root density at 20- to 30-cm depth (Fig. 25). With low soil moisture, tall 63-83 from Senegal, IB6 from Ivory Coast, OS6 from Zaire, and IRAT13 from Ivory Coast yielded more than the semidwarfs. Deep roots were better for drought avoidance than stomatal closure. Differences in leaf water status were primarily related to differences in the moist soil horizon.

Toposequence screening has some limitations.

- It is only possible in wet season, when weather is highly variable, and heavy rain can cause erosion and damage the toposequence.
- Drought at a particular growth stage is not certain.
- Only a few varieties can be included in one toposequence.



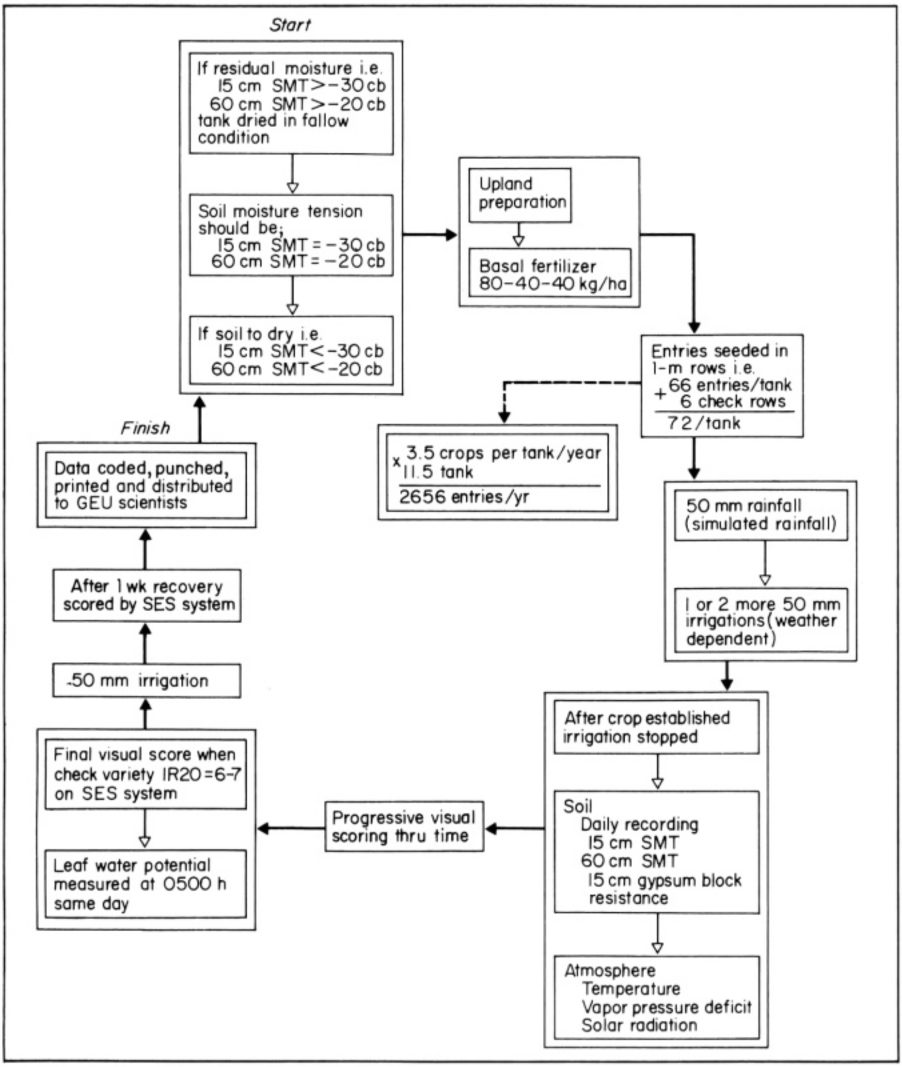
24. Vertical elevation of a toposequence screening site with water table depth and treatment locations. Level a= flood before the August break; level b= water level during the August break (112).



25. Relation between root density and relative grain yield (112).

Greenhouse screening for drought resistance can be useful in wet season. At IRRI, rices are screened in a specially constructed greenhouse (71, 72, 141) with 12 concrete tanks 7.0 × 3.64 × 1.35 m. Each tank contains 1 m of upland soil on a 0.35-m-deep sand and gravel drainage bed. Irrigation is by simulated rainfall, and soil moisture is monitored by tensiometers and electrical resistance blocks. Intake and exhaust fans change the greenhouse air every 6 min and maintain temperature and relative humidity at near-outdoor levels.

Figure 26 shows the screening steps. Soil matric potential is first adjusted to −0.03MPa at 15-cm depth and −0.02MPa at 60 cm depth. Seventy-two entries —



26. Sequence of operational procedures for each tank in the drought screening greenhouse. SES = Standard evaluation system for rice, 1975 (141).

66 test cultivars and 2 check cultivars at each of 3 locations — are grown in each tank. The tanks are irrigated when soil matric potential at 15 cm falls below −0.03 MPa. Irrigation is stopped after crop establishment, as judged by check variety growth, and the soil is allowed to dry until the susceptible check (IR20) has a visual score of 7 (69, 70).

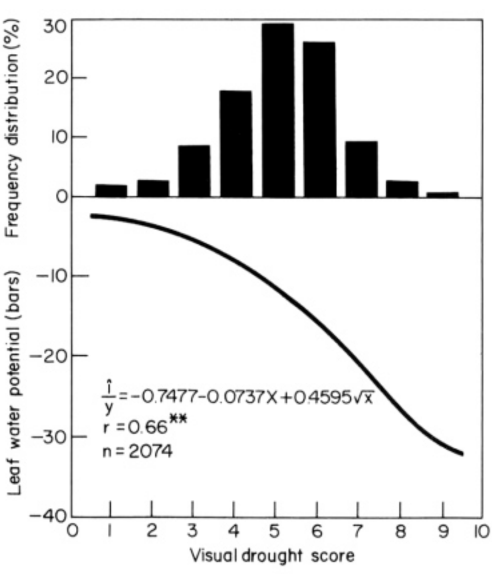
On scoring day, dawn leaf water potential is measured at 0500 h and visual scoring is at 0900 h. The entries are irrigated after scoring, and scored for drought recovery 4-5 d later. About 2,000 lines can be screened each year (72).

O'Toole and Maguling (141) found a close relationship (r = 0.66**) between dawn leaf water potential and visual scoring for drought resistance based on 2,074 entries tested in the greenhouse (Fig. 27). Most entries that performed well were from West Africa and Brazil and a few were South and Southeast Asian hill rices.

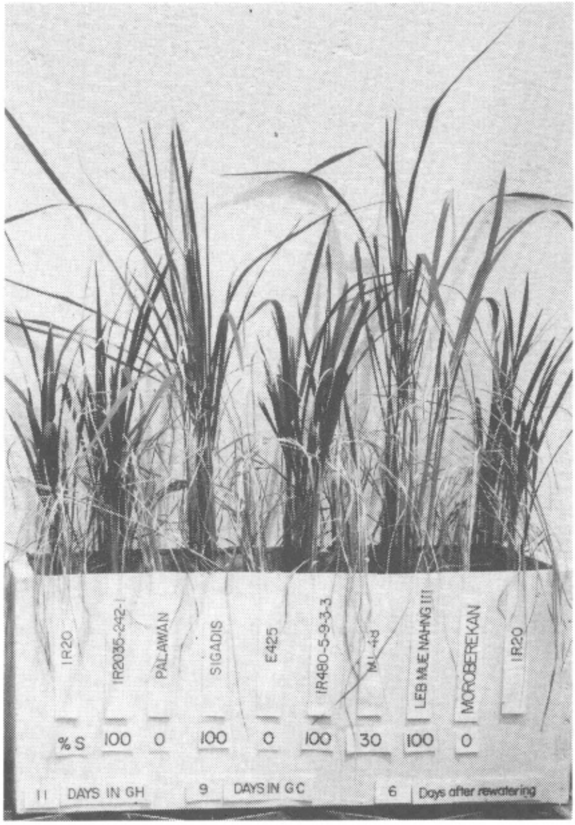
O'Toole et al (135) evaluated rices for seedling stage drought resistance in a glasshouse and growth chamber. Seedlings were grown to three-leaf stage in the glasshouse and then placed in a growth chamber with programmed diurnal changes in light, temperature, and humidity. After 10 d without irrigation, the plants were moved back to the glasshouse and watered. Three days later, seedling survival percentage was determined.

Most of the rices with high seedling survival were rainfed lowland types (Fig. 28). Lowland rices IR2035-242-1 and IR480-5-9-3-3 from the Philippines, Goiral from Bangladesh, Leb Mue Nahng III from Thailand, and Sigadis from Indonesia had almost 100% seedling survival.

If water is not a limiting factor, rices extract it from the shallow layers (182). As topsoil water potential decreases, water in deeper layers becomes more important. Varieties with relatively deep root systems can use moisture from deeper soil layers and thus live longer and yield higher in drought conditions. Plant water status and internal water deficits are related to root system development (136, 142, 143).



27. Frequency distribution of 2,074 entries visually scored for response to water stress in the drought screening greenhouse, and relation between predawn (0500 h) leaf water potential and visual drought score at 0900 h the same day (141).



28. Seeding survival test results. Pretreatment was 11 d in the glasshouse (GH) and 9 d in the growth chamber (GC). The tray was photographed 6 d after rewatering. IR20 provided guard rows (135).

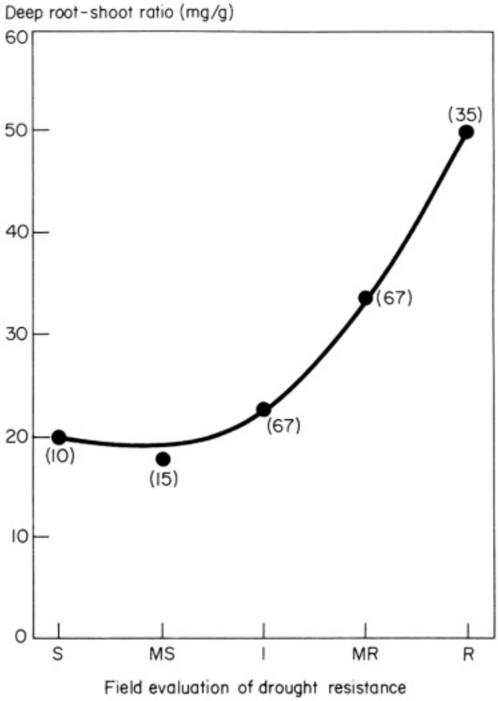
Several techniques are used to screen rices for root growth, including growing plants in root boxes, extracting root core samples from the soil, and aeroponic culture (7, 68, 77, 80, 92, 136, 182).

Plants are grown in plywood root boxes with drainage holes in the bottom (69). At flowering, the roots are sampled by cutting the soil horizon into 10 cm slices. Rootshoot and deep root (root fraction below 30 cm) ratios are used to compare cultivars, and are highly correlated with field drought scoring results (Fig. 29) (71, 182). Results of screening 1081 entries at IRRI showed that upland rices usually are tall, low tillering, and deep rooted (77).

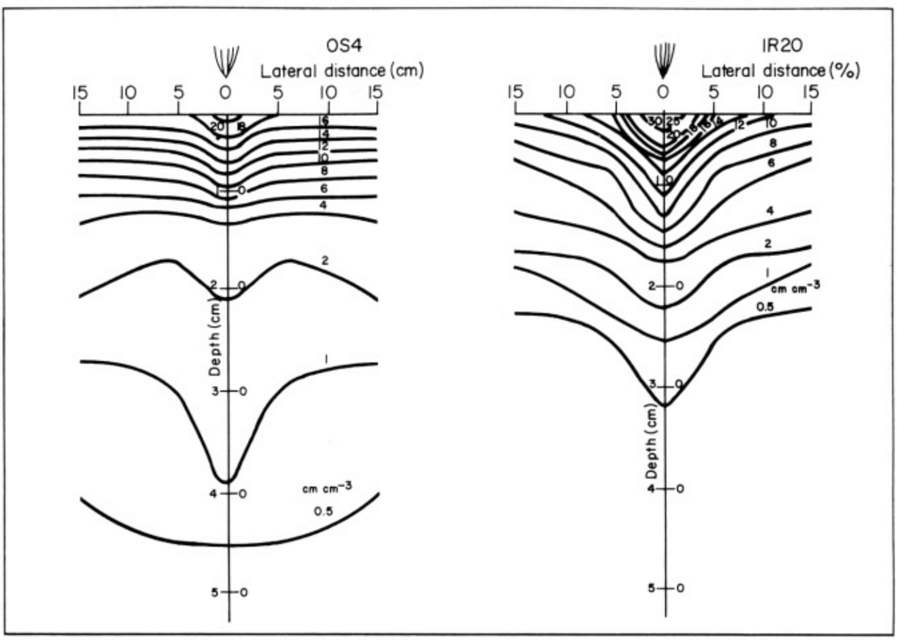
Soil cores are taken from various depths in the field. Roots are separated from the soil, and their lengths are determined (74, 99). Total root length is then divided by soil core volume to get root length density:

$$\textbf{Root length density} = \frac{\textbf{total root length (cm)}}{\textbf{soil core volume (cm}^3\textbf{)}}$$

A root length density value of one implies a root segment 1 cm long in 1 cm^3 soil. Core sampling is good for studying vertical and lateral root distribution. Because it is laborious, however, it cannot be used for routine screening (74).



29. Relation between deep root-to-shoot ratio and field evaluation of drought resistance scored at IRRI. Numbers in parenthesis indicate number of genotypes examined. S = susceptible, MS = moderately susceptible, MR= moderately resistant R = resistant (182).

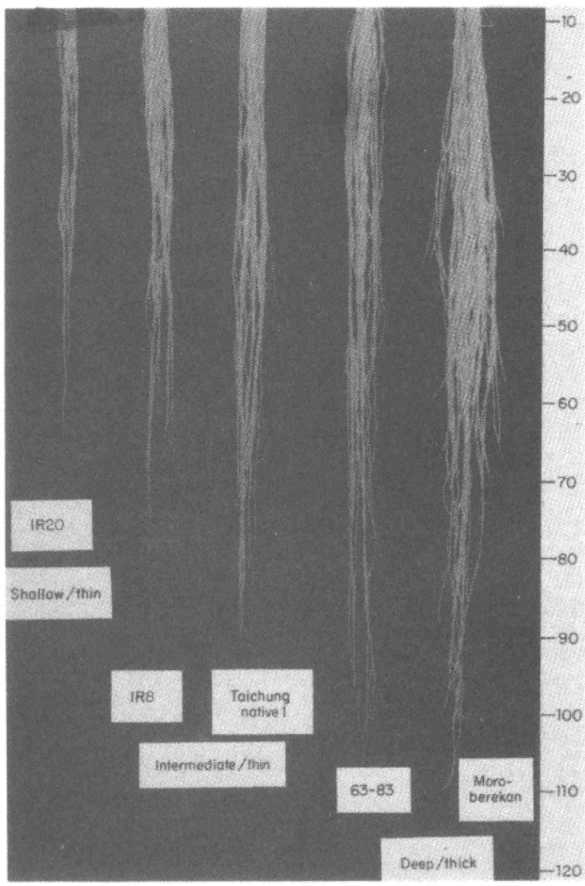


30. Iso-root density diagrams of OS4 and IR20 at 41-43 d after sowing (74).

Figure 30 illustrates the vertical and lateral distribution of roots of traditional tall OS4 and semidwarf IR20. Iso-root length density curves show equal root length density vertically and laterally. IR20 roots were concentrated around the center of the plant. OS4 roots were well spread laterally. The vertical distribution of roots was significantly different below 30 cm soil depth (74).

IRRI used aeroponic culture for rapid, systematic screening of rices for root characters patterned on the model of Carter (7, 21, 80, 88). Elevenday-old seedlings were transplanted into holders on the lid of circular drums at 97 plants per drum. Water and nutrients were provided by a mist nozzle at the bottom of the 1-m-deep drum. When roots reached the bottom of the drum, the plants were removed and intact roots and shoots were measured. Through aeroponic culture, scientists could study the root and shoot relationship of different varieties. Marked differences in root characters have been found (7, 80).

In 1982, 27 rices were compared by aeroponic culture at IRRI (88). IR20 had the smallest roots and LAC25, Kalakan, and Black Gora had the longest. IR20 had short, thin roots and Moroberekan had extremely long, thick roots (Fig. 31). Deep,



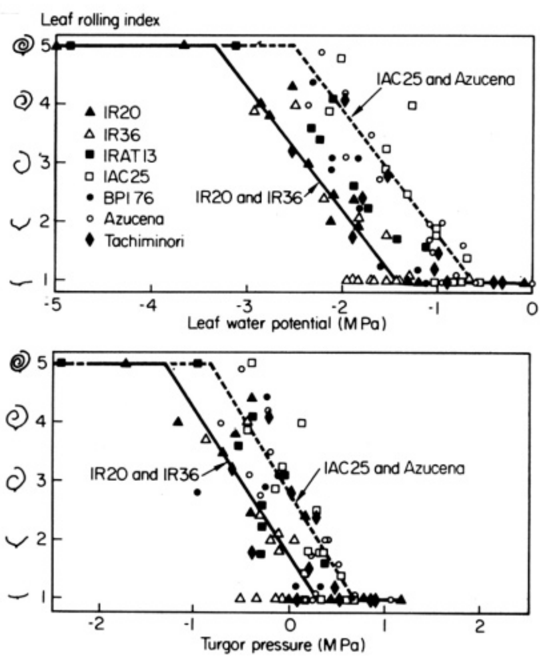
31. Comparison of root systems of five rices grown in aeroponic culture. IR20 has shallow, thin roots and Moroberekan has deep, thick roots. IRRI, 1982 (88).

thick roots appeared to be a stable trait and could be useful in selecting for drought resistance. The data on root characters obtained from aeroponic culture were reproducible and more reliable than data from root boxes or field sampling, especially for screening many genotypes. Aeroponic culture, however, does not show root penetration ability.

Using leaf rolling as a criterion when selecting for drought resistance must be done with caution. Generally, leaf rolling increases with decreased water potential; however, this relationship may vary when widely divergent genotypes are tested (142). Leaf rolling (1 = no rolling, 5 = completely rolled) was studied at IRRI in 1983 (Fig. 32). The visual leaf rolling score failed to indicate leaf water potential (LWP) or leaf turgor because it was higher at lower leaf water potential in upland varieties such as LAC25 and Azucena than in lowland varieties such as IR20 and IR36 (92).

Remote sensing of canopy temperature by infrared thermometer is useful for measuring plant water stress (145). The canopy temperature of 11 cultivars was inversely related to LWP (curvilinear) and linearly related to relative spikelet sterility (r = 0.79**) (88). Relative sterility increased by 0.20 with every degree (°C) of increase in canopy temperature.

The ability of a cultivar to satisfy evapotranspiration demand and maintain low canopy temperature and high plant water status may be attributed to its rooting behavior. IR52 canopy temperature was 2°C cooler and it had higher leaf water potential than IR36. IR52 root length density was 24% greater than that of IR36 in the top 30 cm of soil, where about 93% of the water extraction occurred (88).

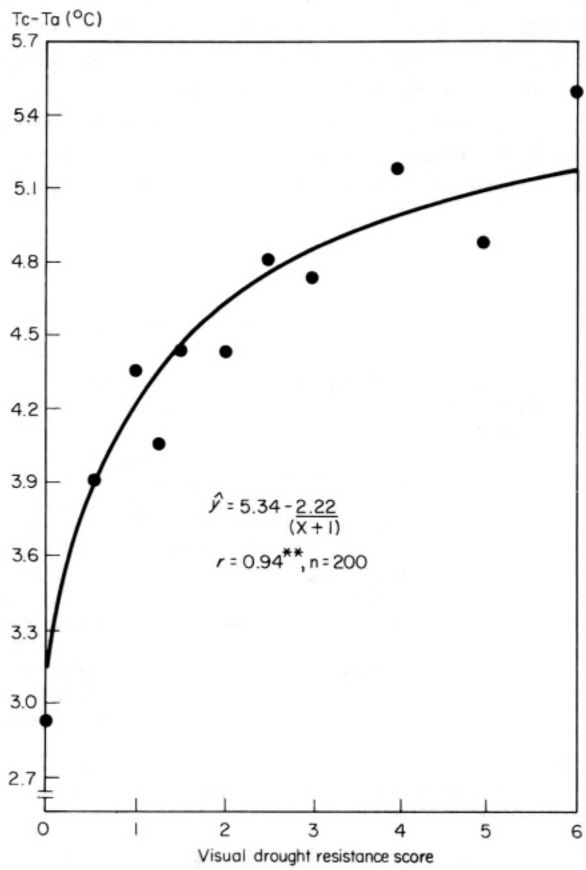


32. Relation between leaf rolling index and midday leaf water potential and midday leaf turgor pressure in seven rices (92) IRRI, 1982.

IRRI developed a canopy temperature screening method for evaluating drought response. Canopy temperature minus air temperature (Tc – Ta) was related to visual drought resistance scores of IURON varieties grown on the IRRI farm in 1983. There was a curvilinear relationship between visual scoring and Tc – Ta methods (Fig. 33). Tc – Ta can detect differences in the visual scoring range of 0-2, a very mild stress level found early in the stress period. With further refinement, the Tc – Ta technique may be very useful (92).

Osmotic adjustment is an adaptive mechanism that occurs in crop plants in response to water deficits. Extensive reviews by Begg and Turner (16) and Turner (173) concluded that osmotic adjustment as a primary adaptation of crop plants to water deficits needed further investigation. Osmotic adjustment may postpone tissue death after desiccation (56), and plants capable of osmotic adjustment will suffer less leaf tissue death than plants that cannot adjust osmotically, and have a better chance of recovery when rewatered.

O'Toole (134) concluded that rice exhibited osmotic adjustment that appeared to be limited to 0.5 to 0.8 MPa, which is similar to the capacity of other crop species. Osmotic adjustment caused leaves to continue to elongate (perhaps the most



33. Relation between canopy temperature-mmus-air temperature (Tc – Ta) and visual drought resistance scores of the same replicated plots from IURON (92). IRRI, 1983 dry season.

sensitive crop response to water deficit) at more negative leaf water potential than unadjusted control plants. Little genetic diversity in osmotic adjustment has been noted in rice (92, 134, 171).

Varietal differences in cuticular resistance in rice have been reported (139, 140). Cuticular resistance was associated with the formation of epicuticular wax that was a barrier to water vapor flux. Thickness of epicuticular wax varies among rice genotypes by as much as 500%, but there is no consistent relationship with drought resistance (139).

Larger xylem vessels reduce root axial resistance and thus, help extract water from deep in the soil profile. In a 1982 IRRI study of 30 cultivars, the diameter of the main xylem vessels of seminal roots ranged from 29 to 57 μm. West African and Brazilian upland rices 63-83, Moroberekan, and IRAT13 had seminal roots with large vessels. Most lowland and deep water rices had xylem with small vessels. The same trend was found in adventitious and nodal roots (88).

Only a few years ago, drought was considered a nonspecific stress and it was felt that drought resistance in rice could not be increased. Today, it is quite probable that rices with increased drought resistance will be developed. Ample genotypic variation exists for mass screening and specialized tests for particular adaptive mechanisms. Choosing the appropriate selection criteria will be based on an understanding of what constitutes drought in the target area. Appreciation of edaphic and climatic interactions with crop phenology will indicate the use of one or several of the tests that have been described, or development of a special screening method for a specific location. Until now, the most successful screening has been through controlled irrigation during dry season. Specialized observation of particular root and shoot traits may be applicable for selecting parent lines.

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CHAPTER 6

Soil Management

Soil management for upland and irrigated rice is very different. Fertility of almost all soils increases when they are flooded, but upland rice depends upon rain and stored soil moisture for growth and production. Upland rice suffers from mineral deficiencies and toxicities that seldom affect rice grown in flooded soil. Additionally, erosion is a serious problem in high rainfall areas with unstable topsoil. Soil-related constraints are most severe in moderately favorable and unfavorable upland rice ecosystems (9). Proper soil management is important for stable upland rice yields.

SOIL WATER MANAGEMENT

Rainfall pattern and distribution may be erratic and evapotranspiration sometimes exceeds precipitation; thus upland rice experiences drought stress. For stable upland rice yields, it is necessary to conserve soil moisture and increase water use efficiency.

Soil loses water through surface runoff, evaporation from the soil surface, transpiration from plant surfaces, and deep percolation. Most water received during a heavy rain runs off (53). Although infiltration generally is rapid in upland soils with low activity clays, the slaking effect of quick wetting and raindrop impact create a surface seal during heavy rain that decreases infiltration (57). Mean evapotranspiration from upland rice may vary from 0.6 to 1.3cm d^{-1} (104). Upland soils, particularly those above basement complex parent rocks, have relatively low water-holding capacity of 3 to 5 cm per 30-cm soil depth (68).

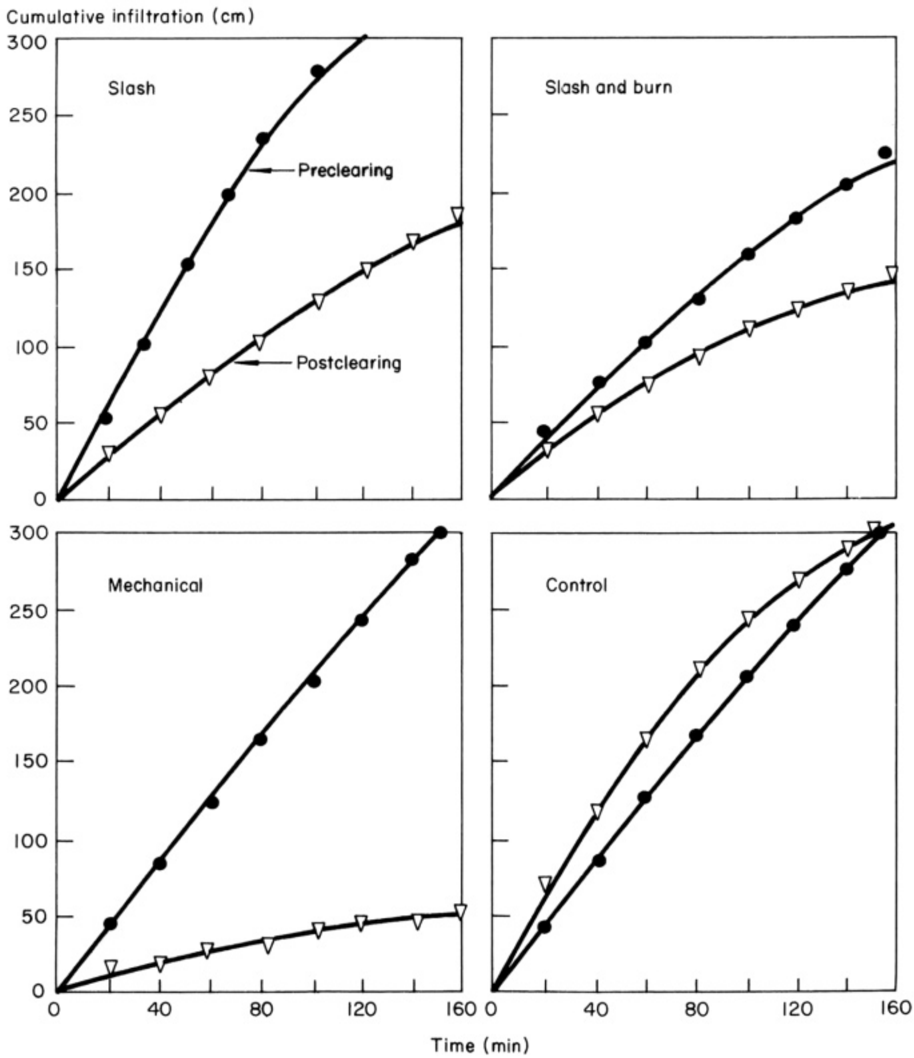
Rice is generally considered a semiaquatic species with a shallow, fibrous root system which cannot extract subsoil moisture reserves. Root penetration and development in subsoil horizons may be further limited by easily compactable soils or soils with shallow gravelly horizons (57). In such soils, a 5- or 10-d rainless period can limit rice growth (104).

Soil moisture conservation should include (55)

- maintaining high infiltration capacity to permit absorption of even heavy rain,
- decreasing losses to soil water evaporation,
- retaining water in the root zone, and
- increasing effective rooting depth for extracting water from more soil.

Table 1. Influence of land clearing method on saturated hydraulic conductivity at 0-10 cm depth and on infiltration capacity (58).

Clearing method	Hydraulic conductivity ($cm\ min^{-1}$)		Infiltration capacity ($cm\ h^{-1}$)	
	Initial	After clearing	Initial	After clearing
Mechanical	16.1	1.3	115	17
Slash and burn	15.2	5.0	68	44
Slash	9.8	4.6	141	62
LSD (0.05)	9.9			



1. Effect of deforestation on water infiltration (58).

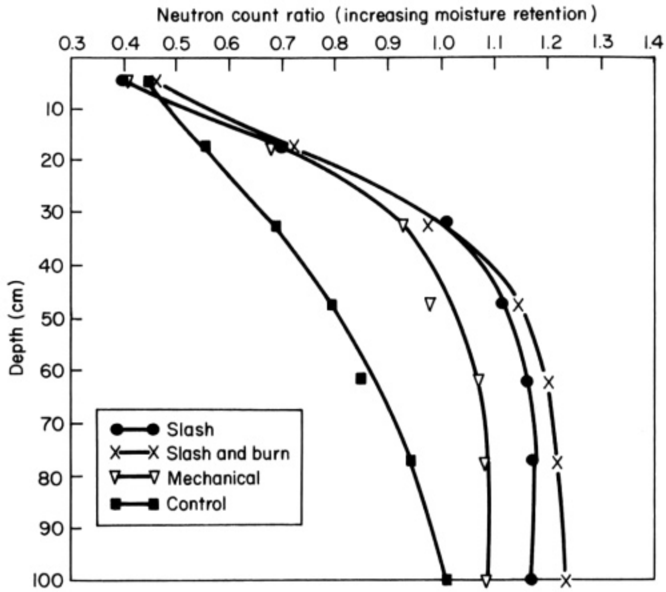
Conserving soil moisture

There are several soil management techniques and cultural practices for conserving soil moisture in upland rice fields.

Land clearing and development. Methods of land clearing and development significantly influence soil structure, pore size distribution, and infiltration capacity, and therefore the water available for crop growth. Mechanized land clearing can compact soil and increase runoff and soil erosion and thus soil water retention capacity (35, 55, 58). Clearing methods such as manual clearing, that cause little soil disturbance, help maintain a favorable physical environment for upland rice (Table 1; Fig. 1, 2). Hydraulic conductivity and infiltration capacity are reduced most by mechanical and least by slash-and-burn clearing. Three years after clearing in Ibadan, Nigeria, soil compaction (measured by penetrometer and bulk density), runoff, and soil erosion were greater where land was cleared by a tree pusher and conventionally plowed than where traditional farming was practiced (35) (Table 2).

Mulching. Crop residue mulch, dry soil mulch, and artificial mulches are used with varying success to reduce runoff and conserve soil moisture for upland crops.

Tropical humid and subhumid soils associated with rolling topography lose most rainwater through runoff. Lal et al (59) studied the changes in a tropical Alfisol 1 yr after clearing and found that cumulative infiltration rate and saturated hydraulic conductivity increased with increasing rates of rice straw mulch (Table 3, Fig. 3). Other studies at Ibadan(68) confirmed the value of 6 t straw mulch ha^{-1} for rice grown on hydromorphic soils. Grain yield in mulched plots was 0.5 to 1.0 t higher than in bare plots (Fig. 4).

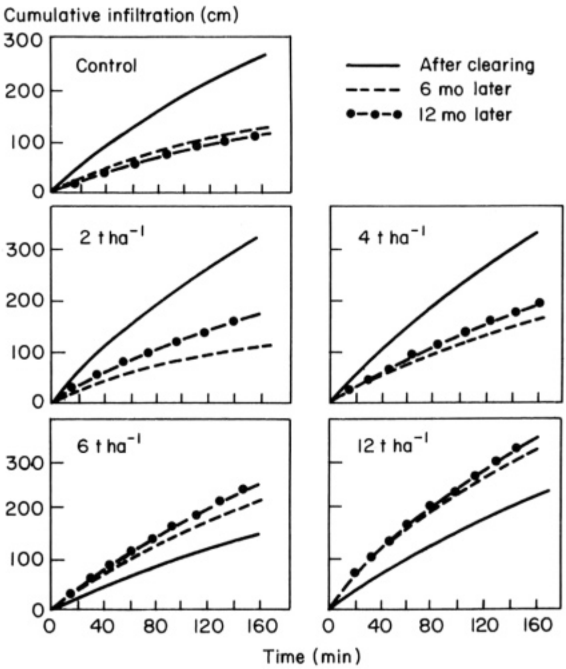


2. Effect of clearing method on soil moisture profile (58).

Table 2. Effect of land clearing method and tillage system on soil compaction, runoff, and soil erosion[a] (35).

Treatment	Penetrometer resistance (kg cm^{-2})	Bulk density (g cm^{-3})	Runoff (mm)	Soil erosion (kg ha^{-1})
Traditional farming	1.23	1.27	0.4 a	1 a
Manual clearing, no tillage	1.67	1.40	0.4 a	2 a
Manual clearing, conventional tillage	0.70	1.38	19.4 b	101 b
Shear blade, no tillage	2.19	1.38	14.1 b	173 b
Tree pusher, no tillage	1.81	1.47	13.9 b	265 c
Tree pusher, conventional tillage	0.60	1.37	32.3 c	543 d

[a] Separation of means in a column by DMRT at the 5% level.



3. Effect of mulch rates on cumulative infiltration (59).

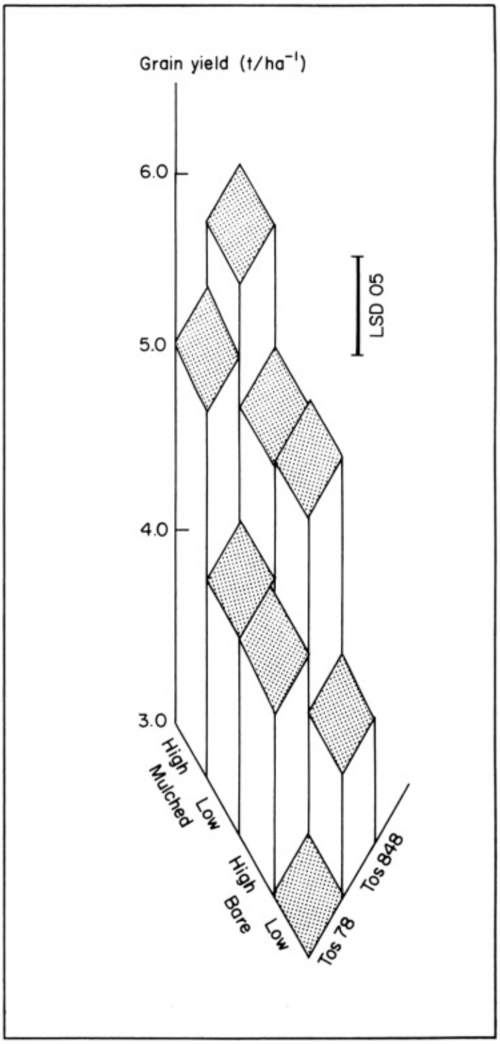
Mulching treatments were evaluated for their effect on soil moisture retention and upland rice grain yield at IRRI in 1977 (40). Treatments were shallow tillage (10 cm), deep tillage (20 cm), 10-cm incorporation of 3 t rice straw ha^{-1}, spreading 3 t rice straw mulch ha^{-1} on the surface, weed-free (with herbicide) fallow, and weedy fallow. In plots where shallow tillage, deep tillage, and straw incorporation was at the end of the previous wet season, soil water potential (SWP) did not decrease below −0.085 MPa. In weedy-fallow plots, SWP at 15-cm depth was −2.5 MPa at the end of dry season.

Table 3. Saturated hydraulic conductivity at 0- to 5-cm soil depth at different mulching rates (59).

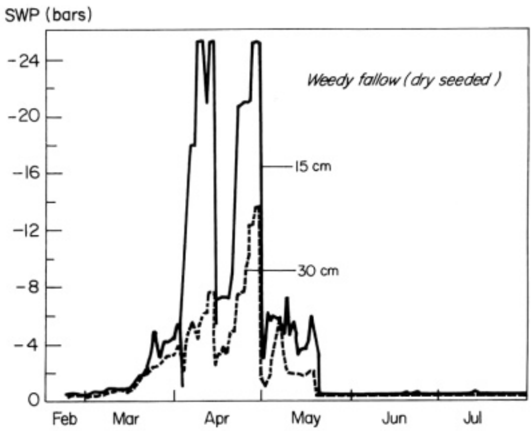
Mulch (t ha^{-1})	Saturated hydraulic conductivity[a] (cm h^{-1})		
	6 mo	12 mo	18 mo
0	55 a	54 a	30 a
2	57 a	72 b	45 a
4	128 b	96 c	70 b
6	122 b	130 c	132 c
12	167 d	182 d	129 c

[a] Each value is a mean of 9 replications. Figures followed by the same letter are statistically identical.

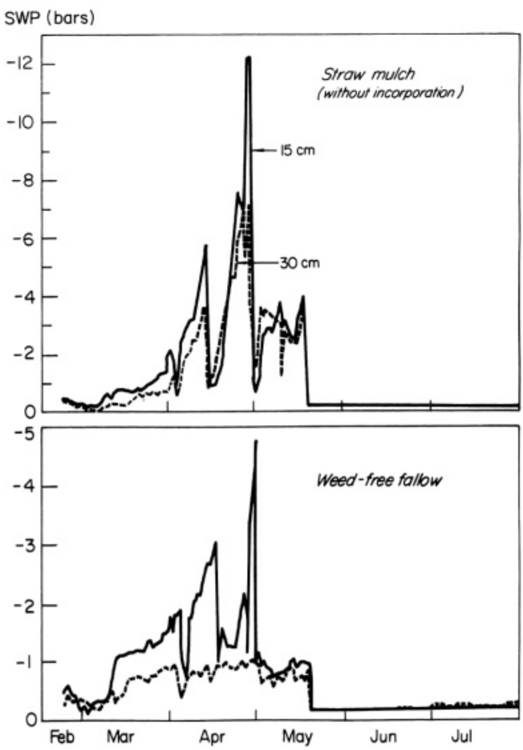
4. Effect of mulch, soil moisture, and variety on rice grain yield (68).



Early in dry season. SWP for weed-free fallow and straw-mulch plots was lower than in weedy fallow plots (Fig. 5, 6). By the end of dry season, weeds began to emerge through the mulch and SWP at 15 cm decreased to –1.2 MPa. In the weed-free fallow, SWP at 15 cm was—0.5 MPa, and reached –0.084 MPa at 30 cm. Keeping plots weed-free conserved some soil moisture. and unincorporated straw mulch suppressed weeds. Straw incorporation gave the highest average yield,



5. Effect on soil water potential (SWP) of a dry-season weedy fallow followed by dry seeded upland rice. Tillage consisted of I plowing and 3 rototillings. Rices were dry-seeded on 9 May (40).



6. Effect on soil water potential (SWP) of 3 t unincorporated straw mulch ha^{-1} and weed-free fallow treatments during a dry seeded upland rice crop. Tillage consisted of 3 rototillings in straw mulch and 2 rototillings in weed-free fallow plots. Rices were dry-seeded in straw mulch plots on 5 May and in weed-free fallow plots on 2 May (40).

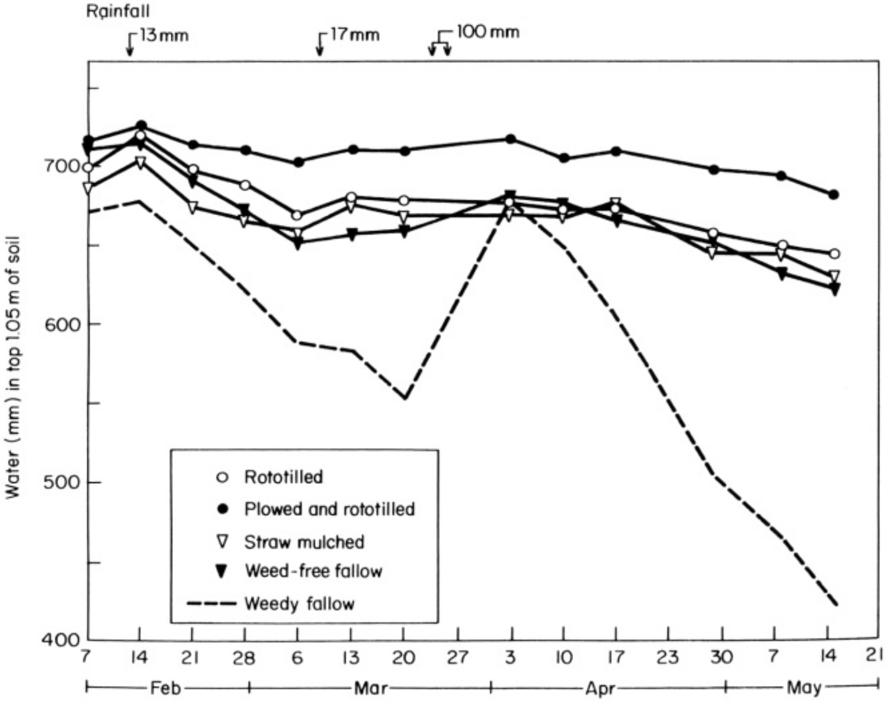
Table 4. Effect of different dry-soil and straw-mulch treatments on upland rice grain yield, IRRI, 1977 wet season (40).

Variety[a]	Grain yield (t ha^{-1})						
	Shallow tillage (10 cm)	Deep tillage (20 cm)	Straw incorporation (3 t ha^{-1})	Straw mulch (3 t ha^{-1})	Weed-free fallow	Weedy fallow (dry seeded rice)	Mean
IR1529-4303	2.8 a	4.1 a	3.6 a	3.6 a	3.1 a	2.6 a	3.3
IR2035-117-3	2.6 a	3.0 b	3.0 b	3.0 b	2.4 b	22 b	2.7
IR9575	2.3 b	2.5 c	2.5 c	2.3 c	2.3 b	2.3 ab	2.4
IR20	1.8 c	1.8 d	2.4 c	1.9 d	1.7 c	1.5 c	la
Mulching[c] (mean)	2.4	2.8	2.9	2.7	2.4	22	

[a]Average of 4 replications. [b]Separation of means In a column at the 5% level. [c]CV for mulching: 4.5%; CV for varieties: 6.5%.

followed by deep tillage and straw mulch; the weedyfallow yielded lowest (Table4).

Tillage for soil moisture conservation, weed control during dry season fallow, and use of maximum tillage for dry seeding were evaluated at IRRI in 1980. Rice was dry seeded in May in all but the weedy fallow (control). At the end of dry season, plots where weeds were controlled by mulch or herbicide had significantly more moisture in the upper 1 m of soil than weedy plots (Fig. 7).



7. Soil profile water storage to 1.05 m depth with different dry season land management practices (31).

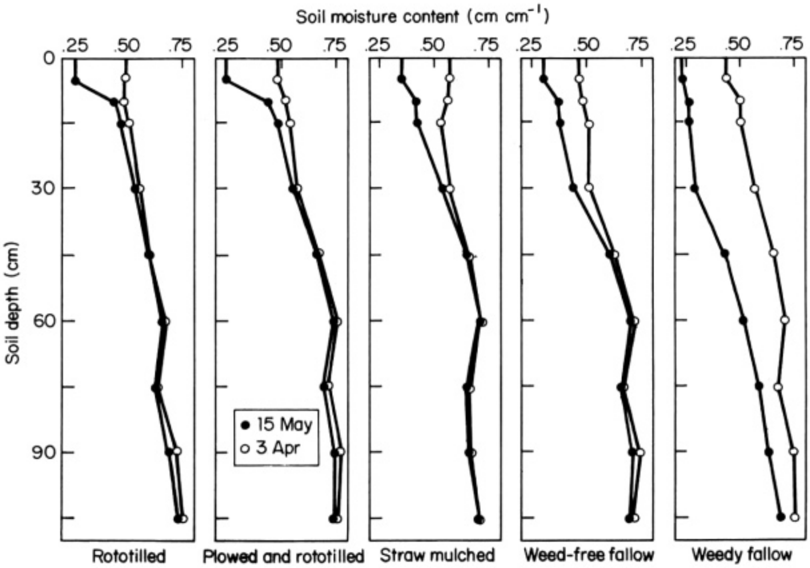
In soil, water moves upward as liquid or vapor in response to evaporative demand. Liquid losses are more rapid than vapor losses. A tillage-created soil mulch reduces liquid movement by breaking capillary pathways, thus conserving moisture stored below the tilled layer (31) (Fig. 8). Tillage also prevents shrinkage cracks, which cause drying to greater depths in expanding clay soil. In the study, depth of the tilled layer did not affect moisture loss, which suggests that tillage to 5-10 cm depth may be adequate to create a soil mulch.

Weed-free plots lost soil moisture to greater depths than tilled plots. Surface straw mulching preserved more surface soil moisture than the other treatments. In weedy-fallow plots, soil moisture evaporated and was used by weeds, which caused severe drying throughout the 1-m soil layer (31).

Organic chemicals such as bitumen, polyacrylamide, and polythene have been used as conditioners or mulches to improve soil physical properties (55, 75, 76), but they are expensive and not always effective. Applying bitumen to Alfisols 1 yr after clearing increased infiltration rate but not as much as applying 6 t of crop residue mulch (55).

In Japan, where cold limits upland rice growth in April plantings, polythene film mulching made it possible to plant seeds 2 wk earlier (75, 76). Polythene mulching promoted growth, increased dry matter production, and improved grain ripening by raising soil temperature, conserving moisture, and inhibiting N leaching (75).

Cover crops and planted fallows. Fallowing with grasses and legumes can rapidly improve infiltration in degraded soils. Lal et a1 (62) studied changes in soil physical properties when 3 grass and 5 legume coven were grown on an eroded



8. Soil moisture depletion during a 6-wk (3 Apr-15 May) dry period under different dry Season land management practices (31).

Alfisol for 2 yr (Table 5). Infiltration rate, field capacity, and bulk density were significantly improved by fallowing with wild winged bean (Psophocarpus).

Deep tillage. Deep plowing conserves moisture by killing weeds and permitting greater water absorption. In East India, Pande and Bhan (82) found that upland rice yields were higher and weed dry matter was lower with deep (21-28 cm) than with shallow (7-14 cm) tillage. Singh and De Datta (109) found that IR43 yielded more in deep tillage, straw incorporation, and straw mulch treatments than in shallow tilled plots.

Tillage and moisture conservation. There is scant information on the effect of tillage method on moisture status of upland soils. Minimum and zero tillage are being considered to save energy in land preparation and to improve soil physical conditions (56). Zero tillage increases soil fertility and organic matter content (53, 56). Enhancing organic matter content may increase availability of soil water.

Sidiras et al (102) studied the effect of different tillage methods on soil moisture content of eroded and degraded soils in Parana, Brazil. They found soil water content was 4-5% higher in the 0- to 10-cm and 10- to 20-cm soil layers at SWP −0.033 MPa with zero tillage than with conventional tillage. Soil water content was consistently higher in the zero tillage plots at all water potentials greater than −0.1MPa. Water content in minimum tillage plots cultivated with a chisel plow was between that in no and conventional tillage treatments (Fig. 9).

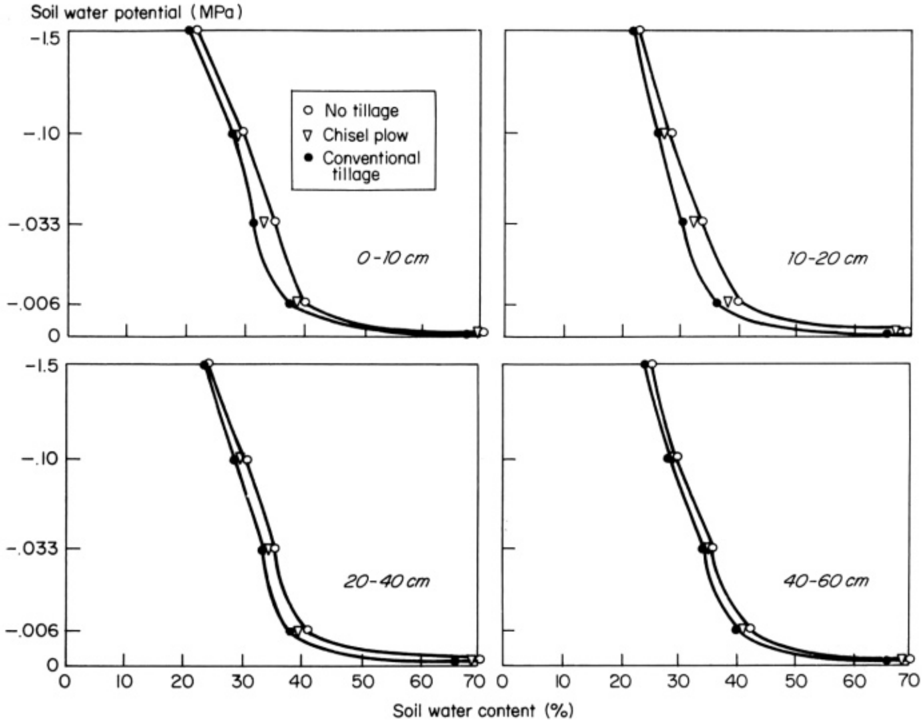
Figure 10 shows water capacity of soil at SWPs −0.006and −0.033M Pa after 4 yr of conventional, chisel plow, and zero tillage. Up to 40-cm depth at 0.006 MPa. water capacity was highest with zero tillage.

SOIL CONSERVATION AND EROSION CONTROL.

Soil erosion by wind and water is inevitable when natural vegetation is replaced by commercial farming (54), but what is the acceptable limit of soil erosion beyond which it constrains crop production? The answer depends on soil and climate and the cropto be grown. Wischmeier and Smith (120) defined soil loss tolerance as the

Table 5. Effect of cover crop on infiltration rate and field capacity of an eroded Alfisol (62).

Cover crop	Infiltration rate ($cm\ h^{-1}$)	Field capacity (% wt/wt)	Soil bulk density ($t\ m^{-3}$)
Brachiaria	19 ± 16	10.1 ± 4.0	1.34 ± 0.06
Paspalurn	14 ± 1	9.7 ± 3.7	1.35 ± 0.04
Cynodon	18 ± 14	14.8 ± 6.2	1.30 ± 0.02
Pueraria	16 ± 14	20.1 ± 7.1	1.32 ± 0.03
Stylosanthes	16 ± 2	18.5 ± 4.6	1.33 ± 0.03
Stizolobium	21 ± 4	14.7 ± 5.0	1.33 ± 0.03
Psophocarpus	42 ± 8	21.2 ± 3.9	1.14 ± 0.04
Centrosema	18 ± 8	15.9 ± 6.5	1.33 ± 0.04
Control	13 ± 8	11.0 ± 0.05	1.42 ± 0.05
LSD (0.5)	17	6.2	0.041



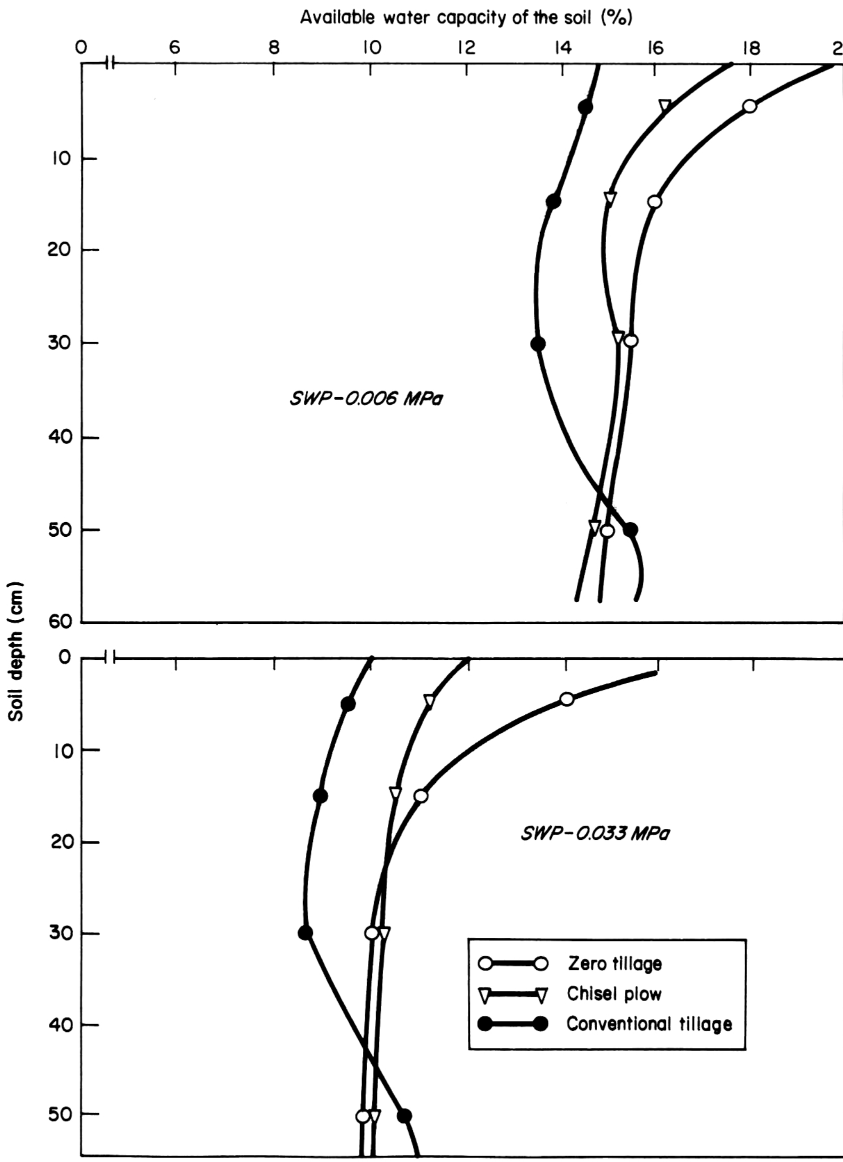
9. Soil water content and water potential (SWP) at different soil depths after 4 yr of conventional, chisel plow, and zero tillage on an Oxisol in Londrina, Parana, Brazil (102).

maximum rate of soil erosion that permits sustained crop productivity, economically and indefinitely.

Erosion is dangerous when land productivity cannot be restored even by implementing improved soil and crop management practices (6). Erosion affects soil nutrient profile, rooting depth, and physicochemical properties of subsoil horizons.

Upland rice is grown on Alfisols in West Africa and Oxisols and Ultisols in Brazil and South and Southeast Asia. Most West African Alfisols have a shallow gravelly horizon and topsoil that is unstable to raindrop impact, which encourages severe erosion. Some Oxisols and Ultisols with deep, weak profiles have serious gully erosion and subterranean or pipe erosion. When gullying starts, it is difficult to stop (54).

La1 (54), while summarizing soil erosion in tropical Africa, observed that where erosion factor exceeds 400 foot-ton per year and where slope exceeds 5%, an annual loss of 100 t soil ha^{-1} is not uncommon. An increase in erosion factor, however, does not necessarily result in increased erosion because of intervening factors. Soil erodibility, landform (slope and shape), and soil management substantially affect the magnitude of soil loss.



10. Available water capacity of soil at −0.006and −0.033MPa soil water potential after 4 yr of conventional, chisel plow. and zero tillage on an Oxisol in Londrina, Parana, Brazil (102).

Erosion stages

Erosion is a broad sequence of soil detachment, sediment transport, and sedimentation. Early conservationists classified erosion by stages corresponding with the progressive concentration of surface runoff. Sheet erosion (washing surface soil from arable lands) was first, followed by rill erosion as water concentrates into small rivulets in fields, gully erosion, and stream bank erosion.

This classification is misleading because it omits the splash (impact) effect of raindrops, which is the first and most important erosion stage. Also, sheet erosion implies that soil is removed uniformly by an even flow of thin sheets of water, which is wrong. Laminar flow of water over soil beds never causes erosion, and runoff rarely occurs as flat sheets.

If, however, splash erosion is substituted for sheet erosion, the classification is correct. Rill erosion is local, defined channels that are small enough to be eliminated by normal cultural methods. Gullies are large, well established channels that cannot be crossed by farm implements (7).

Erosion in upland rice soils

Water erosion is of primary importance in upland rice soils. Wischmeier and Smith (119) developed the *Universal Soil Loss Equation* (USLE) to predict or evaluate soil losses caused by erosion:

$$A = R \times K \times (SL) \times C \times P$$

where A = annual soil loss (t/acre), R = climatic erosivity (foot/t), K = soil erodibility, SL= topographical index linked to length and steepness of the slope, C = crop/cover management factor, and P = effectiveness of erosion control. Although the equation does not integrate all erosion factors, it provides an estimate of soil losses caused by erosion, and has worked well in West African Alfisols (53).

Factors affecting erosion losses

Climatic erosivity (R). R includes the erosivity of rainfall and runoff. Effective rainfall erosivity of a surface depends on canopy and groundcover. Runoff erosivity depends on runoff volume and rate, which depend on rainfall, infiltration, ground cover, surface roughness, and runoffflow pattern. These factors are in turn influenced by soil cover, management, and supporting practices (27).

R was chosen as a measure of erosivity based on empirical evaluation of several potential erosivity measures in temperate conditions in the United States (121). Chopart (11) described R under tropical conditions in West Africa, where R > 600, and may reach 2000 in coastal areas of Monrovia, Liberia.

Soil erodibility (K). Permeability, texture, structure, and organic matter content affect K. In the USLE, erodibility is defined as annual soil loss from a unit plot per unit of erosivity factor R. K therefore should be determined under field conditions (54).

K can be estimated for a soil by comparing its properties with those of soils with known K values (27). Wischmeier et a1 (118) estimated erodibility based on texture, structure, organic matter content, and permeability. Those estimates should be verified for a range of tropical soils. K of West African soils with predominantly kaolinitic clay is from 0.02 to 0.2 (11).

Topographical index (SL). When soil is bare or sparsely covered, SL is important to runoff and erosion. Wischmeier and Smith (120) described the relationship between slope, length of slope, and erosion as

$$SL = \frac{\sqrt{L}}{100}\,(0.76 + 0.53S + 0.076\,S^2)$$

where S= length of slope and L= percent inclination of slope. The USLE irregular slope procedure should be used in the tropics if the slope is concave or convex (27).

SL is markedly influenced by ground cover. Lal (53) reported that the contribution of SL to soil erosion decreases on cultivated or straw-mulched soil. It seems that SL is a weakness of Wischmeier and Smith's equation for predicting because knowing the actual influence of slope is essential to predict erosion (11).

Crop/cover management (C). Plant cover reduces raindrop impact. In the USLE, C is the ratio between erosion on a cultivated plot at different cropping intensities and on a base plot that has been shallowly plowed along the slope direction.

C is different in tropical and temperate climates because of different cropping intensities (27). A continuously tilled soil is more erodable than a soil plowed after permanent cover. Different crops have different canopies and ground cover, and therefore different C values.

Chopart (11) gave C values for tropical soils in West Africa. Forest vegetation has very low C — 0.001. Studies in Ivory Coast and Senegal show that upland rice provides better coverage than peanut and maize (Table 6). At Bouaké, Ivory Coast, erosion in upland rice fields is high for 20 d after seeding, after which the plant canopy covers the soil, thus limiting erosion (Table 7).

Table 6. Influence of plant cover on erosion in Sefa, Senegal (Charreau, according to results published by Charreau and Nicou 1971, as cited in [11]).

Crop	Replication no.	Mean C value	Erosion ($t\ ha^{-1}$) Minimum	Maximum
Upland rice	17	0.26	0.20	18.4
Maize	17	0.36	1.80	26.7
Millet	4	0.37	5.00	12.6
Peanut	32	0.37	2.30	20.8
Protected forest	11	0.05	0.02	0.2
Burnt forest	13	0.13	0.02	0.8
Bare soil	11	1.00	6.50	54.5

Table 7. Erosion in upland rice at Bouake, Ivory Coast (Bertrand 1967, as cited in [11]).

Period	Rainfall (mm)	Erosion ($t\ ha^{-1}$)
From sowing to 20 d	192	1.57
20 d after sowing	592	0.06

Erosion control coefficient (P). P refers to the influence of management practices such as contouring, strip cropping, terraces. and contour furrows used to support protection provided by crop rotation, canopy cover. and residue mulches (27), many of which are expensive and impossible for upland rice farmers. Roose (%) gave several P values for practices common in western Africa.

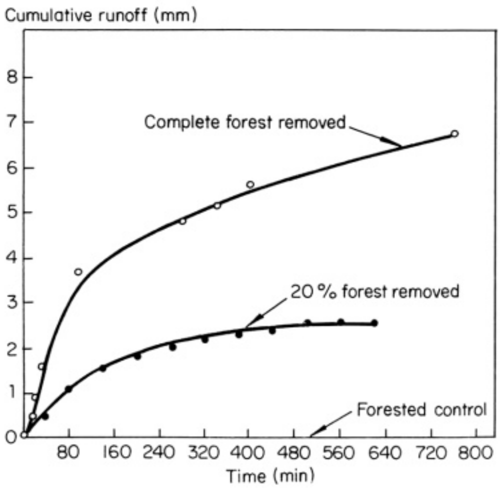
Erosion in upland rice fields is greatest early in the season when the canopy cover is incomplete. Erosion potential is greater on soils with poor plant cover or steep slope. There is erosion potential during the first few weeks of rice cultivation even on gently sloped soils (11).

Erosion control

Erosion can be minimized by modifying the values of one or several USLE coefficients. However, soil and crop management techniques that minimize water runoff by improving soil structure and water infiltration should be emphasized. Some of them involve engineering and maintenance that upland farmers cannot afford, and therefore are not suitable for upland rice. There are simple practices, however, that can minimize erosion in upland rice.

Incomplete land clearing. In tropical Africa and Latin America, 6-10 million ha of forest is cleared every year for cultivation of upland crops (55). Raindrop impact in these areas is greatly reduced if small trees are retained and upland rice or other crops are planted between them. A tree canopy also helps minimize drought by reducing wind speed. Studies at IITA on a 40-ha watershed showed there was almost no surface runoff from a forested watershed. Runoff was significantly greater when 20 to 100% of the trees were cut (Fig. 11).

Land clearing method also affects runoff. Generally, heavy machinery disturbs soil more and causes greater erosion than manual clearing (57), but not much information is available on clearing for upland rice (11).



11. Effect of forest removal on runoff from two 25-mm rainstorm observed in Aug 1978 and Apr 1979. Runoff measurements were made with 5:1 triangular weir installed on a 40-ha watershed (55).

Grassy strip contouring. In the tropics. growing any crop on a slope greater than 5-10% risks erosion if the soil is bare during rainfall. On such land, it is better to plant permanent pasture or shrubs. However, if the land must be cropped, grassy strips should be planted perpendicular to the slope between cultivated plots. The strips intercept surface runoff, and can provide economic erosion control (11).

Tillage and land preparation. Tillage and land preparation practices have a diverse effect on soilerosion. In some soils. tillage decreases cohesion and increases detachability. In others, it brings to the surface coarse soil particles that resist raindrop impact and thus minimize erosion (11). In poorly structured soil, tillage may improve root systems, which can limit erosion. Tillage also can increase percolation.

The effectiveness of tillage for erosion control in upland rice depends on soil characteristics, slope, tillage equipment, and extent of tilling. Rough tillage that leaves clods on the surface and infrequent tilling may minimize erosion damage (11).

Seeding practices. Any upland rice seeding practice that quickly provides ground cover minimizes erosion. Where erosion is a more serious constraint than drought, fields should have high plant density and narrow row spacing. Random planting may be beneficial.

Weed control. Where manual weed control is practiced, delaying weeding for 2-3 wk after seedling emergence may reduce erosion, and does not decrease yield (11). Also, in erosion prone areas, crop residue should not be disturbed and weed control should be through repeated herbicide sprays.

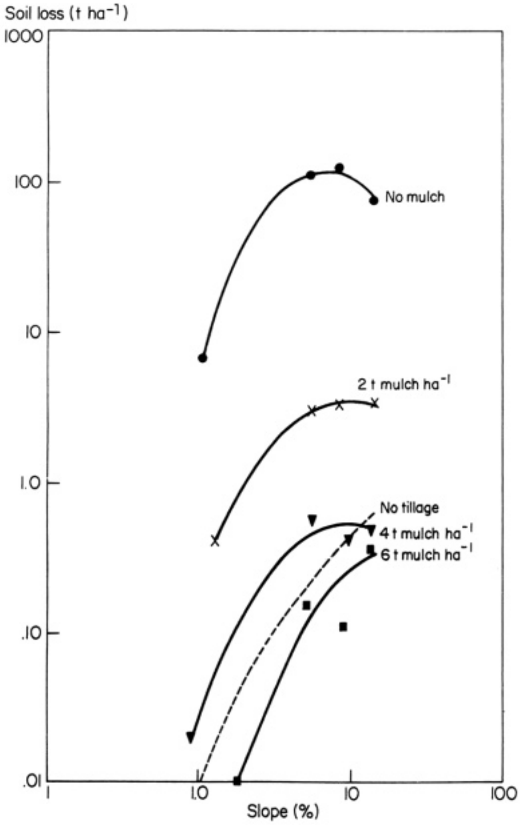
Crop residue mulch. Crop residue mulch is one of the most effective ways to reduce soil erosion. Mulch prevents direct raindrop impact on soil, maintains pore space continuity and high infiltration rate, and helps crops develop an early ground cover by improving soil and moisture regimes and other physicochemical properties.

At IITA in 1974-75, applications of 0, 2, 4, and 6 t rice straw mulch ha^{-1} were evaluated for controlling erosion (Fig. 12, 13). In both seasons, maximum erosion occurred in the no-mulch treatment. No-till farming and 6 t straw mulch ha^{-1} considerably reduced soil losses (53).

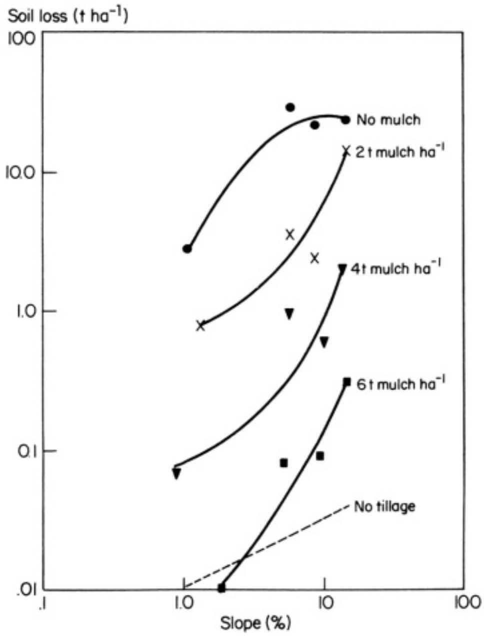
Tillage and straw mulching, and minimum tillage were studied in southern Senegal on a slightly sloping, ferrallitic soil. Erosion losses for both treatments were negligible, but yields were higher in the tillage treatment (11). With adequate rainfall, straw or cotton mulch did not improve grain yield of upland rices in West Africa (11). In Thailand, mulching reduced soil erosion in upland rice 85-90% the first year and 95-98% the second year (113).

Sometimes, straw or crop residue mulches are not completely satisfactory, are expensive, are not always available, or cannot be used because slopes are too steep (69). There is, therefore, interest in soil conditioners as an alternative.

At Iowa State University, Mausbach and Shrader (69) evaluated two polyvinyl alcohols (PVA) and a polyacrylamide (PAM) for erosion control. Energy required to initiate runoff (ENTOR) was used to measure effectiveness. ENTOR was much higher on treated than on untreated clods. PVA and PAM polymers



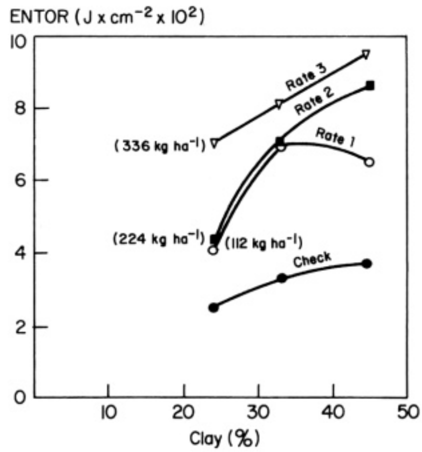
12. Effect of mulch rate, zero tillage, and slope on soil erosion (53).



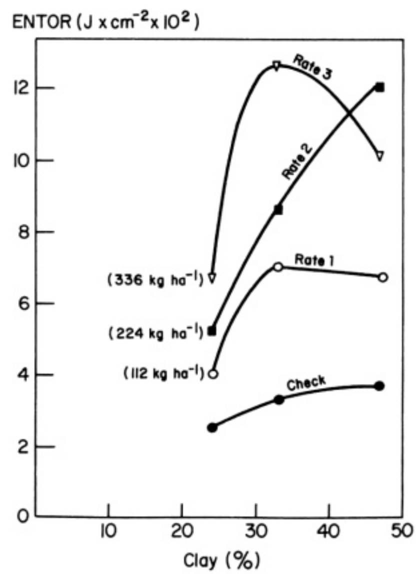
13. Effect of mulch rate, zero tillage, and slope on soil erosion (53).

were most effective on subsoil that contained 30% clay. Energy required to reach 6.5 cm h^{-1} infiltration capacity (ENTOP 65) was a good indication of the response of polymers under field conditions (Fig. 14, 15, 16). They should be studied for erosion control in upland rice grown in humid and subhumid areas.

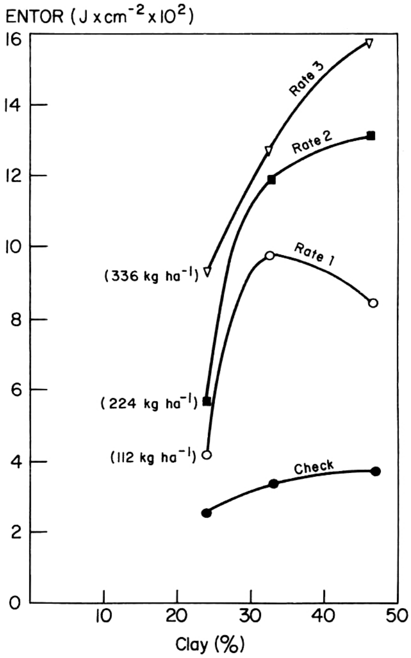
No-till farming. Crop residue mulch is an effective tool for controlling erosion, but it only can be used in arable farming with reduced tillage and where weeds are controlled by appropriate herbicides. Excessive tillage destroys soil structure and develops a thin impermeable layer just beneath the plow layer that decreases infiltration, increases runoff, and impedes root development. Crust formation also decreases infiltration rate and soil water capacity of bare, plowed soil.



14. Energy required to initiate runoff (ENTOR) with percent clay for three rates of PVA 71-30 polymer (69).



15. Energy required to initiate runoff (ENTOR) with percent clay for three rates of PVA 72-60 polymer (69).



16. Energy required to initiate runoff (ENTOR) with percent clay for three rates of PAM polymer. (69).

Lal (53) found that, in maize, zero tillage controlled erosion better than conventional tillage. Mahapatra and Shrivastava (65) studied runoff and soil losses with bunding, tillage, and mulching on land with a 15% slope. In bunded fields. plowing produced highest rice yields. Without bunding. however, no-tillage gave the highest yield, followed by straw mulch, perhaps because these practices reduced runoff and soil losses. Chopart (11), however, did not find that no-till and cotton mulch treatments reduced erosion in Bouaké, Ivory Coast.

Further research on weed control, planting equipment, fertilizer application, and insect pest and disease control are necessary for no-till farming in upland rice.

Cover crops. Cover crops are important to erosion control in upland and plantation crops. A suitable cover crop rotation improves soil physical and chemical properties. Infiltration rate of a structurally degraded soil improves rapidly if a deep-rooted fallow cover crop is planted such as *Cajanus cajan, Stylosanthes guianensis,* or *Psophocarpus palustris.* By improving soil physical properties and preventing raindrop impact, cover crops prevent runoff and erosion during their growth and that of the following food crops in the rotation (54).

For maize and cassava intercropping at IITA, a herbicide was applied to kill the cover crop. The residue remains as a protective mulch through which the following crop is planted (33). This technique may be useful for upland rice in erosion-prone areas.

Cropping systems. A cropping system that provides early and continuous ground cover lessens erosion. Upland rice is generally intercropped with maize, soybean, cassava, or coconut. Intercropping with a fast-growing crop like maize can provide early ground cover. Lal (54) found that mix-cropped maize + cassava allowed less erosion than cassava alone.

Alley cropping can control erosion and conserve moisture in degraded tropical soils (33). In alley cropping, a gram (rice or maize) or root crop is sown or planted between rows of a fast growing shrub or tree planted 1 yr earlier. IITA has used *Leucaena leucocephala* and is testing *Cajanus cajan, Tephrosia candida,* and *Gliricidia sepium* as potential shrubs for alley cropping. These shrubs recycle nutrients, provide organic matter, and protect against erosion.

SOIL FERTILITY MANAGEMENT

Traditionally. upland rice farmers have applied little fertilizer because rains are uncertain and soils have poor water holding capacity. Moreover. weeds and diseases reduce yields, and most upland varieties have low response to fertilizer. The development of high yielding, fertilizer-responsive, pest-resistant. semidwarf rices and better understanding of proper fertilizer application techniques offer great potential for the judicious use of fertilizers to increase upland rice yields in normal- and above-normal rainfall areas and stabilize them in low rainfall years and areas.

Nutrient uptake

Nutrient uptake depends upon dry matter production, which is influenced by soil. climate, and cultural practices. Malavolta and Filho (67) quantified the nutrients necessary to produce 1 t of rice from IAC47. IAC104, IAC165, and IR8 in Brazilian upland conditions (Table 8) and found great differences between the requirements of upland and lowland rices.

Table 8. Nutrients necessary to produce 1 t of rice (67).

Element	Quantity[a]			
	IAC47	IAC164	IAC165	IR8
	Macroelements (kg)			
N	56-86	64	56	19
P	10-15	10	10	5
K	58-66	68	52	36
Ca	16-19	19	19	3
Mg	10-13	11	10	4
S	6-20	4	3	2
Si	—	—	—	102
	Microelements (g)			
B	48-148	83	63	76
Cl	385-4,721	7,135	6,925	11,200
Cu	26-124	120	88	6
Fe	122-1,132	669	386	551
Mn	226-348	161	134	152
Mo	10	2	2	-
Zn	100-151	149	112	40

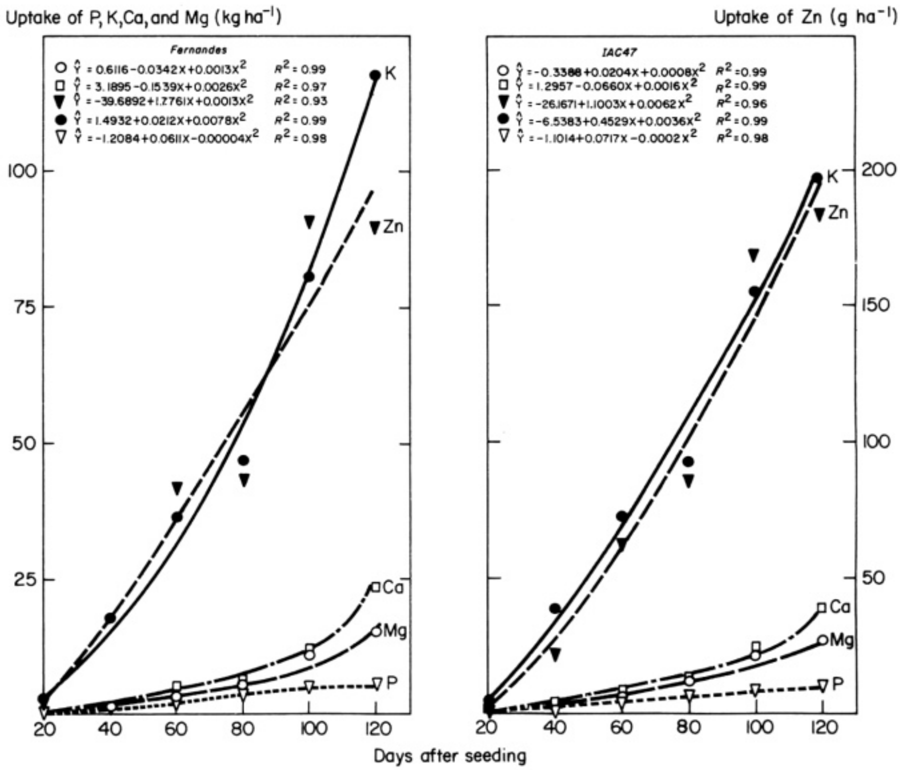
[a] Basis for calculation: IAC47 = 2.25 t ha^{-1} ; IAC164 = 1.55 t; IAC165 = 1.44 t; IR8 = 8.7 t.

Lal et al (61) reported large variations in NPK uptake in 19 genotypes grown in rainfed conditions in eastern Uttar Pradesh, India. Nutrient uptake (grain + straw) ranged from 53 to 100 kg N ha^{-1} , 7.6 to 11 kg P ha^{-1} and 44 to 78 kg K ha^{-1} . Grain yield ranged from 2.5 to 4.4 t ha^{-1} .

Santos et a1 (101) quantified K, Zn, Ca, Mg, and P uptake in varieties Fernandes and IAC47 in Goiania, Brazil. Nutrient uptake increased with plant age (Fig. 17), and was higher in Fernandes than in IAC47. In Fernandes, K uptake exceeded 100 kg ha^{-1} at 120 d after sowing.

In upland rice, N and K uptake are highest, and then Ca, Mg, P, and S. Highest micronutrient uptake is that of Fe, followed by Mn, Zn, Cu, and B (67).

Kumbhar and Sonar (52) made a detailed study of the uptake pattern for N, P, K, Fe, and Mn. They found that N, P, K, and Mn uptake by tall, upland Krishnasal and semidwarf, lowland Pusa 33, were slow until tillering, increased until flowering, and thereafter decreased. K and Fe uptake were very slow at tillering, rapidly increased until panicle initiation, and thereafter increased gradually. Up to flowering, leaves and sheaths stored most N, P, and K (Table 9). At maturity, substantial Nand P moved to the panicles, but there was little translocation of K. Fe uptake was different, possibly because substantial quantities of Fe are retained in the roots, leaves, and sheaths. At maturity, Fe content increased in stem tissues.



17. Nutrients absorbed by Fernandes and IAC47 rices (102).

Table 9. Nutrient uptake at different growth stages in two rice varieties (52).

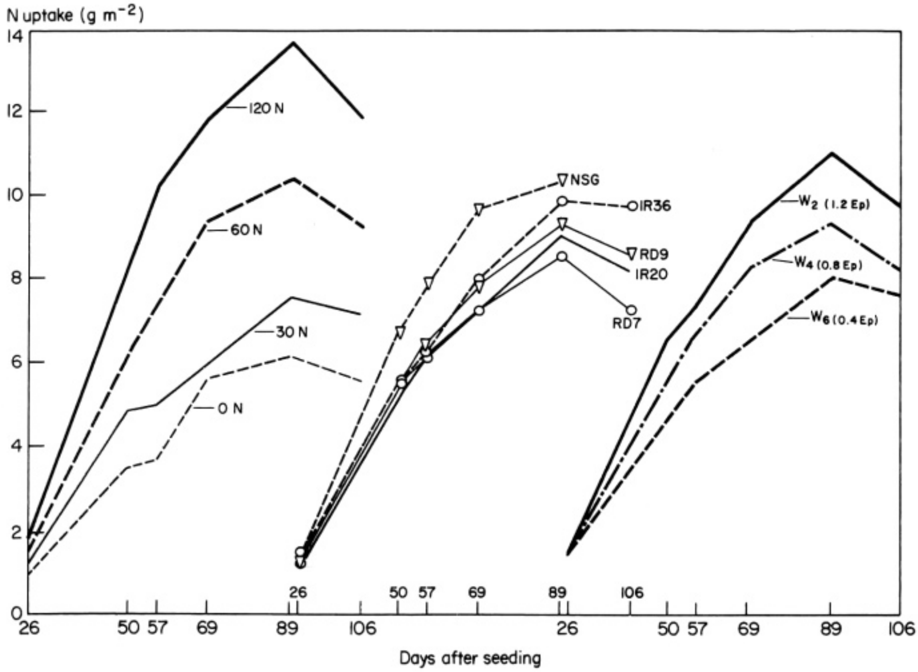
Growth stage	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})		Fe (g ha^{-1})		Mn (g ha^{-1})	
	Krishnasal	Pusa 33	Krishnasal	Pusa 33	Krishnasal	Pusa 33	Krishnasal	Pusa 33	Krishnasal	Pusa 33
Total										
Tillering	12	7	1.2	0.5	6	2	214	188	22	7
Panicle initiation	65	39	7.7	3.3	59	21	1526	1017	204	54
Flowering	89	52	12.2	7.7	63	28	1742	1183	724	207
Harvest	93	54	13.1	11.0	64	34	2195	1440	788	271
Tillering										
Leaf	6.05	3.52	0.44	0.20	2.69	0.90	36	35	11	3
Sheath	4.98	2.45	0.63	0.26	3.19	1.26	124	65	9	3
Root	1.01	1.10	0.08	0.08	0.20	0.27	54	68	2	1
Panicle initiation										
Leaf	30	19	2.2	1.5	20	7	458	179	91	15
Sheath	25	14	5.0	1.4	34	12	626	447	96	31
Root	9	6	0.5	0.4	5	2	442	391	17	8
Flowering										
Leaf	32	18	1.6	1.5	17	9.0	351	158	246	72
Sheath	31	16	5.6	2.0	20	6.4	303	342	318	71
Stem	8	5	2.8	2.1	14	9.6	833	415	216	45
Panicle	5	5	1.7	1.6	4	2.0	81	50	11	10
Root	12	7	0.6	0.6	8	2.4	174	218	23	10
Harvest										
Leaf	22	9	0.6	0.7	7	5.4	347	163	246	94
Sheath	19	10	1.1	0.3	15	5.5	261	312	307	80
Stem	15	8	0.9	1.1	31	16.4	1229	616	173	61
Panicle	30	24	10.1	8.8	8	4.8	141	142	42	26
Root	7	4	0.3	0.2	3	1.7	127	207	20	11

[a]Mean of 3 replications.

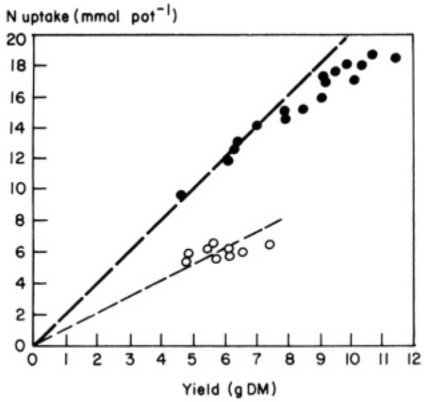
Mn was continuously translocated to leaf and sheath. Krishnasal, which produces more foliage, took up greater quantities of all nutrients than Pusa 33. Singh and Modgal (107) found that anaverage upland rice crop removes 61 kg N ha^{-1}. Plants accumulated about 15% of total N by tillering, 50% by panicle initiation, and 85-95% by heading.

Chinchest (10) studied N uptake of five rices in upland fields with different N and water application rates. A line source sprinkler system provided water levels 1.25, 1.20, 1.0, 0.8, 0.6, and 0.4 times class A pan evaporation (mm d^{-1}). N uptake increased with N and water applications (Fig. 18). Uptake patterns at different growth stages changed with each N and water application rate. At higher water rates, N uptake was highest 89 d after seeding (flowering stage) and then sharply decreased. At the lowest water level, N uptake did not decrease at late flowering. NSG had the highest and RD7 the lowest N uptake.

When topsoil dries, plants use water stored in the subsoil, but cannot use nutrients in the upper horizon. In such situations, poor nutrition is likely to reduce rice growth before the soil dries to a deeper layer and water deficit begins to affect growth. Rehatta et al (95) studied N uptake by rice in experiments where N and water were supplied from different compartments. N uptake where N and moisture were in a common soil compartment was more than when plants were grown where N and moisture were in different compartments (Fig. 19).



18. Cumulative N uptake of 5 rices as influenced by N rate, variety, and applied water at different growth stages (10). Ep = pan evaporation.



19. Relation between the amount of N absorbed and dry matter production by rice grown on the soil columns with Nand soil moisture in a common soil compartment (black circles) or in separate compartments (open circles) (95).

Nitrogen management

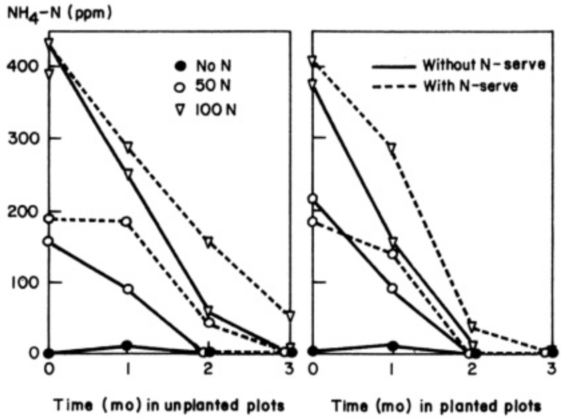
Almost all upland rice soils have low N (3, 65). Varietal, environmental, and economic constraints require efficient application and management of N fertilizer for upland rice.

Nitrogen fertilizer recovery. In upland environments, unfavorable conditions limit recovery of applied N, which reduces rice growth and yield.

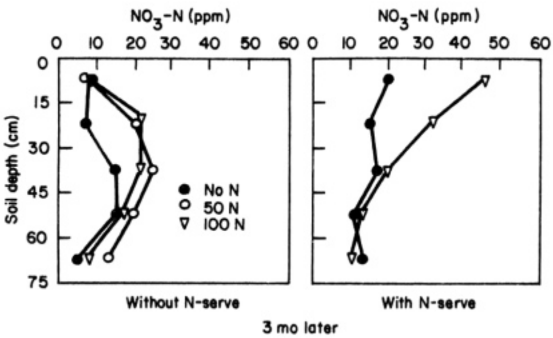
Where rainfall is high, substantial N leaches from highly permeable Ultisols and Oxisols. Arora and Juo (4) found that, at Onne, Nigeria, leaching losses in maize and upland rice varied from 28 to 53%, depending upon N application method. In Cuttack, India, N recovery in sandy loam soil ranged from 19 to 32%. averaging 22% (86), which is every poor.

Nitrogen transformation in upland soils. In upland conditions, most N is taken up as NO^-_3. Ammoniacal N, applied as ammonium fertilizers such as urea, converts quickly into nitrates. In the tropics, nitrification is very active because of favorable temperatures. N transformation in upland soils was studied extensively at IRRI (38, 40). Ammonium fertilizers with and without a nitrification inhibitor (N-serve) were applied at 0, 50, and 100 kg N ha^{-1} and evaluated for transformation in upland rice soils for 5 mo. Ammonium N content of the top 15-cm soil layer decreased markedly in planted and unplanted plots where 50 and 100 kg N/ ha were applied (Fig. 20). In unplanted plots without N-serve, about 50% of the ammonium nitrified in 1 mo and more than 90% nitrified after 2 mo. N-serve retarded nitrification for 2 mo, but after 2-3 mo, nitrification began again with a 20- to 200-fold increase in the number of *Nitrosomonas* in plots with applied N. After 3 mo, ammonium N content in all but the N-serve plots to which 100 kg N/ha had been applied was low. After 5 mo, ammonium N content in all plots was lower than when the N fertilizer was applied.

The lower level of ammonium N in planted than in unplanted plots after 2 mo indicated vigorous N uptake by rice. Vertical distribution of N through the soil profile 3 mo after N application (Fig. 21), when nitrification was complete, showed that nitrate content in plots without N-serve was highest at 30- to 45-cm depth. In



20. Changes in ammonium N in surface soil as affected by N level and nitrification inhibitors (38).



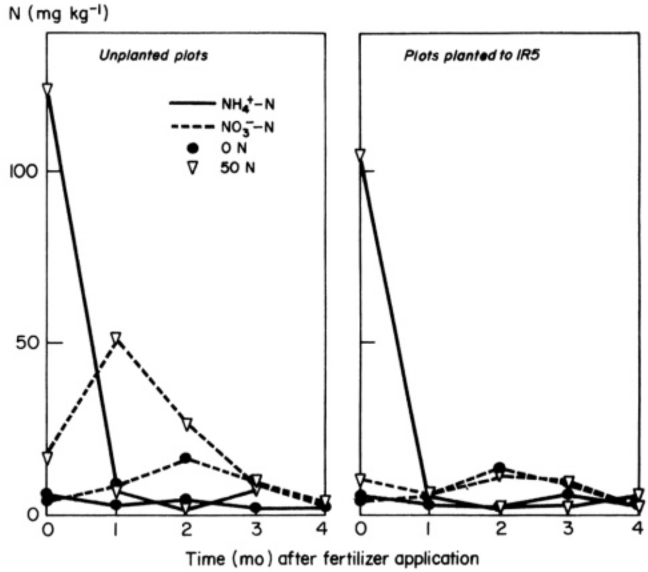
21. Vertical distribution of nitrate N in the soil 3 mo after fertilizer application (38).

N-serve-treated plots, nitrate remained in the topsoil. After 5 mo, mineral N decreased to the same level as before fertilizer application.

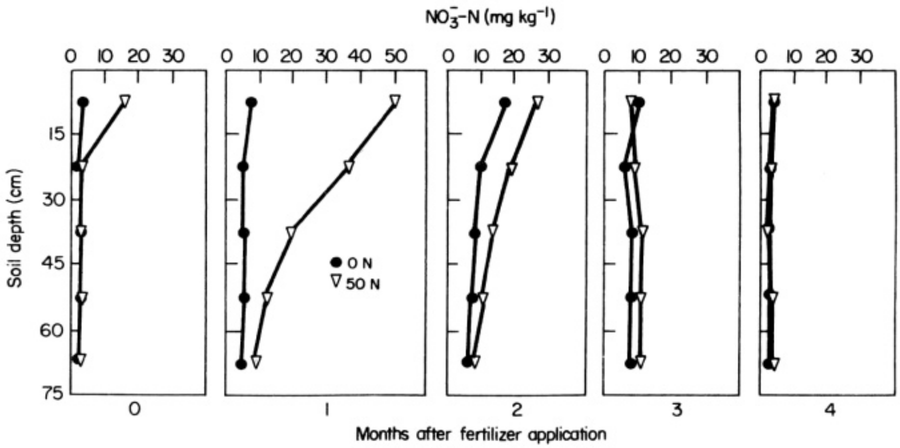
In another study, ^{15}N-labeled ammonium at 50 kg N ha^{-1} was applied in 18.5-cm-diameter metal cylinders inserted in furrows. Half of the cylinders were covered with plastic film to prevent leaching. In planted and unplanted plots with good drainage, ammonium N disappeared rapidly from the 0- to 15-cm layer 1 mo after fertilizer was applied (Fig. 22). In unplanted plots, nitrate level increased during the first month, then decreased. At harvest, 5 mo later, nitrate level was about the same as in the zero tillage plot at the beginning of the experiment.

The disappearance of ammonium N in the 0- to 15-cm layer of unplanted plots was followed by appearance of nitrate in all 5 deeper soil layers 1 mo after application. The nitrate present between 15 and 75 cm equaled that which disappeared from the 0- to 15-cm layer (Fig. 23).

The nitrate that leached to the different soil layers during the first month decreased gradually, and at harvest almost equaled that found at the start of the experiment. There was no peak level of nitrate accumulation up to 75-cm depth. Nitrate may have leached below 75 cm. In the open cylinders, soil nitrate content to 75-cm depth 5 mo after fertilizer application almost equaled the amount before N application.



22. Changes in content of ammonium and nitrate N in the surface (0–15 cm) soil layer (40).



23. Vertical distribution of nitrate N in the 0-75 cm soil profile (40).

Because of lower moisture content in the covered cylinders, most nitrate accumulated in the 0- to 15-cm layer. ^{15}N recovery at 75-cm depth was 25% with open cylinders and 65% with covered cylinders.

Nitrate leaching loss is an important factor affecting N fertilizer efficiency in upland rice areas with high rainfall (4). Denitrification also can be important in soils with poor drainage (40).

Nitrogen response. Plant response to N generally is lower in dry than in wet soils because water deficits prevent plants from making full use of N. Varieties also differ in their ability to use applied N. Modern semidwarf rices are more responsive to applied N than tall traditional rices. Traditional varieties tend to lodge at high N levels.

In India, upland rice responds to N between 60 and 120 kg ha^{-1} (65, 73, 84, 94, 105, 108, 110, 112). Tall, traditional Dular produced well with 60 kg added N ha^{-1}, but applying more caused it to lodge (84). Modern semidwarfs respond favorably to 120 kg N ha^{-1}. Singh and Singh (110) found that semidwarf Bala responds well up to 90 kg N ha^{-1} in eastern Uttar Pradesh, India.

Singh et al (112) evaluated the response of three modern semidwarfs at four levels of applied N at Varanasi, Uttar Pradesh. For 2 consecutive years, grain yields were highest with 120 kg N ha^{-1}. Singh and Modgal (105) obtained similar results with semidwarf Padma and Bala. In Tripura, India, 40-45 kg applied N ha^{-1} gave highest yields (1.9 t ha^{-1}) with a 75-80 d variety (29).

Singh (92, 108) summarized the N response of upland rice in India based on rainfed farming projects trials (Table 10). Applying 80 kg N ha^{-1} increased grain yield by 1-3 t. N response (kg grain:kg applied N) varied from 12 to 23.

In addition to grain yield, fertilizer management should consider economic efficiency. On a benefit:cost basis, Mahapatra and Shrivastava (65) found that 40-60 kg applied N ha^{-1} was optimum for upland rice in India. Similarly, Rao and Prasad (94), using benefit:cost >30, found that 60 kg N ha^{-1} was economically optimum for 20 modern upland semidwarfs. Singh et al (112) found that 40 kg N ha^{-1} gave the highest return to fertilizer investment.

In the Philippines, 80 kg N ha^{-1} is recommended for upland rice (88). Malabuyoc et al (66) quantified yield response of upland rice at three Philippine sites. At IRRI, on a clay loam soil with pH 5.2, yield response was economic up to 40 kg applied N ha^{-1}. At Santo Tomas and Cuenca in Batangas, on acid loam and clay loam soils, response was economic up to 80 kg N ha^{-1}.

In Bangladesh, upland rice farmers seldom apply fertilizer to upland rice, but the recommended N level is 40 kg ha^{-1} (91).

In West Africa, where upland rice is planted after clearing the bush, little fertilizer is required for the first year crop. In subsequent years, however, N fertilizer should be applied. Das Gupta (13) evaluated yield response of some upland rices to N levels at Suakoko, Liberia, from 1980 to 1982 after clearing thick bush in 1979 (Table 11). For the first crop, 20-40 kg N ha^{-1} may be needed to

Table 10. Response of upland rice to N (108).

Crop regional[a]	Yield (t ha^{-1})		Kg grain/ kg N
	Without N	With 80 kg N ha^{-1}	
Dehradun (3)	2.8	3.8	12.4
Varanasi (4)	1.3	2.7	17.8
Rewa (2)	1.6	3.5	22.7
Bhubaneswar (3)	1.3	2.5	13.7
Ranchi (6)	1.4	2.6	15.0

[a] Numbers in parentheses indicate the number of years.

Table 11. Rice response to N levels in upland bush - fallow rice cropping systems in a high rainfall area at Suakoko, Liberia (13).

Variety	Days to 50% flowering	Yield (t ha^{-1}) at given N ha^{-1}					
		0	20 kg	30 kg	40 kg	60 kg	90 kg
				1980			
LAC23	95	1.6	2.5	-	3.1	-	-
4418	93	1.0	2.8	-	3.6	-	-
MRC172-9	86	1.1	3.1	-	3.3	-	-
IR2035-108-2	94	1.1	2.5	-	3.0	-	-
ROK3	88	1.5	1.8	-	2.4	-	-
Mean		1.3	2.5	-	3.1		
LSD (0.05) of N X V			0.2				
				1981			
LAC23	95	0.8	1.1	-	1.3	1.5	-
4418	93	1.0	1.3	-	1.4	1.7	-
C22	99	0.7	0.9	-	1.4	1.7	-
IRAT132	92	0.7	0.8	-	1.0	1.3	-
Mean		0.8	1.0	-	1.3	1.5	
LSD (0.05) of N X V			0.1				
				1982			
LAC23	104	0.7	-	1.2	-	1.7	2.1
SEL IRAT 194/1/2	86	0.7	-	1.0	-	1.5	1.9
LS(1)-19-1-1	107	0.5	-	0.9	-	1.5	1.9
TOx502-2SLR-LS2-5B	97	0.5	-	0.8	-	1.2	1.9
Mean		0.6	-	1.0	-	1.5	2.0
LSD (0.05) of N			0.1				
LSD (0.05) of V			0.2				

harvest 2-3 t rice ha^{-1}. Without added N, yield was 1.0 t ha^{-1} . For the second and third crops, more than 40 kg N ha^{-1} may be necessary to harvest 1.5-2.0 t ha^{-1}. Based on local cultivar LAC23, Das Gupta computed the N response equations:

$$1980: \; Y = 1648.0 + 48.87x - 0.33x^2$$
$$1981: \; Y = 798.7 + 17.01x - 0.10x^2$$
$$1982: \; Y = 715.9 + 15.96x - 0.005x^2$$

where Y= grain yield and x= N level in kg ha^{-1}. The equations indicate that yield response to applied N is almost linear. Estimated yield increase (kg kg^{-1} N) decreased as N level increased.

In 4 yr of research with IR305, Agboola (2) found that 60 kg N ha^{-1} as ammonium sulfate was optimum for upland rice in western Nigeria. Based on trials in farmers' fields, Jones et al (47) found that applying N fertilizer to upland rice was highly remunerative in Sierra Leone. Applying N or K in a bush fallow - rice system almost always gave high returns (Table 12).

In Campinas, Brazil, response is good up to 80 kg N ha^{-1} in Latosolic B Tersa Roxa soils, but high N levels are associated with increased blast disease and excessive vegetative growth. Therefore, only 30 kg N ha^{-1} is recommended for early varieties such as Batatais (87).

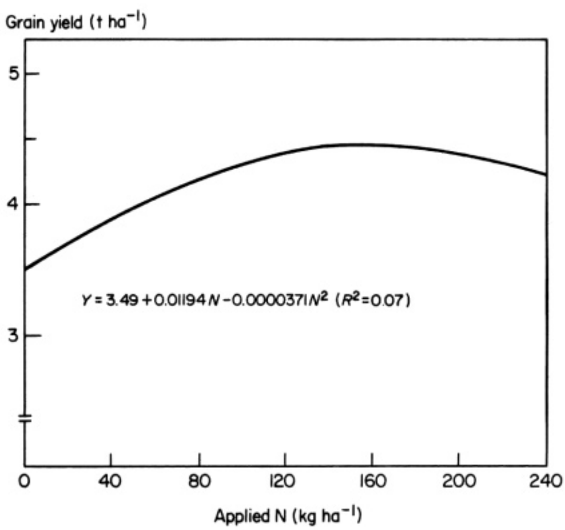
Table 12. Net returns to investment in fertilizer application to upland rice, Rokupr, Sierra Leone, 1978 wet season[a] (47).

District	Net return ($ per $1 investment)			
	60 kg N ha^{-1}	30 kg K ha^{-1}	60-30 kg N K ha^{-1}	60-30-30 kg NPK ha^{-1}
Kambia	7.23	4.86	5.91	2.64
Bombali	3.63	7.94	4.90	5.38
Tonkolili	2.70	3.1 6	3.07	3.50
Kaoinadugu	3.30	7.80	0.78	0.71
Bo	1.87	5.39	1.05	1.07
Moyamba	7.00	20.35	8.81	5.09
Kailahun	4.41	26.92	6.37	3.01

[a]Price of 1 kg N = $0.49, 1 kg P_2O_5, = $0.70, 1 kg K_2O = $0.25, and 1 kg rice grain = $0.22.

In Costa Rica, a basal application of 144 kg of 10-30-10 is recommended, and 64 kg N ha^{-1} is applied in equal splits 30 d after sowing and 60 d after germination. Usually, 46% N urea is used, but some farmers apply ammonium sulfate (92 kg/ ha) 30 d after sowing (97). Oelsligle et a1 (78) summarized various N experiments in upland rice in Costa Rica in a regression equation (Fig. 24). The equation, which agrees with national results, sets the economically optimum fertilizer rate at 110 kg N ha^{-1}. Costa Rica researchers find that 120 kg N/ha is profitable.

Nitrogen sources. N comes from organic and inorganic sources. Table 13 lists N fertilizers and their characteristics: Some of them, however, may be inappropriate for upland rice. Identifying an appropriate N fertilizer depends upon local availability, economic considerations, soil type, and crop response.



24. General N response of upland rice in western Costa Rica, as assembled from 807 observations from 6 sites in 1973 and 1974 (78).

Table 13. Characteristics of some common N fertilizers (adapted from [17]).

Fertilizer	Chemical formula	N content (%)	N form (% total N)		S content (%)	Potential acidity (kg $CaCO_3$ kg N^{-1})
			NH_4	NO_3		
Ammonium sulfate	$(NH_4)_2SO_4$	21	100	-	24	5.3
Ammonium chloride	NH_4Cl	25	100	-	-	5.1
Ammonium nitrate	NH_4NO_3	33	50	50	-	1.8
Urea	$(NH_2)_2CO$	45-46	100	-	-	1.8

For Indian uplands, Mahapatra and Shrivastava (65) found no difference between ammonium sulfate, ammonium sulfate nitrate, calcium ammonium nitrate, and urea. In a similar study at IITA (36), calcium ammonium nitrate gave a slightly higher grain yield than urea or ammonium sulfate. Crop uptake of N applied as ammonium sulfate and total N recovery (71%) were higher than in other sources, however (Table 14).

Fertilizer shortages and heavy fertilizer N losses to leaching and denitrification in upland soils have led scientists to evaluate slow-release N fertilizers for upland culture. Slow-release fertilizers have several potential advantages for increasing fertilizer use efficiency, including lowering application costs because fewer applications are necessary; minimizing leaching losses, fixation, and decomposition; and reducing damage to crop plants.

Sulfurcoated urea, ammonium sulfate, and urea were evaluated at IRRI in 1976 with different varieties and application methods (39, 116). With basal application, slow-release sulfurcoated urea performed better than prilled urea.

Table 14. Effect of N sources on leaching and utilization of fertilizer N by maize and rice, Onne, Nigeria, 1982 (36).

N source	Yield (t ha^{-1})	Applied N[a] recovered in grain and stover (%)	Total N recovered (%) by crop and soil (0-120 cm)
	Maize (TZPB)		
Control	1.1	-	-
Calcium ammonium nitrate	3.1	23	49
Urea	4.6	51	61
Ammonium sulfate	3.9	27	50
LSD (5%)	0.7	13	-
	Upland rice (ITA118)		
Control	1.0	-	-
Calcium ammonium nitrate	3.0	30	50
Urea	2.4	29	36
Ammonium sulfate	2.6	40	71
LSD (5%)	0.4	17	-

[a] N was applied at 150 kg ha^{-1} for maize and 120 kg ha^{-1} for rice.

However, if urea and ammonium sulfate were applied in two or three splits they were as effective as sulfur-coated urea applied singly at planting (Table 15).

At Ibadan, Nigeria, Agboola (2) studied the effect of urea, ammonium sulfate, ammonium nitrate, sulfur-coated urea, calcium nitrate. nitrophosphate, and totafert 15-15-15 on IR20 and OS6 in the greenhouse and lR305 in the field. All N sources were equally effective in the greenhouse experiment. In the field, nitrophosphate and totafert were inferior to the other N sources (Table 16). In sandyloam soil in India, Soundara Rajan and Mahapatra (114) found that upland Pusa 22 performed similarly with sulfur-coated urea. neem cake-coated urea, AM (2-amino-4 chloro-6-methylpyrimidine) fertilizer, and split-applied urea.

Timeand method of nitrogen application. To maximize N efficiency, fertilizer application should be timed to meet the N requirements of plants. Upland rice requires little N fertilizer up to tillering(107). N requirements increase after tillering and 85-90% of N is used by heading. N fertilizer should be applied at different growth stages. Split application also minimizes N losses through leaching and denitrification.

Several experiments showed that applying N fertilirer in 2-3 splits was better than a single application at sowing (4, 34, 39, 65, 73, 78, 85, 93, 98, 105, 107, 110, 11 1,116). The total N to be applied should be split into 3 equal or varying doses and applied at planting, and 30 and 60 dafter planting. The second and third doses also can be applied at tillering and panicle initiation (4. 34. 38, 73, 107, 110). Split N

Table 15. Effect of different methods, sources, and time of N application on yield of IR9575 and IR2035-117-3, IRRI, 1976 wet season (39).

Method[a]	Source[b]	Rate (kg ha^{-1}) of N applied at[c]				Yield (t ha^{-1})		
		Planting	10 DE	30 DE	PI	IR9575	IR2035-117-3	Mean[d]
-	-	0	0	0	0	2.2	2.1	2.1 c
B&I	SCU	60	0	0	0	3.5	2.9	3.2 b
BP	SCU	60	0	0	0	3.5	2.8	3.1 b
B&I	U	60	0	0	0	3.2	3.3	3.2 b
BP	U	60	0	0	0	3.3	3.2	3.3 ab
S	U	20	0	20	20	3.7	3.1	3.4 ab
S	U	0	20	20	20	3.5	3.3	3.4 ab
B&I	AS	60	0	0	0	3.7	3.3	3.5 ab
BP	AS	60	0	0	0	3.6	3.0	3.3 ab
S	AS	20	0	20	20	3.9	3.5	3.7 a
S	AS	0	20	20	20	3.7	2.9	3.3 ab
B&I	SCU	90	0	0	0	3.8	3.3	3.6 ab
BP	SCU	90	0	0	0	3.8	3.2	3.5 ab
B&I	U	90	0	0	0	3.4	3.4	3.4 ab
BP	U	90	0	0	0	3.4	3.6	3.5 ab
S	U	30	0	30	30	3.9	3.3	3.6 ab
S	U	0	30	30	30	3.8	3.2	3.5 ab
S	AS	30	0	30	30	4.0	3.3	3.7 a

[a]B&I = broadcast and incorporated, BP = band placement, S = split. [b]SCU = sulfur-coated urea, U = urea, AS = ammonium sulfate. [c]DE = days after rice emergence, PI = panicle initiation. [d]Separation of means at the 5% level.

Table 16. Effect of N sources on yield of varieties under upland conditions (2).

N source	Yield (g pot^{-1}) with split application in greenhouse		Yield (t ha^{-1}) of IR305 with single application in field
	IR20	OS6	
Control	10 b	9 c	1.5 c
Urea	15 a	13 b	2.9 a
NH_42504	18 a	18 a	3.1 a
(NH_4) No. 3	17 a	14 b	-
SCU-D	15 a	12 b	2.7 ab
Ca (No. 3) 2	-	-	3.0 a
Nitrophosphate	-	-	2.4 b
Totafert 15-15-15	-	-	2.5 b

application reduced leaching losses from 53 to 28% in Onne. Nigeria (4. 34) (Table 17).

Applying the first split of N at seeding may increase weed growth. To limit weed infestation, N application should be delayed 2-3 wk and made after the first weeding (65, 86, 93). With dry seeding, the first N fertilizer generally is applied 10 d after seedling emergence.

Topdressing the second and third N doses sometimes is difficult because the soil is dry. Fertilizer applied on dry soil volatilizes. This problem has encouraged the evaluation of foliar N application. Singh and Singh (110) and Singh and Modgal (106. 107) found a foliar spray of N fertilizer as effective as topdressing. Foliar spray could be applied when soil conditions did not permit topdressing.

Table 17. N fertilizer efficiency and leaching in a maize and upland rice rotation at Onne, Nigeria. Data are mean values of unlimed and limed (2 t ha^{-1}) plots (4,34).

N treatment[a]	Yield (t ha^{-1})		N uptake (kg ha^{-1}) by part of crop aboveground	Retention of applied N (kg ha^{-1}) in 0-120 cm soil	Estimated recovery (%) by crop and 0-120 cm soil[b]
	Grain	Stover			
			Maize TZPB, 1st season		
One application	2.7	3.7	58	46	52
Two splits	3.3	4.3	78	38	60
Three splits	3.5	4.1	88	57	79
LSD (0.05)	0.6	0.6	17	-	-
			Upland rice ITA 118, 2d season		
One application	1.6	3.0	53	52	46
Two splits	1.9	3.2	60	47	55
Three splits	2.6	4.3	79	55	71
LSD (0.05)	0.3	0.4	9	-	-

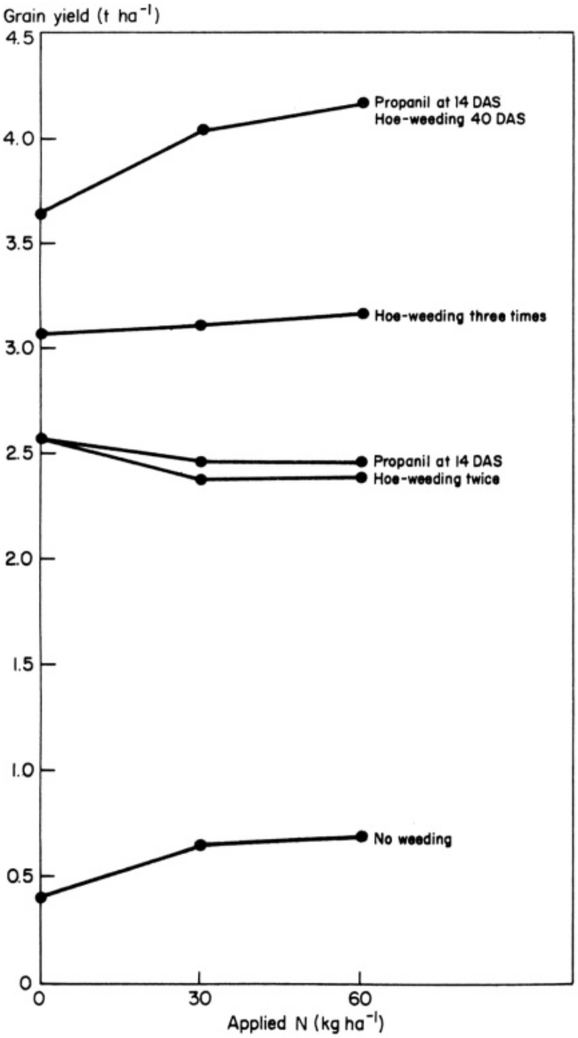
[a]Calcium ammonium nitrate applied at 150 kg N ha^{-1} to maize in first season and 90 kg N ha^{-1} to rice in the second season under no-tillage and stubble conservation. [b]Calculation of recovery of applied N at the end of second season is based on total application of 240 kg N/ha.

Factors affecting nitrogen response

Weeding, cultural practices, tillage management, solar radiation, and moisture supply influence upland rice response to N fertilizer.

Weed control. Upland rice response to N fertilizer is markedly improved by weed control. Soundara Rajan and Mahapatra (114) had highest upland rice yields with split applied N fertilizer and repeated weeding by hoeing. In Nigeria, Fagade (21) found there generally was no response to applied N in weedy fields, but that with good weed control applying N increased rice yields by 11-15% (Fig. 25).

Plant density. Most upland rice varieties are medium to low tillering. With favorable rainfall, increasing plant density may increase grain yield. Partohardjono et al (85) evaluated plant spacing 40 × 15 cm, 25 × 15 cm, and 20 × 15 cm at 0, 60, and 90 kg N ha^{-1} with varieties Seratus Malam, Gati, and Bicol on a red yellow



25. Effect of N application and weeding on upland rice yield (21). DAS = days after seeding.

Podzolic soil in southern Sumatra. Grain yield increased only up to 60 kg N ha^{-1}. At 60 or 120 kg N ha^{-1}, yield did not increase with spacing closer than 40 x 15 cm. At 0 N, closer spacings yielded highest. Gati yielded more than Seratus Malam and Bicol.

Sowing date and solar radiation. Plant growth and response to N is modified by climate, especially soil moisture and solar radiation. Crop environment and response to N can be altered by changing the planting date.

After several years of experiments at IRRI and in two farmer fields in the Philippines, Malabuyoc et al (66) reported that plantings with least soil moisture stress yielded higherthanthose affected by drought. If soil water potential at 20-cm depth went below –0.07 MPa for 4 to 14 d, reproductive stage was most affected. Grain yield increased up to 40 kg N ha^{-1} in 1977 and 1979 and up to 80 kg in 1980 at IRRI (Fig. 26). Yield response to planting date varied each year.

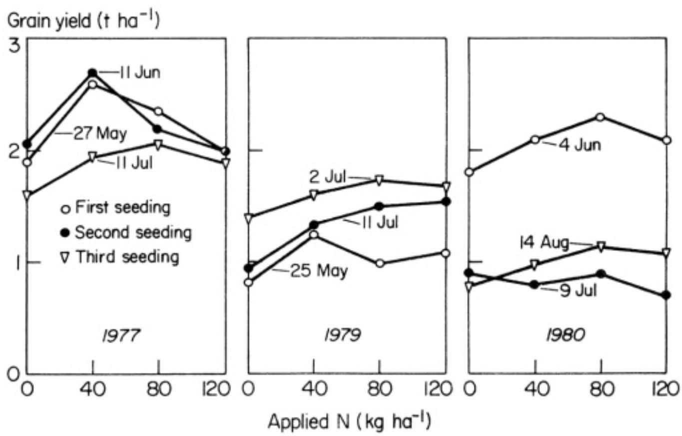
In wet season, low solar radiation may reduce upland rice response to N. For high grain yield and N response, rice must receive adequate solar energy at reproductive and ripening stages (46). Usually, however, solar energy is less critical than moisture supply (14).

Moisture supply. N status is closely related to soil moisture. N use decreases with soil moisture.

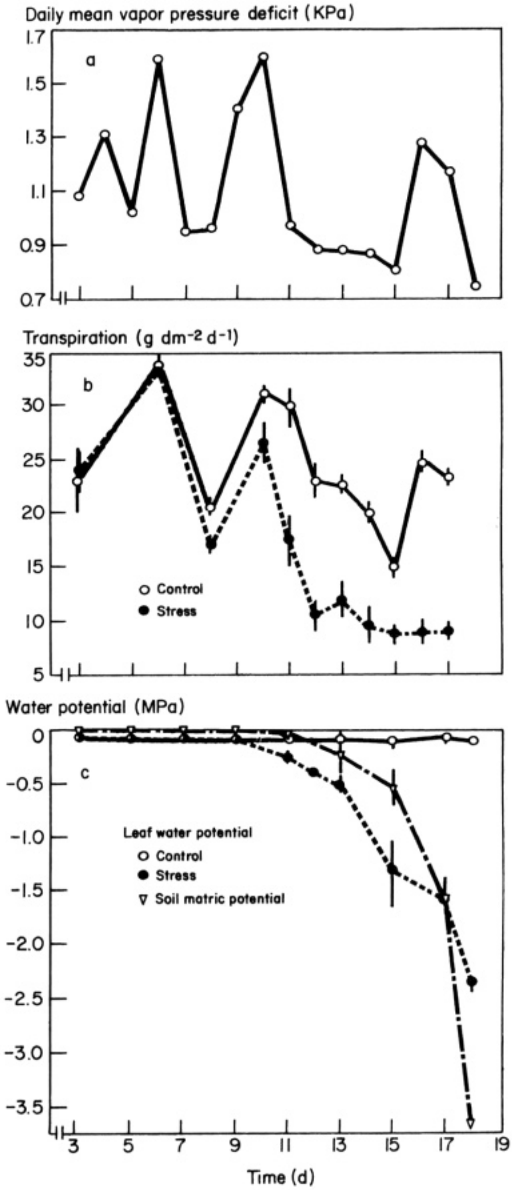
O'Toole and Baldia (81) studied N, P, and K uptake under moisture deficit. Transpiration rate was the most sensitive variable to water stress (Fig. 27). Cumulative N, P, and K uptake were lower in stressed rice plants (Fig. 28). Their results illustrated the interactions between soil and plant water potential, cumulative transpiration, and cumulative uptake of N, P, and K.

At Goiania, Brazil, Stone et al (115) studied the influence of water deficiency on N response of IAC1246, IAC47, and CICA4. When soil water content was not limiting, grain yield increased in response to N fertilization up to 60 kg N ha^{-1} When soil water content was low, there was no response to fertilizer.

A line source sprinkler system is a convenient way to evaluate the effect of drought on rice. Sprinklers are placed along an irrigation line so that water



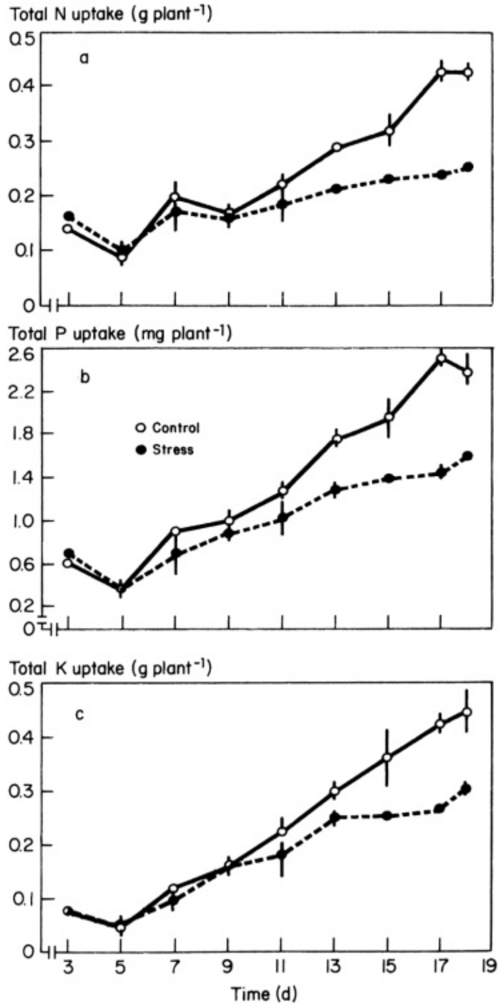
26. Grain yield response of upland rices to applied N and seeding date (66).



27. Time course of changes in a) daily mean vapor pressure deficit, b)transpiration rate, and c) water potential of leaf and soil during an 18-d drying period (81).

distribution is constant along any line parallel to the sprinkler line. The system produces a water application pattern that is uniform along the length of the sprinkler line and continuously but uniformly variable at right angles to it.

Aragon and De Datta (3) evaluated the yield and growth responses of four rices at seven irrigation and three N levels using the line source sprinkler system. Varieties were also scored for visible drought reaction and leaf water potential (LWP).

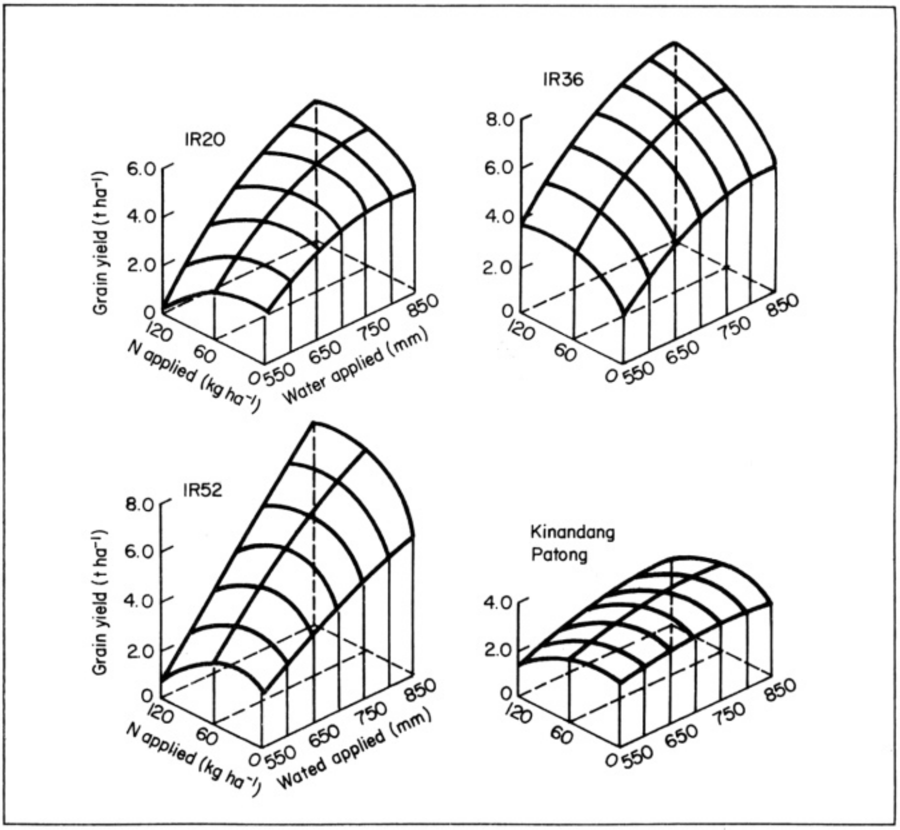


28. Time course of cumulative uptake of a) N, b) P, and c) K during an 18-d drying period (81).

Traditional Kinandang Patong was least affected by drought and IR20 was most affected. Increasing N from 0 to 60 and 120 kg N ha^{-1} increased the degree of water stress, which decreased LWP. At all N levels, Kinandang Patong had significantly higher LWP than IR20.

The yield-water-fertilizer relationships of the four varieties revealed different production surfaces (Fig. 29). Early maturing IR52 yielded highest at 120 kg N ha^{-1} and maximum water (850 mm). Without N, Kinandang Patong yielded highest with 550 mm of water. At 120 kg N ha^{-1} and 550 mm water, IR36 yielded more than the other rices.

Tillage. In the humid tropics, the aerobic condition of upland rice soils permits quick transformation of ammoniacal N to nitrates, which are easily lost to leaching. Nair et a1 (74) studied the effect of soil bulk density on leaching loss and grain yield.



29. Yield response surfaces of 4 rice varieties at different water and N levels (3).

N was applied at 0, 40, or 80 kg ha^{-1} at bulk densities varying from 1.2 to 1.3 Mg m^{-3}. Increasing bulk density increased grain production at all N levels (Table 18), but it is difficult to increase bulk density in the field.

Scientists at Ibadan and Onne, Nigeria, studied the effect of different tillage methods on water and fertilizer use efficiency of ITA 118. Tillage treatments were conventional tillage by plow and harrow, no-tillage with chemical weed control, and no-tillage plus 4 t straw mulch ha^{-1}. Fertilizer treatments were no fertilizer, 45-6.5-7.5 kg NPK ha^{-1}, and 90-13-15 kg NPK ha^{-1}. No-till plots were treated with 2.5 litre paraquat ha^{-1} 1 wk before seeding. Postemergence weed control in all plots was with 4 kg Stam F34 ha^{-1}.

At Ibadan, yields were significantly affected by tillage method, fertilizer level, and their interactions (Fig. 30). Conventional tillage produced 34 and 25% higher yields than zero tillage, with and without mulch. Fertilizer response also was much higher with conventional tillage. It should be noted, however, that the experiment was on plots that had been cultivated by conventional tillage for about 10 yr and were in poor condition.

Table 18. Rice response to N as influenced by soil compaction (mean grain yield of 3 seasons) (74).

N (kg ha^{-1})	Yield (t ha^{-1}) at bulk density of 1.200 t m^{-3}	1.260 t m^{-3}	1.318 t m^{-3}	Mean yield (t ha^{-1})
0	0.7	0.8	0.8	0.8
40	1.2	1.4	1.5	1.4
80	1.7	2.0	2.1	1.9
Mean	1.2	1.4	1.5	

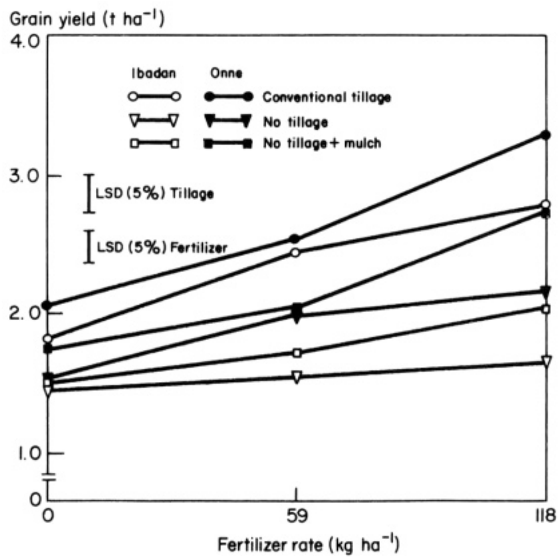
Rice yields at Onne were higher than at Ibadan. Conventional tillage plots outyielded no-tillage with and without mulch. Fertilizer response was highest with conventional tillage, followed by no-tillage with mulch (36).

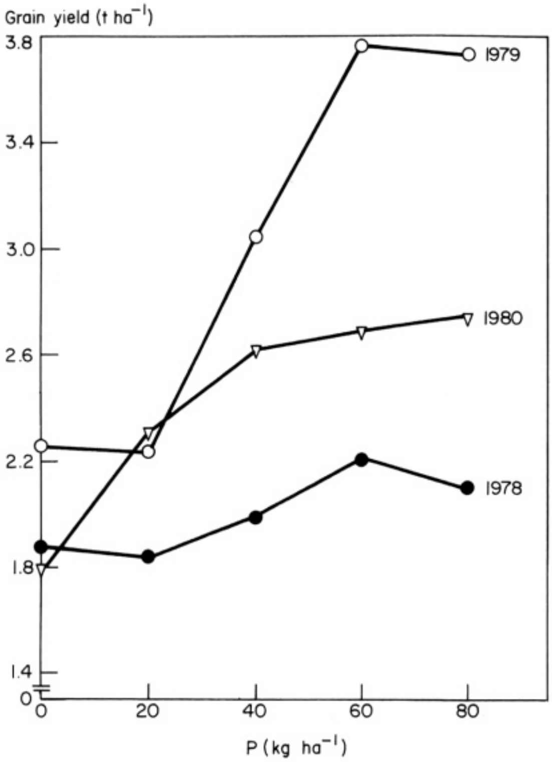
Phosphorus management

P deficiency is common in upland rice, especially in Oxisols and Ultisols in Brazil, West Africa, and some parts of South and Southeast Asia. These soils have low P and high P fixation capacity.

Singh and Modgal (l06) found that modern semidwarf rices removed 16 kg of P from the soil, of which 60% was translocated to the grain. N application significantly influenced P uptake in grain and straw. Short duration (100-110 d) upland rices responded to up to 18 kg applied P ha^{-1} in laterite soils of eastern India (65, 84) (Fig. 31). In the Philippines, 18 kg P is recommended for upland rice (88).

30. Effect of fertilizer rate and tillage method on upland rice yield, Ibadan and Onne, Nigeria (36).





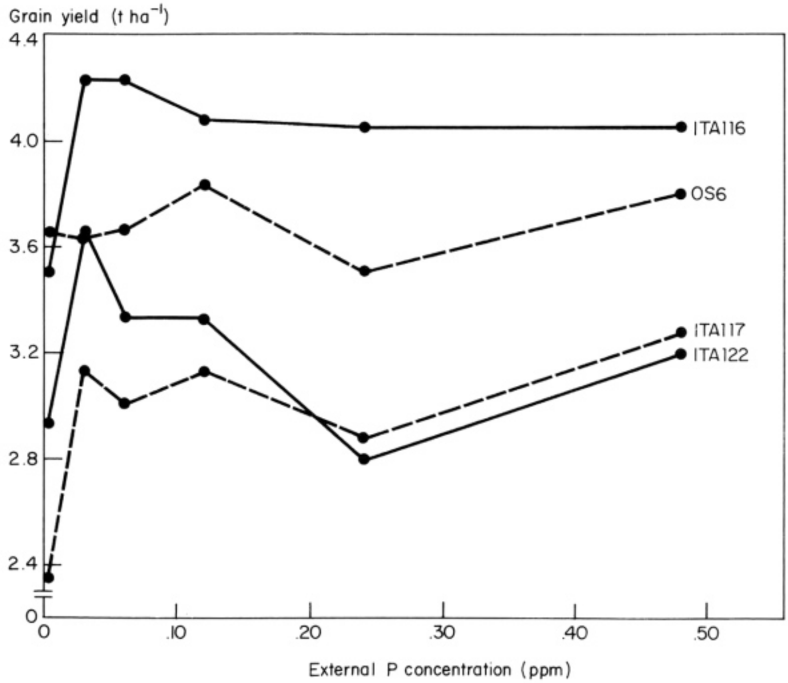
31. Response of rainfed terraced upland rice to different levels of applied P (65).

In Nigeria, where upland rice is a major crop, response to applied P has been inconsistent. Increasing P did not affect upland Agbede, but swamp variety BG79 yielded higher with added P (20). IITA pot and greenhouse studies (36) indicated that upland varieties responded significantly to added P. In pot experiments, OS6 and ITA122 responded to 0.06, ITA117 to 0.03, and ITA116 to 0.12 ppm of added P.

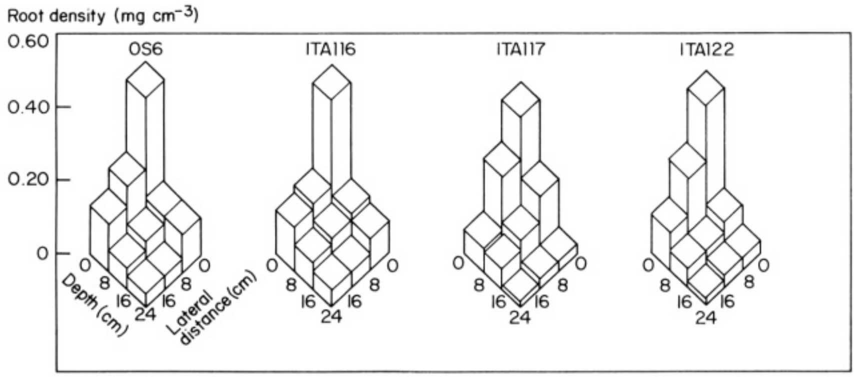
Rice responded less to added P in the field, and OS6 showed no response. The other varieties responded only up to 0.03 ppm (Fig. 32). Low response in the field may be attributed to more extensive root growth, which enables varieties to use P from a larger soil volume. OS6 and ITA116, which yielded high with or without added P, have extensive root systems (Fig. 33).

In cerrado soils in central Brazil, Fageria (22) found that for upland rice P is the most limiting factor after water. Cerrado soils have low available P, high P fixation, low pH, and low cation exchange capacity. Under normal conditions, yield increased up to 66 kg P ha^{-1}. In another study (23), grain yield increased significantly up to 66 kg P in 1977-78 and up to 44 kg P in 1978-79 (Fig. 34). With these P levels, rice yielded 4.4-4.8 t ha^{-1}. Dry matter production, leaf area index, and tillers per unit area increased with P (Fig. 35, 36, 37).

Phosphorus sources. Table 19 lists P fertilizers and their characteristics. There is limited information on the efficiency of these P fertilizers for upland rice. Lal and

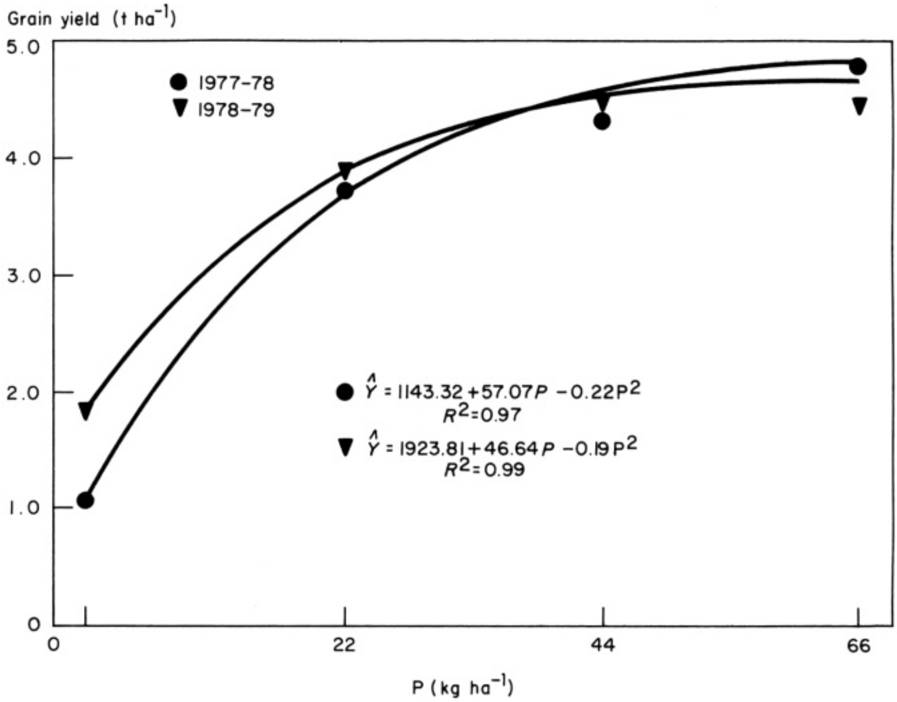


32. Effect of P concentration on yield of 4 upland rices grown on an Alfisol (oxic Pa1eustalf) at Ikene, Nigeria (35).

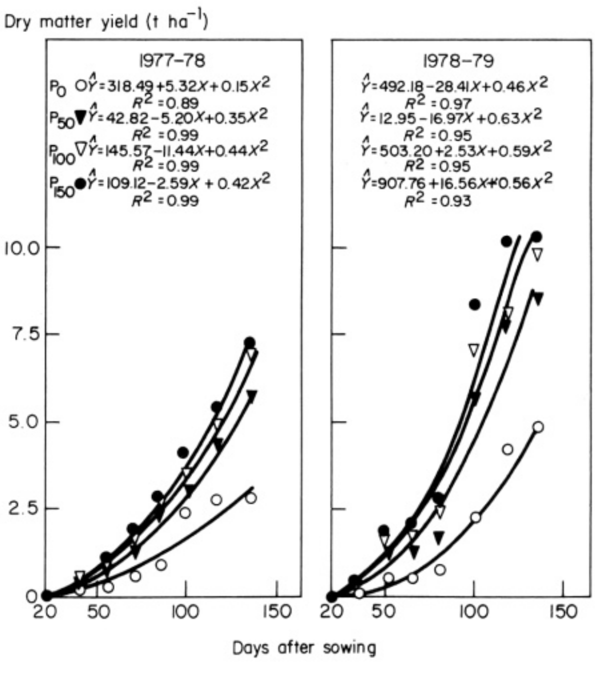


33. Root distribution at 60 d after planting of 4 rices grown under upland conditions without applied P on Alagba soil at Ikene, Nigeria (36).

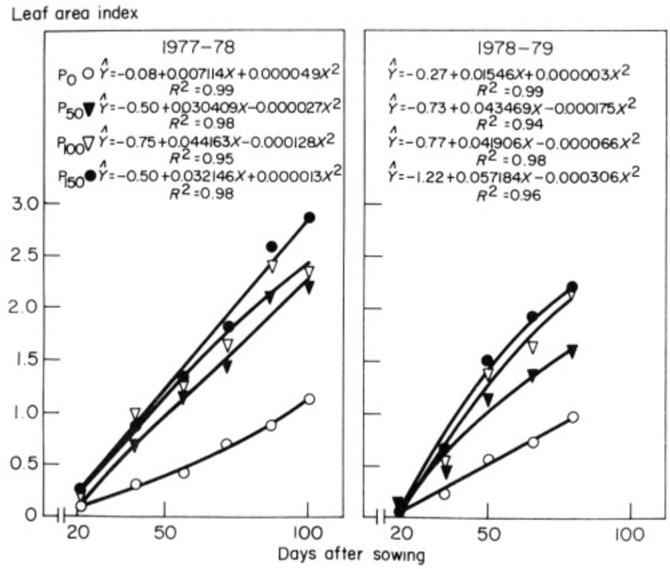
Mahapatra (60) studied P transformation in welldrained and waterlogged alluvial, black, laterite, and red soils in India. Ca-P dominated in alkaline alluvial and black soils and Fe-P in acid laterite soil. Neutral red soil fixed both Ca-P and Fe-P. In red and laterite soils, P sources with low water-soluble P can be used because the added P is transformed to Fe-P and A1-P, which is available to rice. In alluvial and black



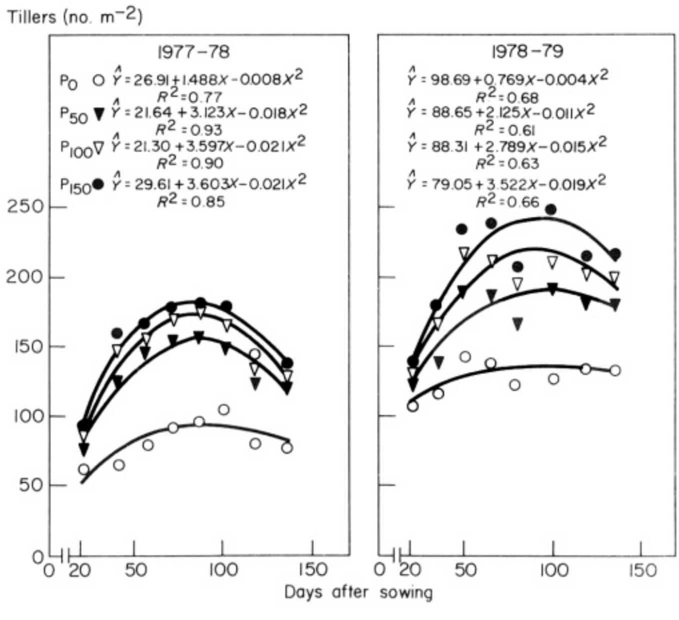
34. Grain yield with P fertilization (23).



35. Effect of P fertilization on dry matter production (23).



36. Effects of P fertilization on leaf area index (23).



37. Effect of P fertilization on tiller number (23).

soils, P sources must have 50% or more water-soluble P to be effective for rice.

At Rokupr and Kenema, Sierra Leone, Mahapatra et al (63) compared single superphosphate with rock phosphate and basic slag. The Rokupr soil's pH was 5.5 to 5.7. The Kenema soil had more clay than the Rokupr soil, but both soils were

Table 19. Characteristics of common P and NP fertilizers (adapted from [17]).

Fertilizer	Representative grades (% $N\text{-}P_2O_5\text{-}K_2O$)[a]	Water solubility of P (%)	Major compounds present
P source			
Ordinary superphosphate (H_2SO_4)	0-20-0	85	$Ca(H_2PO_4)_2 \cdot H_2O$, $CaSO_4 \cdot 2H_2O$
Triple superphosphate (WP H_3PO_4)	0-45-0	87	$Ca(H_2PO_4)_2 \cdot H_2O$
Basic slag	0-9-0	2	Ca silico-carnotite
Florida phosphate	0-32-0	1	Carbonato apatite
NP source			
Monoammonium phosphate	11-48-0	90	$NH_4H_2PO_4$
Diammonium phosphate	21-53-0	100	$(NH_4)_2HPO_4$

[a] Convert $N\text{-}P_2O_5\text{-}K_2O$ to N-P-K by multiplying by 1.0-0.44-0.83.

well drained. The experiment used a continuous function design to allow fertilizer-soil contact from 10-90% of the soil surface area. Except at Kenema, where rock phosphate gave the lowest yield, rock phosphate, basic slag, and single superphosphate performed similarly (Table 20). Rock phosphate and basic slag gave the highest yield at 70-90% contact area. For single superphosphate, there was no

Table 20. Yield response of upland rice with different P sources and placement (18 kg P ha^{-1}) (63).

P source	Soil surface area (%) receiving fertilizer	Mean grain yield (t ha^{-1})	
		Rokupr	Kenema
Control		0.8	1.8
Single superphosphate			
1	10	1.4	1.9
2	30	1.6	2.4
3	50	2.0	2.6
4	70	1.8	2.7
5	90	1.9	2.5
Rock phosphate			
1	10	1.3	2.0
2	30	1.7	2.0
3	50	1.7	1.8
4	70	2.1	2.2
5	90	2.0	2.3
Basic slag			
1	10	1.3	2.3
2	30	1.5	2.2
3	50	1.7	2.3
4	70	1.9	2.8
5	90	2.1	2.5
LSD (5%) Soil contact area		0.1	0.3
Soil contact X source		0.2	0.7
CV (%)		10	3

significant difference between 50 and 70% contact areas. For water-soluble P sources such as single superphosphate, 50% contact is needed for optimum efficiency. For water-insoluble forms, 70% or more contact is required.

Timing and application. P seldom moves more than 3-4 cm from the placement site in soil. The phosphate ion ($PO4^-$) is precipitated as Ca, Fe, or Al phosphates, which explains the reduction of the phosphate solution when water-soluble phosphate is added to the soil.

In experiments at Ranchi, India, in 1978-80, a basal application of compost with single superphosphate at 18 kg P ha^{-1} (Table 21) gave good results and was similar to a basal application of compost with rock phosphate or an application of compost with single superphosphate at active tillering (65).

For moisture stress conditions, seed treatment with a nutrient solution has increased grain yield (19, 104). In Sarawak, Malaysia, where shifting cultivation is common, Dunsmore (19) found that mixing 3.8 litres of seed with 0.9 kg of monoammonium phosphate (11% N:21% P) just before dibbling produced yields equivalent to those with 1.1 kg added N and 2.2 kg P ha^{-1}.

In West Bengal, India, Singh and Chatterjee (104) found that soaking seed in water for 24 h and drying it back to the original moisture content increased upland rice yield by 17%. Soaking in a Na_2HPO_4 solution increased grain yield an additional 7-10%. Applying a foliar spray of P fertilizer, $ZnSO_4$, or Agromin, a nutrient compound containing Mg, Zn, Fe, Cu, Mn, B, and Mo, increased grain yield 10-20%. Plants grown from treated seeds had good stand establishment, fairly fast seedling growth, and well developed roots.

Potassium management

Substantial K is absorbed by upland rice plants, but only a small portion is translocated to grain. The rest remains in the straw (23, 106). K deficiency is not so serious a problem as N and P deficiency, but some coarse-textured soils in high rainfall areas are affected. Muriate of potash (KCl) is the most common K fertilizer. Other K fertilizers and their characteristics are listed in Table 22.

Table 21. Treatments to increase P-use efficiency of short-duration rainfed rim in terraced upland soils, Ranchi, India, 1979-80 (65).

Treatment	Yield (t ha^{-1})		
	1979	1980	Mean
No P	2.2	1.6	1.9
Basal application of SSP (18 kg P ha^{-1})	2.2	2.5	2.5
Application at active tillering by topdressing (18 kg P ha^{-1})	2.8	2.5	2.6
Basal application of compost-treated SSP (18 kg P ha^{-1})	3.1	2.8	3.0
Application of compost-treated SSP (18 kg P ha^{-1}) at active tillering	2.8	2.6	2.7
Basal application of compost-treated Mussorie rock phosphate (18 kg P ha^{-1})	2.8	2.8	2.8
CD at 5%	0.3	0.3	

Table 22. Characteristics of common K fertilizers (adapted from [17]).

Fertilizer	(%) K_2O	(%) K	Salt index[a]
Muriate of potash	60-62.5	49.8-51.9	32
Sulfate of potash	50-52	41.5-43.2	14
Potassium nitrate	44	36.5	20

[a] Per equal weight of nutrients; sodium nitrate = 100.

At Ranchi, India, upland rice responded to 33 kg K ha^{-1} applied at planting. Applying it in equal splits at planting and as a topdressing or foliar application 30 d after sowing was similar to applying a single basal dose (65). In Njala and Kenema, Sierra Leone, Mahapatraet al (64) applied 33 and 66 kg K ha^{-1} in 2, 3, 4, or 5 splits. At Njala, 66 kg K in 4 splits outyielded the control. At Kenema, upland rice responded up to 66 kg K ha^{-1}, but response did not differ with application method (Table 23). Applying 33 kg K ha^{-1} has been adequate in some African countries (37).

Other nutrients

Zn, Fe, and S deficiencies in upland rice have been reported (16, 26, 50, 79, 80). Zn deficiency identified by De Souza (16) in Brazil in a soil with pH <7 was corrected by applying 1 kg Zn ha^{-1} in the rows at planting. Zn deficiency symptoms were visible when plant tissue had less than 15 ppm Zn.

Barbosa Filho et al (26) evaluated different sources and methods of Zn application in Brazilian cerrado soils. $ZnSO_4$, ZnO, and ZnCl were better than FTEBR-12 and Micronutri-222. There was no significant difference among responses to $ZnSO_4$, ZnO, and ZnC1. In one of three experiments, broadcast and banded application performed better than seed treatment and foliar application.

Table 23. Grain yield of ROK3 with different K application times (64).

Time of K application	Njala		Kenema	
	Yield (t ha^{-1})	% over control	Yield (t ha^{-1})	% over control
66 kg K ha^{-1}				
2 splits	1.2	26	1.2	47
3 splits	1.3	36	1.3	59
4 splits	1.4	48	1.3	61
5 splits	1.2	21	1.1	43
33 kg K ha^{-1}				
2 splits	1.1	10	1.0	22
3 splits	1.2	20	1.0	30
4 splits	1.3	30	1.0	30
5 splits	1.3	36	1.1	38
Control yields	1.0		0.8	
LSD 5%	0.4		0.4	
CV	23.3		22.7	

Performance did not significantly differ in the two other experiments. Grain yield was significantly less in the no-Zn treatment.

Zn deficiency is common in sandy soils of subhumid West Africa. Symptoms include chlorotic, yellow young or newly developed leaves. Older leaves are dark green. All the leaves of a seriously affected plant may become whitish.

Acute Zn deficiency was recently observed on upland rice grown in Atebubu. central Ghana (51).

Iron deficiency has been observed in calcareous soil with high pH in Hyderabad, India, where it causes chlorosis in upland rice seedlings (79). Sulfuric acid treatment effectively removed the chlorosis. FeEDDHA, an Fe-chelator, also corrected chlorosis.

Kang et al (50) found that Fe deficiency was an important problem in upland rice in western Nigeria. Fe deficiency increases with soil pH and is closely associated with burnt spots and sites where village refuse once was dumped. Adding high rates of ash induced Fe chlorosis, increased soil pH, and reduced plant dry weight.

In greenhouse and field experiments, Kang et al found a strong relationship between soil pH and Fe chlorosis. Fe in the rooting medium became less soluble as pH increased. Adding wood ash increased soil pH and induced Fe deficiency. A foliar application of $Na_2FeDTPA$ corrected Fe deficiency and significantly increased grain yield. Applying S dust did not reduce chlorosis, perhaps because of the low rate of bacterial oxidation of S in soil with high pH. Applying Fe to the soil as $Na_2FeDTPA$ did not eliminate Fe deficiency.

In Maharastra, India, on a calcareous Vertisol with pH 8.7, coating seed with 2% Fe as $FeSO_4.7H_2O$ and FeEDTA increased grain yield and Fe uptake (32). The Fe treatments performed similarly (Table 24).

S deficiency was observed by Osiname and Kang (80) in the western Nigerian forest zone in soils derived from tertiary sedimentary rocks and in sandy soils

Table 24. Yield and nutrient uptake in rice as influenced by coating seed with Fe compounds (32).

Treatment	Rice yield (t ha^{-1})		Nutrient uptake in rice grain		
	Grain	Straw	P (kg ha^{-1})	Fe (g ha^{-1})	Mn (g ha^{-1})
Presowing soil water treatments					
Control	2.08	2.43	13.86	288	86
Soil saturation	2.30	2.70	15.36	330	95
F test	**	**	**	**	**
SE ±	0.02	0.02	0.19	1.8	1.4
CD at 5%	0.06	0.05	0.57	5.4	4.0
Seed coating					
Control	2.09	2.43	14.55	289	89
$FeSO_4.7H_2O$	2.24	2.63	14.64	319	91
Fe EDTA	2.25	2.64	14.64	319	91
F test	**	**	ns	**	ns
SE ±	0.02	0.02	0.23	2.2	1.7
CD at 5%	0.07	0.06	-	6.6	-

derived from a basement rock complex. They found that applying S to upland rice in the greenhouse increased growth and dry matter content. Grain yield was highest with 20 ppm S applied as Na_2SO_4. S content in leaves was highest during early growth and decreased with plant age. Critical S was estimated at 0.15% for OS6 and IR20. S content was best judged by testing the leaf nearest the flag leaf at flower emergence.

Organic manure

There is very little information on the effect of organic and green manures on upland rice soils. Moormann and Veldkamp (71) found that organic matter increased available water-holding capacity and cation exchange capacity, improved soil structure, and through mineralization provided nutrients, primarily N, to rice. Organic and green manures are intended to increase organic matter content of the soil as well as provide nutrients to upland rice.

Nagai (72) found that applying compost and farmyard manure significantly increased upland rice yields in P-deficient volcanic soils in Kanto and Kyushu, Japan. Applying 29,545 kg compost, 127 kg ammonium sulfate, 136 kg single superphosphate, and 46 kg potassium chloride is recommended for upland rice to provide 198-74-124 kg NPK ha^{-1}. Applying well-cured night soil to supply 91-141 kg N ha^{-1} also is recommended.

Applying 10 t cattle manure and urine ha^{-1} to broadcast-seeded upland rice in Japan significantly increased growth and yield, and particularly spikelets per panicle (5).

Pande et a1 (83) compared inorganic fertilizers with farmyard and green manure at 45 kg N ha^{-1}. One- and one-half-month-old *Sesbania aculeata* plants (grown elsewhere) were used as green manure (Table 25). Farmyard and green manure were applied 2 wk before sowing upland rice. Ammonium sulfate was applied at 67.5 kg and 22.5 kg N ha^{-1} in combination with farmyard and green manure. The manure combinations were as effective as 45 or 67.5 kg N as ammonium sulfate or ammonium nitrate, indicating that part of the N needed by upland rice can be provided by farmyard or green manure. Organic manure also lowered bulk density, and increased organic C and mean weight-diameter of water-soluble aggregates, which benefits upland rice and succeeding crops.

A problem with green manuring upland rice is that a green manure crop often must be planted at the same time as rice. This can be overcome by growing green manure somewhere else and bringing the leaves and stems to the rice field. A green manure crop also can be grown with rice at 2-3 m spacing and leaves and stems can be incorporated in a 4- to 6-wk-old standing rice crop. Where growing season is long, a green manure crop can be planted before rice. More research should be conducted on green manuring of upland rice.

Sometimes, farmyard manure is enriched by adding inorganic fertilizers. In Tamil Nadu, India, 10 kg of $FeSO_4$ and 50% of recommended P and K are added to 5 t of farmyard manure, incubated for 15 d in pits covered with trash, and stirred. The compost can be used after 1 mo.

Rice straw contains about 2.2% K, 0.4% N, and 0.2% P. If properly recycled, it can provide part of the NPK needed for the next crop, and can improve soil

Table 25. Effect of different organic manures with and without ammonium sulfate (applied on an equal N basis) on upland rice and soil physicochemical properties (83).

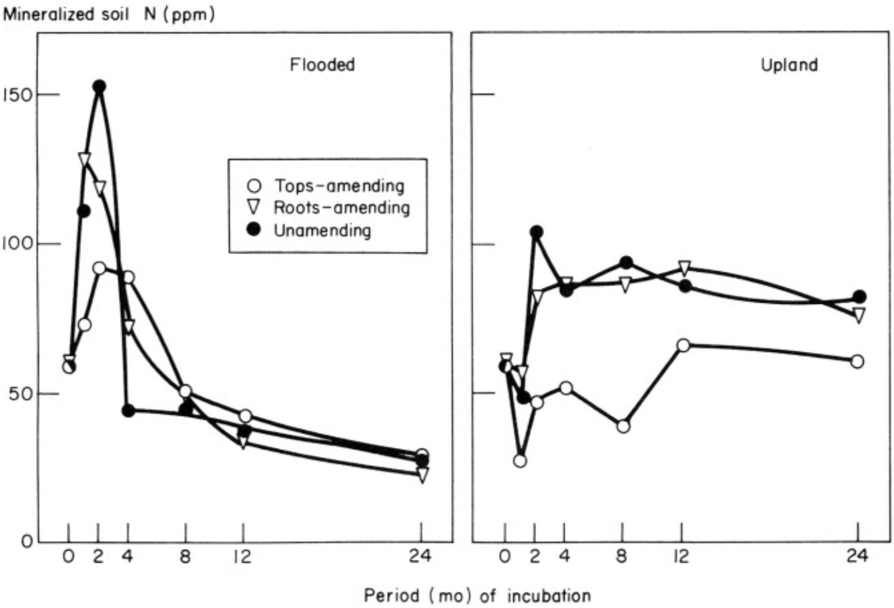
Treatment	Grain yield (t ha^{-1})	N in plant at harvest (%)	P in plant at harvest (%)	K in plant at harvest (%)	Mean wt-diam of soil aggregates	Soil bulk density (t m^{-3})	Organic C of soil (%)	N content of soil (%)
Control	1.3	1.081	0.177	1.102	.3023	1.604	.3902	.0377
Farmyard manure (FYM)	1.7	1.171	0.207	1.222	.3839	1.504	.4112	.0402
Green manures (GMS)	1.8	1.156	0.188	1.137	.3727	1,505	.4087	.0391
AS-N 45.0	2.5	1.290	0.157	1.017	.3412	1.552	.4003	.0384
FYM + AS-N 22.5	2.6	1.370	0.201	1.202	.4042	1.502	.4269	.0408
GMS + AS-N 22.5	2.5	1.328	0.182	1.101	.3917	1.509	.4091	.0394
AS-AN 67.5	2.5	1.441	1.130	0.937	.3345	1.549	.4047	.0382
SEm. (+)	0.16	0.050	0.008	0.017	.0218	0.015	.0049	.0006
CD 5%	0.3	0.147	0.023	0.049	.0641	0.044	.0144	.0017
CD 1%	0.4	0.200	0.031	0.067	–	0.060	.0196	–

physical conditions. Fageria et al (23) found that incorporated rice straw was a rich source of K. Kanazawa and Yoneyama (48) studied the degradation of ^{15}N labeled rice straw in flooded and upland soils, and found that incorporating fresh plant material increased microbial activity in the soil. Microorganism population was higher in upland than in flooded soil, mainly because of a higher actinomycetous population. Actinomycetous fungi cause cellulose and lignin to decompose. In the first months after incorporation, C content of the residue decreased rapidly.

In flooded soil, decomposition of plant residues immobilized soil N, thus decreasing net mineralized soil N (Fig. 38), and substantial N was lost to denitrification. Upland soils lost less mineral N than flooded soils, and ammonium concentration derived from rice residues was less. The concentration of residue-derived nitrate increased gradually during the experiment. The ammonium produced may nitrify quickly, resulting in a gradual increase in residue-derived nitrate. Immobilized N is then mineralized through the autolysis of microbes. More studies of crop residue management for upland rice are necessary.

PROBLEM SOIL MANAGEMENT

Upland rice grows on many soils. Some, such as Oxisols. are highly weathered and some, such as Andisols, are very fertile. Several soil problems limit upland rice productivity. The soil problem may be physical, hydrological, or chemical and include erodibility, poor water retention, poor nutrient status, and toxicities.



38. Changes in inorganic mineralized N in soils incubated in flooded and upland conditions. Treatments were tops-amending (rice tops were incorporated) (O), roots-amending (rice roots were incorporated) (∇), and unamending (•) (49).

Von Uexkull(117) defied problem soils of the humid tropics as

Soils that after the removal of their forest cover cannot be permanently cropped with annual crops by small holder farmers with the financial and technological means currently available to them.

Dudal (18), in *Soil related constraints to agricultural development in the tropics,* gives a detailed description of the problems of various soil groups of the world.

The distribution of problem soils varies greatly. Sanchez and Cochrane (100) report that 70% of the soils of tropical America are acidic. Most soil constraints are chemical, and the most common are A1 toxicity; P deficiency and fixation; N, K, Ca, Mg, S, and Zn deficiency; and low cation exchange capacity.

In Southeast Asia, about 14% of soils pose no major problem for agriculture, but 59% suffer from mineral stress, 19% from excess water, 6% from shallow depth, and 2% from drought (15). Moormann and Greenland (70) listed low nutrient status, rapid erosion, and increased acidity as the major soil constraints to crops caused by prolonged cultivation in the humid tropics of Africa. Saline and sodic soils, acid, and acid sulfate soils cover about 60 million of 140 million cultivated ha in India (28).

Ponnamperuma (90) listed 11 problem lowland rice soils: saline, saline sodic, sodic, acid sulfate, Fe toxic, peat, K deficient. Zn deficient, cold, highly reduced, and highly oxidized. Most upland soil problems are nutrient deficiencies, which have already been described, and toxicities. Major upland soil problems include Al and Mg toxicities in acid soils.

Acid soils and aluminum toxicity

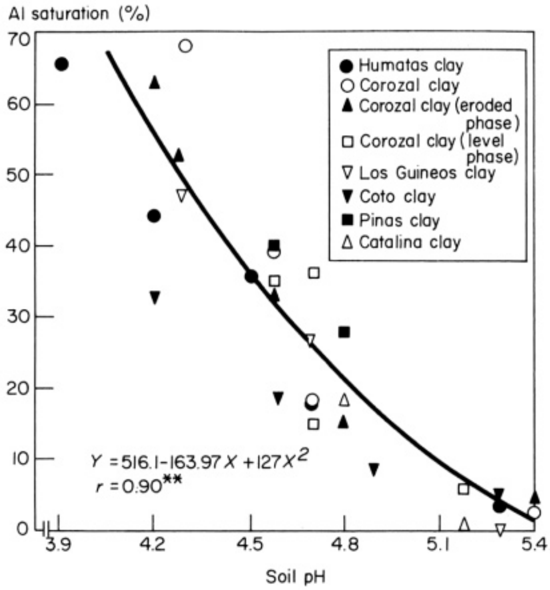
There are millions of hectares of acid soils in the humid tropics because of intense weathering caused by high temperatures and rainfall. Weathered soils are generally acidic, low in bases, and highly Al saturated. Upland rice frequently is grown on such soils in Brazil, West Africa, and South and Southeast Asia.

A1 is a dominant cation associated with acid soils. Al content is determined by saturating the soil with an unbuffered normal salt solution such as 1N KCI. Soil pH and A1 saturation are closely related (Fig. 39). Al content in the soil solution increases with salt content because other cations displace exchangeable Al. If exchangeable A1 is 60%, there is less than 1 ppm Al in the soil solution. If exchangeable A1 rises above 60%, Al in the soil solution increases dramatically. Al content of the soil solution decreases as organic matter content increases because Al forms complex with organic matter (99).

Effect of aluminum saturation and pH on rice growth

pH does not harm crop growth if it is not less than 4.2 (99). Coronel (12) found no adverse effect of pH 3.5-5.0 on rice root growth in a nutrient culture study at IRRI. Growth reduction occurred at pH 3.0 and 6.0; therefore acid soil infertility is caused by A1 or Mn toxicity and Ca or Mg deficiency.

Rice roots rapidly absorb Al. Without nutrient cations, water soluble Al concentrations as low as 1-2 ppm markedly inhibit root growth (8). Fageria and Carvalho (25) found that 40-60 ppm AI concentration decreases nutrient uptake in upland rice. In the tops of 21-d-old plants, critical A1 level varied from 100 to



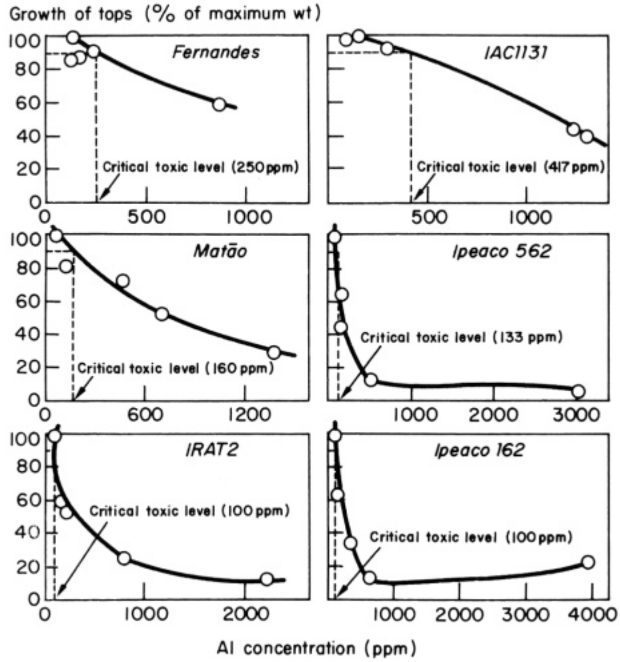
39. Relation between pH and Alsaturatlon for Puerto Rico's Ultisols and Oxisols (1).

417 ppm, depending on the cultivar (Fig. 40). At IRRI, Al concentration from 0-60 ppm did not affect rice seed germination (41). Such data indicate that there is no fixed critical level for Al toxicity in rice. It varies with variety and medium. Al content is 1-5 ppm in most soil solutions.

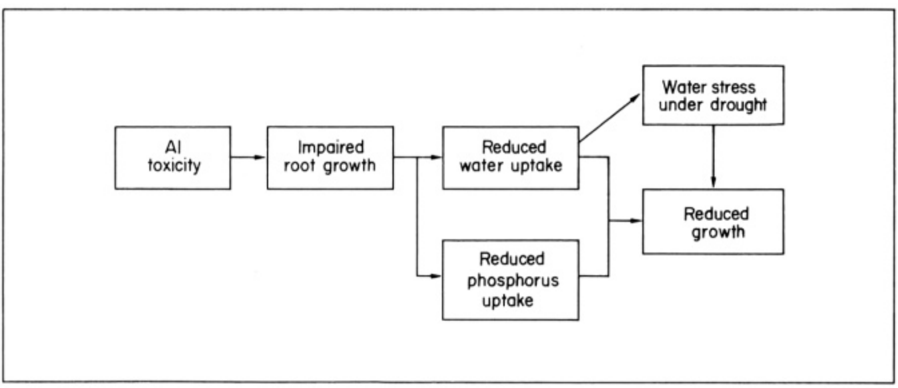
The effect of Al toxicity on rice was studied at IRRI (41), where it was observed that although Al concentration of 0-60 ppm in solution did not adversely affect germination, it did reduce root length (Table 26). At only 3 ppm Al, roots of susceptible varieties were affected. At 10 ppm, roots of all varieties were severely damaged.

Fageria and Carvalho (25) found that Al concentrations of 40-60 ppm inhibited nutrient uptake of upland rice. Uptake of macronutrients was affected in the order Mg > Ca > P > K > N > S > Na and micronutrients in the order Mn > Zn > Fe > Cu > B. Some reasons for reduced nutrient uptake follow:

- Al inhibits root growth.
- Al reduces cellular respiration in plants and thus inhibits the uptake of all ions.
- Al increases the viscosity of protoplasm in plant root cells and decreases overall permeability to salt.
- Al blocks, neutralizes, or reverses the negative charge on the pores of the free space and thereby reduces the abilities of such pores to bind Ca.
- Al may compete for common binding sites at or near the root surface and thereby reduces K, Ca, Mg, and Cu uptake.
- Part of the Ca accumulation mechanism may be inactivated by Al.
- Al interferes with cell division in plant roots, decreases root respiration, interferes with enzymes that govern polysaccharide deposition in cell walls,



40. Relation between dry matter production and Al concentration in the tops of 21-d-old rice plants (25).



41. Effect of Al toxicity on rice (41).

increases cell wall rigidity (by cross linking pectins), and interferes with uptake, transport, and use of elements such as K, Ca, and Mg.

- Al injures plant roots and reduces Ca uptake.
- Al decreases sugar content, increases the ratio of nonprotein to protein N, and decreases P content of the leaves of plants grown on acidic soils.

Additionally, because Al reduces root growth (41, 42), it increases susceptibility to drought (Fig. 41).

Table 26. Effect of Al on maximum and total root length[a] of 6 varieties grown in a culture solution (41).

Variety	Al concentration (ppm)			
	0	3	10	30
	Maximum root length (cm)			
IR20	7.2	5.9	3.2	1.5
CICA4	13.0	9.8	4.2	2.4
IR5	14.8	12.6	6.7	4.0
Bluebonnet	15.5	15.9	7.3	5.3
Monolaya	19.3	19.3	9.5	8.1
E425	19.5	16.7	12.9	9.1
	Total root length (cm plant^{-1})			
IR20	194	112	46	19
CICA4	539	282	98	13
IR5	686	385	163	56
Bluebonnet	380	370	176	119
Monolaya	587	464	258	194
E425	474	456	232	142

[a]Measured at 2 wk after sowing pregerminated seeds.

Acid soils also have Mn toxicity. Mn is highly soluble at pH <5.5, and if present in high concentrations, Mn toxicity can occur with Al toxicity at pH 5.5 to 6.0. Al toxicity, however, is more common than Mn toxicity.

Amelioration of acid soils

The adverse effects of acid soils can be ameliorated by applying lime to raise pH, by planting varieties resistant to Al and Mn toxicities, and adding organic matter.

Liming. Liming neutralizes exchangeable Al and Mn by raising pH to 5.5-6.0. Amount and quality of lime and placement method are important considerations.

Computing the lime requirement of an acid soil based on laboratory incubation with $CaCO_3$ is tedious. Sanchez (99) described a simple procedure for computing lime requirements of tropical soils based on Al saturation. Appropriate liming rates can be calculated based on 1.65 t $CaCO_3$ equivalent ha^{-1} per meq exchangeable Al. Applying this amount of lime will raise pH to 5.5-6.0 and virtually eliminate Al saturationin most mineral soils. This technique significantly reduces lime requirements. If Al is 1-3 meq, the requirement is only 1.6 to 5.0 t lime ha^{-1}.

Lime sources are scarce in the tropics, and selection should consider Ca and Mg content of the lime and the soil. Lime should be 60-mesh or above; it is better if it is 100-mesh grade.

Lime commonly is incorporated in the top 15 cm of soil 3-4 wk before planting rice. Where drought is a problem, deep placement may favor extraction of water from deeper horizons because roots can go deeper if Al toxicity is neutralized. Deep placement, however, depends upon soil type and available equipment, and is easier in sandy soil.

Downward movement of lime is important to improve the subsoil, but occurs only with high rates of liming. If Ca and Mg are left free after saturating the topsoil, they move downward with rainwater in porous soil. Downward movement of lime is necessary in tropical soils with deep, acidic layers.

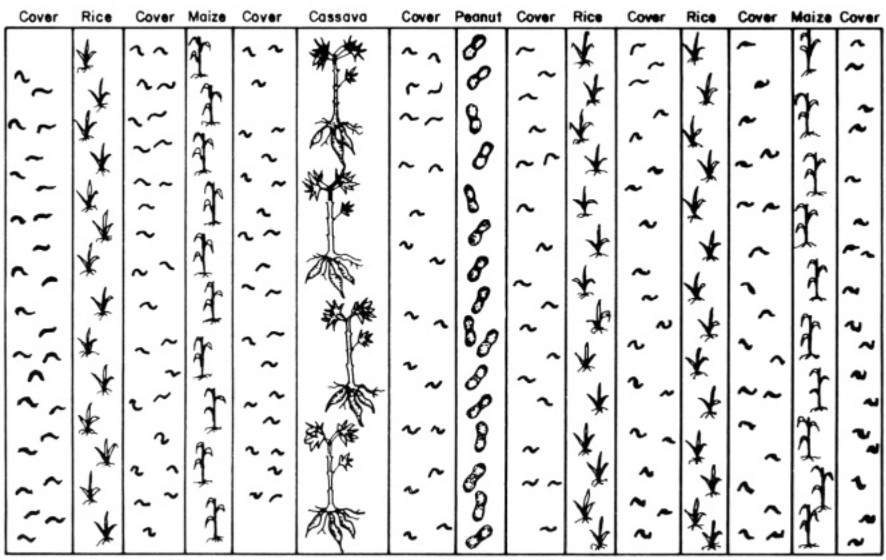
Liming above pH 6.0 sometimes causes more harm than good. It may reduce K availability and cause Zn, B, and Mn deficiency. Pande et al (83) studied the residual effect of lime applied to winter crop on the following upland rice crop. Lime benefited the winter crops, but raised pH to 7.06 and caused Fe and Mn deficiency in upland rice. They suggested that applying more than 3.4 t $CaCO_3$ equivalent ha^{-1} might harm upland rice.

Use of varieties tolerant of Al and Mn. Liming is expensive and impossible for many upland rice farmers. Planting Al and Mn tolerant varieties may be less expensive and more convenient than liming.

Several varieties have been identified as tolerant of Al and Mn (24, 30, 43, 77, 89) (Chapter 5). Most Al-tolerant varieties are from Latin America and Africa (43). ITA116 and Salumpikit were the most promising entries for acid uplands in the 1981 and 1982 IRTP (44,45).

Organic matter and crop management. Organic matter complexes Al and Mn and thereby decreases the Al and Mn in the soil solution (99). When crop organic residues are available, they should be incorporated in acid soil: However, relatively large amounts of organic residue are required for significant improvement.

Von Uexkull (117) suggested a low-cost management system for Indonesia to eliminate soil problems that develop after deforestation. He wrote that any management system must aim to maintain conditions as close as possible to those found under natural forest. In tropical soils with low pH and low cation exchange



42. Suggested upland cropping system based on rotating cover crops and food crops (117)

capacity it is important to keep the topsoil cool, moist. and shaded. Therefore, the soil must be covered by a living crop or mulch. He suggested the following practices:

- minimum disturbance of topsoil during clearing and cultivation (zero tillage);
- keeping the soil covered;
- stimulating biological activity through continued, small dosages of P, K, Ca, and Mg; and
- rotating food crops with leguminous covers (Fig. 42).

Depending on original fertility and fertility inputs, the ratio between the area used at any time for food crops and the area under legume fallow can vary from 1:1 to 1:3. Food crops should alternate with legume crops, which maintains fertility and keeps fields free from grasses.

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CHAPTER 7

Land Preparation and Crop Establishment

Tillage prepares soil for crop establishment and plant growth (7). Tillage methods generally have their greatest influence on plant growth early in the growing season, during germination and seedling root extension. In row-crop tillage, certain conditions must be created around the seed for germination and seedling growth. Larson (20) recognized two soil zones in row-crop tillage: the interrow seedling environment zone and the interrow water management zone.

Tillage tools can be used to create various microreliefs to manage water. Loosening the soil and increasing porosity by tillage forms a reservoir for temporary water storage and can prevent runoff losses and erosion (29). Tillage also controls weeds, incorporates crop residue and fertilizers, increases soil porosity and aeration, gives the soil a fine tilth to increase nutrient absorption, and increases moisture supply to the seed-soil interface.

LAND PREPARATION

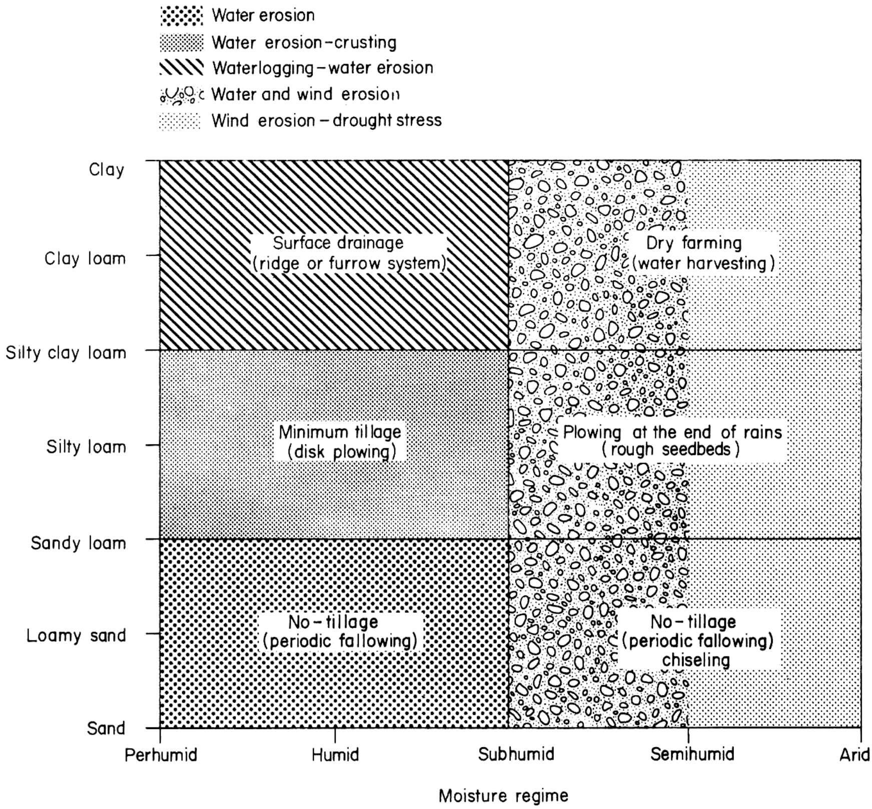
Land preparation for upland rice varies greatly depending upon rainfall pattern and soil type. Lal (18) proposed a tillage system for the tropics, where most upland rice is grown (Fig. 1).

In Nigeria, Senegal, Gambia, Sierra Leone, Liberia, Ghana, and Ivory Coast, where shifting cultivation is common, land preparation begins with slash and burn forest clearing before the monsoon begins. When the forest is cleared, land is prepared mostly by hand tools (Plate 7.1).

In South and Southeast Asia, land preparation starts when enough rain has fallen to permit tillage. There is very little mechanization (8, 22, 28). Fields are plowed by bullocks in South Asia and water buffalo in Southeast Asia.

In most of India, land preparation for upland rice begins with the monsoon in May-June. Fields are plowed with an animal drawn country plow and harrowed with a blade harrow. Weeds that have grown for 10 d are plowed into the soil. Fields are harrowed and leveled to form smooth, clod-free seedbeds. For shifting cultivation, bushes are cut and burned and the ashes are broadcast before plowing. Shifting cultivation is discouraged in hilly regions because it causes soil erosion (28).

Deep plowing and subsoiling across the slope conserve soil moisture in rainy season (22), preserve uniform soil structures, and enhance root growth and extraction of soil moisture from deeper soil layers. Summer plowing helps promote



1. Appropriate tillage systems for the tropics (18).

quick germination and control weeds. In Ranchi, India, summer plowing with a tractor-drawn disc plow reduced weed population better and increased upland rice yields more than with a bullock-drawn moldboard plow or a tractor-drawn cultivator (Table 1).

Deep plowing (25 cm or deeper) of moist soil at the end of rainy season is recommended for upland rice grown in the West African savannah (9). Deep plowing facilitates early planting; lowers soil bulk density, which improves root development and increases yields; increases soil structural stability; and reduces erosion.

In a tillage experiment in Ibadan, Nigeria, with 10 treatments on newly cleared land on Egbeda soil series (Table 2), deeper tillage treatments slightly reduced bulk density in the 0 to 10-cm zone. Hand hoeing did little to loosen the soil. Average bulk density in the 10- to 20-cm layer of all treatments increased with time from 1.45 to 1.62 t m^{-3}. Bulk density may have increased because of rainfall compaction, reduced organic C, and increasing gravel content in the topsoil (9).

Recent studies in India indicate the need for year-around tillage to ensure adequate weed control and moisture conservation. Periodic tillage also keeps soil

Table 1. Effect on rice yield of summer plowing by different implements under weeded and nonweeded conditions (22).

Implement	Grain yield (t ha^{-1})	
	Hand weeded	Nonweeded
No plowing	1.5	1.0
Dosi plow	2.0	1.4
Bullock-drawn moldboard plow	2.8	2.4
Tractor-drawn cultivator	2.7	2.4
Tractor-drawn disc plow	3.1	2.9
Mean	2.42	2.01
CD at 5% (plowing) =	0.07	
(weeding) =	0.03	

Table 2. Bulk density with 10 tillage treatments at 3 wk after planting during 4 yr in the 0-10 cm and 10-20 cm soil layers (9).

Treatment	Bulk density[a] (t m^{-3})							
	1971		1972		1973		1974	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Zero tillage	1.41	1.48	1.53	1.56	1.58	1.62	1.65	1.68
Hand hoeing, 8-10 cm	1.35	1.49	1.49	1.61	1.58	1.64	1.64	1.68
Rotary tillage, 12-15 cm	1.40	1.51	1.44	1.60	1.49	1.60	1.57	1.66
Japanese reversible plow, 12-15 cm,	1.37	1.49	1.44	1.60	1.45	1.63	1.52	1.66
Moldboard plow, 15 cm	1.31	1.44	1.47	1.59	1.48	1.60	1.60	1.64
Moldboard plow, 25 cm	1.37	1.43	1.40	1.49	1.53	1.54	1.53	1.54
Disk plow, 15 cm	1.36	1.42	1.46	1.58	1.48	1.60	1.60	1.66
Disk plow, 25 cm	1.36	1.43	1.41	1.50	1.52	1.57	1.58	1.56
Rototiller, 20 cm	1.29	1.36	1.39	1.41	1.41	1.53	1.56	1.58
Rototiller and subsoiler 20 cm and 50 cm[b]	1.39	1.46	1.44	1.51	1.43	1.59	1.55	1.58
Average	1.36	1.45	1.45	1.55	1.49	1.59	1.58	1.62
Significance	ns	5%	1%	5%	1%	1%	1%	1%
LSD (0.05)	-	0.08	0.07	0.11	0.06	0.06	0.06	0.04

[a] Av of 5 replications. [b] No tillage treatment in 1974 to study the residual effect of rototilling,

loose enough for tillage by animal power during the off season and when early rains begin (29).

In the Philippines, level and sloping upland fields are tilled when rains have softened the soil in early May, when rainy season begins. Fields are plowed with an animal-drawn *lithao* and harrowed with a spike-tooth harrow (kalmot) to achieve good tilth. Tillage is uncommonin hilly areas with shifting cultivation. Trees are cut and burned during summer and land is ready for wet season planting (21, 27).

Land preparation for upland rice varies greatly in Latin America (8). Shifting cultivation is common in the forests of Peru, Colombia, and Bolivia. Trees are felled and burned and seeds are dibbled with little land preparation (16), which is similar to slash and burn systems in Malaysia, Burma, Thailand, and the Philippines.

In Brazil, land preparation varies from farmer to farmer. Subsistence farmers, who own up to 50 ha of land, do most land preparation by hand. Transitional farmers, who may own 50-500 ha, use animal-drawn implements (Plate 7.2). Commercial farmers, who own more than 500 ha, use tractor-drawn implements (Plate 7.3). The land is plowed once, harrowed two-three times, and seed is drilled by machine.

ZERO TILLAGE VS CONVENTIONAL TILLAGE

The search for alternatives to conventionall and preparation has generated interest in zero tillage crop production. Eliminating or reducing tillage could reduce erosion of tropical soils, reduce rapid organic matter losses, and make possible the intensive use of tropical soils on a sustained yield basis (1).

Zero tillage is an extreme form of conservation tillage. Young (39) defines it as

> *placing the crop seed or seed transplant into the soil by a device that opens a trench or slot through the sod or previous crop residue only sufficiently wide or deep to receive the seed or transplant roots and to provide satisfactory seed or root coverage. No soil manipulation is required. Weeds are controlled by herbicides, crop rotation and plant competition (Plate 7.4).*

Warren (38) listed the advantages and disadvantages of zero tillage.

Possible advantages

- Can be used on hilly, rocky, rough land where animal or tractor tillage is difficult or impossible;
- Reduces fuel and animal and human energy required for crop production;
- Requires smaller, less expensive equipment;
- Greatly reduces water and wind erosion;
- Conserves soil moisture and organic matter;
- May improve or maintain soil structure;
- Increases water infiltration rate;
- Leaves mulch or crop residues on the soil surface, thus reducing weed germination and suppressing annual grass weeds; avoids stimulating germination of weed seeds through burning; and does not bring new seeds to the surface;
- Lowers soil surface temperature and reduces daily temperature fluctuations, thus favoring the growth of many crops in hot climates;
- Saves time and moisture in critical planting periods by reducing turnaround time between harvesting one crop and planting the next;
- Allows optimum spacing between plants to obtain maximum yields;
- Eliminates injury to roots of crop plants by between-row mechanical tillage and hand weeding;

- Reduces incidence of some soil-borne diseases spread by equipment and plant infection caused by machine-related injury;
- May reduce insect problems; and
- May provide a more favorable environment for biological activity.

Possible disadvantages

- May increase some insect, disease, and other pest problems;
- Can increase perennial weed population unless effective controls are used; and
- May increase runoff losses if there is little or no surface mulch or crop residue.

Nyoka (23) described a zero tillage farming system for upland rice in Sierra Leone, where slash-and-burn is common. When cutting and burning are well timed, and if there is enough dry plant residue, fields are weed free for crop establishment and rice can be drilled or dibbled. Experiments showed that if rice is directly drilled with zero tillage in such fields, grain yield is as high as from conventionally tilled land (Table 3). Data from high rainfall areas with Ultisols in southern Nigeria (13) and in Liberia (19) show there were no significant grain yield differences between zero tillage and conventional tillage.

Zero tillage, however, is not always successful for upland rice. Stone et a1 (36) found that zero tillage restricted upland rice root development and reduced grain yield. Olofintoye and Mabbayad (24) found that UPL Ri-5 had higher seedling establishment and yielded more with conventional than with minimum or zero tillage. Reduced seedling establishment with zero and minimum tillage was partly due to preemergence butachlor application, which was toxic to rice seedlings at 2 kg ai/ha (Table 4). In another study, the same authors (25) again found grain yields higher with conventional land preparation than with zero tillage. Zero tillage fields had poor seedling establishment and plant growth because of undisturbed roots of previous maize crops and *R. exaltata* residues. In the laboratory, water extracts of decomposing maize roots and *R. exaltata* inhibited the growth of rice roots.

CROP ESTABLISHMENT

Crop establishment is the capacity of a crop to germinate, emerge, cover, and rapidly and uniformly dominate a field surface. Crop establishment is an important determinant of yield, and is a problem in rainfed crops such as upland rice because

Table 3. Effect of tillage and weeding on upland rice grain yield (23).

Tillage method	Grain yield (t ha^{-1})	
	Hand weeding	Herbicide
Conventional [b]	1.5	1.4
No-tillage [c]	1.4	1.6

[a]Formulated mixture of propanil and tenoprop. [b]Hoeing. [c]Hand pulling of weeds followed by rice drilling.

Table 4. Grain yield of UPL Ri 5 with 4 tillage and 4 seeding rates (24).

Tillage	Grain yield[a] (t ha^{-1}) for each seeding rate (kg seeds/ha)				Tillage mean
	75	100	125	150	
Conventional tillage	3.0	3.7	3.1	3.1	3.2 a
Zero tillage	1.4	2.2	2.1	1.7	1.9 c
Minimum tillage	1.3	2.3	2.0	2.2	2.0 c
Delayed seedbed	2.2	2.6	2.3	2.0	2.3 b
Seeding rates mean	2.0 c	2.7 a	2.4 b	2.3 b	

[a] Av of 4 replications. Mean tillage and seeding rates followed by the same letter are not significantly different at 5% level by DMRT.

of environmental, biotic, and cultural factors that reduce seed germination, seedling vigor, and growth, thereby reducing plant population.

Seeding time

Seeding time of upland rice is rain dependent and fluctuates greatly. Early planting assures more rainfall from seeding through grain filling. Late-planted crops may suffer drought, which can substantially reduce yields (22, 27. 35).

In northeast India, it is best to sow upland rice when the monsoon begins — about the third week of June. If the monsoon doesn't begin by 20 Jun, dry seeding 10 d before it begins is better than late sowing. Sowing after the first week of July drastically reduces grain yield (22, 34, 35) (Table 5).

In Thailand, upland rice is planted when rains come and harvested when they end. Planting generally begins in May in northern Thailand and from June to August in the south (17).

In western Africa, the upland rice season begins when rains come, from April to June (6). In southern Brazil, the season is from September to April (31).

Seeding methods

There are three common seeding practices for upland rice: broadcasting, dibbling or hilling, and drilling.

Table 5. Effect of sowing time on upland rice yield, 1972-75 (22).

Sowing time	Yield (t ha^{-1})		
	1972	1975	Mean
Dry sowing beyond 20 Jun (in anticipation of rain)	2.7	2.4	2.6
Normal sowing (3 d wk of Jun) after onset of monsoon	2.4	2.9	2.7
1st wk of Jul	2.4	2.6	2.5
2d wk of Jul	2.2	2.4	2.3
3d wk of Jul	1.8	1.5	1.7

Broadcasting is common in many Asian. African. and Latin American countries. Land is prepared dry or wet and the seeds are broadcast (8, 22, 28). A modified broadcast method is used in Luzon. Philippines. A harrowed field is furrowed with an animal-drawn furrower (lithao) that has 5 wooden pegs 20 to 25 cm apart. Seeds are broadcast (88 kg ha) and then covered by soil with a peg-toothed (kalmot) harrow (27).

Dibbling or hilling is practiced in African and Asian slash and burn systems. Holes are poked in the soil with a pointed bamboo stick, 4 to 8 unsprouted seeds are dropped in them, and the holes are covered with soil. Exact practices vary by country (8. 17, 22, 27).

Because weeds are hard to control in broadcast and dibbled fields, line sowing is popular in India (28, 29). Drilling is increasing with mechanization in Latin America (15, 30, 31). In many Asian countries drilling at close spacing has performed better than broadcasting (27, 28).

Alluri (2) evaluated dibbling, space planting, and drilling at IITA. Seed rate was kept constant by adjusting number of seedlings per hill — 6 seedlings/hill at 30 × 30 cm, 3 seedlings at 30 × 10 cm, 1 seedling at 45 × 3.3 cm. Row drilling gave the highest yields in moisture stressed or nonstressed treatments. Lowland ADNY11 outyielded upland OS6 at both moisture regimes and with most planting methods (Table 6).

Seeding rate and plant spacing

In most upland areas, high plant population is essential to quickly develop a canopy to suppress weed growth (28, 29). In eastern India, Bhan (3) found 15-cm row spacing with 140 kg seed/ha was best for upland Dular, and controlled weeds best. At 15 cm spacing, plants provided early ground cover. In Varanasi and Rewa. India, the All India Coordinated Research Project for Dry Land Agriculture recommends planting 100 kg seed/ha for broadcast rice and 80 kg for drilled upland rice. Recommended spacing is 22.5 to 30 cm (11).

Seeding rate depends on seeding method. In India, seed rate should be 100–120 kg ha^{-1} for broadcasting and 70-90 kg for dibbling or drilling (28). Row spacing can be 15-20 cm. In the Philippines, however. 30-cm row spacing is best (5).

Table 6. Grain yield of OS6 and ADNY 11 under 3 planting methods and 2 moisture regimes in upland rice culture (2).

Planting method	Spacing[a] (cm)	Grain yield (t ha^{-1})			
		Drought stress		No stress	
		OS6	ADNY 11	OS6	ADNY 11
Dibbling	30 × 30	1.7	2.6	3.2	3.7
Space planting	30 × 10	1.9	1.9	2.5	3.3
Drilling	45 × 3.3	2.4	1.5	3.5	6.8
Av		2.0	2.0	3.1	4.6

[a] Seed rate was equalized by adjusting the number of seedlings per hill.

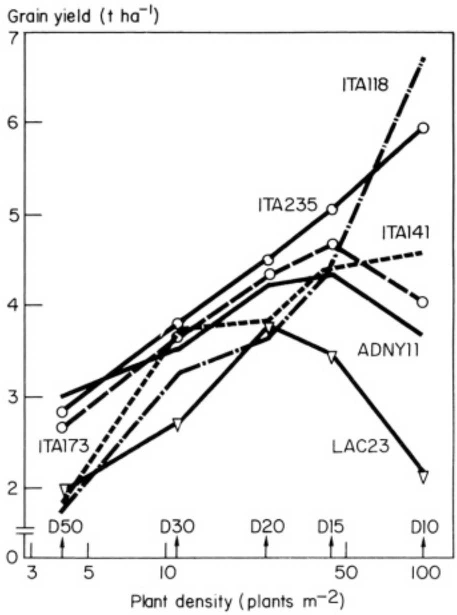
In northern Thailand, most upland rice is dibbled with variable plant population and distribution. A local glutinous variety was evaluated with 15 to 60 kg seed/ ha with 15-, 30-, and 45-cm hill spacing or band seeding. Plant population ranged from 37 to 147 m^{-2} and 2 to 22 plants/ hill. Grain yield and grain size did not vary with seeding rate and plant distribution (32).

Seeding rate also depends upon the variety planted. Tall, leafy varieties should be planted at wider spacing than semidwarfs. Growing tall varieties at narrow spacings increases lodging. Oyedokun (26) tested eight upland rices at three planting densities. TOs2339, TOs46, TOs78, and TOs4019 yielded more with higher plant densities, and TOs2404, TOs2466, TOs2570, and TOs486 (OS6) yielded less.

Ten varieties with a wide range of genetic backgrounds were evaluated at IITA at Ibadan and Ikenne, Nigeria, at 10 × 10 cm, 15 × 15 cm, 20 × 20 cm, 30 × 30 cm, and 50 × 50 cm spacings containing 100, 44.4, 25, 11.1, and 4 plants m^{-2}. Grain yield of all the varieties increased with plant density between 4 and 25 plants m^{-2} (Fig. 2). At higher densities, yields of LAC23, ITA173, and ADNY11 decreased and those of ITA118, ITA141, and ITA235 increased. Lowland ADNY11 and ITA235 yielded more than upland varieties at least density. ITA118 yielded highest (more than 6 t/ha) at highest density (14).

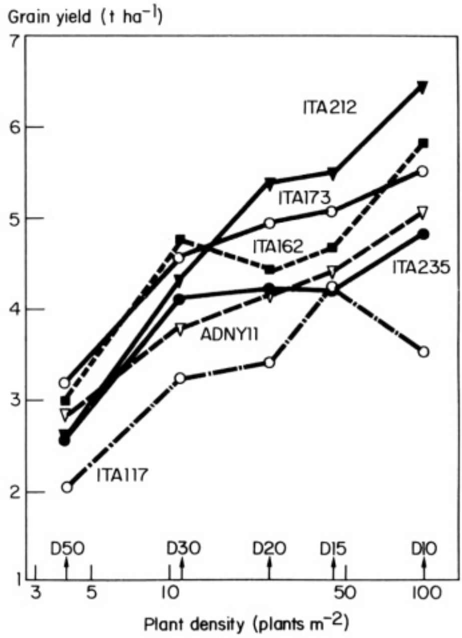
At Ikenne, most varieties yielded more with higher plant densities (Fig. 3), and average yield was slightly higher than in Ibadan, which received less rainfall. Lowland ITA212 yielded highest.

In Ivory Coast, Chabalier and Posner (4) tested several plant densities to improve upland rice yield. Grain yields of IRAT varieties exceeded 5 t ha^{-1} without significant differences among treatments. A high rate of seeding at 30 × 30 cm



2. Upland rice yield response to plant density in Ibadan, Nigeria, 1981 (14). D= distance.

3. Upland rice yield response to plant density in Ikenne, Nigeria. 1981 (14). D = distance.



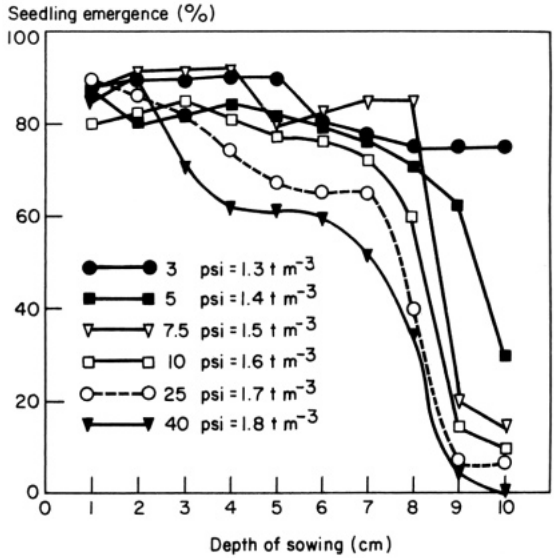
spacing was best in favorable conditions because it favored rapid plant growth for maximum yields. At lower seeding rates, similar yields were obtained by slow continuous growth to maturity. In drought conditions, a lower seed rate at 30 × 30 cm spacing was best because plants could regulate their growth and still produce acceptable yield.

In Latin America, seeding rate and spacing vary with planting methods. Seed is broadcast at 100-120 kg/ha (15, 30) and dibbled at 40-60 kg/ha. In mechanized systems where planting is by tractor-drawn drills, row spacing is 50-60 cm to permit interrow cultivation, and seed rate is 35-40 kg ha^{-1} (31). In Nicaragua, between-row spacing in mechanically drilled upland rice is 18-23 cm and seed rate is 65-100 kg ha^{-1} (30).

Seeding depth

To obtain a uniform stand, seed must be placed at proper depth in relation to its size and soil moisture status. Tillering is inhibited if seeds are planted deeper than 34 cm (22). Soil compaction also influences seeding depth. Hussain and Reddy (10) at Hyderabad, India, found 3-cm depth at 0.7 kg cm^{-2} compaction best for root and shoot growth of semidwarf TN1 and IR8 and tall Ch 45 and Hr 67 in upland conditions.

Varade and Ghildyal (36) investigated the interaction between seeding depth and bulk density. Seeding depth down to 8 cm with bulk densities below 1.6 t m^{-3} caused slight limitation to seedling emergence when soil moisture was above field capacity. At depths greater than 8 cm, however, the same level of bulk density was limiting to seedling emergence. When seeding depth was 5 cm with bulk densities of



4. Influence of seed placement depth and bulk density on upland rice emergence (37).

1.7 and 1.8 t m^{-3}, seedling emergence was limited. The effect of seeding depth and its interaction with soil bulk density is obvious in Figure 4. Complete limitation of seedling emergence occurred at 10 cm seeding depth coupled with a bulk density of 1.8 t m^{-3}.

Seed treatment

Some presowing seed treatments have increased upland rice yields in empirical experiments, but no cause and effect relationship has been established. Singh and Chatterjee (33) found that treating seeds increased upland rice stand and caused 8-24% more leaf area, 13-63% better root growth, and 15-20% higher yield compared with crops established from untreated seeds. The best results were obtained in Na_2HPO_4 and $Al(NO_3)_3$ solutions and water soaking. Coating seeds with $FeSO_4 \cdot 7H_2O$ and Fe EDTA also significantly increased grain yield, probably because it increased Fe availability (12).

Dry seeding

Sowing upland rice depends upon receiving enough rain to soak the topsoil. In many tropical countries, onset of monsoon is erratic. In such cases, upland rice can be seeded in dry seedbeds. Singh and Hedge (34) found that, if the monsoon was late, rice could be dry seeded in Ranchi, India, any time after 15 Jun. Dry seeding reduced planting dependence on rain, but efficient weed management was essential.

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CHAPTER 8

Farm Equipment

Use of farm equipment in upland rice production depends upon farm size and availability of traction power. In Asia (excluding China), 50% of traction power is from animals, 25% from humans, and 25% from machines. In Africa, about 58% is from machines and 35% from humans. In Latin America, more than 70% is from machines (1).

In West Africa, particularly northern Ivory Coast, northern Ghana, and northern Nigeria, farms are small and population pressure is high. Hoe cultivation is traditional, particularly in dry zones where trees are scarce. In the southern, humid forest areas, shifting cultivation is common and almost no machines are used. Land is cleared and planted by hand. Animal power is limited by tsetse flies and trypanosomiasis (2, 30). Forest can be cleared by heavy machines, but such methods increase soil erosion.

Upland rice in tropical Asia depends on animal power, especially during land preparation. Water buffalo and bullocks are common draft animals. Bullock power is most common in upland areas and water buffalo are used on lowlands. Table 1 gives the draft capacity, speed, and horsepower generated by different animals (24). Upland rice cultivation in Latin America is highly mechanized, but some subsistence farmers depend on family labor (3).

The most common machines used for upland rice are power tillers and tractors. A power tiller is a two-wheeled tractor used primarily as a substitute for animal power. With attachments, power tillers can be used for harvesting, cutting grass; and powering a thresher. A power tiller consists of an engine, transmission, drive wheels, and a long steering handle, and is designed for easy implement attachment. The operator walks beside or behind the tiller. To turn it, the operator physically changes direction by using the handle or steering clutches. Powertillers may have single or double axles with 5 to 12 hp (24).

Most tractors have four wheels. They have adjustable wheels or treads, steering wheels, drive wheels, and a hydraulic system for lifting and lowering implements. They may have 20 to more than 250 hp. Equipment for land preparation, seeding, interrow cultivation, and harvesting and threshing can be attached to them. They are frequently used to cultivate upland rice in Brazil.

LAND PREPARATION EQUIPMENT

Similar equipment can be used to cultivate all upland crops, but is chosen depending on available traction power — human, animal, or machine — and local

Table 1. Average capacity of draft animals (24).

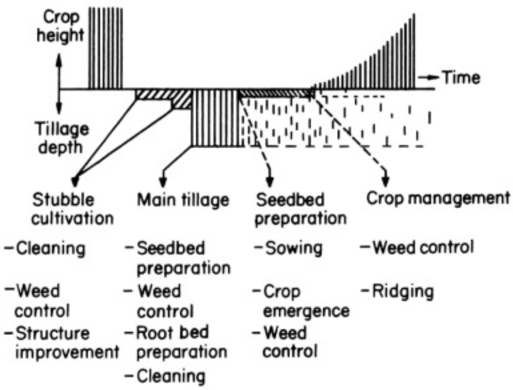
Animal	Weight (kg)	Draft (kg)	Speed (m/s)	Hp
Carabao	452	55	1.0	0.75
Cow	400-600	50-60	0.7	0.45
Bullock	500-900	6080	0.6-0.8	0.75

tillage requirements. In northeastern Brazil, northern India, and parts of Southeast Asia, for example, upland rice is grown in shifting cultivation, and, very little equipment is used.

Tillage is the mechanical manipulation of soil to make it suitable for crop growth. There are four basic tillage operations (7) (Fig. 1).

1. *Stubble or postharvest cultivation* is shallow tillage shortly after harvest to remove crop residues and seeds and restore soil structure.
2. *Main tillage* is the deepest normal tillage between crops. It controls weeds, restores soil structure in the arable layer where most roots grow, and readies soil for seedbed preparation.
3. *Seedbed preparation* is shallow tillage to prepare a seedbed. It controls weeds and improves the soil structure for germination and early plant growth.
4. *Crop management tillage* is very shallow tillage to control weeds, to improve early root growth if ridging is practiced, and to facilitate harvest of root crops.

Conventional tillage operations are appropriate for most upland rice systems. However, where erosion is a problem, such as in the humid forest zones of West



1. Aims of different soil tillage operations (7).

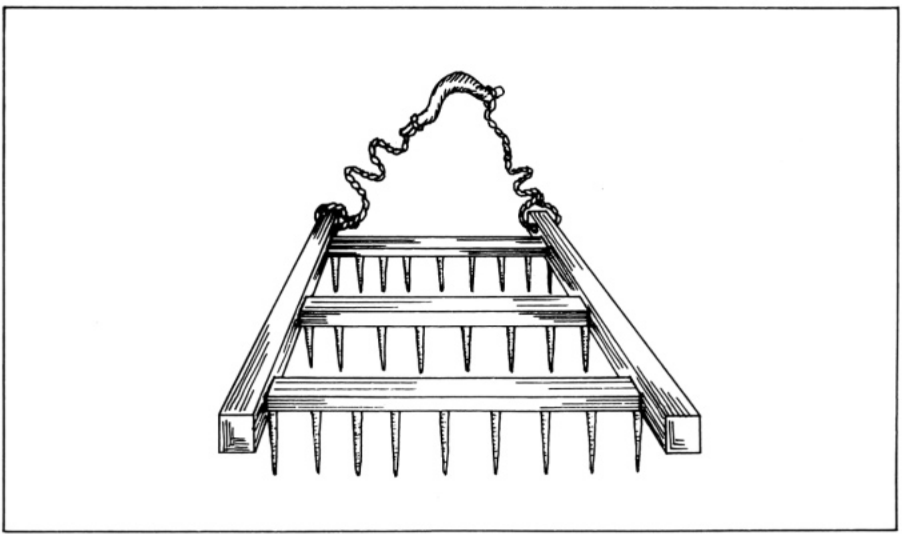
Africa and parts of Indonesia, zero tillage is being tried (7, 13, 14). Zero tillage helps provide constant ground cover, which reduces erosion and may conserve soil moisture.

Equipment for conventional tillage

There are no special implements for upland rice. Hand tools such as spades and hoes are used for small fields. Animal- or machine-powered moldboard plows and disks, and rotary tillers are used in larger fields. Disk plows are most appropriate for dry and sticky soils where moldboard plows are difficult to use, but they need about 10% more draft power (24). The rough surface left after disk plowing may increase water retention.

Horizontal-shaft rotary tillers are widely used. Rotary tillers are more flexible than plows because changing the rotor speed changes the degree of soil fragmentation. Also, the energy to turn the rotors is transmitted through the engine rather than through traction devices. When a tractor operates a rotary tiller, weight does not have to be added to the tractor wheels to increase draft forces; therefore, the tractor can weigh less, thus limiting soil compaction. A major disadvantage of rotary tillers, however, is that most of them require more power per unit volume of soil loosened than do draft tools (24).

Different harrows are used to cover seeds, destroy weeds, and break up soil crusts. Spike-tooth harrows, flexible harrows, spring-tooth harrows, blade harrows, and rotary harrows are used to prepare seedbeds for upland rice. A blade harrow performs well in dry soils. Philippine upland rice farmers use a peg harrow to cover seeds (Fig. 2). It also can be used to control grasses after seedbed preparation. For intrarow weed control after rice emergence, the peg harrow (kalmot) is passed over the crop at a 45° angle to the row direction.



2. Spike-tooth harrow (*kalmot*) (9).

Zero tillage equipment

Zero tillage requires a suitable planting machine and effective herbicides. The planting machine must manipulate a band of soil about 5 cm wide and 5 cm deep, place the seed, and cover it, all in one pass. These operations may be difficult where there is substantial plant residue on the surface. Rolling injection and conventional no-till planting machines have been evaluated at IITA (14).

SEEDING EQUIPMENT

Seeding practices for upland rice vary from dibbling to broadcasting to drilling. Most tall, traditional land races are dibbled or broadcast, and improved and semidwarf rices are line-drilled. Rowdrilling is superior to broadcasting.

No special equipment is used to plant upland rice in shifting cultivation. Farmers dig a hole in the ground with a wooden or bamboo stick and drop in a few seeds. Hand broadcasting also is common. Often, farmers drill seed in furrows opened by a plow or other local implement. In the Philippines, farmers use *lithao* to open the furrow, broadcast seeds, and cover them with a spike-tooth harrow. Most of the seeds fall in the furrows.

A lithao is a hardwood implement with a handle, five to six equally spaced legs that open furrows, and a hitch bar where the rope to pull it is tied. It is pulled by a bullock or water buffalo (Fig. 3). As the lithao passes through the soil, it loosens the soil crust and leaves a shallow furrow. Lithaos also are used in some cases to cover the seed and during early crop growth to control small weeds. During these operations the legs travel between the rows.

The spike-tooth harrow (Fig. 2) has a wooden frame that holds teeth made of round metal or hardwood bars. The teeth are slightly bent. The harrow has hitch points on two sides, which makes the implement reversible. For covering seed, the harrow is pulled with the bend turned backward; for weeding the bend is forward.

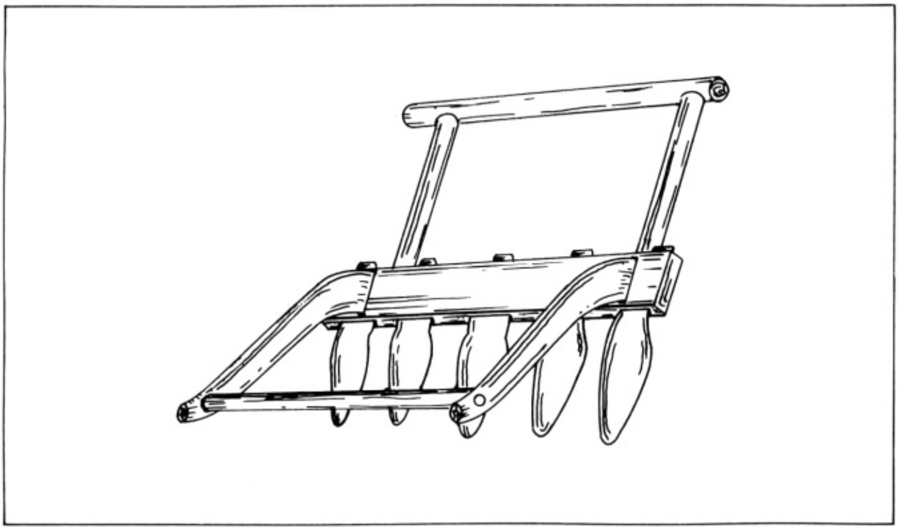
Crop planters

Crop planters are seldom used to plant upland rice in West Africa or South Asia and Southeast Asia. On large farms in Brazil and other Latin American countries, however, grain drills are used to plant upland rice. A seed planter generally must

- open seed furrows to the proper depth,
- meter the seed,
- place seed in the furrow in an acceptable pattern, and
- cover seed and compact the soil around it.

Furrow openers. Choosing a furrow opener depends upon soil moisture, planting depth, and soil stickiness. Common furrow openers used with grain drills are hoe, deep-furrow single disk, single disk, and double disk. The runner opener is sometimes used on small drills designed for animal or tractor power. Hoe openers can be used in rocky or root-filled soils. Disk openers are more suited to trashy and hard ground. Single disks effectively cut and penetrate trash. Runner openers work well in pulverized soil (23).

Meters. Fluted wheel and double-run force-feed meters are used for grain drills. The fluted wheel is usually best for small seeds. The double-run force-feed



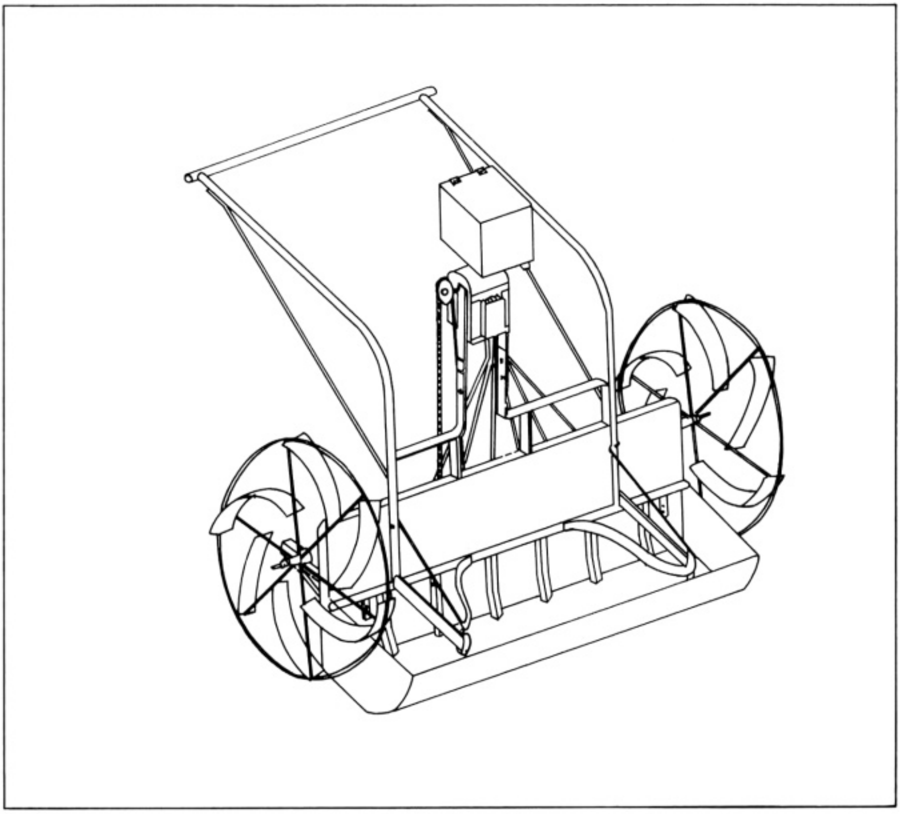
3. Furrow opener *(lithao)* (9).

meter is suitable for large and small seeds. Seeding rate with the fluted wheel is controlled by moving the wheel axially to change the length of flutes exposed to the seed in the feed cup. The double-run force-feed meter controls seeding rate by changing the speed ratio between the ground wheels and the feed shaft (23).

Furrow closers. The most common furrow closer is a drag chain. It drags over furrows and covers seed, but does not pack the soil. In subhumid regions, when soil is dry, press-wheels are used to cover seeds and compact the soil around them. In well-prepared fields, disks or inclined coulters can be used to close furrows. For multirow seeders used in well-prepared fields, an implement similar to a comb harrow is used to cover seeds (31).

Fertilizer sometimes is drilled at the same time as seed. A fertilizer grain drill has a divided hopper: the front section for seed and the rear for fertilizer. Fertilizer may be deposited through the same tubes with the seed or through tubes behind the seeding tubes. Different drills are available for seeding, fertilizer application, and seeding + fertilizer application (23). Seed drills can be powered by animal, power tiller, or tractor, and can save time as well as uniformly plant fields.

Chakkaphak and Fischer (4) stressed the need for machine-planting of upland rice. Some seeders for rice and other upland crops have been developed. In the Philippines, Selispara et al (29) developed a direct seeder for upland and lowland use that can be pulled by man or animal. As the seeder is pulled, a drive wheel rotates and turns a feed wheel. Seeds fall into holes in the feeder. The number of seeds flowing into the seed tube is regulated by a brush attached to the feeder housing. Seed tubes guide seeds from the feed wheel into furrows cut by a furrow opener, and are covered by a drag chain. Furrow depth is regulated by lifting or pressing the handle of the seeder (Fig. 4). Seed rate for upland grains ranges from 73.3 to 103.1 kg ha^{-1}, depending upon grain type. About 0.25 ha can be planted in an hour.



4. Direct-seeding machine (29).

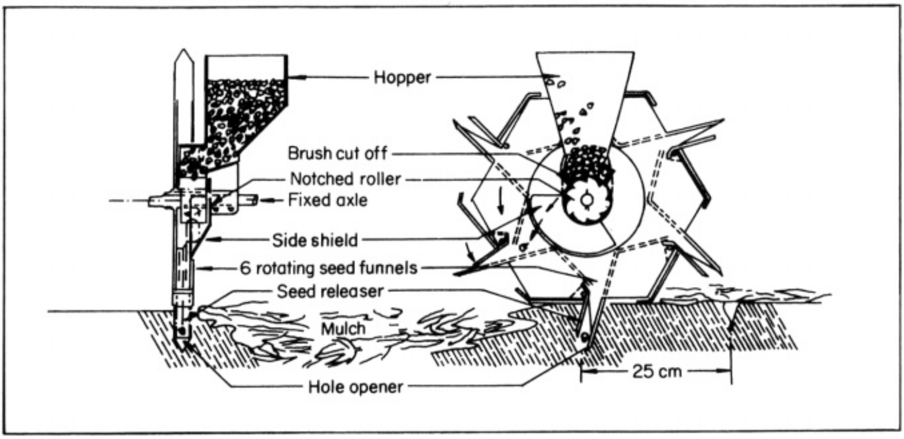
Rolling injection planter

The rolling injection planter was developed in 1978 at IITA with assistance from Volunteers for International Technical Assistance (11). The planter punches holes in the soil and drops seeds in them. It was designed for zero tillage systems where substantial plant residue is left in the field.

The rolling injection planter has a series of five or six jaws around a wheel into which metered seed is dropped (Fig. 5). As the planter rolls over a field, the jaws punch through the mulch layer, open, and place seeds at precise depth and in-row spacing. The standard design is for 25-cm in-row spacing. There are metering rollers available for different grains. The rolling injection planter is more effective than the punch planter (11).

IITA has developed a fertilizer band applicator that can be attached to a double- or single-row injection planter for simultaneous fertilizer application, and several other modifications have been made (12, 14, 20, 21) (Table 2).

The success of the rolling injection planter for other crops led IITA to develop for zero tillage upland rice a four-row planter that plants about 160,000 hills ha^{-1} (Table 3). The machine successfully inserts seed into the soil through herbicide-desiccated stubble and weeds. Because most rice soils have high moisture content,



5. Rolling injection planter (10).

Table 2. Speed of different planting machines (12).

Machine	Labor ha^{-1}
Single-row rolling injection planter	10
Single-row rolling injection planter with a fertilizer band applicator	13
Double-row rolling injection planter	6
Double-row rolling injection planter with fertilizer applicator	9
Single-row rolling injection planter with fertilizer band applicator row mark	13

Table 3. Time inputs for growing upland rice in zero and minimum tillage systems (11).

Field operation[a]	Minimum tillage		Zero tillage	
	Tractor h ha^{-1}	Labor h ha^{-1}	Tractor h ha^{-1}	Labor h ha^{-1}
Tillage at presowing				
Rotary tillage (2-wheeled tractor)	25	25		
CDA spraying of herbicide			-	9
Seeding				
Broadcasting pregerminated seed	-	4	-	
Seeding with a 4-row rolling injection planter				12
Pest control				
CDA spraying postemergence herbicide	-	9	-	
CDA spraying preemergence herbicide				9
CDA insecticide spraying		-		-
Fertilizer application				
Broadcast in three applications		4	-	4
Total (labor h ha^{-1})	25	42	nil	34
Yield (t ha^{-1})	6.6		6.6	

[a]CDA = controlled droplet applicator.

covering the seeds and compacting the soil is unnecessary. Rain tends to provide efficient cover. To plant 1 ha at 25- x 25-cm spacing takes 8-12 h, depending upon soil moisture content. In wet soils, injectors need frequent cleaning and planting took 15-20 h, still considerably less than for manual seeding, which requires 300 h ha^{-1}.

Garman and Navasero (8) described advantages of the rolling injection planter.

- It has few moving parts — a metering roller. a planting wheel, and six moving openers — which minimizes breakdowns and maintenance.
- A single-row planter can be easily pushed by hand over uneven terrain.
- It plants seeds through crop and weed residue.
- It is affordable to small farmers.

They also pointed out disadvantages.

- Within-row spacing is fixed.
- Maximum speed is 3.5 km h^{-1}.

Multicrop upland seeder

A multicrop upland seeder was developed by IRRI in 1978 to plant maize, upland rice, mungbean, etc. while also applying fertilizer (17, 18). The seeder has five seed and fertilizer hoppers. Metering plates beneath each hopper are driven by a cam on the press wheel axle. They meter seed and fertilizer which pass alternately through a single tube into the furrow. To halt metering during transport and turning at the end of the rows, the cam drive disengages when furrow openers are lifted. Row spacing can be varied from 10 to 100 cm. Seed plate changes and other adjustments require no tools (Fig. 6).

WEED CONTROL EQUIPMENT

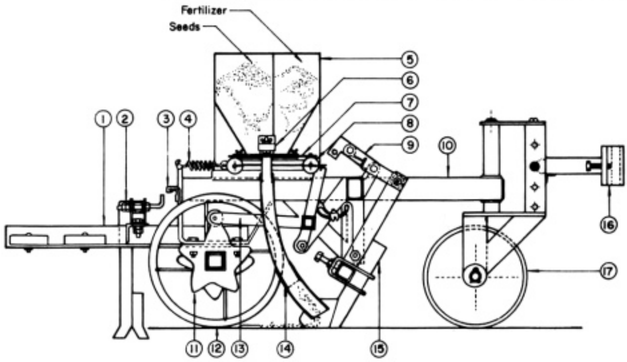
Weeds are a major constraint to upland rice production. Mechanical cultivationin upland rice seeks to destroy weeds and aerate the soil for better root growth. However, excessive cultivation may damage rice roots and cause soil moisture losses.

Irregularly spaced crops are difficult to cultivate. except with hoes, which is labor intensive and expensive. Row crops with regular, sufficiently wide spaces and only small clods can be mechanically cultivated. Irregular spacing and hand cultivation are common in West Africa and tropical Asia. In Brazil, upland rice is planted in rows spaced 50-60 cm apart and is cultivated by tractor-drawn implements.

Hand tools

Chopping hoes, pulling hoes, pushing hoes, push-pull hoes, wheel hoes, hand cultivators, and rotary hand weeders are used to control weeds in upland crops (25). The Regional Network for Agricultural Machinery has tested several mechanical weeders. In the Philippines, the wheel hoe, blade hoe, light blade hoe, and V-blade hoe perform well in upland conditions. The chopping hoe, Swiss hoe, V-blade hoe, and wheel hoe were tested in Sri Lanka; the spade hoe (local), V-blade hoe,

COMPONENT PARTS LIST					
REF.	REQ'D	DESCRIPTION	REF.	REQ'D	DESCRIPTION
1	1	Running board assembly	10	1	Main frame assembly
2	1	Marker assembly	11	1	Cam assembly
3	1	Scraper assembly	12	1	Press wheel assembly
4	2	Return spring	13	1	Rocker arm assembly
5	1	Hopper assembly	14	5	Seed tube assembly
6	5	Brush cut-off assembly	15	1	Furrow opener assembly
7	5	Metering plate	16	1	Hitch attachment
8	1	Oscillating frame	17	1	Caster wheel assembly
9	1	Furrower lock assembly			



6. IRRI multicrop seeder (30).

single-row rotary weeder, and wheel hoe were tested in Thailand. The weeding index was highest (93%) in spade weeding. It took 30-40 h to hoe-weed 1 ha (27).

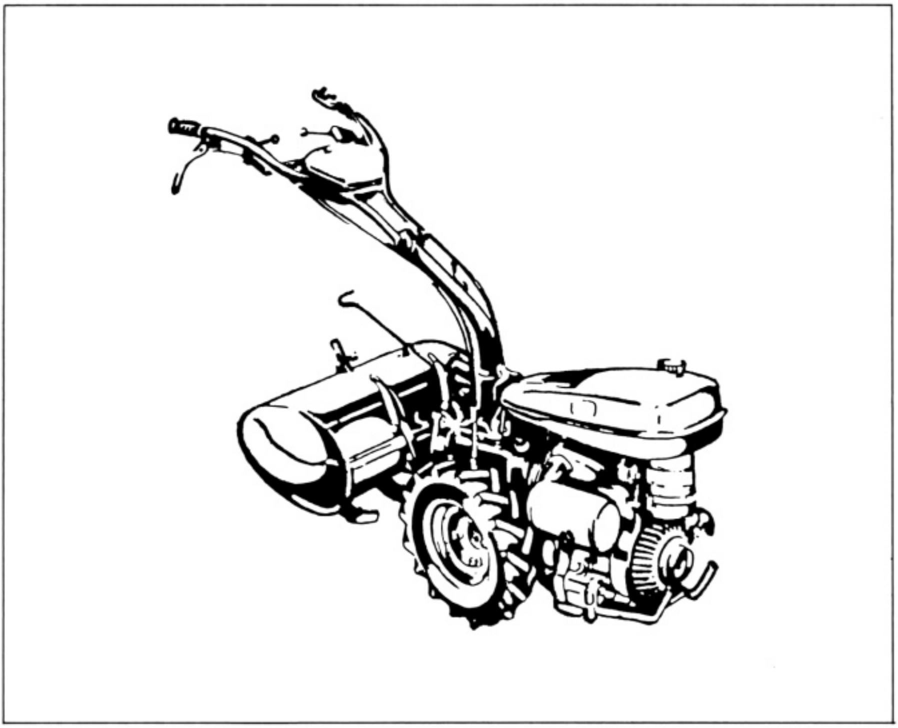
Animal-drawn weeders

Interrow cultivation with animal-drawn implements requires well-trained animals and skilled workers. Implements can have sweeps for shallow weeding and curved tines to uproot strong-rooted weeds and aerate the soil. Farmers in Batangas and Laguna Provinces of the Philippines pull a spike-tooth harrow diagonally across the rows to kill sprouting weeds a few days after seeding upland rice. When rice plants are a few centimeters tall, the crop is cultivated by pulling the furrow opener that was used during planting between the rows two or three times. Both implements are animal-drawn (9).

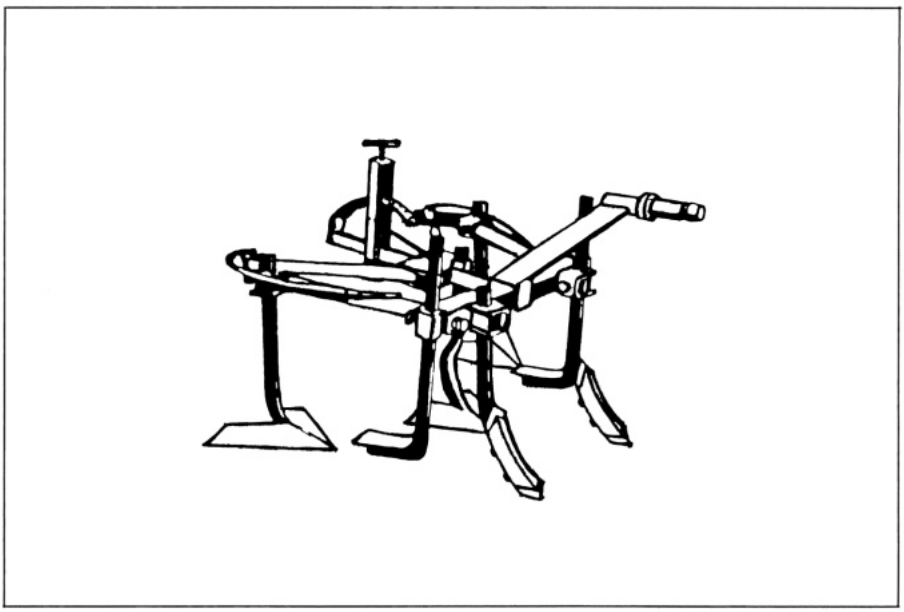
Tractor-drawn weeders

Various power tiller- and tractor-drawn implements are used to control weeds on medium and large farms. A powertiller with a rotary tiller attachment with special blades or a tool bar with interchangeable tools (duckfoot sweep, curved tines) are useful for interrow cultivation (Fig. 7, 8, 9). Rotary hoe blades mounted on lightweight tillers also are used (25).

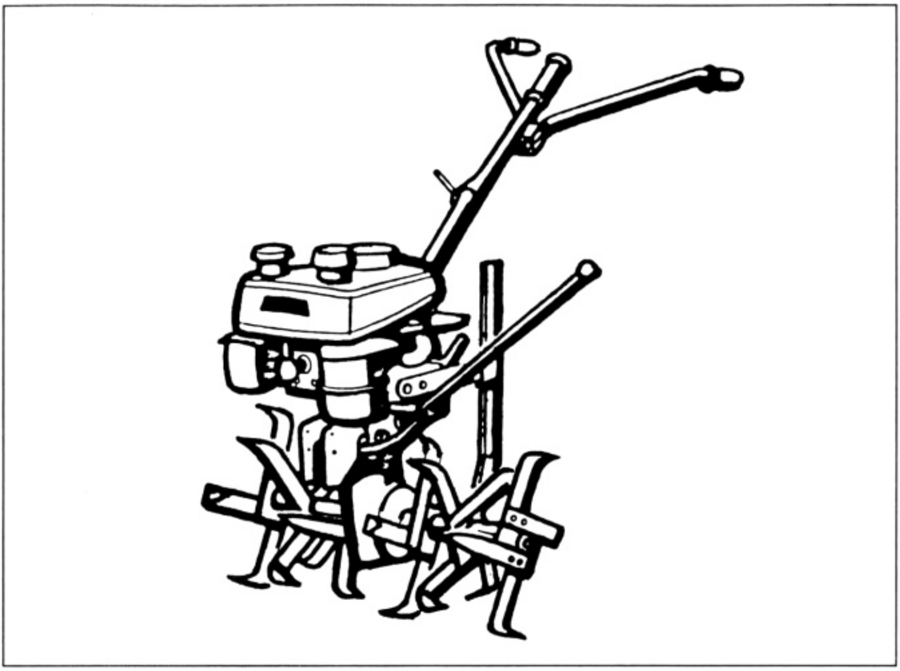
Tractor-drawn implements are most suitable for large areas, especially if crops are planted in wide rows, as in Brazil. Manalili (25) described four toolbar arrangements for weed control and interrow cultivation.



7. Two-wheel tractor with a rotary cultivator (25).



8. Two-wheel tractor toolbar with interchangeable tools (24, 25).



9. Motor hoe (25).

- A rear-mounted toolbar without independent steering can be used for ridging and for cultivating crops planted in wide rows.
- A rear-mounted toolbar with independent steering is needed for accurate hoeing. It requires an extra operator.
- A mid-mounted toolbar can be used only on tractors with sufficient clearance. Mid-mounted hoes are controlled by steering the tractor.
- A front-mounted toolbar is not easy to operate because the hoes are hard to see. Hoes or tines should be behind the rear wheels to eliminate wheel tracks.

Comparison of different weed control equipment

Most upland rice farmers, except those in Brazil and other Latin American countries, use hand or hoe weeding. Chapter 9 compares mechanical and other weeding methods. Here, we describe the efficiency of machines tested for weed control in upland rice during the International Coordinated Research Project: 1970-1976 on mechanization of rice production in Nigeria (7).

Seven mechanical weed control treatments were evaluated (Table 4). Weed weight was recorded 6 wk after planting and at harvest. Grain yield was low because of poor rainfall distribution. These conclusions were reported.

- Hand weeding and hoeing are best if only two weedings are done.
- Rotary weeding is better than other mechanical weeding.
- Blade or tine weeders perform better when pushed by hand than when pulled by a tractor.

Table 4. Weed weight 6 wk after planting and at harvest (7).

Treatment	Weed weight (g dry weight m^{-2})	
	6 wk after planting	Harvest
Hand weeding	12	42
Hoe-weeding, short-handled hoe	13	28
Blade weeding, hand-pushed	39	106
Blade weeding, with hand tractor	53	170
Tine weeding, hand-pushed	60	129
Tine weeding, with hand tractor	58	165
Rotary weeding, with hand tractor, blades on driver axle	51	96

Another experiment with strip tillage (8 cm wide and 6-8 cm deep), minimum tillage of 2 cross passes with a cultivator with 5 tines m^{-1}, and conventional plowing and harrowing compared 12 weed control treatments. Weed growth was recorded 5, 6, and 8 wk after planting and at harvest (Table 5). Two or three hand weedings controlled weeds best.

Another study recorded the time required for each weeding method (Table 6). Hand weeding took 500 h ha^{-1} and hoe weeding took 260 h. Hoe weeding was as efficient as hand weeding. Mechanical methods were faster, but less effective than hoe and hand weeding.

HARVESTING AND THRESHING

When a crop has matured, it should be promptly harvested and threshed to avoid lodging and shattering losses. Lodging is a serious problem in upland rice because many tall varieties are planted. Timely harvesting is important where upland rice is followed by other crops, and may be slowed by labor shortages. Jacobi (22) found that upland rice in Orissa, India, is harvested in Sep-Oct if it will be followed by another crop; however, if it is continuously cropped, harvest is in Nov-Dec.

Factors affecting harvesting and threshing

Straw stiffness, length, and strength; lodging; and shattering affect rice harvesting. Threshing is affected by shatterability, kernel size, strength, and moisture content; straw length, thickness, and stiffness; and specific weight of kernels and other plant parts and their aerodynamic characteristics (7). Weather at harvesting and level of mechanization also influence harvesting and threshing.

Optimum harvest time

Farmers decide when to harvest rice by the percentage of ripened grain in the panicles. The crop is ready to harvest when 80% of the panicles are straw colored and the grains in the lower part of panicles are in hard dough stage (5). There are very few data that describe the right time to harvest upland rice.

Table 5. Weed growth with 3 tillage practices and 12 weed control methods (7).

Weed control method	Weed growth (g dry weight m^{-2})			
	5 WP	6 WP	8 WP	At harvest
Hand weeding				
3 + 6 wk after planting (WP)		21		213
2 + 5 + 8 WP	15		15	143
Hoe-weeding				
3 + 6 WP		35		186
2 + 5 + 8 WP	23		20	114
Time weeding, hand-pushed				
3 + 6 WP (1 row)		72		491
2 + 5 + 8 WP (1 row)	92		100	492
Time weeding, frame on hand tractor				
2 + 5 + 8 WP (3 rows)	61		192	501
Blade-weeding, hand-pushed				
2 + 5 + 8 WP (1 row)	65		167	581
Blade-weeding, frame on hand tractor				
2 + 5 + 8 WP (3 rows)	42		125	412
Rotary weeding, brush cutter				
2 + 5 + 8 WP (1 row)	52		136	470
Rotary weeding, hand tractor				
3 + 6 WP (3 rows)		76		530
2 + 5 + 8 WP (3 rows)	48		85	304
Mean	50	51	105	370
Strip tillage	85	70	154	455
Minimum tillage, cultivator	36	48	83	345
Plowing and harrowing	28	35	78	309
Significance level:				
Tillage	5%	5%	5%	–
LSD (0.05)	44	22	47	–
Weeding	1%	1%	1%	1%
LSD (0.05)	38	30	67	225
Interaction	–	5%	–	1%

[a]WP = weeks after planting.

TOx7-3-13-B1-B, IR528, and IR154 were grown in wet season at IITA and evaluated for optimum harvesting time beginning at 50% heading. Rice was threshed on a threshing frame and usable grain yield, hulling recovery, and head grain recovery after milling were recorded (Fig. 10). Hulling recovery decreased when varieties were harvested late. Head grain recovery peaked for TOx7-3-13-B1-B and IR528 at 30-35 d after 50% heading. From maximum usable grain point of view, harvest should be 35-40 d after 50% heading, but for head grain recovery, harvesting and threshing should be 30-35 d after heading (7).

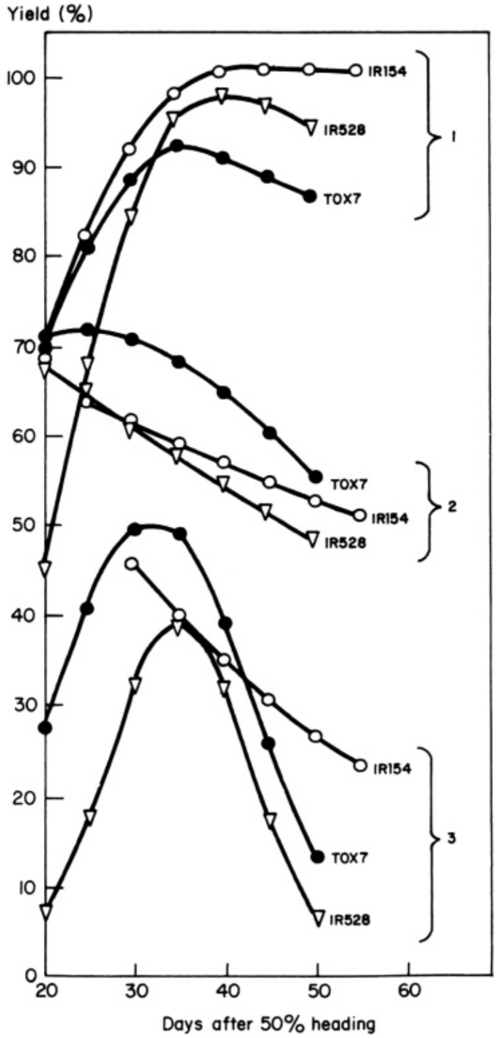
Harvesting equipment

In developing Asia, about 25% of labor for grain production is used at harvest (28). Panicle knives and sickles are used for manual harvesting and there are several different reaping and combining machines.

Table 6. Time requirements for weeding (7). Values in parentheses indicate the time required for each weeding task.[a]

Weeding method	Time (h) required to weed 1 ha		
	Strip tillage	Cultivator	Plowing
Hand weeding			
3 + 6 wk after planting (WP)	525 (335 + 190)	481 (286 + 195)	407 (242 + 165)
2 + 5 + 8 WP	623 (293 + 192 + 138)	539 (251 + 170 + 118)	457 (189 + 159 + 109)
Hoe weeding			
3 + 6 WP	282 (118 + 164)	282 (120 + 162)	193 (76 + 117)
2 + 5 + 8 WP	304 (92 + 120 + 92)	265 (74 + 101 + 90)	226 (72 + 82 + 72)
Time weeding, hand-pushed			
3 + 6 WP (1 row)	72 (39 + 33)	62 (30 + 32)	55 (27 + 28)
2 + 5 + 8 WP (1 row)	86 (31 + 22 + 33)	85 (28 + 22 + 35)	79 (25 + 20 + 34)
Time weeding, frame on hand tractor			
2 + 5 + 8 WP (3rows)	57 (21 + 18 + 18)	54 (20 + 16 + 18)	82 (20 + 14 + 18)
Blade weeding, hand-pushed			
2 + 5 + 8 WP (1 row)	89 (31 + 21 + 37)	83 (25 + 22 + 36)	80 (27 + 20 + 33)
Blade weeding, frame on hand tractor			
2 + 5 + 8 WP (3 rows)	70 (26 + 19 + 25)	66 (22 + 19 + 25)	63 (24 + 17 + 22)
Rotary weeding, brush cutter			
2 + 5 + 8 WP(1 row)	438 (123 + 163 + 152)	342 (94 + 134 + 114)	262 (60 + 100 + 102)
Rotary weeding, hand tractor			
3 + 6 WP (3 rows)	34 (18 + 16)	29 (14 + 15)	26 (13 + 13)
2 + 5 + 8 WP (3 rows)	37 (11 + 14 + 12)	33 (11 + 11 + 11)	31 (11 + 9 + 11)

[a]WP = weeks after planting.



10. Usable grain yield, total hulling recovery, and head grain recovery after milling for 3 varieties of grain grown under upland conditions. 1 = usable grain yield, 2 = hulling recovery, 3 = head grain recovery after milling (7).

Panicle knives. In parts of West Africa and the Philippines, rice panicles are individually harvested with knives (Plate 8.1) (7, 9), and it may take 240 h to harvest 1 ha (26). Panicle harvesting is common in shifting cultivation where foot-threshing is practiced.

Sickles. Sickles are the most traditional harvesting tools for cereal crops (Plate 8.2). It takes about 120 labor h ha^{-1} to harvest rice with sickles (26). Because upland rice has a low grain to straw ratio, sickle-harvesting efficiency is 25-35 kg rough rice h^{-1} compared to 45-50 kg for lowland rice (7).

Mechanical harvesters. In some Latin American countries, upland rice is harvested and threshed by combine (7). Little progress has been made in mechanized upland rice harvesting in Africa and tropical Asia. Some cutters and reapers have been developed for harvesting lowland rice (6, 19, 20, 21, 26, 28), but their applicability for upland rice has not been tested. Uneven landscape, rocks and stones, low seed to straw ratio, lodging, tall stature, and weeds make machine harvesting of upland rice difficult.

A Japanese brush cutter with a 1.1 kW (1.5 hp), 2-stroke engine and an Italian harvester binder with a 5.6 kW (8 hp)-diesel engine and 1.25 m cutterbar were used to harvest upland fields of TOx 7, IR528, and IR154 at IITA. The Japanese brush cutter had twice the capacity of sickle harvesting. Good windrowing was obtained with 1-m swaths. The Italian harvester-binder did not perform well (7).

IRRI is working with the Chinese Academy of Agricultural Mechanization Sciences (CAAMS) to adapt a reaper windrower to the IRRI 3-hp powertiller. The reaper takes 1.6- or 1.0-m swaths. It

- handles the crop gently, which minimizes shattering;
- harvests lodged and standing rice;
- prevents rice from falling free when the reaper stops or comes to the end of a field; and
- is simple to manufacture in small metal shops (Fig. 11).

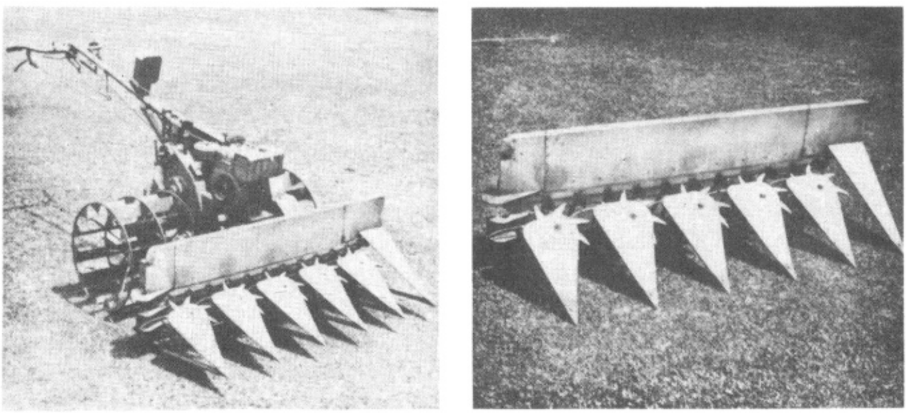
The 1.6 m reaper harvests about 0.5 ha h^{-1} and the 1.0-m, 2 ha d^{-1}. Several modifications have been made to reduce production costs and simplify manufacturing (19, 20, 21), but the reaper has not been evaluated for upland rice.

Wheat combine harvesters have been adapted to harvest rice, but rice crop characters have reduced harvesting speed. The dense, hard stalks and high moisture content limit speed at the cutterbar level and the large volume of straw, often green. can cause high grain losses over the shakers. Harvesting losses vary from 300 to 900 kg ha^{-1} for different varieties (7).

Threshing equipment

Threshing equipment used for upland rice varies depending upon the quantity of crop threshed, availability of labor, and degree of mechanization. The following describe common threshing methods and equipment.

- Foot threshing commonly accompanies panicle cutting.



11. IRRI-CAAMS reaper (19).

- Animal treading is done on small farms in many parts of South Asia and some in Latin America (Plate 8.3).
- Beating rice on wooden bars is done in South Asia, the Philippines, and West Africa (Plate 8.4). In Nigeria, 30-40 kg grain h^{-1} could be threshed on a wooden frame (7).
- A foot-operated pedal thresher is operated by two persons. A Japanese pedal thresher with a wire loop drum threshed 60-100 kg grain h^{-1}, but was labor intensive (7).
- Power threshers are available in several forms. Kerosene-powered or tiller-mounted threshers are used for irrigated rice in many Asian countries, but little is known of their use for upland rice.

Threshing machines. In Nigeria, tests compared a wooden threshing frame and a Japanese thresher. The Japanese automatic-feeding thresher with a wire loop drum driven by a 4.4-kW (6 hp) two-wheel tractor threshed 80-90 kg h^{-1} versus 30-40 kg^{-1} for the threshing frame.

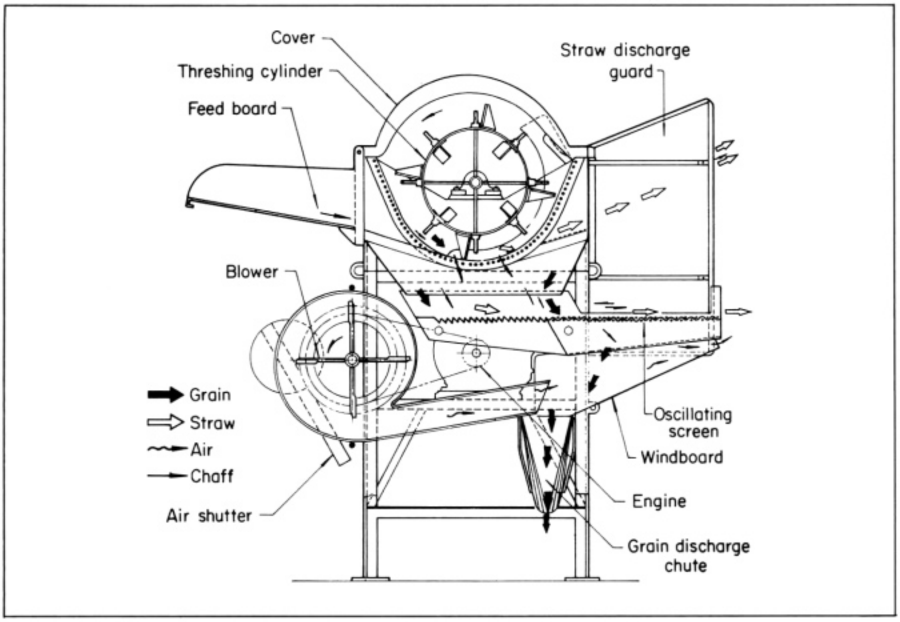
A small rasp-bar thresher attached to a two-wheel tractor also was evaluated with TOx 6 — seed:straw 0.36, 16.5% moisture content — harvested 40 dafter 50% heading. Highest threshing capacity was with 4 mm clearance at 1700 r/min (Table 7), with few broken kernels. On the average, 1300 r/min and low clearance were best (7).

Two threshers have been developed at IRRI, the axial-flow thresher and the portable axial-flow thresher. The first axial-flow thresher was developed in 1972. It

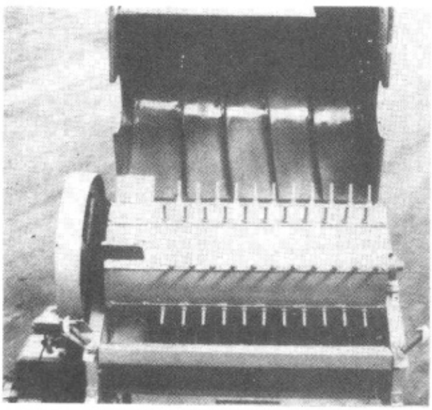
Table 7. Effective threshing capacity and percent unthreshed and broken and cracked kernels after threshing with a rasp-bar drum thresher attached to a light 2-wheel tractors [a] (7).

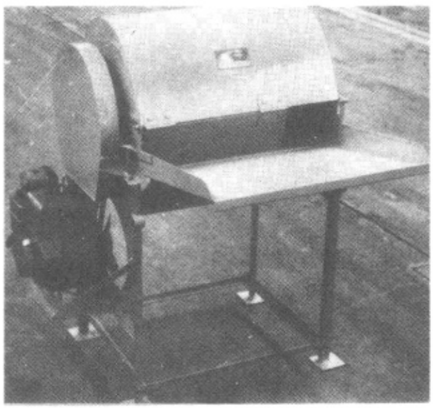
Clearance (mm)	Drum r/min	Effective threshing capacity (kg h^{-1})	Unthreshed grain (%)	Broken and cracked kernels (%)
4	1100	66	5.59	22
	1300	78	4.74	30
	1500	122	4.49	40
	1700	147	4.57	43
	Mean	103	4.85	33
6	1100	56	6.07	26
	1300	82	5.77	37
	1500	75	6.84	41
	1700	104	8.47	48
	Mean	79	6.79	38
8	1100	52	9.32	29
	1300	71	5.12	41
	1500	74	7.15	62
	1700	96	7.74	58
	Mean	73	7.33	47
10	1100	63	12.65	33
	1300	50	6.53	40
	1500	73	7.66	56
	1700	85	7.43	55
	Mean	68	8.57	46

had a wire loop threshing drum enclosed in a concave screen and was powered by a 6.5 hp aircooled engine. Spiral baffles in the upper concave moved the material in an axial direction. A blower winnowed the grain falling through the concave and an auger moved the winnowed grain toward one end of the thresher. Heavier impurities were removed by a rotary cleaner. Rubber flaps lifted the grain in a trough for delivery (15). The thresher has been modified several times. Today's thresher (Fig. 12) threshes 0.5 t h^{-1} and needs 3-4 persons to operate.



12. Axial-flow thresher.





13. Portable axial-flow thresher (16).

A new version of the axial-flow thresher that is being developed has two oscillating screens under the concave (21). The screens run at the same speed but in opposite directions to reduce oscillating assembly imbalance. The top screen has large holes to remove large impurities. The grain falls through an airstream from two blowers onto an inclined wind board and a second screen for final cleaning. An auger conveys the cleaned grain to a screen oscillating at 320 cycles/min powered with an eccentric cam with a 2.5 cm stroke. Performance tests show the machine has a field capacity of 1 t h^{-1}.

Heavy tractor- or trailer-mounted threshers are difficult to move through small rice fields. A portable axial-flow thresher developed in 1976 (16) can be used for throw-in or hold-on threshing. It is powered by a 5 hp aircooled engine and weighs about 100 kg. The thresher has no cleaning system. Threshed grain falls through a woven wire concave and collects beneath the thresher. The threshing drum and the thresher are much shorter than in the standard thresher. Grain separation loss is less than 2%. The portable thresher can be operated by 2-3 persons, and has 0.3 to 0.6 t h^{-1} capacity (Fig. 13). About 3,000 units have been sold in the Philippines.

In response to requests by manufacturers, a cleaning system has been developed for the thresher to increase its field capacity. If powered by a 7 hp-engine, it can thresh up to 0.85 t h^{-1} with separation losses of about 0.5% and blower or screen losses approaching 1.0% with 95% purity (21). These threshers need to be tested for upland rice.

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CHAPTER 9

Weed Management

Weeds rank only second to drought stress in reducing upland rice grain yield and quality (19). They also host insect pests and diseases, require expensive labor and energy to control, reduce harvesting and processing efficiency, and sometimes are poisonous. Estimates of yield losses caused by weeds in upland rice vary from 42 to 100% (17, 25, 46, 74, 93, 112).

COMMON WEEDS

Effective control requires knowing names, distribution, ecology, and biology of weeds in upland rice growing areas.

Weeds are classified as grasses, broadleaf weeds, and sedges. Some common weeds of upland rice in South and Southeast Asia, West Africa, and Latin America are listed in Tables 1, 2, and 3. Lists of names and information on weed distribution for the following countries are available from the indicated scientists.

India. Mukhopadhyay and Bag (60), Patro and Tosh (80), Ghosh et al (33), Bhagat et al (2), Sharma et a1 (93), Raghavulu and Murthy (84), Kohle and Mittra (49), Dixit and Singh (21), Singh and Singh (97).

Philippines. Domingo and Palis (22), Vega et al (108), Bueno et al (8), IRRI (37, 38, 39, 40, 41, 42).

Thailand. Kittipong (48).

Indonesia. Utomo (1 07).

Japan. Chisaka and Kusanagi (14).

Nigeria. Fagade (29), Fagade (30).

Ivory Coast. Merlier (52).

Sierra Leone. Jones and Tucker (46).

Brazil. Victoria Filho and Carvalho (109), Silveira Filho and De Aquino (94).

Important weeds of upland rice vary by country and continent (55). De Datta (16) found *Mimosa invisa* Mart. (broadleaf, seed-propagated), *Cyperus rotundus* L. (sedge, tuber-propagated), and *Imperata cylindrica* L. (Beauv) (grass, rhizome-propagated) hard to control in Asia. *I. cylindrica* was a particular problem in shifting cultivation in Indonesia (27).

In weed control experiments with the All India Coordinated Rice Improvement Project, Pillai et al (83) identified *C. rotundus* and *Cynodon dactylon* as major weeds of upland rice in India. *C. rotundus* is the most serious weed in all of tropical Asia, Africa, and Latin America (18).

Table 1. Common weeds of upland rice in South and Southeast Asia (17.55).

Annual grasses	
Echinochloa colona (L.) Link	*Dactyloctenium aegyptium* (L.) Beauv.
Digitaria sanguinalis (L.) Scop.	*Paspalum dilatatum* Poir.
Eleusine indica (L.) Gaertn.	*Rottboellia exaltata* L. f.
Annual broadleaf weeds	
Ageratum conyzoides L.	*Commelina diffusa* Burm, f.
Amaranthus spinosus L.	*Elipta alba* (L.) Hassk.
Calopogoium mucunoides Desv.	*Ipomoea triloba* L.
Celosia argentea L.	*Portulaca oleracea* L.
Commelina benghalensis L.	*Trianthema portulacastrum* L.
Annual sedge	
Cyperus iria L.	
Perennial grass	
Imperata cylindrica (L.) Beauv.	
Perennial sedge	
Cyperus rotundus L.	

Table 2. Common weeds of upland rice in West Africa (112).

Grasses	
Imperata cylindrica	*Brachiaria deflexa*
Digitaria horizontalis	*Pennisetum pedicellatum*
Rottboellia exaltata	*Eleusine indica*
Broadleaf dicots	
Eupatorium odoratum	*Euphorbia heterophylla*
Aspillia africana	*Ageratum conyzoides*
Striga hermonthica	
Grasslike weeds	
Cyperus rotundus	*Mariscus umbellatus*
Cyperus esculentus	*Mariscus alternifolius*
Cyperus distans	

Striga root parasite, which is difficult to control, destroys upland rice in northern Ivory Coast and the Comoro Islands (7, 87). Infected plants have few tillers and many infertile panicles and may die. *Striga asiatica* and *Striga forbesii* are the most common species.

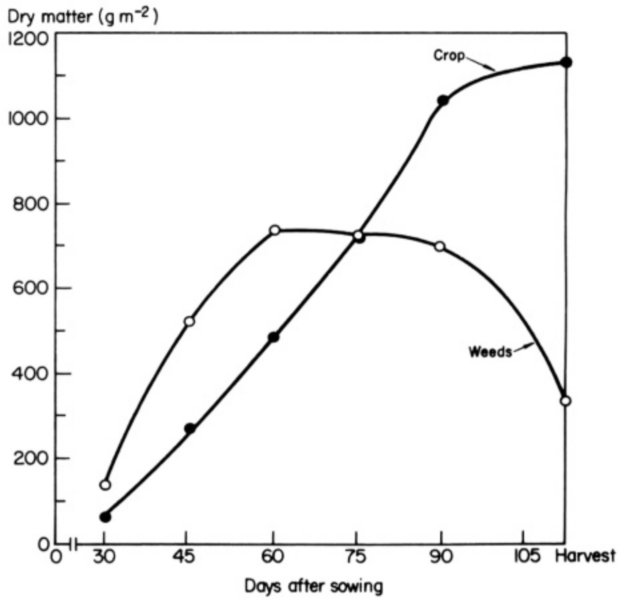
COMPETITION

Rice and weeds compete for sunlight, water, nutrients, and space. This competition, which reduces rice growth and yield, is more serious in upland than in lowland rice. In lowland rice, standing water lessens weed growth. One IRRI study found that weed growth in unweeded plots reduced grain yield 34% in transplanted rice and 67% in upland rice (17). A study in West Africa estimated that losses to weeds were 33-75% in lowland and 70-100% in upland rice (1 12).

Bhan (3) compared weed competition and found weeds more limiting in upland rice (Fig. 1, 2). Maximum competition was during early crop growth, when

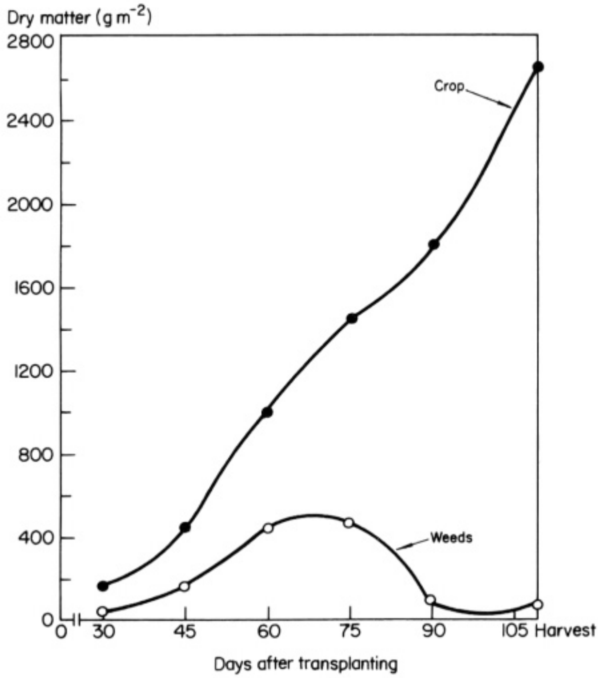
Table 3. Common upland rice weeds in Latin America (34).

Grasses	
Brachiaria plantaginea	*Leptochloa uninervia*
Cenchrus echinatus	*Oryza sativa (red rice)*
Cynodon dactylon	*Panicum fasciculatum*
Digitaria sanguinalis	*Panicum maximum*
Echinochloa colona	*Panicum repens*
Echinochloa crus-galli	*Paspalum* sp.
Eleusine indica	*Rottboellia exaltata*
Ischaemum rugosum	*Sorghum halepense*
Ixophorus unisetus	*Tripogandra multiflora*
Leptochloa panicea	
Broadleaf dicots	
Amaranthus sp.	*I. purpurea*
Amaranthus spinosus	*Ludwigia* sp.
Bidens pilosa	*Ludwigia leptocarpa*
Cassia obtusifolia	*Malachra* sp.
Eclipta prostrata	*Physalis angulata*
Emilia sonchifolia	*Portulaca* sp.
Euphorbia hirta	*Sida rhombifolia*
Ipomoea sp.	
Grasslike weeds	
Commelina diffusa	*Cyperus odoratus*
Cyperus sp.	*Cyperus rotundus*
Cyperus ferax	*Cyperus strigosus*
Cyperus iria	*Fimbristylis dichotoma*
Cyperus luzulae	*Mariscus mutisii*



1. Dry matter production of direct seeded upland rice and of weeds, Hissar, India, 1980 (3).

weed dry matter production exceeded that of upland rice. In lowland rice, weed dry matter production increased up to 60 d after transplanting, but never exceeded that of the crop.



2. Dry matter production of transplanted rice and of weeds, Pantnagar, India, 1978 (3).

Critical weeding period

Weeds germinate earlier and grow more vigorously than upland rice. Several studies indicate critical weed competition occurs up to 4-9 wk after sowing rice (33, 49, 51, 66, 67, 70, 82, 91, 108, 111). When rice is dry seeded, weeds must be removed by 20 d after rice emergence for good grain yields. Farmers can delay weeding for only 10 d after sowing rice (33).

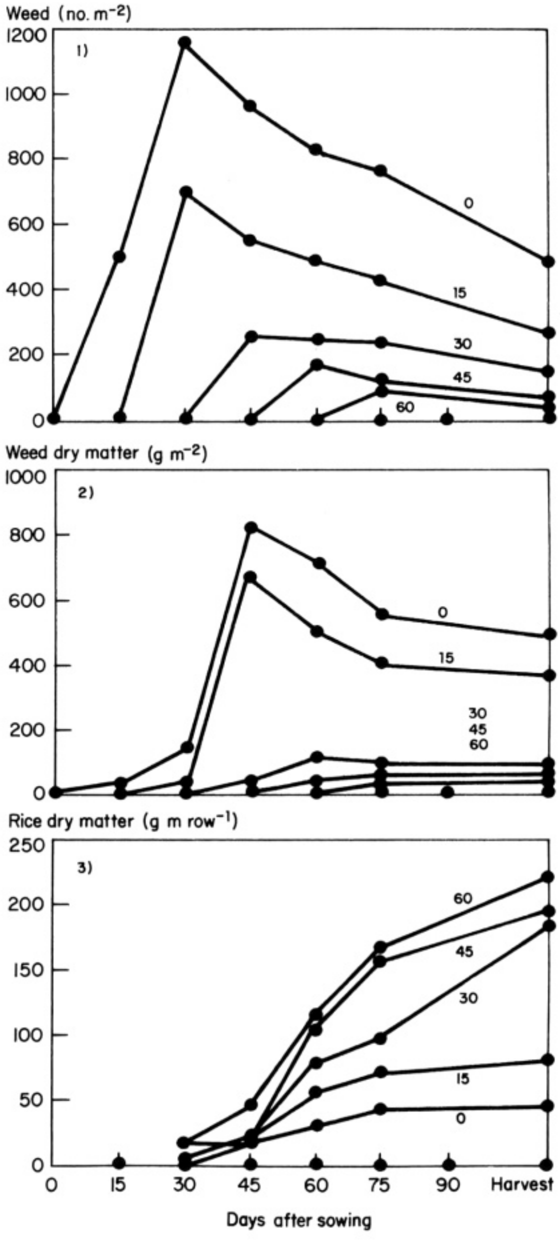
Sahai et al (91) found that weeds grew rapidly for 30 d after sowing in unweeded plots, after which growth declined toward rice harvest (Fig. 3). Weeding up to 60 d substantially reduced weed population and increased rice dry matter production. After 60 d, few new weeds grew. Weed dry weight and rice grain yield were negatively and linearly related (Fig. 4).

Competition for nutrients

Weed competition for nutrients severely limits rice growth and yield, but available data for upland rice are limited and confined to N. Pande and Bhan (77) found weeds produced more dry matter in fertilized than in unfertilized plots. Weed dry matter significantly increased to 60 kg N ha^{-1}, and N uptake increased to 80 kg N ha^{-1}. There was a quadratic relationship between weed dry matter production and N application (Fig. 5).

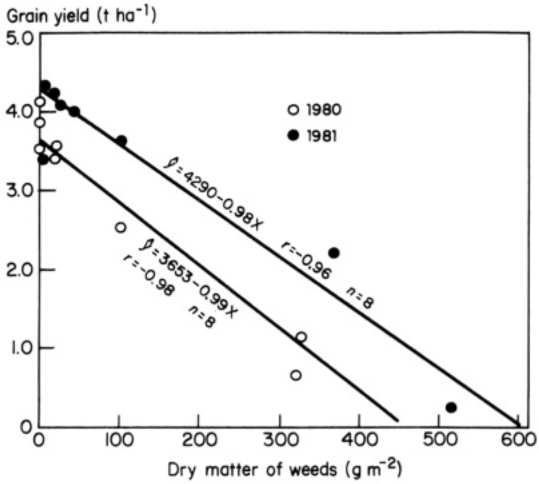
Chakraborty (11) found weed N content was up to 4% higher at earlier than at later growth. *Vandellia crustacea* Benth., *Ludwigia parvifora* Roxb., *Digitaria* sp., and *Trianthema monogyna* Linn. had higher N content than *Gomphrena celosoides* Mart at early vegetative stage. Proportional N content decreased as

3. Effects of weed-free periods of various lengths on weed number, weed dry matter, and rice plant dry matter (91).

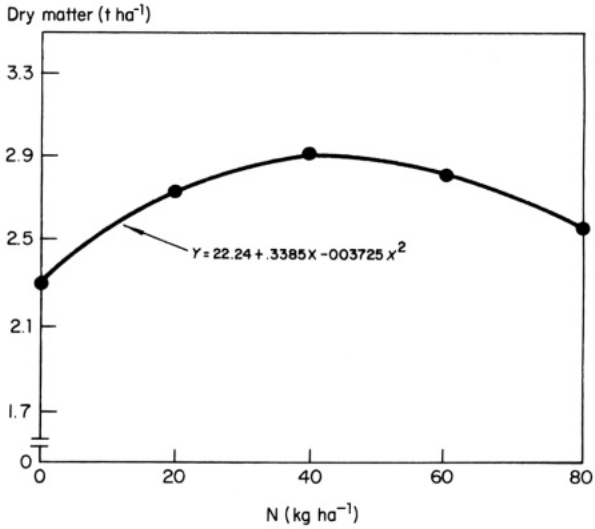


plants matured, but a mixed population of weeds contained more N than did rice variety Dular.

In West Bengal, India, weeds when uncontrolled removed 30-37 kg N ha^{-1}, while upland rice removed only 1.4-15.0 kg N (Table 4). When weeds were controlled by nitrofen, they removed only 4.6-10.8 kg N ha^{-1}. When weed-free, a good rice crop used 80-89 kg N ha^{-1} (58).



4. Correlation coefficient and regression relationship between weed dry matter and rice grain yield (91).



5. Effect of various N levels on weed dry matter production in upland rice (77).

On fertilized fields, Noguchi and Nakayama (71) observed that relative growth rate of all weeds exceeded that of upland rice in the first 70 d.

In an IRRI study, applying N benefited *C. rotundus* more than upland rice. *C. rotundus* dry weight and rice yield reduction were maximum at 60 kg N ha^{-1} (75).

Cultural practices

Cultural practices can influence rice-weed competition. Pande and Bhan (77) found competition was greater when rice was planted at wide than at narrow row spacings. Increasing row spacing from 15 to 30 cm and 30 to 45 cm significantly increased weed population and dry matter. Weed dry matter had a quadratic

Table 4. N use and yield with different weed control treatments (58).

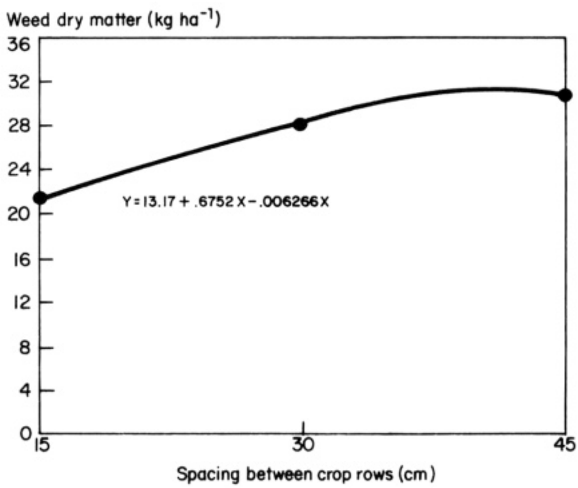
Treatment	N uptake (kg ha^{-1})				Yield (t ha^{-1})	
	Weeds		Rice		1968	1969
	1968	1969	1968	1989		
T1 No weeding	30.4	37.1	15.5	1.4	1.1	0.0
T2 Propanil 3 litres ha^{-1}	13.9	20.6	63.1	65.4	3.2	3.2
T3 Nitrofen 4 litres ha^{-1}	4.6	10.8	88.7	80.2	4.6	4.0
T4 3 hand weedings	5.2	5.3	85.5	78.1	4.3	3.9
Difference between T1 and T4	25.1	31.8	70.0	76.7	3.2	3.9
SEm =					0.2	0.1
CD at 5%					0.4	0.2

relationship with row spacing (Fig. 6). Okafor and De Datta (75) found no significant difference in weed competition between broadcast and row-seeded upland rice, although weed population was slightly higher in broadcast rice.

Annual and perennial weed competition

Competitiveness depends on weed growth habit. Okafor and De Datta (74) evaluated the relative competitiveness of perennial *C. rotundus* and annual weeds in upland rice. Weed-free, annual weed, *C. rotundus,* and *C. rotundus* + annual weed communities in broadcast and drilled IR5 were compared. In broadcast plots, annual weeds reduced yield 67% and *C. rotundus,* 51%; when all weeds grew, yield was 82% less than in weed-free plots (Table 5).

Perennial purple nut sedge *(C. rotundus)* is a problem around the world. It reproduces from tubers, is very difficult to control, and competes with upland rice for N, water, and sunlight (75). Fertilizing weedy plots benefits purple nut sedge more than rice.

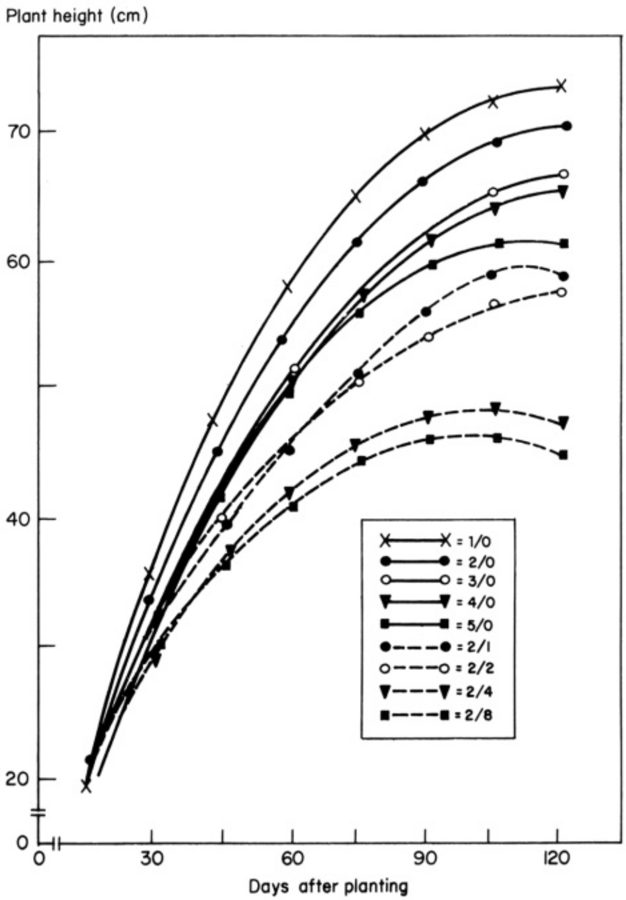


6. Effect of various between-row spacings on weed dry matter in upland rice (77).

Table 5. Effect of weed density on grain yield of drilled or broadcast upland IR5 (74).

Weed community	Drilled			Broadcast		
	Weed population[a] (no. m^{-2})	Grain yield (t ha^{-1})	Yield reduction (%)	Weed population[a] (no. m^{-2})	Grain yield (t ha^{-1})	Yield reduction (%)
Annual weeds	301	1.2	74	412	1.6	67
Cyperus rotundus	439	2.7	42	435	2.4	51
Annual weeds + *C. rotundus*	642	0.8	83	748	0.9	82
Weed free	79	4.7	-	34	4.9	-
LSD (5%)	67	0.4		67	0.4	

[a] 30 d after crop emergence.

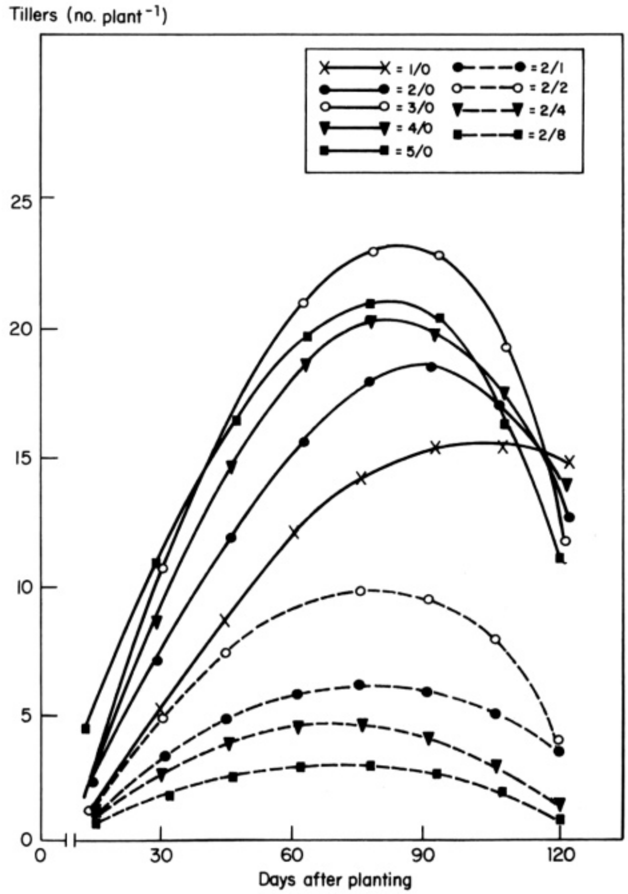


7. Effect of weed competition on rice height (100). The numerator indicates number of rice plants; the denominator, number of weeds per pot.

Rake and Mimbar (84) studied competition between upland rice and *Euphorbia prunifolia* in Indonesia. In a mixed rice and *E. prunifolia* population, competition reduced growth of each species. The species with the highest population competed most successfully.

Takayanagi and Iwata (102) studied competition between large crabgrass *Digitaria adscendens* Henr. and upland rice in Japan. Until 40-50 d after sowing, large crabgrass was little problem. After 50 d, however, it had greater leaf area and dry weight than rice. Leaf area ratio was the major reason for differences in relative growth rate between rice and crabgrass. Net assimilation rate was about the same. Iwata and Takayanagi (45) also found that middle stage upland rice growth was most affected by weed growth. The most important weeds were large crabgrass and goose grass.

D. ciliaris is one of the worst weeds in Southeast Asia (100). Competition decreases rice plant height and tiller number (Fig. 7, 8). In an experiment with no



8. Effect of weed competition on tiller number (100). The numerator indicates number of rice plants; the denominator, number of weeds per pot.

weeds and 2 rice plants pot^{-1}, grain yield was 4.5 g pot^{-1}. When there were 1, 2, 4, or 8 weeds pot^{-1}, yield decreased 48, 72, 73, and 91%.

Allelopathy

Allelopathy is the harmful effect on a lower plant form of chemical retardants produced by a higher plant form. Rice (88) suggested that allelopathy should include any direct or indirect harmful effect by one plant, including micro-organisms, on another through the production of chemical compounds.

The contribution of allelopathy to the competitive ability of weeds is not fully documented for rice. Although considerable research has been done on allelopathic responses in plant communities, most has sought to explain observed phenomena. Little research has evaluated the potential of allelopathy for weed control (98).

Although *alang-alang* (*I. cylindrica*) is an important weed of upland rice, its allelopathic effect has not been reported. In Sumatra, Indonesia, it grows in pure stands or where there is little additional weed growth. Eussen and Wirjaharja (28) and Eussen (26) attributed this phenomenon to allelopathy. There was a significant negative correlation between growth of *Cucumis sativus* on soil collected from alang-alang areas and the number of tillers of *alang-alung* present in the sample plot. Roots originating from the tillers appeared to be the allelopathic mechanism (26, 28). In 1977, Eussen found that aqueous extracts of *alang-alang* leaves, rhizomes, and roots inhibited shoot elongation of *Lyropersicon esculentum.*

Soetrismo et a1 (100) found that *D. ciliaris* exuded substances that retarded the weed's growth and that of rice. Possible allelopathy was observed between rice and weeds in dry seeded rainfed rice at IRRI (43). One week after rice emergence, there was a negative linear relation between rice stand and *C. rotundus* density (Fig. 9).

WEED CONTROL PRACTICES

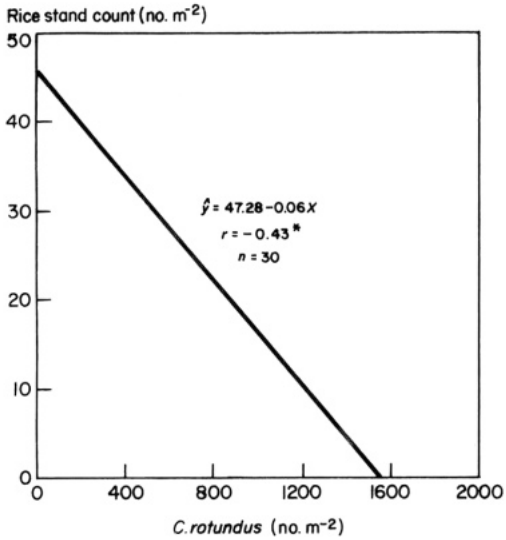
Weed control practices for upland rice include land preparation, stale-seedbed technique, blind cultivation, interrow cultivation, manual weeding, and herbicides. No single practice or combination of practices, however, has provided satisfactory weed control (3).

Time of land preparation

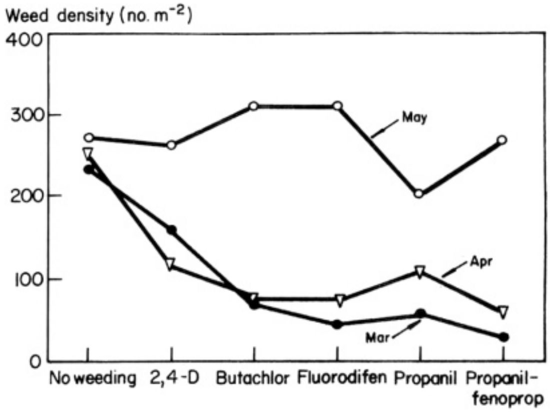
It may be better to plow upland rice fields in dry months after rice is harvested than when rainy season begins. In studies at IRRI, Castin and Moody (10) and Castin et al (9) found that weed flora in upland rice fields changed depending upon time of land preparation. When land was tilled in dry season, *C. rotundus* predominated. When land was tilled at the beginning of rainy season, grasses *Digitaria* sp. and *Eleusine indica* (L.) predominated. Total weed biomass in unweeded plots, however, was not significantly affected by time of land preparation. But when herbicides were applied, dry season plowing was better than late plowing (Fig. 10).

Land preparation method

Several studies have compared conventional and zero tillage for weed control in upland rice. At IRRI, conventional land preparation with one plowing followed by



9. Effect of *C. rotundus* density on stand of dry seeded rice 1 wk after emergence, IRRI, 1980 wet season (43).



10. Weed density 2 wk after emergence as affected by time of land preparation and weed control method, IRRI, 1979(9).

rototilling immediately before planting, 15 d and immediately before planting, and 15 d, 7 d, and immediately before planting did not significantly affect weed weight or grain yield (Table 6) (39, 40).

The success of zero or minimum tillage depends on the availability of suitable herbicides. With direct seeded rice, Mukhopadhyay and Rooj (64) found that spraying paraquat at 2.5 or more litres ha^{-1} immediately after harvesting rice and seeding the next rice crop without cultivation was as effective as conventional tillage plus hand weeding. In contrast, Chisaka and Kusanagi (14) found that zero tillage plots of direct seeded rice in Japan had more weeds than other treatments.

The chances of successful weed control in a zero tillage system are greatly reduced if fields are infested with perennial weeds (56). Castin et al (9) compared zero tillage with conventional tillage (plowing followed by three rototillings) in wet

Table 6. Effect of tillage on weed weight and grain yield of 3 upland rices, 1976 wet season, IRRI (39).

Tillage treatment[a]	IR1529-430-3		IR9575		M1-48		Tillage mean	
	Weed wt ($g\ m^{-2}$)	Yield ($t\ ha^{-1}$)	Weed wt ($g\ m^{-2}$)	Yield ($t\ ha^{-1}$)	Weed wt ($g\ m^{-2}$)	Yield ($t\ ha^{-1}$)	Weed wt[b]	Yield[c] ($t\ ha^{-1}$)
Plowing fb 1 rototilling	131	1.5	144	2.1	191	1.1	155 b	1.6 a
Plowing fb 2 rototillings	114-	1.7	123	2.3	132	1.1	123 a	1.7 a
Plowing fb 3 rototillings	124	1.8	110	2.1	105	1.0	113 a	1.6 a
Mean	123 a	1.6 a	125 a	2.2 a	143 a	1.1 b		

[a] fb = followed by. [b] Weeds sampled at 50 d after rice emergence. [c] Average of 4 replications and 3 weed control treatments. Means in a column or row followed by a common letter are not significantly different at the 5% level.

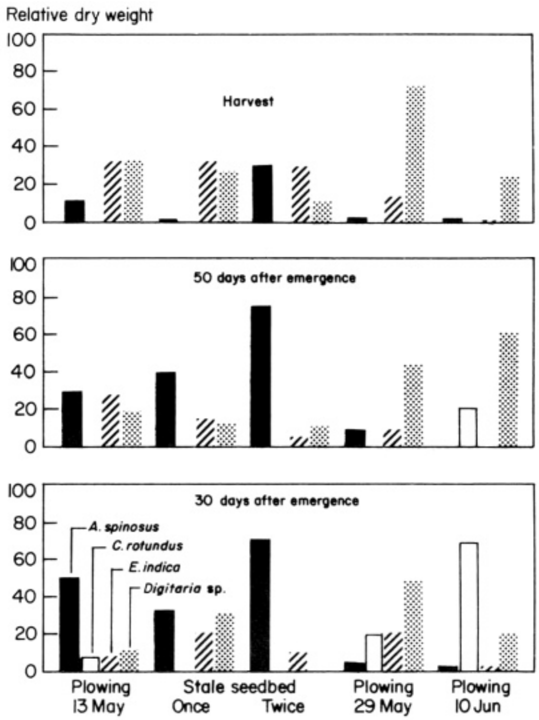
season at IRRI. Different combinations of glyphosate, ametryn, paraquat, and diquat were used to control weeds in zero tillage plots.

Total weed weight did not differ significantly among treatments. In zero tillage, however, relative dry weight of *C. rotundtus* was 72-86% versus 28% with conventional tillage, and the weed continued to regenerate from tubers. Castin et al concluded that zero tillage should not be used for upland rice until suitable herbicide technology with preplanting and postplanting treatments is developed.

Stale seedbed weed control

It may be possible to reduce weed infestation by using the stale seedbed technique. The technique involves seedbed preparation 2 wk before planting. The field is left idle to allow weed seeds to germinate. The weeds are destroyed before planting by chemical, mechanical, and manual means. Chemical control does not bring new seeds to the soil surface. If mechanical or manual methods are used, soil disturbance should be as shallow as possible. Herbicide should be applied or cultivation should be done when most weeds in the sufface soil have germinated and have 2-5 leaves (56).

Data on the effectiveness of the stale seedbed technique for upland rice are limited. Theoretically, it should be possible to use the technique to suppress weeds in long growing environments where planting can be delayed 2-3 wk, but not where growing season is short. IRRI research showed no advantage for the stale seedbed technique over conventional tillage (9, 39) (Fig. 11).



11, Relative dry weight of 4 major weed species at 3 sampling times as affected by time and method of land preparation (9).

Blind cultivation

Cultivation after planting rice and before seeds emerge breaks the soil crust, favors rice seedgermination, and kills weed seedlings. Blind cultivation is commonly done with a spike tooth harrow or implements that have short. fingerlike tines. Shallow cultivation is better because deep cultivation turns up weed seeds.

Rice varieties

Rice varieties differ in competitive ability. Vegetative vigor, large leaf area, plant height, and high N absorption at early growth are related to competitive ability. Research in Peru showed tall, fast-growing rices were more competitive against *C. esculentus, E. colona,* and *Eclipta alba* than slower-growing rices (47).

In a wet season weed control experiment at IRRI. semidwarf IR1529-40-3 and intermediate IR9575 yielded similarly and significantly more than tall M1-43. irrespective of weed control treatment (38). In wet and dry season experiments, upland semidwarf IR43 yielded best, but only with low weed population. Traditional Kinandang Patong had the highest competitive ability against weeds. Intermediate IR39575 was moderately competitive (50). Moody and Mukhopadhyay(56) observed a negative correlation between competitive ability and grain yield. They suggested that cultivars that emerge rapidly. have high seedling vigor, and rapidly develop a canopy compete best with weeds.

Seeding method and rate

Broadcasting upland rice delays weeding, makes it difficult and expensive, and makes herbicide application essential (54). Tosh et al (105) found that drilled rice yielded more than broadcast seeded rice because there was higher plant population and lower weed dry matter accumulation.

Theoretically, increasing upland rice density should reduce weed growth because of faster canopy development, but there are few confirming data. In Orissa, India, higher rice seeding rates resulted in higher plant population, lower weed dry matter accumulation, and higher grain yield than lower seed rates (105).

Hand weeding

Hand weeding is the most common weed control method used by upland rice farmers in South and Southeast Asia and West Africa. However, it has several disadvantages (56).

- It is slow and laborious, especially in direct seeded rice.
- Repeated hand weedings are necessary because it is difficult to completely remove weeds.
- Weeds regenerate from vegetative propagules left in the field and seeds continue to germinate.
- Labor for timely weeding is expensive and often unavailable.
- Weather often hinders weeding operations.
- If weeding is delayed, control costs increase.
- The rice crop often is injured during hand weeding.

Despite its disadvantages, many studies show that 14 hand weedings after sowing upland rice control weeds best (5, 15, 21, 32, 35, 50, 72, 92, 101). Tosh et al (105), however, found that spraying propanil 1.5 kg ai ha^{-1} 15 and 30 d after sowing was better than hand weeding.

The first hand weeding should be 12-30 d after sowing (15, 32, 35, 92), followed by weedings 40 to 85 d after sowing (15, 32, 92). Lopez et al (50) found that one hand weeding 30 d after rice seedlings emerged controlled most weeds.

Hoe weeding

Like hand weeding, hoe weeding has disadvantages, but is faster, can be done earlier, and, if within-row weeds are removed by hand, is more thorough (54). In Nigeria, Fagade (29) found hoe weedings at 14 and 28 d after sowing gave the highest upland rice yield. One to two hoe weedings 30-40 d after sowing are recommended in dry areas in India (35). Hand and hoe weeding are suitable for small farms (54).

Interrow cultivation

Interrow cultivation controls weeds well under ideal soil and climatic conditions. but heavy rains during early crop growth may prevent mechanical controls in sticky clay soils. Even if a field can be cultivated, wet soil may reduce the effectiveness of weed control (56).

In Orissa. India, Misra and Pradhan (53) compared weed populations in line sown rice that had interrow cultivation with spade and wheel hoe and broadcast rice that was hand weeded. Line sowing followed by spade interrow cultivation yielded highest. In the Philippines, interrow cultivation with a spade harrow 10 and 20 d after seedling emergence is recommended for weed control in upland rice (81). In Latin America, many farmers plant upland rice in rows 50-60 cm apart and use tractor-drawn implements for interrow cultivation.

A recent IRRI study (43) compared interrow cultivation with hand weeding and herbicide controls. Within-row hand weeding reduced weed population 11% more than interrow cultivation alone. Weed weight was 92% less in hoe-weeded than in unweeded plots, 86% less in high wheel cultivator plots, and 15% less in rolling weeder plots.

Herbicides

Herbicides can complement manual weeding and, used alone, provide varying degrees of control. Their use in upland rice depends upon reliability, phytotoxicity. availability, and economics.

Herbicide terminology. The following terms and definitions describe weed control by herbicides.

- Preplant indicates herbicide application or incorporation before the crop is planted.
- Preemergence indicates herbicide application after the crop is planted but before weeds or crop emerges.
- Postemergence indicates herbicide application after crop or weeds emerge.
- Contact herbicides are applied on foliage and kill plant tissue by contact.
- Systemic or translocated herbicides are applied on foliage or in soil but move within the plant.

- Selective herbicides kill or injure some plant species but are harmless to others.
- Nonselective herbicides kill all plants.

Herbicide formulations are described as water and oil soluble, emulsions, wettable powders, granules, water dispersible slurry, and slow-release compounds.

The ideal herbicide for upland rice should provide weed control for 4-8 wk after sowing; be effective against grasses, broadleaf weeds, and sedges; be less expensive than other weed control measures; and be locally available. Such herbicides, however, seem nonexistent.

Published data describing herbicide use for upland rice are mostly for South and Southeast Asia, but results are inconsistent. Herbicide effectiveness varies by site and year. Some herbicides that are as, or nearly as, effective as manual or hand weeding are listed in Tables 7, 8, and 9.

Preplant herbicides. Two nonselective, preplant herbicides, paraquat (1 ,l'-dimethyl-4, 4'-bipyridylium ion) and glyphosate [N-(phosphonomethyl) glycine], are used to kill weed flushes before planting. Paraquat is a fast-acting contact herbicide; effects are visible in 1 d. Glyphosate is translocated and acts more slowly, but is comparatively safe. Application of both is 0.6-1 kg ai ha^{-1} , depending upon weed infestation.

Preemergence herbicides. To be effective, a preemergence herbicide must keep fields weed-free during the first 2 mo of rice growth, when weed competition is particularly harmful. Applying 1-2 kg butachlor ha^{-1} 2-4 d after sowing rice has provided the most effective control among several preemergence herbicides (Table 7). Butachlor is effective against grasses and broadleaf weeds but less effective against perennial sedges and *Setaria glauca* (Table 7). The efficacy of all preemergence herbicides depends upon soil moisture. Applying them on dry seedbeds substantially reduces their efficiency (92).

Oxadiazon is another important preemergence herbicide. Applying 1, kg oxadiazonai ha^{-1} effectively controls most weeds (Tab1e 7) for 3-4 wk, but does not control *C. rotundus* (2), *Cynodon dactylon,* and *Hedyotis umbellata* (53).

Applying 2-3 kg piperophos + dimethametryn ai ha^{-1} 2-3 d after sowing controls most weeds (Table 7), and is especially good for *E. colona* (57). It does not control *C. rotundus* (2).

Nitrofen, dinitramine, pendimethalin, and thiobencarb are other preemergence herbicides for upland rice. They should be applied (Table 7) 1-3 d after sowing rice and before weeds germinate. Dinitramine is not effective against *Veronica* sp., *Cassia tora,* and *Paspalum scorbiculatum* (57), and thiobencarb is less effective than others against broadleaf weeds (24). Other preemergence herbicides with some promise are fluorodifen, butralin, alachlor, oxyfluorfen, trifluralin, and terbutryn (Table 7).

Postemergence herbicides. Propanil is the most widely tested postemergence herbicide (Table 8). One application 15-30 d after seeding or at 2- to 4-leaf stage controls most weeds, and is particularly effective against grasses, including *E. colona,* a major upland rice weed. If one application is ineffective, a second application 3 wk later may be useful (54). Propanil is less effective than other herbicides against *Acanthospermum hispidum* and *Ipomoea* sp.

Table 7. Promising preemergence herbicides for upland rice.

Name	Application time[a]	Rate[b] (ai ha^{-1})	Effective against	Not effective against	Reference
Butachlor (N-butoxymethyl-a-chloro-2', 6'diethylacetanilide)	2-4 DAS	1-2 kg	Grasses and broadleaf weeds	Perennial sedge *Sefaria glauca*	Bueno et al (8) Pillai et al (83) PCARR (81) Clarete and Mabbayad (15) Schiller and Indhaphun (92) Dubey et al (24) Tasic et al (104) Bongolan et al (5) Moorthy and Dubey (60) Sabio and Pastores (90) Mukhopadhyay (59) Pande et al (78) Singh and Singh (97)
Oxadiazon (5-*terft*-butyl-3 (2,4-dichloro-5-isopropoxyphenyl)-1,3,4-oxadiazol-2-one)		1 kg	Most weeds		Bhagat et al (2) IRRI (38) IRRI (39) Merlier (52) Silveira Filho and Aquino (94)
Piperophos + dimethametryn (*S*-2 methyl-piperi-dinocarbonylmethyl *00*-dipropyl phosphorodithioate) + [2 · (1, 2-dimethylpropilamino)-4-ethylamino-6-rnethylthio-1,3,5-triazine]	2-3 DAS	1-2 kg	All weeds		Bhagat et al (2) Dubey et al (24) Moorthy and Dubey (57)
Nitrofen (2,4-dichloro-4'nitrodiphenyl ether)	1-2 DAS	24 litres 3 kg			Mukhopadhyay et al (61) Dubey et al (24) Moorthy and Dubey (57) Mukhopadhyay (59)

Continued on next page

Table 7 continued

Name	Application time[a]	Rate[b] (ai ha^{-1})	Effective against	Not effective against	Reference
Dinitramine (*N'N*-'diethyl-2,6-dinitro-4-trifluoro-methyl-m-phenylenediamine)	2 DAS	1.5-2.0 kg		*Veronica* sp. *Cassia tora* *Paspalum scrobiculatum*	Pillai et al (83) IRRI (39) Dubey et al (24) Moorthy and Dubey (57)
Pendimethalin [(*N*- (1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine]		0.6-2.0 kg			IRRI (39) Sabio and Pastores (90) Silveira Filho and Aquino (94)
Thiobencarb (*S*-4-chlorobenzyl-diethyl thiolcarbamate)	3 DAS	2.0-2.5 kg		Less effective against broadleaf weeds	Bueno et al (8) Dubey et al (24)
Fluorodifen (4-nitrophenyl 2-nitro-4 -trifluoromethylphenyl ether)		3.0 kg			Deuse et al (20) Falais (31)
Butralin [4-(1,1-dimethylethyl)-*N* -(1-methylpropyl)-2,6-dinitrobenzene amine]		2.0 kg			IRRI (39) Deuse et al (20)
Alachlor [2-chloro-2',6'-diethyl-N-(methoxy-methyl) acetanilide]		2.5 kg			Ghosh et al (32)
Oxyfluorfen [2-chloro-1-(3)-ethoxy-4-nitrophenoxy)-4-(trifluoro-methyl) benzene]		0.5 kg			IRRI (39)
Trifluralin (2,6dinitro-*N,N*-dipropyl-4-trifluoro-methylaniline)	Just after sowing	0.4 kg			Bongolan et al (5)
Terbutryn 2-tert-butylamino-4-ethylamino-6 -methylthio-1,3,5-triazine		1.25 kg			Vuong et al (110)

[a] DAS = days after sowing. [b] ai = active ingredient.

Table 1. Estimated rice area by dominant water regime (11).

Location	Total rice area (thousand ha) 1978-80	Rice area (thousand ha) by water control						% upland to total rice area
		Irrigated		Rainfed				
		Dry season	Wet season	Shallow[a]	Deep water[b]	Floating[c]	Upland	
India	39,500	2,700	12,700	11,100	4,500	2,500	6,000	15.2
China	35,300[d]	[e]	33,600	1,800	0	0	0	0
Bangladesh	10,100	1.000	200	4,300	2,600	1,100	900	8.9
Thailand	9,300	500	1,300	4,900	1,100	400	1,000	10.8
Indonesia	9,000	2,700	4,600	600	300	200	700	7.8
Vietnam	5,200	800	1,200	1,400	900	400	400	7.7
Burma	4,800	100	700	2,000	1,000	200	700	14.6
Philippines	3,400	600	900	1,200	400	0	400	11.7
Pakistan	2,000	0	2,000	0	0	0	0	0
Nepal	1,300	0	300	700	200	50	50	3.3
Korea	1,200	[e]	1,200	0	0	0	0	0
Sri Lanka	700	200	300	200	0	0	50	7.1
Malaysia	700	200	200	200	0	0	100	14.3
Lao People's Republic	700	0	50	300	0	0	300	42.8
Kampuchea	600	0	50	200	50	100	100	16.7
Developing Asia	126,000[f]	8,800	61,400	29,000	11,200	4,950	10,700	8.5
Latin America	8,200[g]	0	1,200	0	900	0	6,100	74.4
Africa	4,600	0	800	700	700	0	2,300	50.0
Other[h]	4,800	[i]	4,800	0	0	0	0	0
World	143,500	8,800	68,200	29,700	12,800	4,950	19,100	13.2

[a]0-30 cm. [b]30-100 cm. [c]More than 100 cm. [d]Allocation by estimation rather than data. [e]All rice grown during the summer months and shown under wet season. [f]Including 1,800,000 in countries not separately identified. [g]Brazil has 6,200,000 ha. [h]Japan has 2,500,000 ha, the USA has 1,250,000 ha. [i]Physically Included in the irrigated wet season area, but harvested in dry and wet season.

Table 9. Rice production in Brazil *by* area and yield (7).

Year	Southern Brazil (irrigated)			Rest of Brazil (upland)			Total		
	Area (thousand ha)	Yield (t/ha)	Production (thousand t)	Area (thousand ha)	Yield (t/ha)	Production (thousand t)	Area (thousand ha)	Yield (t/ha)	Production (thousand t)
1970	2617	1.8	4647	2362	1.2	2906	4979	1.5	7553
1971	2422	1.6	3797	2342	1.1	2596	4764	1.3	6393
1972	2390	1.9	4545	2431	1.4	3379	4821	1.6	7924
1973	2365	1.6	3841	2430	1.4	3326	4795	1.5	7167
1974	2306	1.7	3936	2359	1.2	2828	4665	1.4	6764
1975	2509	1.7	4372	2798	1.2	3410	5307	1.5	7782
1976	2882	1.8	5312	3774	1.2	4445	6656	1.5	9757
1977	2429	1.8	4490	3563	1.3	4504	5992	1.5	8994
1978	2117	1.7	3567	3506	1.1	3729	5623	1.3	7296
1979	1846	1.8	3324	3593	1.2	4265	5439	1.4	7589
1980	2146	2.2	4764	4325	1.1	4874	6471	1.5	9638
1981	2134	2.2	4746	4492	0.9	3892	6626	1.3	8638
1982	2014	2.6	4550	4120	1.2	5041	6134	1.6	9591

Table 1. General description of environmental factors that directly or indirectly interact with a rainfall-deficit condition to create an array of complexes referred to as drought. The factors are considered in relation to their variability across location and through time and to the principal cultural systems in which rainfed rice is grown (30).

Variability[a]	Factor	Cultural system: Upland	Cultural system: Lowland	Cultural system: Deep water
	Edaphic			
	Physical			
I	Depth (potential root zone)	Often deep	Averaging 10-30 cm	Usually deep
*	Texture	Light (sandy to clay loam)	Heavy (clays, few loams)	Heavy (clays)
*	Physical obstruction (plow or hard pan)	Uncommon	Present	Absent
*o	Hydraulic conductivity	High	Low	Low
	Chemical			
*+0	Biochemical	Aerobic	Anaerobic (possibly alternately aerobic)	Aerobic - anaerobic
*o	Deficiencies or toxicities			
	e.g., Fe deficiency	Yes	No	No
	Zn deficiency	No	Yes	Yes
	Al toxicity	Yes (at pH <5.0)	No	No
*	Native fertility	Low	Wide range	High
	Climatic			
*+0	Rainfall			
	Totals (crop season)	500-1 500 mm	700-2000 mm	Not relevant; influx is from surface flow
	Distribution (crop season)	34 mo > 200mm	3-7 mo > 200 m	Deficits in early stage associated with erratic onset of monsoon
*+0	Temperature			
	Air	----Variable by geographic location - longitude, latitude, elevation---- and hydrological conditions		
	Soil			

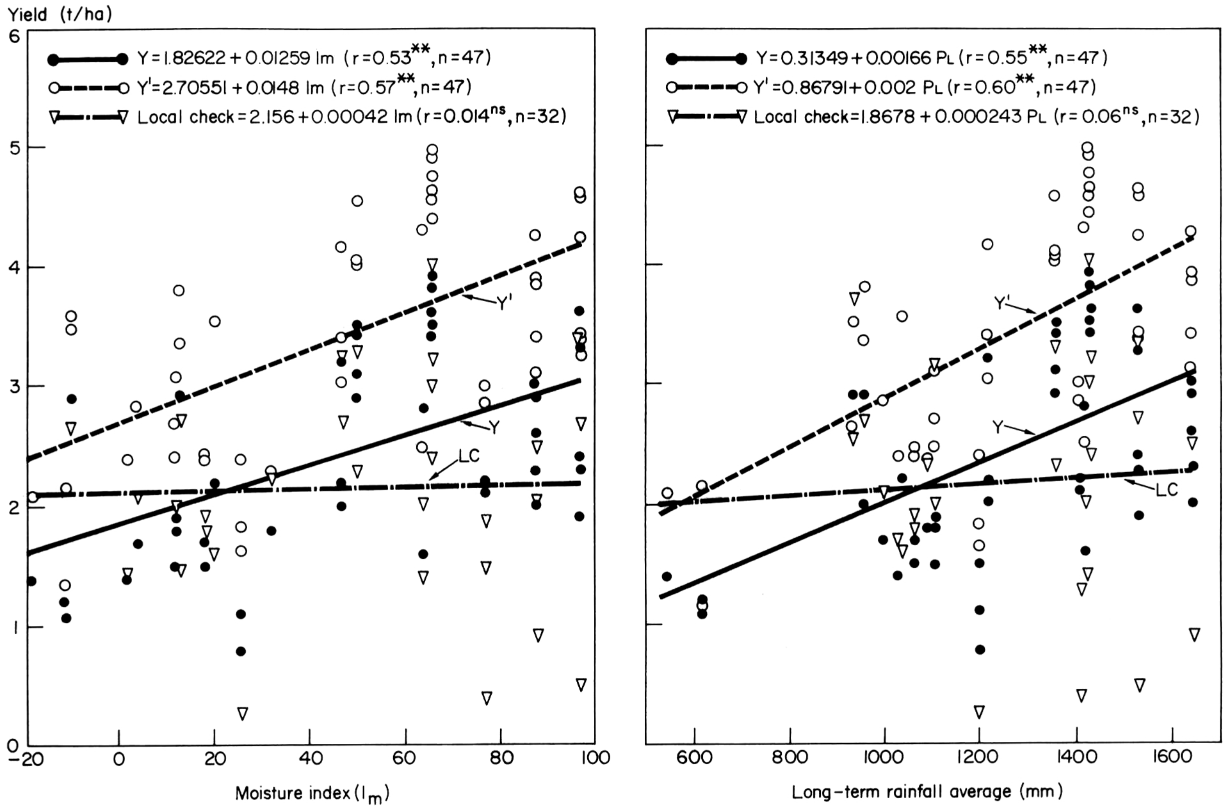
*+o	Atmospheric evaporative demand	----Determined primarily by macroclimatic conditions but respond----- significantly to microclimatic modifiers		
*+o	Wind			
*+o	Solar radiation (crop season)	-----Generalization on quantity or photoperiod not possible------		
	Hydrologic			
*+o	Water depth			
	(surface)	Rarely >O	0-50 cm	1-6 m
	(subsurface)	Low	High (often perched)	Positive
*+o	Occurrence of water excess (flood)	Rare	Rare to annual flooding	Annually
	Biotic			
*+o	Competitive	Severe	May be severe	Severe during establishment
	Plants (weeds)	-------- Drought accentuates the problem in all systems-----		
	Agronomic			
*+	Land preparation	Dry	Wet	Dry
*+	Crop establishment	Direct sown (dry)	Direct sown or trans-planted (wet)	Direct sown (dry)
*+	Use of agrochemicals	Negligible	Wide range related to water control	Negligible

[a] Across locations (*), across seasons (+), and within seasons (o).

Table 5. Number of autolyzed IR2061-464-2-4 rice plants in dark culture grown in continuously cropped soils at IRRI (64).

Field soil condition	Treatment	Plants (no.) at indicated days after sowing										
		16	18	20	22	24	26	28	30	32	34	36
		Feb 1976 dark culture										
4 rice crops	Unsterilized	0	3	8	27	37[a]						
	10% acetone	0	0	5	22	26	36	37	37	39[a]		
	Steam	0	0	0	5	7	14	25	25	36	39[a]	
1 rice crop	Unsterilized	0	0	1	14	22	31	33	35[a]			
	10% acetone	0	1	5	13	16	18	18	32	34	37	39[a]
	Steam	0	0	0	3	13	17	23	27	30[a]		
		Feb 1977 dark culture										
7 rice crops	Unsterilized	0	3	14	16	22	25	30[a]				
	10% acetone	0	0	0	3	10	12	18	23	28	28	30[a]
	Steam	0	0	0	3	13	17	23	27	30[a]		
30 mo fallow	Unsterilized	0	0	6	19	23	24	30[a]				
	Unsterilized (with root residues)	6	17	24	28	30[a]						
	10% acetone	0	0	0	7	13	20	24	26	26	28	30[a]
	Steam	0	0	0	12	19	23	27	29	30[a]		
10 mungbean crops	Unsterilized	0	1	2	10	20	24	29	30[a]			
	10% acetone	0	0	0	5	14	20	21	24	24	28	30
	Steam	0	0	3	8	16	17	27	28	28	30	

[a] All seedlings autolyzed (64).



3. Yield of 1975-77 IURYN entries as related to the Thornthwaite moisture index lor the growing season at 47 locations. Y = mean yield of all varieties (n = 25) at a location. Y= mean of 2 highest yielding varieties at a location; local checks = locally adapted variety grown with same agronomic practices as IURYN entries (138).

Table 2. Characteristics of superior upland rices developed at IITA (4, 5).

Variety	Parentage	Grain yield[a] (t ha^{-1})	Plant height (+10 cm)	Days to maturity (+ 10 d)	Resistance[b]		Grain characteristics
					Bl	Drought	
ITA116	63-83/IR773	5.2	140	115	R	MR	Long, bold, translucent
ITA117	13a-18-3-1-3/TOx 7	5.5	110	110	R	R	Medium-long, translucent
ITA118	TOx 7-4-2-5-1/63-83	5.3	120	110	R	MR	Long, bold, with specks of abdominal white
ITA141	LAC 23/(TOx 7, IET1444)	6.1	135	120	R	R	Long, slender, translucent
ITA162	Moroberekan/(ROK1, TOx 7)	6.2	130	120	R	MR	Medium-long, bold, trace of white specks
ITA225	63-83/(ROK1, Dourado Precoce, Se 363G)	5.0	115	120	R	MR	Medium-long, bold, abdominal white, highly resistant to shattering
ITA235	OS6 mutant/OS6	5.5	115	115	R	MR	Medium-long, translucent
ITA257	IRAT13/Dourado Precoce/TOx 490-B	3.7	90	95	R	MR	Medium–long, translucent

[a] Under experimental conditions. [b] R = resistant, M = moderately resistant, S = susceptible.

Table 8. Performance of promising IRRI lines in upland trials at 3 rites, 1977-80 wet seasons (37).

Line	Adapted environment	Mean yield (t ha^{-1})	Range of yields (t ha^{-1})	Stability index	Mean maturity (d)	Drought rating	
						Vegetative stage	Reproductive stage
IR3839-1	Favorable	2.4	0.1-3.8	1.35	118	5	3-5
IR3880-10	All	2.4	0.4-3.5	1.08	129	3-4	5
IR3880-17	All	2.2	0.2-3.7	0.99	128	4	5-7
IR5178-1-14	Unfavorable	1.6	0.2-2.9	0.79	116	4	5
IR5929-12-3	All	2.0	0.1-3.4	1.04	119	4	3-5
IR5931-110-1	Favorable	2.5	0.1-3.9	1.37	121	5	5-7
IR6023-10-1-1	All	2.1	0.6-3.4	1.11	132	3	5
IR6115-1-1-1	Favorable	3.0	0.2-4.3	1.42	130	4-5	7
IR9669 sel.	Favorable	2.9	0.4-4.5	1.34	132	5	7
IR43 (check)	Favorable	2.8	0.3-4.7	1.40	132	4	7-9
IR45 (check)	Favorable	2.4	0.3-4.0	1.17	135	5	7-9
Kinandana Patong (check)	Unfavorable	1.4	0.2-2.6	0.67	126	3	4

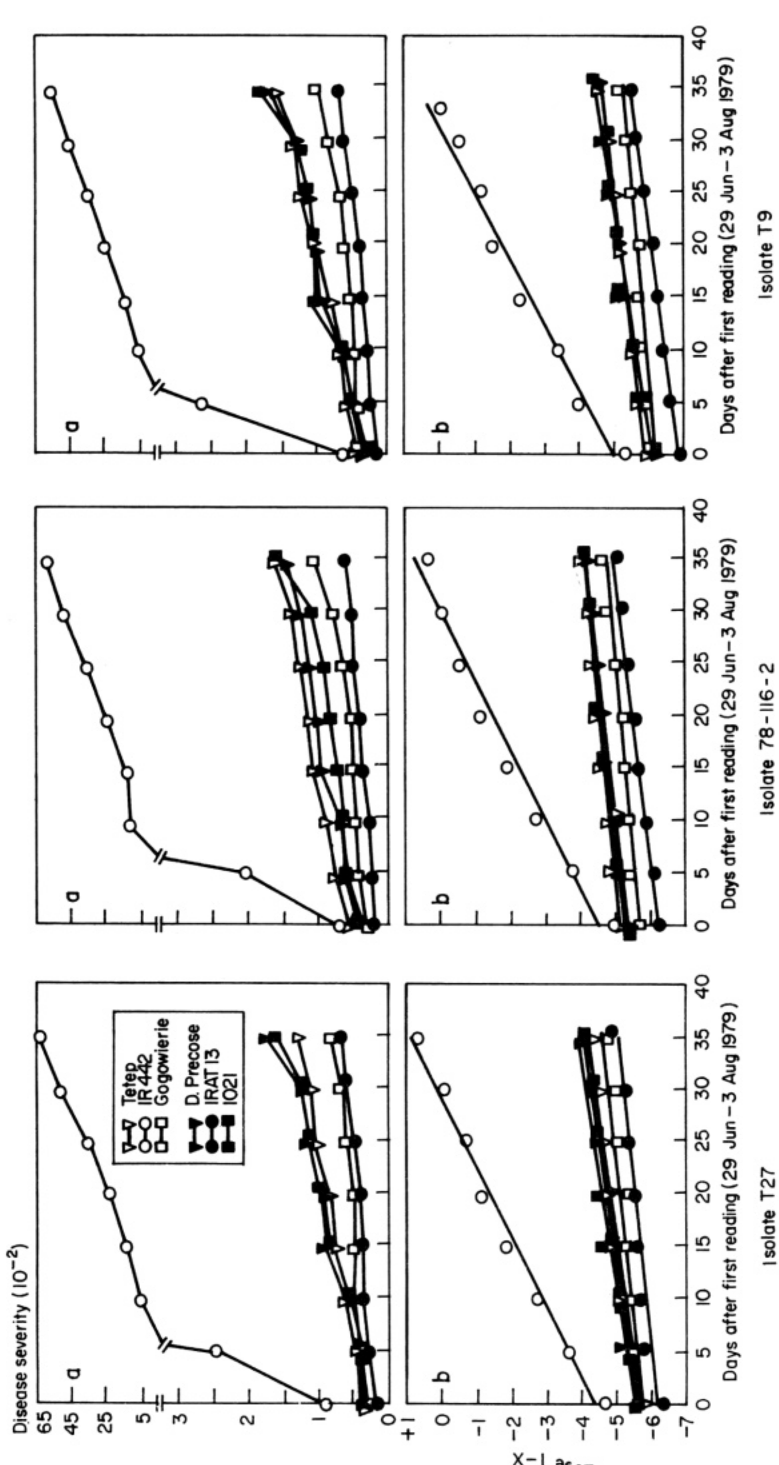
Table, 9. Agronomic characteristics of improved upland rice varieties grown in Latin America. Data are from two sites in Colombia[a] (23).

Variety	Duration (d)	Plant height (cm)	Disease reactions				Reaction to *Sogatodes oryzicola* (1-5)	Grain quality	
			Leaf BI	Neck BI	Hoja[b] blanca	LSc (1-9)		White belly	Grain length[c]
CICA4	135	89	5	22	MR	6	2.5	0.6	L
CICA6	136'	89	2.3 (4)	-	MR	-	1.5	0.6	L
CICA7	130	90	2	16	R	8	2.0	0.6	L
CICA8	143	94	4	75	S	5	2.0	0.8	L
CICA9	138	103	4	50	R	5	1.5	0.8	L
CR1113	141	94	1	51	S	5	5.0	0.2	L
Anayansi	145	86	3	40	-	5	3.0	1.6	L
Damaris	149	83	2	96	-	5	5.0	0.8	L
Bluebonnet 50	134	140	3	20	S	5	5.0	0.5	L
Eloni	141	90	2	-	-	3	2.0	0.8	EL
Pico Negro	133	109	-	-	-	-	-	1.0	L
IR1529 (IR43)	132	92	4	-	-	5	2.0	2.0	L
IAC25	135	130	3 (4)	0.1	S	7	5.0	1.4	L
IAC47	130	146	3 (4)	-	S	6	5.0	3.4	L
IAC164	110	114	1 (3.4)	-	S	5	5.0	3.6	L
IAC165	105	104	1 (3)	-	S	5	5.0	3.0	L
Diwani	131	94	1	-	MS	3	3.0	-	L
Ciwini	136	106	2.3	0	MS	3	2.5	0.2	EL
Carolino	147	144	-	-	S	-	-	2.2	L
CR201	139	103	-	-	-	3	4.0	0.4	L
Iniap 6	140	84	-	-	MR	5	2.5	0.8	L
Iniap 415	141	96	-	-	R	5	2.0	0.8	L
Iniap 7	142	100	4	-	R	6	2.0	0.4	L
Nilo 1	160	135	-	-	-	3	3.0	-	L
Tikal 2	131	94	4	98	-	5	3.0	0.6	L
Bamoa A75	136	90	-	-	-	-	-	-	L
Donato	150	109	-	-	R	-	-	-	L
Canilla	140	128	-	-	R	-	-	2.2	M
Dawn	124	90	1	86	S	5	5.0	0.6	L
Metica 1	124	75	1	0.5	R	5	3.0	0.2	L
Dourado	120	146	-	-	S	-	9.0	1.6	M

[a]Data are from CIAT-Palmira with disease evaluations at Villavicencio in Colombian llanos. A dash (—) indicates data not available. [b]S = susceptible, MS = moderately susceptible, R = resistant. [c]M = medium, L = long, EL = extra long.

Table 11. Performance of top entries in the 1976-81 IURYN (73, 75, 76, 79, 82, 85).

Entry	Yield (t ha^{-1})	Days to maturity	Days to flowering	Entry	Yield (t ha^{-1})	Days to flowering
		1976			1979	
IET1444 (India)	3.3		77	UPL Ri-5 (Philippines)	2.8	101
IR36 (IRRI)	3.1		83	IR9669 Sel. (IRRI)	2.8	106
IR1529-430-3 (IRRI)	3.1		93	BG35-2 (Sri Lanka)	- 2.7	91
IR2061-522-69 (IRRI)	3.1		78	IR2061-522-69 (IRRI)	2.7	88
B541b-Kn-19-34 (Indonesia)	3.0		89	IR45 (IRRI)	2.7	103
		1977			1980	
IET1444 (India)	3.0	116		IR5931-110-1 (IRRI)	3.9	91
IR36 (IRRI)	3.0	118		BG35-2 (Sri Lanka)	3.6	89
C22 (Philippines)	3.0	130		B733C-167-3-2 (Indonesia)	3.5	94
C4815/IR42^{2} (Philippines)	3.0	128		CR 156-5021 -207 (India)	3.5	95
KN361-1-8-6 (Indonesia)	2.9	118		IR5853-118-5 (IR52) (IRRI)	3.5	97
IR1529-430-3 (IRRI)	2.9	131		IR6115-1-1-1 (IRRI)	3.5	91
IR2061-522-69 (IRRI)	2.9	122		IR9560-26-3-1 (IRRI)	3.5	102
IR3839-1 (IRRI)	2.9	124		IR995-96-2 (IRRI)	3.5	101
		1978			1981	
IR1529-430-3 (IR43) (IRRI)	3.8		102	IR5931-110-1 (IRRI)	2.5	96
IR9669 Sel. (IRRI)	3.7		108	IR6115-1-1-1 (IRRI)	2.4	93
IET1444 (India)	3.6		86	UPL Ri-5 (Philippines)	2.5	100
IR36 (IRRI)	3.6		94	IR43 (IRRI)	2.4	100
B541b-Kn-19-34 (Indonesia)	3.5		107	BPI Ri-6 (Philippines)	2.3	101
Gama 318 (Indonesia)	3.5		107	CR156-5021-207 (India)	2.3	9
KN96 (Indonesia)	3.5		102	IR52 (IRRI)	2.3	100
IR2035-242-1 (IR45)	3.5		107			
IR3839-1 (IRRI)	3.5		94			
MRC172-9 (Philippines)	3.5		101			
IR9575 Sel. (IRRI)	3.5		98			



9. Disease progress curves (a) for 3 isolates of *P. oryzae* Cav. on 6 rice cultivars and their logit plots (b), 1979 (77).

Table 19. Scoring[a] system for drought resistance screening at vegetative phases I and II[b] (108).

Decimal score	Plant type	Stress symptoms			
		Leaf rolling	Leaf drying	Plant color	Growth stunting
1	Tall traditional	Slight folding from early morning to late afternoon.	No drying.	Green	No stunting
	Semidwarf	No rolling.	Few leaf tips drying.	Green	No stunting
3	Tall traditional	Partial rolling from early morning to late afternoon.	Few tips drying more than 1 cm in length; 5-10% basal leaves dried.	Green	No stunting
	Semidwarf	No roiling.	75% leaf-tip drying extended to ¼ of leaf blade; 5-10% of lower leaves dried.	Green	No stunting
5	Tall traditional	Complete, tight rolling from early morning to late afternoon. Partial unrolling when temperature cools during day; complete unrolling at night.	Most younger leaf tips dried; 25-50% lower leaves dried.	Unusually dark green	No stunting
	Semidwarf	Complete, tight rolling; partial unrolling at night.	50% younger leaves with ½-1/3 area dried; 25-40% lower leaves dried.	Ashen gray or yellow	Slight
7	Tall traditional	Tube-like rolling; no unrolling at night,	Most upper leaves with 2/3-3/4 area dried; 60-80% lower leaves dried.	Ashen gray or yellow	Stunted
	Semidwarf	Same as tall traditional.			
9	Tall traditional	Tube-like rolling; no unrolling at night.	100% of all leaves dried; plants generally approach permanent wilting, some die.	Meristematic tissues show a slight green to light green tinge	Severe stunting
	Semidwarf	Same as tall traditional.			

[a] Scores were taken 15-20 d from the start of imposed stress or when susceptible checks showed symptoms of moisture stress. Preliminary scoring should be when plants show the first signs of stress. [b] Vegetative phase I refers to active tillering stage of both early and late-maturing varieties, and ranges from 50 to 60 d after seeding (DAS). Vegetative phase II applies only to the late-maturing varieties at about 80-100 DAS (108).

Table 9. Nutrient uptake at different growth stages in two rice varieties[a] (52).

Growth stage	N ($kg\ ha^{-1}$)		P ($kg\ ha^{-1}$)		K ($kg\ ha^{-1}$)		Fe ($g\ ha^{-1}$)		Mn ($g\ ha^{-1}$)	
	Krishnasal	Pusa 33	Krishnasal	Pusa 33	Krishnasal	Pusa 33	Krishnasal	Pusa 33	Krishnasal	Pusa 33
					Total					
Tillering	12	7	1.2	0.5	6	2	214	188	22	7
Panicle initiation	65	39	7.7	3.3	59	21	1526	1017	204	54
Flowering	89	52	12.2	7.7	63	28	1742	1183	724	207
Harvest	93	54	13.1	11.0	64	34	2195	1440	788	271
					Tillering					
Leaf	6.05	3.52	0.44	0.20	2.69	0.90	36	35	11	3
Sheath	4.98	2.45	0.63	0.26	3.19	1.26	124	65	9	3
Root	1.01	1.10	0.08	0.08	0.20	0.27	54	68	2	1
					Panicle initiation					
Leaf	30	19	2.2	1.5	20	7	458	179	91	15
Sheath	25	14	5.0	1.4	34	12	626	447	96	31
Root	9	6	0.5	0.4	5	2	442	391	17	8
					Flowering					
Leaf	32	18	1.6	1.5	17	9.0	351	158	246	72
Sheath	31	16	5.6	2.0	20	6.4	303	342	318	71
Stem	8	5	2.8	2.1	14	9.6	833	415	216	45
Panicle	5	5	1.7	1.6	4	2.0	81	50	11	10
Root	12	7	0.6	0.6	8	2.4	174	218	23	10
					Harvest					
Leaf	22	9	0.6	0.7	7	5.4	347	163	246	94
Sheath	19	10	1.1	0.3	15	5.5	261	312	307	80
Stem	15	8	0.9	1.1	31	16.4	1229	616	173	61
Panicle	30	24	10.1	8.8	8	4.8	141	142	42	26
Root	7	4	0.3	0.2	3	1.7	127	207	20	11

[a]Mean of 3 replications.

Table 25. Effect of different organic manures with and without ammonium sulfate (applied on an equal N basis) on upland rice and soil physicochemical properties (83).

Treatment	Grain yield (t ha^{-1})	N in plant at harvest (%)	P in plant at harvest (%)	K in plant at harvest (%)	Mean wt-diam of soil aggregates	Soil bulk density (t m^{-3})	Organic C of soil (%)	N content of soil (%)
Control	1.3	1.081	0.177	1.102	.3023	1.604	.3902	.0377
Farmyard manure (FYM)	1.7	1.171	0.207	1.222	.3839	1.504	.4112	.0402
Green manures (GMS)	1.8	1.156	0.188	1.137	.3727	1,505	.4087	.0391
AS-N 45.0	2.5	1.290	0.157	1.017	.3412	1.552	.4003	.0384
FYM + AS-N 22.5	2.6	1.370	0.201	1.202	.4042	1.502	.4269	.0408
GMS + AS-N 22.5	2.5	1.328	0.182	1.101	.3917	1.509	.4091	.0394
AS-AN 67.5	2.5	1.441	1.130	0.937	.3345	1.549	.4047	.0382
SEm. (+)	0.16	0.050	0.008	0.017	.0218	0.015	.0049	.0006
CD 5%	0.3	0.147	0.023	0.049	.0641	0.044	.0144	.0017
CD 1%	0.4	0.200	0.031	0.067	–	0.060	.0196	–

Table 6. Time requirements for weeding (7). Values in parentheses indicate the time required for each weeding task.[a]

Weeding method	Time (h) required to weed 1 ha		
	Strip tillage	Cultivator	Plowing
Hand weeding			
3 + 6 wk after planting (WP)	525 (335 + 190)	481 (286 + 195)	407 (242 + 165)
2 + 5 + 8 WP	623 (293 + 192 + 138)	539 (251 + 170 + 118)	457 (189 + 159 + 109)
Hoe weeding			
3 + 6 WP	282 (118 + 164)	282 (120 + 162)	193 (76 + 117)
2 + 5 + 8 WP	304 (92 + 120 + 92)	265 (74 + 101 + 90)	226 (72 + 82 + 72)
Time weeding, hand-pushed			
3 + 6 WP (1 row)	72 (39 + 33)	62 (30 + 32)	55 (27 + 28)
2 + 5 + 8 WP (1 row)	86 (31 + 22 + 33)	85 (28 + 22 + 35)	79 (25 + 20 + 34)
Time weeding, frame on hand tractor			
2 + 5 + 8 WP (3rows)	57 (21 + 18 + 18)	54 (20 + 16 + 18)	82 (20 + 14 + 18)
Blade weeding, hand-pushed			
2 + 5 + 8 WP (1 row)	89 (31 + 21 + 37)	83 (25 + 22 + 36)	80 (27 + 20 + 33)
Blade weeding, frame on hand tractor			
2 + 5 + 8 WP (3 rows)	70 (26 + 19 + 25)	66 (22 + 19 + 25)	63 (24 + 17 + 22)
Rotary weeding, brush cutter			
2 + 5 + 8 WP(1 row)	438 (123 + 163 + 152)	342 (94 + 134 + 114)	262 (60 + 100 + 102)
Rotary weeding, hand tractor			
3 + 6 WP (3 rows)	34 (18 + 16)	29 (14 + 15)	26 (13 + 13)
2 + 5 + 8 WP (3 rows)	37 (11 + 14 + 12)	33 (11 + 11 + 11)	31 (11 + 9 + 11)

[a]WP = weeks after planting.

Table 6. Effect of tillage on weed weight and grain yield of 3 upland rices, 1976 wet season, IRRI (39).

Tillage treatment[a]	IR1529-430-3		IR9575		M1-48		Tillage mean	
	Weed wt ($g\ m^{-2}$)	Yield ($t\ ha^{-1}$)	Weed wt ($g\ m^{-2}$)	Yield ($t\ ha^{-1}$)	Weed wt ($g\ m^{-2}$)	Yield ($t\ ha^{-1}$)	Weed wt[b]	Yield[c] ($t\ ha^{-1}$)
Plowing fb 1 rototilling	131	1.5	144	2.1	191	1.1	155 b	1.6 a
Plowing fb 2 rototillings	114-	1.7	123	2.3	132	1.1	123 a	1.7 a
Plowing fb 3 rototillings	124	1.8	110	2.1	105	1.0	113 a	1.6 a
Mean	123 a	1.6 a	125 a	2.2 a	143 a	1.1 b		

[a] fb = followed by. [b] Weeds sampled at 50 d after rice emergence. [c] Average of 4 replications and 3 weed control treatments. Means in a column or row followed by a common letter are not significantly different at the 5% level.

Table 7 continued

Name	Application time[a]	Rate[b] (ai ha^{-1})	Effective against	Not effective against	Reference
Dinitramine (*N'N*-'diethyl-2,6-dinitro-4-trifluoro-methyl-m-phenylenediamine)	2 DAS	1.5-2.0 kg		*Veronica* sp. *Cassia tora* *Paspalum scrobiculatum*	Pillai et al (83) IRRI (39) Dubey et al (24) Moorthy and Dubey (57)
Pendimethalin [(*N*- (1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine]		0.6-2.0 kg			IRRI (39) Sabio and Pastores (90) Silveira Filho and Aquino (94)
Thiobencarb (*S*-4-chlorobenzyl-diethyl thiolcarbamate)	3 DAS	2.0-2.5 kg		Less effective against broadleaf weeds	Bueno et al (8) Dubey et al (24)
Fluorodifen (4-nitrophenyl 2-nitro-4 -trifluoromethylphenyl ether)		3.0 kg			Deuse et al (20) Falais (31)
Butralin [4-(1,1-dimethylethyl)-*N* -(1-methylpropyl)-2,6-dinitrobenzene amine]		2.0 kg			IRRI (39) Deuse et al (20)
Alachlor [2-chloro-2',6'-diethyl-N-(methoxy-methyl) acetanilide]		2.5 kg			Ghosh et al (32)
Oxyfluorfen [2-chloro-1-(3)-ethoxy-4-nitrophenoxy)-4-(trifluoro-methyl) benzene]		0.5 kg			IRRI (39)
Trifluralin (2,6dinitro-*N,N*-dipropyl-4-trifluoro-methylaniline)	Just after sowing	0.4 kg			Bongolan et al (5)
Terbutryn 2-tert-butylamino-4-ethylamino-6 -methylthio-1,3,5-triazine		1.25 kg			Vuong et al (110)

[a] DAS = days after sowing. [b] ai = active ingredient.

Table 8. Promising postemergence herbicides for upland rice.

Name	Application time[a]	Rate (kg ai ha^{-1})	Effective against	Not effective against	Reference
Propanil Stam F-34 (3', 4'-dichloro-propionanilide)	15-30 DAS 15 DE 2-4 WLS	1.5-6.0	Grassy, most weeds Monocot, *E. colona*	*Acanthospermum hispidium*, *Ipomoea* sp.	Domingo and Palis (22) Mukhopadhyay and Bag (60) Patro and Misra (79) Mukhopadhyay et al (61) Pillai et al (83) Fagade (29) Dubey (53) Raghavulu and Sreerama Murthy (84) Singh et al (96) Falais (31) IRRI (41) Dixit and Singh (21) Tosh et al (105) Mukhopadhyay (59) Singh and Singh (97)
MCPA (4-chloro,2-methyl-phenoxy acetic acid)	30 DAS	0.5	*Digitaria* sp. *Cyperus rotundus* *Cynodon dactylon*		Dixit and Singh (21)
Fluorodifen (4-nitrophenyl 2-nitro-4-trifluoromethylphenyl ether)		4.0			Vuong et al (110)

[a]DAS = days after sowing, DE = days after emergence, WLS =weed leaf stage. [b]ai = active ingredient,

Table 7. Promising preemergence herbicides for upland rice.

Name	Application time[a]	Rate[b] (ai ha^{-1})	Effective against	Not effective against	Reference
Butachlor (N-butoxymethyl-a-chloro-2', 6'diethylacetanilide)	2-4 DAS	1-2 kg	Grasses and broadleaf weeds	Perennial sedge *Sefaria glauca*	Bueno et al (8) Pillai et al (83) PCARR (81) Clarete and Mabbayad (15) Schiller and Indhaphun (92) Dubey et al (24) Tasic et al (104) Bongolan et al (5) Moorthy and Dubey (60) Sabio and Pastores (90) Mukhopadhyay (59) Pande et al (78) Singh and Singh (97)
Oxadiazon (5-*terft*-butyl-3 (2,4-dichloro-5-isopropoxyphenyl)-1,3,4-oxadiazol-2-one)		1 kg	Most weeds		Bhagat et al (2) IRRI (38) IRRI (39) Merlier (52) Silveira Filho and Aquino (94)
Piperophos + dimethametryn (*S*-2 methyl-piperi-dinocarbonylmethyl *00*-dipropyl phosphorodithioate) + [2 · (1, 2-dimethylpropilamino)-4-ethylamino-6-rnethylthio-1,3,5-triazine]	2-3 DAS	1-2 kg	All weeds		Bhagat et al (2) Dubey et al (24) Moorthy and Dubey (57)
Nitrofen (2,4-dichloro-4'nitrodiphenyl ether)	1-2 DAS	24 litres 3 kg			Mukhopadhyay et al (61) Dubey et al (24) Moorthy and Dubey (57) Mukhopadhyay (59)

Continued on next page

Table 7 continued

Name	Application time[a]	Rate[b] (ai ha^{-1})	Effective against	Not effective against	Reference
Dinitramine (*N'N*-'diethyl-2,6-dinitro-4-trifluoro-methyl-m-phenylenediamine)	2 DAS	1.5-2.0 kg		*Veronica* sp. *Cassia tora* *Paspalum scrobiculatum*	Pillai et al (83) IRRI (39) Dubey et al (24) Moorthy and Dubey (57)
Pendimethalin [(*N*- (1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine]		0.6-2.0 kg			IRRI (39) Sabio and Pastores (90) Silveira Filho and Aquino (94)
Thiobencarb (*S*-4-chlorobenzyl-diethyl thiolcarbamate)	3 DAS	2.0-2.5 kg		Less effective against broadleaf weeds	Bueno et al (8) Dubey et al (24)
Fluorodifen (4-nitrophenyl 2-nitro-4 -trifluoromethylphenyl ether)		3.0 kg			Deuse et al (20) Falais (31)
Butralin [4-(1,1-dimethylethyl)-*N* -(1-methylpropyl)-2,6-dinitrobenzene amine]		2.0 kg			IRRI (39) Deuse et al (20)
Alachlor [2-chloro-2',6'-diethyl-N-(methoxy-methyl) acetanilide]		2.5 kg			Ghosh et al (32)
Oxyfluorfen [2-chloro-1-(3)-ethoxy-4-nitrophenoxy)-4-(trifluoro-methyl) benzene]		0.5 kg			IRRI (39)
Trifluralin (2,6dinitro-*N,N*-dipropyl-4-trifluoro-methylaniline)	Just after sowing	0.4 kg			Bongolan et al (5)
Terbutryn 2-tert-butylamino-4-ethylamino-6 -methylthio-1,3,5-triazine		1.25 kg			Vuong et al (110)

[a] DAS = days after sowing. [b] ai = active ingredient.

Table 1. Estimated rice area by dominant water regime (11).

Location	Total rice area (thousand ha) 1978-80	Rice area (thousand ha) by water control						% upland to total rice area
		Irrigated		Rainfed				
		Dry season	Wet season	Shallow[a]	Deep water[b]	Floating[c]	Upland	
India	39,500	2,700	12,700	11,100	4,500	2,500	6,000	15.2
China	35,300[d]	[e]	33,600	1,800	0	0	0	0
Bangladesh	10,100	1.000	200	4,300	2,600	1,100	900	8.9
Thailand	9,300	500	1,300	4,900	1,100	400	1,000	10.8
Indonesia	9,000	2,700	4,600	600	300	200	700	7.8
Vietnam	5,200	800	1,200	1,400	900	400	400	7.7
Burma	4,800	100	700	2,000	1,000	200	700	14.6
Philippines	3,400	600	900	1,200	400	0	400	11.7
Pakistan	2,000	0	2,000	0	0	0	0	0
Nepal	1,300	0	300	700	200	50	50	3.3
Korea	1,200	[e]	1,200	0	0	0	0	0
Sri Lanka	700	200	300	200	0	0	50	7.1
Malaysia	700	200	200	200	0	0	100	14.3
Lao People's Republic	700	0	50	300	0	0	300	42.8
Kampuchea	600	0	50	200	50	100	100	16.7
Developing Asia	126,000[f]	8,800	61,400	29,000	11,200	4,950	10,700	8.5
Latin America	8,200[g]	0	1,200	0	900	0	6,100	74.4
Africa	4,600	0	800	700	700	0	2,300	50.0
Other[h]	4,800	[i]	4,800	0	0	0	0	0
World	143,500	8,800	68,200	29,700	12,800	4,950	19,100	13.2

[a]0-30 cm. [b]30-100 cm. [c]More than 100 cm. [d]Allocation by estimation rather than data. [e]All rice grown during the summer months and shown under wet season. [f]Including 1,800,000 in countries not separately identified. [g]Brazil has 6,200,000 ha. [h]Japan has 2,500,000 ha, the USA has 1,250,000 ha. [i]Physically Included in the irrigated wet season area, but harvested in dry and wet season.

Table 9. Rice production in Brazil *by* area and yield (7).

Year	Southern Brazil (irrigated)			Rest of Brazil (upland)			Total		
	Area (thousand ha)	Yield (t/ha)	Production (thousand t)	Area (thousand ha)	Yield (t/ha)	Production (thousand t)	Area (thousand ha)	Yield (t/ha)	Production (thousand t)
1970	2617	1.8	4647	2362	1.2	2906	4979	1.5	7553
1971	2422	1.6	3797	2342	1.1	2596	4764	1.3	6393
1972	2390	1.9	4545	2431	1.4	3379	4821	1.6	7924
1973	2365	1.6	3841	2430	1.4	3326	4795	1.5	7167
1974	2306	1.7	3936	2359	1.2	2828	4665	1.4	6764
1975	2509	1.7	4372	2798	1.2	3410	5307	1.5	7782
1976	2882	1.8	5312	3774	1.2	4445	6656	1.5	9757
1977	2429	1.8	4490	3563	1.3	4504	5992	1.5	8994
1978	2117	1.7	3567	3506	1.1	3729	5623	1.3	7296
1979	1846	1.8	3324	3593	1.2	4265	5439	1.4	7589
1980	2146	2.2	4764	4325	1.1	4874	6471	1.5	9638
1981	2134	2.2	4746	4492	0.9	3892	6626	1.3	8638
1982	2014	2.6	4550	4120	1.2	5041	6134	1.6	9591

Table 1. General description of environmental factors that directly or indirectly interact with a rainfall-deficit condition to create an array of complexes referred to as drought. The factors are considered in relation to their variability across location and through time and to the principal cultural systems in which rainfed rice is grown (30).

Variability[a]	Factor	Cultural system		
		Upland	Lowland	Deep water
	Edaphic			
	Physical			
I	Depth (potential root zone)	Often deep	Averaging 10-30 cm	Usually deep
*	Texture	Light (sandy to clay loam)	Heavy (clays, few loams)	Heavy (clays)
*	Physical obstruction (plow or hard pan)	Uncommon	Present	Absent
*o	Hydraulic conductivity	High	Low	Low
	Chemical			
*+0	Biochemical	Aerobic	Anaerobic (possibly alternately aerobic)	Aerobic - anaerobic
*o	Deficiencies or toxicities			
	e.g., Fe deficiency	Yes	No	No
	Zn deficiency	No	Yes	Yes
	Al toxicity	Yes (at pH <5.0)	No	No
*	Native fertility	Low	Wide range	High
	Climatic			
*+0	Rainfall			
	Totals (crop season)	500-1 500 mm	700-2000 mm	Not relevant; influx is from surface flow
	Distribution (crop season)	34 mo > 200mm	3-7 mo > 200 m	Deficits in early stage associated with erratic onset of monsoon
*+0	Temperature			
	Air	----Variable by geographic location - longitude, latitude, elevation---- and hydrological conditions		
	Soil			

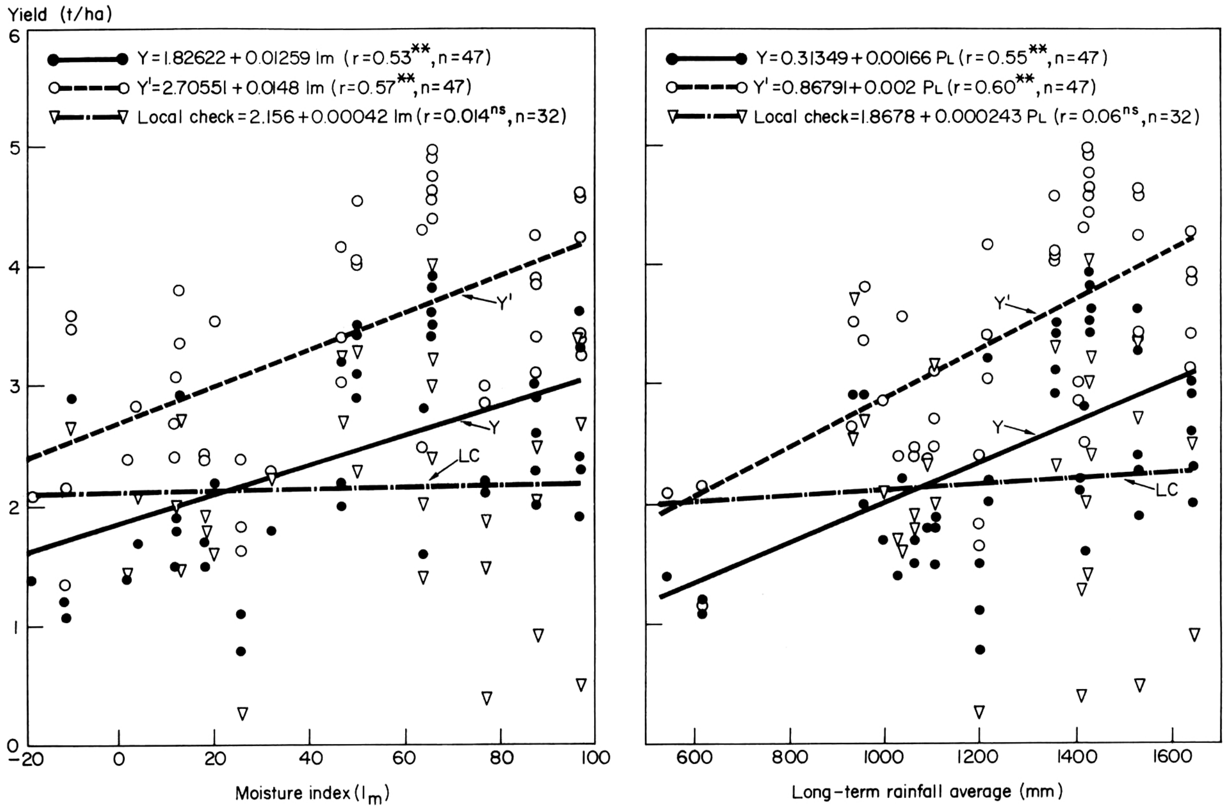
*+o	Atmospheric evaporative demand	----Determined primarily by macroclimatic conditions but respond----- significantly to microclimatic modifiers		
*+o	Wind			
*+o	Solar radiation (crop season)	-----Generalization on quantity or photoperiod not possible------		
	Hydrologic			
*+o	Water depth			
	(surface)	Rarely >O	0-50 cm	1-6 m
	(subsurface)	Low	High (often perched)	Positive
*+o	Occurrence of water excess (flood)	Rare	Rare to annual flooding	Annually
	Biotic			
*+o	Competitive	Severe	May be severe	Severe during establishment
	Plants (weeds)	-------- Drought accentuates the problem in all systems-----		
	Agronomic			
*+	Land preparation	Dry	Wet	Dry
*+	Crop establishment	Direct sown (dry)	Direct sown or trans-planted (wet)	Direct sown (dry)
*+	Use of agrochemicals	Negligible	Wide range related to water control	Negligible

[a] Across locations (*), across seasons (+), and within seasons (o).

Table 5. Number of autolyzed IR2061-464-2-4 rice plants in dark culture grown in continuously cropped soils at IRRI (64).

Field soil condition	Treatment	Plants (no.) at indicated days after sowing										
		16	18	20	22	24	26	28	30	32	34	36
						Feb 1976 dark culture						
4 rice crops	Unsterilized	0	3	8	27	37[a]						
	10% acetone	0	0	5	22	26	36	37	37	39[a]		
	Steam	0	0	0	5	7	14	25	25	36	39[a]	
1 rice crop	Unsterilized	0	0	1	14	22	31	33	35[a]			
	10% acetone	0	1	5	13	16	18	18	32	34	37	39[a]
	Steam	0	0	0	3	13	17	23	27	30[a]		
						Feb 1977 dark culture						
7 rice crops	Unsterilized	0	3	14	16	22	25	30[a]				
	10% acetone	0	0	0	3	10	12	18	23	28	28	30[a]
	Steam	0	0	0	3	13	17	23	27	30[a]		
30 mo fallow	Unsterilized	0	0	6	19	23	24	30[a]				
	Unsterilized (with root residues)	6	17	24	28	30[a]						
	10% acetone	0	0	0	7	13	20	24	26	26	28	30[a]
	Steam	0	0	0	12	19	23	27	29	30[a]		
10 mungbean crops	Unsterilized	0	1	2	10	20	24	29	30[a]			
	10% acetone	0	0	0	5	14	20	21	24	24	28	30
	Steam	0	0	3	8	16	17	27	28	28	30	

[a]All seedlings autolyzed (64).



3. Yield of 1975-77 IURYN entries as related to the Thornthwaite moisture index lor the growing season at 47 locations. Y = mean yield of all varieties (n = 25) at a location. Y= mean of 2 highest yielding varieties at a location; local checks = locally adapted variety grown with same agronomic practices as IURYN entries (138).

Table 2. Characteristics of superior upland rices developed at IITA (4, 5).

Variety	Parentage	Grain yield[a] ($t\ ha^{-1}$)	Plant height (+10 cm)	Days to maturity (+ 10 d)	Resistance[b] BI	Resistance[b] Drought	Grain characteristics
ITA116	63-83/IR773	5.2	140	115	R	MR	Long, bold, translucent
ITA117	13a-18-3-1-3/TOx 7	5.5	110	110	R	R	Medium-long, translucent
ITA118	TOx 7-4-2-5-1/63-83	5.3	120	110	R	MR	Long, bold, with specks of abdominal white
ITA141	LAC 23/(TOx 7, IET1444)	6.1	135	120	R	R	Long, slender, translucent
ITA162	Moroberekan/(ROK1, TOx 7)	6.2	130	120	R	MR	Medium-long, bold, trace of white specks
ITA225	63-83/(ROK1, Dourado Precoce, Se 363G)	5.0	115	120	R	MR	Medium-long, bold, abdominal white, highly resistant to shattering
ITA235	OS6 mutant/OS6	5.5	115	115	R	MR	Medium-long, translucent
ITA257	IRAT13/Dourado Precoce/TOx 490-B	3.7	90	95	R	MR	Medium–long, translucent

[a] Under experimental conditions. [b] R = resistant, M = moderately resistant, S = susceptible.

Table 8. Performance of promising IRRI lines in upland trials at 3 rites, 1977-80 wet seasons (37).

Line	Adapted environment	Mean yield (t ha^{-1})	Range of yields (t ha^{-1})	Stability index	Mean maturity (d)	Drought rating	
						Vegetative stage	Reproductive stage
IR3839-1	Favorable	2.4	0.1-3.8	1.35	118	5	3-5
IR3880-10	All	2.4	0.4-3.5	1.08	129	3-4	5
IR3880-17	All	2.2	0.2-3.7	0.99	128	4	5-7
IR5178-1-14	Unfavorable	1.6	0.2-2.9	0.79	116	4	5
IR5929-12-3	All	2.0	0.1-3.4	1.04	119	4	3-5
IR5931-110-1	Favorable	2.5	0.1-3.9	1.37	121	5	5-7
IR6023-10-1-1	All	2.1	0.6-3.4	1.11	132	3	5
IR6115-1-1-1	Favorable	3.0	0.2-4.3	1.42	130	4-5	7
IR9669 sel.	Favorable	2.9	0.4-4.5	1.34	132	5	7
IR43 (check)	Favorable	2.8	0.3-4.7	1.40	132	4	7-9
IR45 (check)	Favorable	2.4	0.3-4.0	1.17	135	5	7-9
Kinandana Patong (check)	Unfavorable	1.4	0.2-2.6	0.67	126	3	4

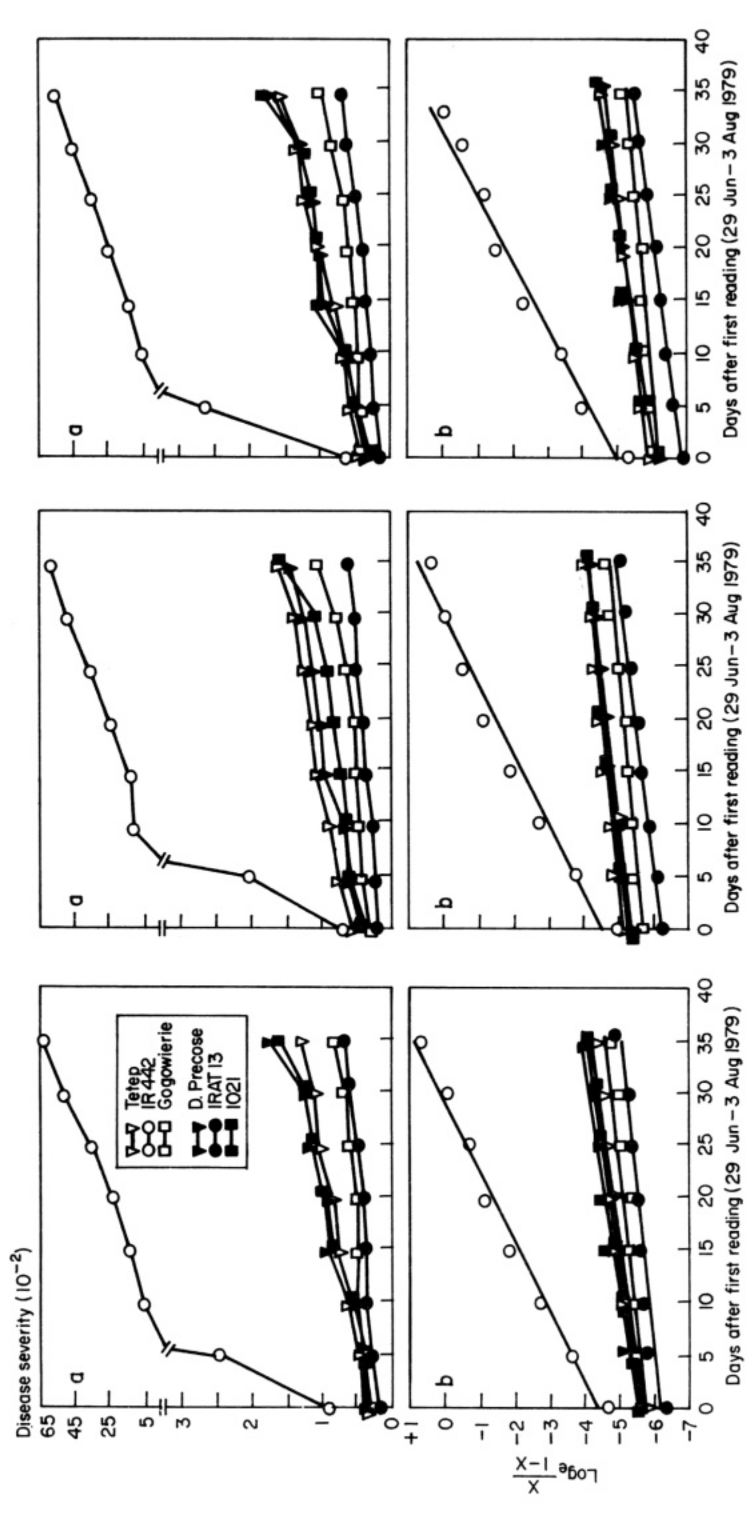
Table, 9. Agronomic characteristics of improved upland rice varieties grown in Latin America. Data are from two sites in Colombia[a] (23).

Variety	Duration (d)	Plant height (cm)	Disease reactions Leaf BI	Neck BI	Hoja[b] blanca	LSc (1-9)	Reaction to *Sogatodes oryzicola* (1-5)	Grain quality White belly	Grain length[c]
CICA4	135	89	5	22	MR	6	2.5	0.6	L
CICA6	136'	89	2.3 (4)	-	MR	-	1.5	0.6	L
CICA7	130	90	2	16	R	8	2.0	0.6	L
CICA8	143	94	4	75	S	5	2.0	0.8	L
CICA9	138	103	4	50	R	5	1.5	0.8	L
CR1113	141	94	1	51	S	5	5.0	0.2	L
Anayansi	145	86	3	40	-	5	3.0	1.6	L
Damaris	149	83	2	96	-	5	5.0	0.8	L
Bluebonnet 50	134	140	3	20	S	5	5.0	0.5	L
Eloni	141	90	2	-	-	3	2.0	0.8	EL
Pico Negro	133	109	-	-	-	-	-	1.0	L
IR1529 (IR43)	132	92	4	-	-	5	2.0	2.0	L
IAC25	135	130	3 (4)	0.1	S	7	5.0	1.4	L
IAC47	130	146	3 (4)	-	S	6	5.0	3.4	L
IAC164	110	114	1 (3.4)	-	S	5	5.0	3.6	L
IAC165	105	104	1 (3)	-	S	5	5.0	3.0	L
Diwani	131	94	1	-	MS	3	3.0	-	L
Ciwini	136	106	2.3	0	MS	3	2.5	0.2	EL
Carolino	147	144	-	-	S	-	-	2.2	L
CR201	139	103	-	-	-	3	4.0	0.4	L
Iniap 6	140	84	-	-	MR	5	2.5	0.8	L
Iniap 415	141	96	-	-	R	5	2.0	0.8	L
Iniap 7	142	100	4	-	R	6	2.0	0.4	L
Nilo 1	160	135	-	-	-	3	3.0	-	L
Tikal 2	131	94	4	98	-	5	3.0	0.6	L
Bamoa A75	136	90	-	-	-	-	-	-	L
Donato	150	109	-	-	R	-	-	-	L
Canilla	140	128	-	-	R	-	-	2.2	M
Dawn	124	90	1	86	S	5	5.0	0.6	L
Metica 1	124	75	1	0.5	R	5	3.0	0.2	L
Dourado	120	146	-	-	S	-	9.0	1.6	M

[a]Data are from CIAT-Palmira with disease evaluations at Villavicencio in Colombian llanos. A dash (—) indicates data not available. [b]S = susceptible, MS = moderately susceptible, R = resistant. [c]M = medium, L = long, EL = extra long.

Table 11. Performance of top entries in the 1976-81 IURYN (73, 75, 76, 79, 82, 85).

Entry	Yield (t ha^{-1})	Days to maturity	Days to flowering	Entry	Yield (t ha^{-1})	Days to flowering
		1976			1979	
IET1444 (India)	3.3		77	UPL Ri-5 (Philippines)	2.8	101
IR36 (IRRI)	3.1		83	IR9669 Sel. (IRRI)	2.8	106
IR1529-430-3 (IRRI)	3.1		93	BG35-2 (Sri Lanka)	- 2.7	91
IR2061-522-69 (IRRI)	3.1		78	IR2061-522-69 (IRRI)	2.7	88
B541b-Kn-19-34 (Indonesia)	3.0		89	IR45 (IRRI)	2.7	103
		1977			1980	
IET1444 (India)	3.0	116		IR5931-110-1 (IRRI)	3.9	91
IR36 (IRRI)	3.0	118		BG35-2 (Sri Lanka)	3.6	89
C22 (Philippines)	3.0	130		B733C-167-3-2 (Indonesia)	3.5	94
C4815/IR42^2 (Philippines)	3.0	128		CR 156-5021 -207 (India)	3.5	95
KN361-1-8-6 (Indonesia)	2.9	118		IR5853-118-5 (IR52) (IRRI)	3.5	97
IR1529-430-3 (IRRI)	2.9	131		IR6115-1-1-1 (IRRI)	3.5	91
IR2061-522-69 (IRRI)	2.9	122		IR9560-26-3-1 (IRRI)	3.5	102
IR3839-1 (IRRI)	2.9	124		IR995-96-2 (IRRI)	3.5	101
		1978			1981	
IR1529-430-3 (IR43) (IRRI)	3.8		102	IR5931-110-1 (IRRI)	2.5	96
IR9669 Sel. (IRRI)	3.7		108	IR6115-1-1-1 (IRRI)	2.4	93
IET1444 (India)	3.6		86	UPL Ri-5 (Philippines)	2.5	100
IR36 (IRRI)	3.6		94	IR43 (IRRI)	2.4	100
B541b-Kn-19-34 (Indonesia)	3.5		107	BPI Ri-6 (Philippines)	2.3	101
Gama 318 (Indonesia)	3.5		107	CR156-5021-207 (India)	2.3	9
KN96 (Indonesia)	3.5		102	IR52 (IRRI)	2.3	100
IR2035-242-1 (IR45)	3.5		107			
IR3839-1 (IRRI)	3.5		94			
MRC172-9 (Philippines)	3.5		101			
IR9575 Sel. (IRRI)	3.5		98			



9. Disease progress curves (a) for 3 isolates of *P. oryzae* Cav. on 6 rice cultivars and their logit plots (b), 1979 (77).

Table 19. Scoring[a] system for drought resistance screening at vegetative phases I and II[b] (108).

Decimal score	Plant type	Stress symptoms			
		Leaf rolling	Leaf drying	Plant color	Growth stunting
1	Tall traditional	Slight folding from early morning to late afternoon.	No drying.	Green	No stunting
	Semidwarf	No rolling.	Few leaf tips drying.	Green	No stunting
3	Tall traditional	Partial rolling from early morning to late afternoon.	Few tips drying more than 1 cm in length; 5-10% basal leaves dried.	Green	No stunting
	Semidwarf	No roiling.	75% leaf-tip drying extended to ¼ of leaf blade; 5-10% of lower leaves dried.	Green	No stunting
5	Tall traditional	Complete, tight rolling from early morning to late afternoon. Partial unrolling when temperature cools during day; complete unrolling at night.	Most younger leaf tips dried; 25-50% lower leaves dried.	Unusually dark green	No stunting
	Semidwarf	Complete, tight rolling; partial unrolling at night.	50% younger leaves with ½-1/3 area dried; 25-40% lower leaves dried.	Ashen gray or yellow	Slight
7	Tall traditional	Tube-like rolling; no unrolling at night,	Most upper leaves with 2/3-3/4 area dried; 60-80% lower leaves dried.	Ashen gray or yellow	Stunted
	Semidwarf	Same as tall traditional.			
9	Tall traditional	Tube-like rolling; no unrolling at night.	100% of all leaves dried; plants generally approach permanent wilting, some die.	Meristematic tissues show a slight green to light green tinge	Severe stunting
	Semidwarf	Same as tall traditional.			

[a] Scores were taken 15-20 d from the start of imposed stress or when susceptible checks showed symptoms of moisture stress. Preliminary scoring should be when plants show the first signs of stress. [b] Vegetative phase I refers to active tillering stage of both early and late-maturing varieties, and ranges from 50 to 60 d after seeding (DAS). Vegetative phase II applies only to the late-maturing varieties at about 80-100 DAS (108).

Table 9. Nutrient uptake at different growth stages in two rice varieties (52).

Growth stage	N ($kg\ ha^{-1}$)		P ($kg\ ha^{-1}$)		K ($kg\ ha^{-1}$)		Fe ($g\ ha^{-1}$)		Mn ($g\ ha^{-1}$)	
	Krishnasal	Pusa 33	Krishnasal	Pusa 33	Krishnasal	Pusa 33	Krishnasal	Pusa 33	Krishnasal	Pusa 33
Total										
Tillering	12	7	1.2	0.5	6	2	214	188	22	7
Panicle initiation	65	39	7.7	3.3	59	21	1526	1017	204	54
Flowering	89	52	12.2	7.7	63	28	1742	1183	724	207
Harvest	93	54	13.1	11.0	64	34	2195	1440	788	271
Tillering										
Leaf	6.05	3.52	0.44	0.20	2.69	0.90	36	35	11	3
Sheath	4.98	2.45	0.63	0.26	3.19	1.26	124	65	9	3
Root	1.01	1.10	0.08	0.08	0.20	0.27	54	68	2	1
Panicle initiation										
Leaf	30	19	2.2	1.5	20	7	458	179	91	15
Sheath	25	14	5.0	1.4	34	12	626	447	96	31
Root	9	6	0.5	0.4	5	2	442	391	17	8
Flowering										
Leaf	32	18	1.6	1.5	17	9.0	351	158	246	72
Sheath	31	16	5.6	2.0	20	6.4	303	342	318	71
Stem	8	5	2.8	2.1	14	9.6	833	415	216	45
Panicle	5	5	1.7	1.6	4	2.0	81	50	11	10
Root	12	7	0.6	0.6	8	2.4	174	218	23	10
Harvest										
Leaf	22	9	0.6	0.7	7	5.4	347	163	246	94
Sheath	19	10	1.1	0.3	15	5.5	261	312	307	80
Stem	15	8	0.9	1.1	31	16.4	1229	616	173	61
Panicle	30	24	10.1	8.8	8	4.8	141	142	42	26
Root	7	4	0.3	0.2	3	1.7	127	207	20	11

[a]Mean of 3 replications.

Table 25. Effect of different organic manures with and without ammonium sulfate (applied on an equal N basis) on upland rice and soil physicochemical properties (83).

Treatment	Grain yield (t ha^{-1})	N in plant at harvest (%)	P in plant at harvest (%)	K in plant at harvest (%)	Mean wt-diam of soil aggregates	Soil bulk density (t m^{-3})	Organic C of soil (%)	N content of soil (%)
Control	1.3	1.081	0.177	1.102	.3023	1.604	.3902	.0377
Farmyard manure (FYM)	1.7	1.171	0.207	1.222	.3839	1.504	.4112	.0402
Green manures (GMS)	1.8	1.156	0.188	1.137	.3727	1,505	.4087	.0391
AS-N 45.0	2.5	1.290	0.157	1.017	.3412	1.552	.4003	.0384
FYM + AS-N 22.5	2.6	1.370	0.201	1.202	.4042	1.502	.4269	.0408
GMS + AS-N 22.5	2.5	1.328	0.182	1.101	.3917	1.509	.4091	.0394
AS-AN 67.5	2.5	1.441	1.130	0.937	.3345	1.549	.4047	.0382
SEm. (+)	0.16	0.050	0.008	0.017	.0218	0.015	.0049	.0006
CD 5%	0.3	0.147	0.023	0.049	.0641	0.044	.0144	.0017
CD 1%	0.4	0.200	0.031	0.067	–	0.060	.0196	–

Table 6. Time requirements for weeding (7). Values in parentheses indicate the time required for each weeding task.[a]

Weeding method	Time (h) required to weed 1 ha		
	Strip tillage	Cultivator	Plowing
Hand weeding			
3 + 6 wk after planting (WP)	525 (335 + 190)	481 (286 + 195)	407 (242 + 165)
2 + 5 + 8 WP	623 (293 + 192 + 138)	539 (251 + 170 + 118)	457 (189 + 159 + 109)
Hoe weeding			
3 + 6 WP	282 (118 + 164)	282 (120 + 162)	193 (76 + 117)
2 + 5 + 8 WP	304 (92 + 120 + 92)	265 (74 + 101 + 90)	226 (72 + 82 + 72)
Time weeding, hand-pushed			
3 + 6 WP (1 row)	72 (39 + 33)	62 (30 + 32)	55 (27 + 28)
2 + 5 + 8 WP (1 row)	86 (31 + 22 + 33)	85 (28 + 22 + 35)	79 (25 + 20 + 34)
Time weeding, frame on hand tractor			
2 + 5 + 8 WP (3rows)	57 (21 + 18 + 18)	54 (20 + 16 + 18)	82 (20 + 14 + 18)
Blade weeding, hand-pushed			
2 + 5 + 8 WP (1 row)	89 (31 + 21 + 37)	83 (25 + 22 + 36)	80 (27 + 20 + 33)
Blade weeding, frame on hand tractor			
2 + 5 + 8 WP (3 rows)	70 (26 + 19 + 25)	66 (22 + 19 + 25)	63 (24 + 17 + 22)
Rotary weeding, brush cutter			
2 + 5 + 8 WP(1 row)	438 (123 + 163 + 152)	342 (94 + 134 + 114)	262 (60 + 100 + 102)
Rotary weeding, hand tractor			
3 + 6 WP (3 rows)	34 (18 + 16)	29 (14 + 15)	26 (13 + 13)
2 + 5 + 8 WP (3 rows)	37 (11 + 14 + 12)	33 (11 + 11 + 11)	31 (11 + 9 + 11)

[a]WP = weeks after planting.

Table 6. Effect of tillage on weed weight and grain yield of 3 upland rices, 1976 wet season, IRRI (39).

Tillage treatment[a]	IR1529-430-3		IR9575		M1-48		Tillage mean	
	Weed wt ($g\ m^{-2}$)	Yield ($t\ ha^{-1}$)	Weed wt ($g\ m^{-2}$)	Yield ($t\ ha^{-1}$)	Weed wt ($g\ m^{-2}$)	Yield ($t\ ha^{-1}$)	Weed wt[b]	Yield[c] ($t\ ha^{-1}$)
Plowing fb 1 rototilling	131	1.5	144	2.1	191	1.1	155 b	1.6 a
Plowing fb 2 rototillings	114-	1.7	123	2.3	132	1.1	123 a	1.7 a
Plowing fb 3 rototillings	124	1.8	110	2.1	105	1.0	113 a	1.6 a
Mean	123 a	1.6 a	125 a	2.2 a	143 a	1.1 b		

[a] fb = followed by. [b] Weeds sampled at 50 d after rice emergence. [c] Average of 4 replications and 3 weed control treatments. Means in a column or row followed by a common letter are not significantly different at the 5% level.

Table 9. Promising herbicide combinations for upland rice.

Combination	Application time[a]	Rate[b] (ai ha^{-1})	Effective against	Not effective against	Reference
Propanil and MCPA	15-25 DAS	Propanil, 3-3.5 kg/3 litres MCPA, 0.5-0.8 kg	All weeds	-	Domingo and Palis (22) Renaut (85) Mukhopadhyay et al (61) Dixit and Singh (21)
Propanil and 2,4-D	25 DE	Propanil, 2.8-4.3 kg 2,4-D,0.5-2.0 kg	Broadleaf weeds	-	Bhan et al (4) Vuong et al (110) Victoria Filho and Carvalho (109) Silveira Filho and Aquino (95)
Oxadiazon fb propanil	PE 15 DAS/ 12 DE	Oxadiazon, 0.75 kg Propanil, 2.0-2.4 kg	-	-	IRRI (42) IITA (36)
Butachlor fb propanil	1 DAS 20-25 DAS	Butachlor, 24.5 kg Propanil, 1.5 kg/2.6 litres	-	-	Borgohain and Upadhyay (6) ICAR (35)
Fluorodifen + propanil	14-15 DAS	3 kg	-	-	Fagade (30) IITA (36)
Thiobencarb + propanil	14 DAS	3 kg	-	-	Fagade (30)
Propanil and parathion methyl	29 DAS	1.98 + 0.24 kg	-	-	Victoria Filho and Carvalho (109)
2,4-D and propanil	7 DBS 30 DAS	1.5 kg 2.0 kg	Most	-	Patro and Tosh (80)

[a] DAS = days after seeding, DE = days after emergence, PE = preemergence, fb = followed by, DBS = days before sowing. [b] ai = active ingredient.

Table 8. Promising postemergence herbicides for upland rice.

Name	Application time[a]	Rate[b] (kg ai ha^{-1})	Effective against	Not effective against	Reference
Propanil Stam F-34 (3', 4'-dichloro-propionanilide)	15-30 DAS 15 DE 2-4 WLS	1.5-6.0	Grassy, most weeds Monocot, *E. colona*	*Acanthospermum hispidium*, *Ipomoea* sp.	Domingo and Palis (22) Mukhopadhyay and Bag (60) Patro and Misra (79) Mukhopadhyay et al (61) Pillai et al (83) Fagade (29) Dubey (53) Raghavulu and Sreerama Murthy (84) Singh et al (96) Falais (31) IRRI (41) Dixit and Singh (21) Tosh et al (105) Mukhopadhyay (59) Singh and Singh (97)
MCPA (4-chloro,2-methyl-phenoxy acetic acid)	30 DAS	0.5	*Digitaria* sp. *Cyperus rotundus* *Cynodon dactylon*		Dixit and Singh (21)
Fluorodifen (4-nitrophenyl 2-nitro-4-trifluoromethylphenyl ether)		4.0			Vuong et al (110)

[a]DAS = days after sowing, DE = days after emergence, WLS =weed leaf stage. [b]ai = active ingredient,

Table 9. Promising herbicide combinations for upland rice.

Combination	Application time[a]	Rate[b] (ai ha^{-1})	Effective against	Not effective against	Reference
Propanil and MCPA	15-25 DAS	Propanil, 3-3.5 kg/3 litres MCPA, 0.5-0.8 kg	All weeds	-	Domingo and Palis (22) Renaut (85) Mukhopadhyay et al (61) Dixit and Singh (21)
Propanil and 2,4-D	25 DE	Propanil, 2.8-4.3 kg 2,4-D,0.5-2.0 kg	Broadleaf weeds	-	Bhan et al (4) Vuong et al (110) Victoria Filho and Carvalho (109) Silveira Filho and Aquino (95)
Oxadiazon fb propanil	PE 15 DAS/ 12 DE	Oxadiazon, 0.75 kg Propanil, 2.0-2.4 kg	-	-	IRRI (42) IITA (36)
Butachlor fb propanil	1 DAS 20-25 DAS	Butachlor, 24.5 kg Propanil, 1.5 kg/2.6 litres	-	-	Borgohain and Upadhyay (6) ICAR (35)
Fluorodifen + propanil	14-15 DAS	3 kg	-	-	Fagade (30) IITA (36)
Thiobencarb + propanil	14 DAS	3 kg	-	-	Fagade (30)
Propanil and parathion methyl	29 DAS	1.98 + 0.24 kg	-	-	Victoria Filho and Carvalho (109)
2,4-D and propanil	7 DBS 30 DAS	1.5 kg 2.0 kg	Most	-	Patro and Tosh (80)

[a] DAS = days after seeding, DE = days after emergence, PE = preemergence, fb = followed by, DBS = days before sowing. [b] ai = active ingredient.

Table 9. Promising herbicide combinations for upland rice.

Combination	Application time[a]	Rate[b] (ai ha^{-1})	Effective against	Not effective against	Reference
Propanil and MCPA	15-25 DAS	Propanil, 3-3.5 kg/3 litres MCPA, 0.5-0.8 kg	All weeds	-	Domingo and Palis (22) Renaut (85) Mukhopadhyay et al (61) Dixit and Singh (21)
Propanil and 2,4-D	25 DE	Propanil, 2.8-4.3 kg 2,4-D,0.5-2.0 kg	Broadleaf weeds	-	Bhan et al (4) Vuong et al (110) Victoria Filho and Carvalho (109) Silveira Filho and Aquino (95)
Oxadiazon fb propanil	PE 15 DAS/ 12 DE	Oxadiazon, 0.75 kg Propanil, 2.0-2.4 kg	-	-	IRRI (42) IITA (36)
Butachlor fb propanil	1 DAS 20-25 DAS	Butachlor, 24.5 kg Propanil, 1.5 kg/2.6 litres	-	-	Borgohain and Upadhyay (6) ICAR (35)
Fluorodifen + propanil	14-15 DAS	3 kg	-	-	Fagade (30) IITA (36)
Thiobencarb + propanil	14 DAS	3 kg	-	-	Fagade (30)
Propanil and parathion methyl	29 DAS	1.98 + 0.24 kg	-	-	Victoria Filho and Carvalho (109)
2,4-D and propanil	7 DBS 30 DAS	1.5 kg 2.0 kg	Most	-	Patro and Tosh (80)

[a] DAS = days after seeding, DE = days after emergence, PE = preemergence, fb = followed by, DBS = days before sowing. [b] ai = active ingredient.

Table 8. Promising postemergence herbicides for upland rice.

Name	Application time[a]	Rate (kg ai ha^{-1})[b]	Effective against	Not effective against	Reference
Propanil Stam F-34 (3', 4'-dichloro-propionanilide)	15-30 DAS 15 DE 2-4 WLS	1.5-6.0	Grassy, most weeds Monocot, *E. colona*	*Acanthospermum hispidium*, *Ipomoea* sp.	Domingo and Palis (22) Mukhopadhyay and Bag (60) Patro and Misra (79) Mukhopadhyay et al (61) Pillai et al (83) Fagade (29) Dubey (53) Raghavulu and Sreerama Murthy (84) Singh et al (96) Falais (31) IRRI (41) Dixit and Singh (21) Tosh et al (105) Mukhopadhyay (59) Singh and Singh (97)
MCPA (4-chloro,2-methyl-phenoxy acetic acid)	30 DAS	0.5	*Digitaria* sp. *Cyperus rotundus* *Cynodon dactylon*		Dixit and Singh (21)
Fluorodifen (4-nitrophenyl 2-nitro-4-trifluoromethylphenyl ether)		4.0			Vuong et al (110)

[a]DAS = days after sowing, DE = days after emergence, WLS =weed leaf stage. [b]ai = active ingredient,

Table 9. Promising herbicide combinations for upland rice.

Combination	Application time[a]	Rate[b] (ai ha^{-1})	Effective against	Not effective against	Reference
Propanil and MCPA	15-25 DAS	Propanil, 3-3.5 kg/3 litres MCPA, 0.5-0.8 kg	All weeds	-	Domingo and Palis (22) Renaut (85) Mukhopadhyay et al (61) Dixit and Singh (21)
Propanil and 2,4-D	25 DE	Propanil, 2.8-4.3 kg 2,4-D,0.5-2.0 kg	Broadleaf weeds	-	Bhan et al (4) Vuong et al (110) Victoria Filho and Carvalho (109) Silveira Filho and Aquino (95)
Oxadiazon fb propanil	PE 15 DAS/ 12 DE	Oxadiazon, 0.75 kg Propanil, 2.0-2.4 kg	-	-	IRRI (42) IITA (36)
Butachlor fb propanil	1 DAS 20-25 DAS	Butachlor, 24.5 kg Propanil, 1.5 kg/2.6 litres	-	-	Borgohain and Upadhyay (6) ICAR (35)
Fluorodifen + propanil	14-15 DAS	3 kg	-	-	Fagade (30) IITA (36)
Thiobencarb + propanil	14 DAS	3 kg	-	-	Fagade (30)
Propanil and parathion methyl	29 DAS	1.98 + 0.24 kg	-	-	Victoria Filho and Carvalho (109)
2,4-D and propanil	7 DBS 30 DAS	1.5 kg 2.0 kg	Most	-	Patro and Tosh (80)

[a] DAS = days after seeding, DE = days after emergence, PE = preemergence, fb = followed by, DBS = days before sowing. [b] ai = active ingredient.

Applying MCPA, another postemergence herbicide, 30 d after seeding at 0.5 kg ai ha^{-1} effectively controls *Digitaria* sp., *C. rotundus,* and *C. dactylon* (21). Vuong et al (110) found postemergence application of fluorodifen was effective in northwestern Madagascar.

Herbicide combinations. Herbicide mixtures or combinations often are effective. Several combinations performed better than applications of individual herbicides (Table 9). Applying propanil postemergence followed by 2,4-D or MCPA effectively controlled weeds, and especially broadleaf weeds, in upland rice.

Applying oxadiazon or butachlor immediately or 1 d after sowing followed by propanil 15-25 d after sowing provided satisfactory to excellent weed control (6, 35, 36, 42).

In Nigeria, applying mixtures of fluorodifen and propanil, thiobencarb and propanil, and oxadiazon and propanil at 2-3 kg ai ha^{-1} 14-15 d after sowing controlled weeds better than a single application of a component herbicide (30, 36).

Phytotoxicity due to herbicide application. Applying large doses of some preemergence and postemergence herbicides can cause phytotoxicity, as can application at certain crop growth stages and soil moisture contents. Herbicide selectivity also must be considered.

Yamane et al (113) found that spraying Swep (methyl 3,4-dichlorophenyl-carbamate) before or soon after seedling emergence was safe for upland rice. Delaying application until 2- to 3-true-leaf stage or increasing concentration above 125 g ha^{-1} injured or killed rice plants (13). At IRRI, preemergence herbicides with 2,4-D in the formulations — thiobencarb - 2,4-D IPE and piperophos - 2,4-D IPE — were highly toxic to germinating rice (41).

Increasing soil moisture or rainfall after applying preemergence herbicides such as thiobencarb and oxadiazon causes severe phytotoxicity when they leach through the soil and contact germinating rice seed. Phytotoxicity reduces plant stand, and causes chlorotic leaves and stunting (57, 68).

Sensitivity of rice seedlings to herbicide depends upon the 1_{50} values, or the herbicide concentration needed to cause 50% root or shoot inhibition (69). Upland rice seedlings are highly sensitive to 2,4-D (Table 10), and moderately susceptible to butachlor. Toxicity due to 2,4-D is characterized by severe root inhibition without a corresponding decrease in shoot growth. In upland soils, plants died quickly because they could absorb little water and nutrient (69).

Nonselective herbicides can be used to control weeds if their selectivity is improved by extraneous methods. Nangju et al (69) tried several methods to overcome herbicide phytotoxicity in upland rice. Their results showed that deep sowing (3.0-4.5 cm) diluted herbicide concentration and protected rice seed.

Table 10. I_{50} values of chloramben, butachlor, oxadiazon, and 2,4-D for rice (69).

Herbicide	I_{50} (ppm)	Part of seedling
Chloramben	0.77	Root
Butachlor	3.30	Shoot
Oxadiazon	88.00	Shoot
2,4-D	0.14	Root

Biological control

Biological control is the use of an organism to control a pest (17). There may be insect pests and diseases that can be used to control weeds without harming crops or the environment. However, no information is available for upland rice.

CONTROLLING PERENNIAL NUT SEDGE

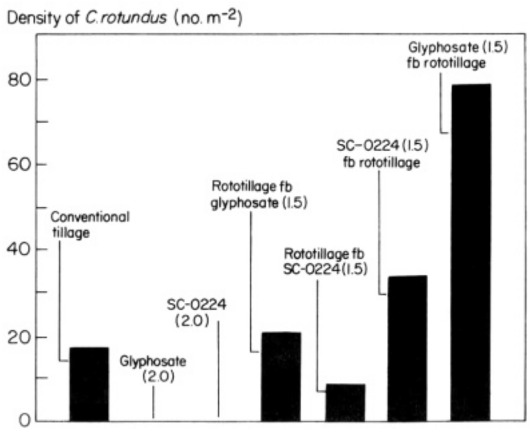
Purple nut sedge *C. rotundus* is a universally troublesome weed of upland rice. It grows from underground tubers and rhizomes and has apical dominance (73). It also germinates just before or simultaneously with rice (75).

Manually removing purple nut sedge shoots and tubers from dry upland fields is laborious and expensive, and several weedings may be necessary. Common herbicides such as butachlor and propanil are ineffective controls.

Ronoprawiro (89) found that applying propanil + 2,4-D postemergence was the most effective control for upland rice. At IRRI in dry season, applying mecoprop [(±)-2-(4-chloro-2-methylphenoxy) propionic acid] at 1 kg ai ha^{-1} 20 d after rice emergence was an effective control. Applying bentazon 2 kg ai ha^{-1} 7 d after crop emergence gave fair control.

Applying perfluidone [1,1,1-trifluoro-N-2-methyl-4-(phenylsulfonyl) phenylmethane-sulfonamide] at 2.0 kg ai ha^{-1} , mecoprop at 1.5 kg, and fenoprop at 1.0 kg ai ha^{-1} 7, 14, and 21 d after emergence provided fair nut sedge control (76). Preemergence application of prodiamine [2,4-dinitro-N^3, N^3–dipropyl-6-(trifluoromethyl) l, 3-benzene diamine] at 1 kg ai ha^{-1} followed by mecoprop at 1 kg 20 d after emergence effectively controlled nut sedge and annual weeds. In dry season, this combination gave the highest yield (73). For effective nutsedge control, Mukhopadhyay (55) also recommended spraying butachlor 2 litres ai ha^{-1} 1 d after sowing followed by postemergence bentazon 1 litre ai ha^{-1}.

Recent IRRI studies show that a preplant application of 2 kg glyphosate or coded SC-0224 (trimethylsulfonium carboxymethylamino methyl phosphonate) ha^{-1} followed by 1.0 kg 2,4-D ha^{-1} 20 d after emergence completely controlled *C. rotundus* (44) (Fig. 12).

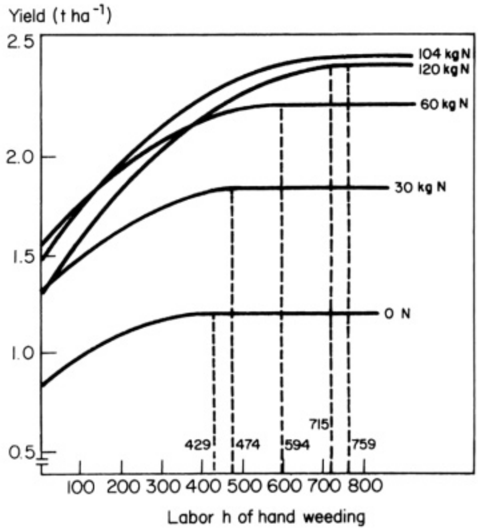


12. Herbicide alone or in combination with cultivation provided adequate to excellent control of *C. rotundus* in upland rice (44).

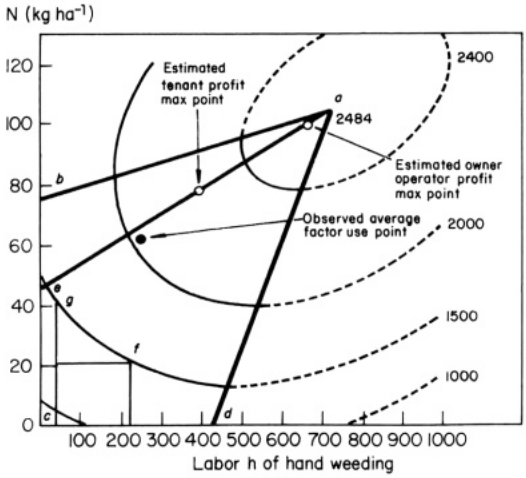
WEED CONTROL AND FERTILIZER INTERACTION

Response to weed control increases with application of fertilizer, especially N. O'Brien and Price (72) found that, in a farmer's field in Batangas, Philippines, applying more than 75 kg N ha^{-1} decreases upland rice yield unless fields are hand weeded. The maximum possible yield for a specified N level increased as N application increased to 104 kg/ha, after which it decreased (Fig. 13).

O'Brien and Price show another interaction of applied N and hand weeding in Figure 14. A series of isoquants (lines of equal rice yields) are mapped in input space. Lines ab and ad mark the rational zone of production. Within abcd, the levels of both inputs required to obtain a specified yield are less than those required



13. Yield response functions for specified N levels and different hand weeding treatments (72).



14. Production Isoquants (lines of equal yield in kg ha^{-1}) for different levels of hand weeding and N application (kg/ha) (72).

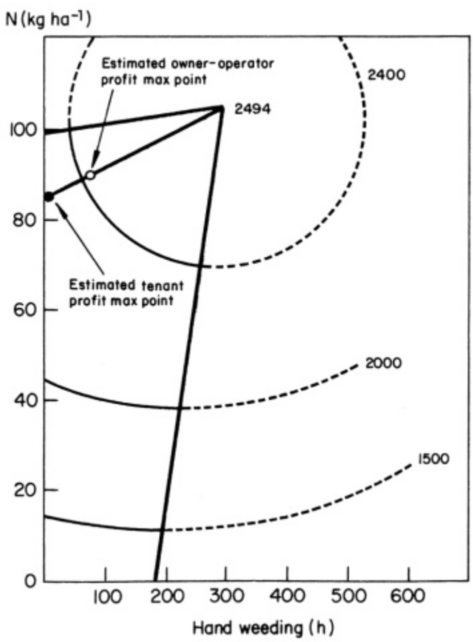
to obtain the same yield outside the rational zone. The specified yield that can be obtained with N application + hand weeding can be derived from this. For example, 1.5 t of rice could be harvested by applying 20 kg N and employing 213 h of hand weeding (0 or with 40 kg N and 38 h of weeding (point g). To obtain the maximum yield of 2.5 t, 715 h of hand weeding and 104 kg N are needed.

O'Brien and Price (72) also estimated the response of upland rice to fertilizer and weeding when 60% hand weeding was theoretically replaced by herbicide (Fig. 15). The effect of a herbicide or fertilizer and hand weeding levels required for maximum or specified yields can be seen by comparing the positions of isoquants and rational zones of production in Figures 14 and 15. For example, to get the highest yield of 2.5 t ha^{-1} with 104 kg N and hand weeding required 715 labor h. By substituting 60% herbicide control, only 2% h of hand weeding was necessary (Fig. 15). Proper herbicide use can substantially reduce labor requirements.

HERBICIDE, INSECTICIDE, AND FERTILIZER COMPATIBILITY

It is more economical to apply herbicides and insecticides together if they are compatible. Propanil is incompatible with organophosphorus insecticides (phorate) and carbofuran. If mixed, they burn rice leaves (59). However, butachlor and bentazon can be mixed with phorate and carbofuran.

Urea fertilizer is compatible with 2,4-D, MCPA, and propanil. Spraying herbicide-fertilizer mixtures saves application time and gives better results with smaller doses. A 3% urea solution mixed with propanil 3 litres ai ha^{-1} in 600 litres of water controlled weeds better and increased rice yield more than when urea and propanil were sprayed separately (63).



15. Production isoquants (lines of equal yield in kg ha^{-1}) for different levels of hand weeding and N application when a hypothetical herbicide that removes 60% of weeds (p = 0.4) is applied, Batangas, Philippines, 1975 data and prices (72).

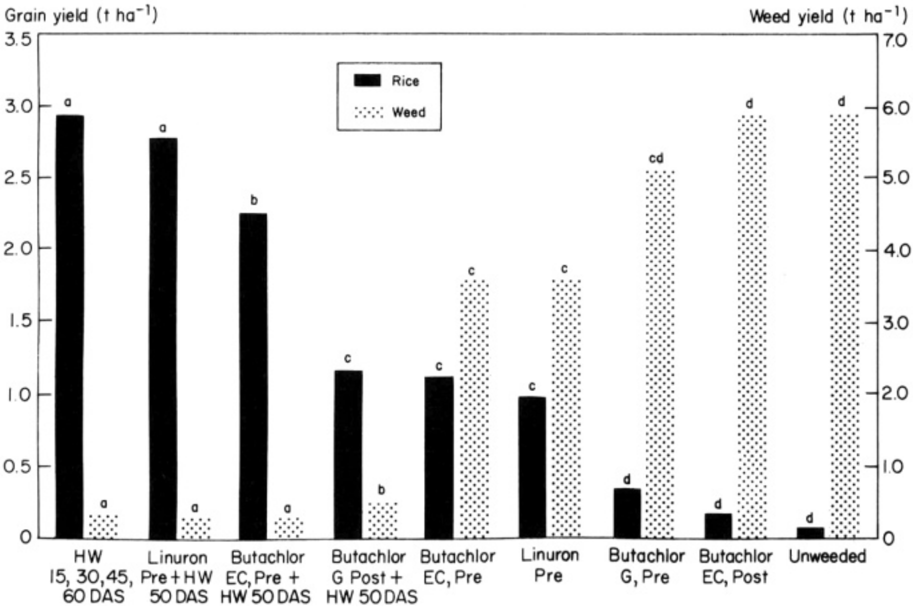
INTEGRATED WEED MANAGEMENT

Each weed control method has advantages and disadvantages. Weed populations vary so much between environments that a single weed control method is not possible. Moreover, repeated use of a particular method may build up weed resistance to the control method.

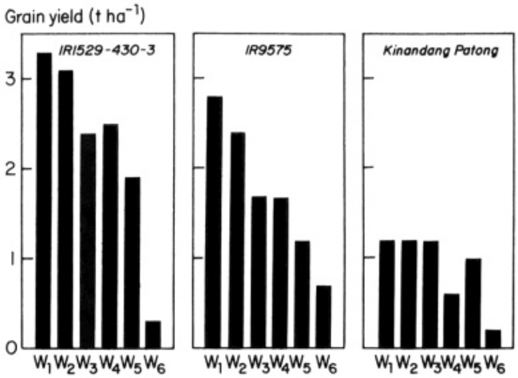
Smith and Reynolds (99) defined integrated weed control as a weed population management system that uses all suitable techniques in a compatible manner to reduce weed populations and maintain them at levels below those causing economic injury. Integrated weed management for upland rice is not well developed or documented. Only one approach, the combination of hand weeding and herbicide application, has been tested.

In India, Philippines, and Thailand, preemergence application of butachlor or pendimethalin at 1-2 kg ai ha^{-1} followed by 1 hand weeding effectively controlled upland rice weeds and produced yields similar to those with 2-3 hand weedings (1, 65, 92, 95) (Fig. 16). At IRRI, applying dinitramine at 1 kg ai ha^{-1} followed by 1 hand weeding 30 d after emergence controlled weeds effectively in simulated upland conditions (40) (Fig. 17). Tasic et al (104), however, found no advantage in combining butachlor and one hand weeding over butachlor alone, or a weed-free check. Similarly, Pande et al (78) found that butachlor at 2 kg ai ha^{-1} and 1 hand weeding was better than butachlor, but inferior to 2 hand weedings.

Applying propanil at 3 kg ai ha^{-1} 14-20 d after sowing followed by 1 hand weeding 14-15 d later effectively controlled upland rice weeds (21, 29), and was



16. Relation of grain and dry matter yield to weed control treatments. Means not sharing a common letter are significantly different at the 5% level by Duncan's multiple range test (92). DAS = daysafter sowing. HW = hand weeding, pre = preemergence, post = postemergence, EC = emulsifiable concentrate, G = granules.



17. Grain yield of 3 upland rice varieties as affected by weed control treatments in simulated upland conditions, IRRI, 1978 dry season (40).

comparable to the best treatment of 2 hand weedings. When less propanil was applied with 2 hand weedings, yield increased 40% (29).

Integrated weed management offers immense potential for upland rice. Probably the best integrated weed control technology will be a combination of cultural, chemical, and manual methods (56).

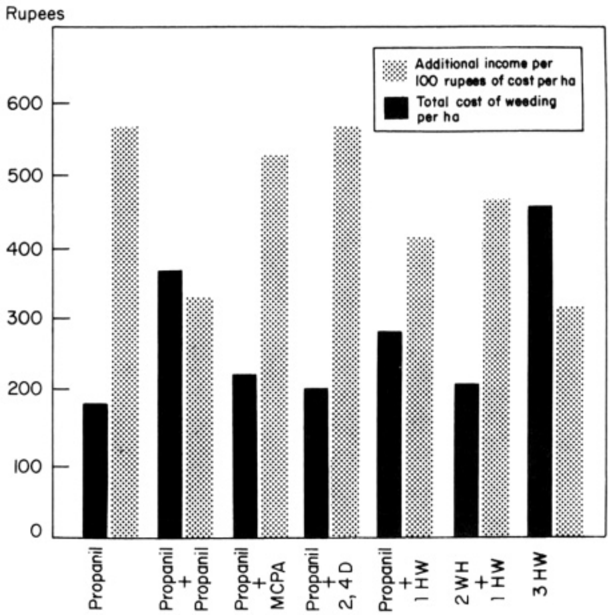
ECONOMICS OF WEED CONTROL PRACTICES

For a weed control technology to be accepted by upland rice farmers, it must be effective and economically feasible. Economic feasibility depends upon the relative cost of weed control. Manual weeding, which is most prevalent, depends on labor costs. Chemical controls depend on herbicide costs and application expenses, and thus vary among regions. It is difficult to generalize the economic superiority of a weed control method.

Generally, manual or hand weeding has been compared with herbicide applicationin cost effectiveness terms. In most trials, applying herbicides costs less than manual or hand weeding (12, 32, 61, 80, 90). However, Upadhyay and Chaudhary (106) found that hand weeding and hoeing 3 and 6 wk after sowing was more economical than applying herbicide.

The net profit from different weed control practices also has been evaluated. In most studies, applying herbicide or herbicide + manual weeding was more economical than manual or hand weeding alone (12, 61, 79, 80, 90, 95, 104). In Orissa, India, applying propanil at 2.4 kg ai ha^{-1} gave higher net profit than 2 hand weedings (79). In the Philippines, applying butachlor at 2 kg ai ha^{-1} was more profitable than 2-3 hand weedings (90, 104). Applying butachlor took 186 h and hand weeding took 604 h ha^{-1} (90). Singh and Chauhan (95) found that applying 2 kg butachlor + 1 hand weeding was more economical than 3 hand weedings.

Sometimes, herbicide combinations are more profitable than manual weeding. In Orissa, India, Patro and Tosh (80) found the following more profitable than 2 hand weedings: 1 presowing application of Na salt of 2,4-D at 1.5 kg ai ha^{-1} after land preparation and 7 d before sowing followed by postemergence propanil at 2 kg ai ha^{-1} 30 d after sowing. In West Bengal, India, Chakraborty and



18. Economics of weed control, 1967-68 (12). 1968 Indian Rs 7.75 = $1. HW = hand weeding, WH= wheel hoeing.

Majumdar (12) obtained best economic return with propanil + 2,4-D, followed by propanil + MCPA (Fig. 18).

Sometimes manual or hand weeding is more profitable than herbicides. Ghosh et al (32) found 4 hand weedings yielded more than the best herbicide treatment of alachlor at 2 kg ai ha^{-1}. Similarly, Upadhyay and Chaudhary (106) obtained maximum profit by hoeing and weeding 3 and 6 wk after sowing rice. This suggests that economic profitability is a locally determined factor.

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CHAPTER 10

Disease Management

Diseases cause substantial losses in upland rice production. Published data on actual losses is limited, however, and estimates vary with region, disease severity, and varietal susceptibility. In Nigeria, for example, ROK3, Mange 2, and CCA grain losses to disease were 3-14% (37). Losses to blast (Bl) may reach 50-80% (38, 40). Because upland rice seldom is continually cropped, and often is a component within a cropping system, disease problems differ markedly from those of lowland rice (Table 1).

Most upland rice diseases are fungus diseases. They include Bl (1eaf and neck), brown spot (BS), leaf scald (LSc), sheath blight (ShB), sheath rot (ShR), glume discoloration (GlD), narrow brown leaf spot (NBLS), and eye spot (1, 5, 9, 13, 20, 41, 50). Bacterial diseases are uncommon, although bacterial leaf streak (BLS) and bacterial blight (BB) may occasionally be found (1, 20). Virus diseases include pale yellow mottle, hoja blanca (HB), and tungro (RTV) (20, 26, 41).

Bl, BS, LSc, and false smut (FSm) or green smut are major upland rice diseases in West Africa (Table 2). Together they may cause negligible to total crop losses (1). Disease problems are more severe in the moist upland zone than in the savanna. In 1976 in Nigeria, 200 ha of Sindano, an East African variety, grown in pluvial conditions was destroyed by neck Bl(3). In Sierra Leone, LSc caused 9-12% loss in yield trials (39).

In Brazil, diseases (Tab1e 3), especially Bl, cause most damage in the southern and central cerrado, where day/night temperatures markedly differ and drought stress is frequent. Yield losses in commonly grown IAC25 and IAC47 range between 17 and 52% (33).

In Asia, where upland rice is cultivated on more than 9 million ha, B1 is a problem in only a few areas. In India, it appears seasonally in the plains and is endemic in the mountains (12).

FUNGUS DISEASES

Blast

Bl is caused by *Pyricularia oryzae* Cav. Its perfect stage is *Magnaporthe grisea* (Hebert) Barr. Bl occurs widely in Brazil, particularly in central and southern cerrado regions (33); most of West Africa (1); and Asia (20). It is most serious in Latin America and Africa.

Table 1. Distribution and severity of rice diseases in different agroecological conditions in Sierra Leone (41).

Disease	Disease severity under given agroecological condition							
	Upland	Inland swamp[a]	Boliland	Irrigated rice development swamp[a]		Mangrove swamp[a]	Associated mangrove swamp[a]	Riverine grassland
				Wet	Dry			
Blast (leaf and neck)	High	Low	Moderate	Moderate	High	Low	Moderate	Low
Brown spot	High	Low to moderate	Moderate	Moderate	High	Low	Low	Low
Leaf scald	High	Low	Low	Moderate	Low	Low	Low	Low
Sheath blight	Low	Low	Low	High	Moderate	Low	Low	Low to moderate
Sheath rot	High	Low to moderate	Low to moderate	Moderate	Moderate	Low	Low	Low
False smut	Low	Low	Low	Low	Low	Low	Low	Low
Sheath blotch	Moderate	Low	Low	Low	Low	Low	Low	Low
Udbatta or sugary disease	Low	Low	Low	Low	Low	Moderate	Moderate	Low
Narrow brown spot	Low	Low	Low	Moderate	Moderate	Low to moderate	Moderate	Low
Leaf smut	Low	Low	Low	Low	Low	Low	Low	Low
Stackburn	Low	Low	Low	Low	Low	Low	Low	Low
Dirty panicle/glume, discoloration	High	Low	Low to moderate					
Pale yellow mottle	High	Moderate	Low	High	High	Low	Low	Low
White tip	Low	Low	Low	Low	Low	Low	Low	Low

[a]Seedling blast can be severe where nurseries are on very fertile areas, particularly those with abnormally high N. Severe BS can occur in nurseries where soil has acute mineral imbalance.

Table 2. Upland rice diseases in major climatic zones of West Africa[a] (1).

Scientific name	Common name	Humid tropic	Guinean savanna	Sudanian savanna (Sahel)
Ustilaginoidea virens	False smut	xx	x	-
Rhizoctonia solani	Sheath blight	x	x	x
	Pale yellow mottle	x	-	-
	Grassy stunt	x	-	-
Pyricularia oryzae	Seedling blast	xx	xx	x
Pyricularia oryzae	Leaf blast	xx	xx	x
Helminthosporium oryzae	Brown spot	xx	x	-
Rhynchosporium oryzae	Leaf scald	xx	xx	-

[a] - = absent, x = uncommon, xx = prevalent.

Symptoms. Bl lesions occur all over the rice plant, but leaf Bl and neck Bl are more serious (Plate 10.1, 10.2). The center of Bl lesions is pale green or dull greyish green and water soaked, with dark brown outer rims. Centers gradually become grey or almost straw colored. On susceptible varieties, lesions coalesce and completely dry infected leaves.

Neck Bl attacks are most easily recognized because they produce brownish grey to black lesions that are confined to the neck or nodes of the panicle. Neck Bl is the most destructive form of the disease and can cause complete crop failure. Bl lesions also can occur on the rachis and glumes of the panicle.

Ecology. Bl is more severe in upland than in lowland ecologies (4, 28, 40). In a toposequence study at IITA, Moormann et al (28) found severe Bl infection at higher, dry-zone sites but none at lower, wetter sites (Fig. 1). There was a close relationship between superficial soil moisture and Bl incidence and between Bl incidence and groundwater level.

1. Relation between Bl incidence, groundwater depth, and moisture content at 10- to 20-cm depth, 26 May-5 Jun 1973 (28). Dashed lines show groundwater depth; percentages indicate moisture content.

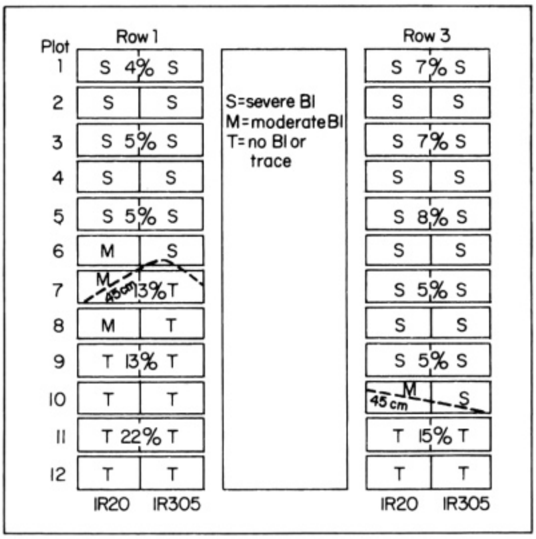


Table 3. Upland rice diseases in Mato Grosso, Brazil (27).

Site	Variety	Blast		Narrow brown leaf spot	Scald	Stackburn	Sheath blight	Sheath rot	Glume blotch	Brown spot
		Foliar	Neck							
Cuiaba										
Umurama Farm	IAC47	Severe	Severe (20-30%)	Severe	-	-	-	Mild	Moderate	Trace
Prata Farm	IAC47[a] IAC25 IAC164	Trace	Severe (20%)	-	Severe	-	-	Mild	-	-
Rondonopolis	Uniform Variety Trial, 18 entries	Trace	-	Mild	Moderate to severe	Moderate to severe	-	Moderate to severe	Moderate to severe	Mild
Jaciara										
Guarita Farm	IAC47	-	Mild	Very severe (neck region affected)	Trace	-	-	Moderate	-	-
Experimental fields	UVT, 18 entries	Trace	Mild	-	Moderate	-	-	Moderate	-	-
Santa Fe Experimental Station EMPA	IAC256[b]	-	-	-	-	Moderate	-	-	Moderate	-
Chapada dos Guimaraes										
Estrella do Norte	IAC47[c]		Trace to mild	Moderate to severe (neck region affected)	Mild	-	Mild	Mild	Trace	Mild

[a] Disease severe at early growth. [b] prayed twice with B1M '75 PM fungicide. [c] Sprayed with IBP.

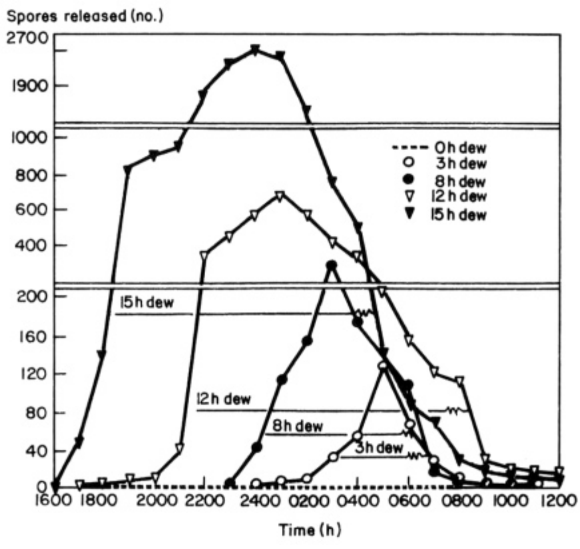
Bonman (4) suggested three reasons for increased Bl seventy in upland environments: 1) dew period is longer than in lowlands, 2) drought stress increases susceptibility to Bl, and 3) upland rice plants have relatively low silica content. IRRI studies show that Bl spores, which are airborne, are released from lesions by dew or light rain (14). A longer dew period releases more spores earlier (Fig. 2).

In Africa, upland rice fields usually are small and separated by patches of brush that act as windbreaks and favor longer retention of water droplets from rain, drizzle, and dew. The condition favors Bl development and transmission (41). Also, there is no standing water to moderate temperature changes and delay dew point, as there is in lowland rice environments (4).

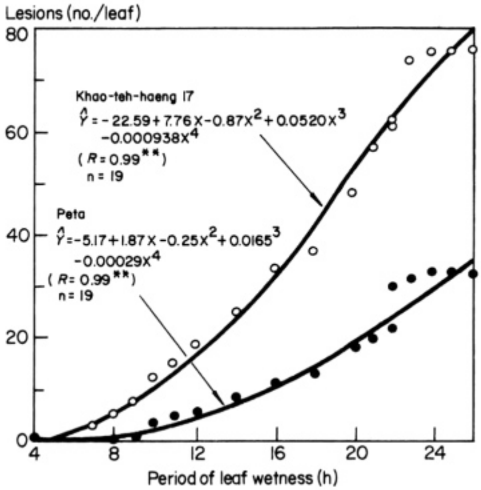
IRRI researchers studied the effect of length of leaf wetness on Bl lesions. Rice seedlings were sprayed with a Bl spore suspension and placed in a dew chamber in the phytotron for 4 to 26 h, and then moved to a room kept at about 25° C and 70% relative humidity. Prolonging wetness increased lesion development (Fig. 3). There were fewer lesions on moderately resistant Peta than on susceptible Khao-teh-haeng 17. In the field, dew is the major cause of leaf wetness. Rain also causes wetness, but it usually washes the spores from leaves (Fig. 4) (14).

High silica content of lowland rice lessens Bl seventy. Silica toughens rice cell walls, which inhibits penetration and establishment of the Bl fungus. The low silica content of upland rice increases its susceptibility to Bl (4,41). Jayachandran-Nair and Chakrabarti (24) found that rice plants grown on flooded soil had higher phenolic compounds and total and reducing sugars than plants grown in upland conditions.

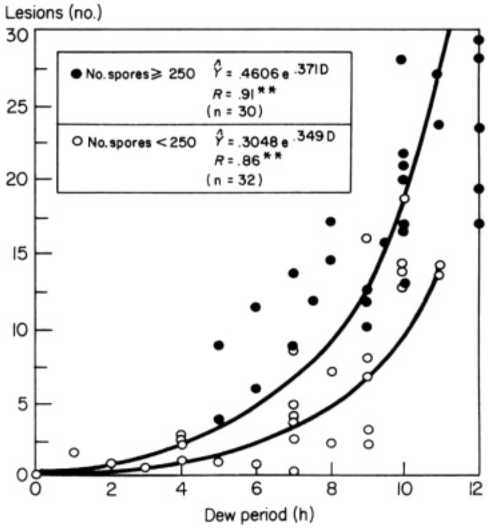
Soil fertility, particularly N, also influences Bl infection. Prabhu (33) found Bl incidence and soil fertility were directly related. Bl incidence always is higher with applied N and when P or Zn deficiencies are corrected. De Faria et al (8) found that increasing ammonium sulfate application from 0 to 60 kg N ha^{-1} increased leaf,



2. Effect of dew period on spore release of B1 lesions on rice leaves (14).



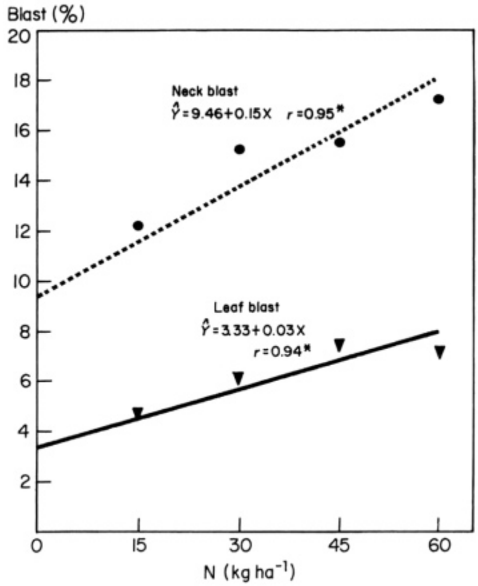
3. Relation of duration of leaf wetness period in a dew chamber to Bl infection on Peta and Khao-teh-haeng I7 (14).



4. Relation of dew period to number of BI lesions per seedling at 2 spore concentrations (14).

neck, and panicle B1 in IAC47 at Goiania, Brazil (Fig. 5). Results were similar at IRRI when N was increased from 20 to 120 ppm. There were more lesions with nitrate N treatment than with ammonium N (Table 4) (22).

Raymundo et al (46) recorded the effect of fertilizers on rice diseases in Sierra Leone. Applying quick-acting fertilizers such as ammonium sulfate at planting or before tillering increased B1 infection more than applying urea or sulfur-coated urea. They also found that B1 infection was very high in newly cleared fields and where there was high organic matter content. In upland agronomic trials at Rokupr Rice Research Station, Makassa, B1 infection was worst when 50 to 75% of N was applied at or before late tillering, At IRRI, B1 and BS lesions increased when K increased from 10 to 60 ppm, but tended to decrease at 100 ppm (22).



5. Relation between N level and Bl incidence (8).

Brown spot

BS is caused by *Helminthosporium oryzae* Breda de Haan, which is the imperfect, asexual state. BS is common in upland rice areas, particularly those with poor soils. In Asia, BS is second only to Bl in distribution (20), and is a major disease in Thailand (51). BS occurs in most of West Africa (1, 13, 31, 41), and some areas in Brazil and other Latin American countries (5, 33).

Symptoms. BS infects rice at all growth stages. Symptoms develop on leaves, leaf sheaths, glumes, and panicles. The spots are circular to oval brown to dark brown and are uniformly distributed on the leaf blade (Plate 10.3). At first, the lesions are dark reddish brown, and often have a yellow or gold halo. With age, the centers become greyish with distinct brown borders. BS causes seedling and leaf blight and sheath, culm, and glume infection.

Brown spot ecology. BS is associated with poor soils and rarely affects rice grown in normal soil. It is difficult to separate BS damage from that caused by poor soil, but the combination can cause up to 50% yield losses (30).

Table 4. Effect of N source and rate on Bl lesions on Tetep, IRRI, 1981 (22).

N source ratio (NH_4:NO_3)	N rate (ppm)	Av lesions (no.)
80:20	20	18
	60	28
	120	27
20:80	20	49
	60	53
	120	78

Raymundo et al (45) studied environmental conditions that favor BS in upland rice in Sierra Leone. BS is not a major problem in shifting cultivation with long fallow, but becomes a serious constraint if the fallow period is decreased or rice is continuously cropped. BS incidence increased when rice was grown continuously for several years. In 4 to 6 yr, several varieties were destroyed before they reached reproductive stage.

On newly cleared land, previous vegetation strongly affected BS incidence. Rice planted in former grasslands had much higher BS incidence than that planted on land that was cleared of deep-rooted forest vegetation. Nutrient recycling is less efficient in grasslands than in forests, where deep roots facilitate nutrient translocation from deep soil to the topsoil.

BS is associated with a nutritional disorder called akiochi disease that occurs in soils deficient in silica, K, Mn, or Mg, or in soils that evolve hydrogen sulfide (4). At IRRI, increasing N from 20 to 120 ppm increased the number of BS lesions. Slightly more lesions developed with nitrate N. Similarly, lesions increased with K from 10 to 60 ppm, but tended to decrease at 100 ppm (Table 5) (21).

BS severity also is influenced by plant density. BS incidence increases with increasing rice plant density because of greater competition for nutrients. Disease severity is more pronounced at late growth stages, when some nutrients have been depleted. Premature leaf desiccation, and panicle discoloration and sterility may occur (41).

Leaf scald

LSc is caused by *Geralchia oryzae,* the new name of the fungus formerly known as *Rhynchosporium oryzae* Hashioka and Yokogi. LSc is common in upland rice in Brazil (9), Latin America (5), and West Africa (13, 50), where up to 45% of plants can be affected (I).

LSc usually infects mature upland rice plants. Lesions start near the leaf tips or margins and are oblong or diamond-shaped. These gradually turn into irregularly shaped, light grey to olive blotches. Bands of dark brown margins and lighter colored inner areas give the disease a characteristic zonation pattern (41) (Plate 10.4).

LSc needs high humidity (30), and prolonged presence of water droplets on leaves encourages development (41). Broad-leafed rices tend to be more susceptible to LSc than those with narrow leaves because broad leaves retain water droplets longer. LSc lesions almost always start on leaf tips and margins where droplets stay longest. Heavy fertilizer application, particularly N, favors LSc (4).

Sheath blight

ShB is caused by *Rhizoctonia oryzae* Ryker and Gooch, the imperfect state of the fungus. The perfect state is *Thanatephorus cucumeris* (Frank) Donk. ShB is not as common as B1 and BS, but can be locally severe. Intensification of upland rice cultivation in Asia is increasing ShB incidence (20).

ShB infects plants at tillering. Early symptoms are greyish green lesions on the leaf sheath. Later they appear as delineated, irregularly shaped blotches with tan centers. Adjoining lesions coalesce and weaken the stem, causing it to topple and

Table 5. Effect of K on 4 rice diseases. IRRI, 1981 (22).

K (ppm)	Bl lesions (no./plant)	ShB (%)	BS lesions (no./plant)	BB lesion length (cm)
10	8	40	27	13
20	16	35	36	14
60	75	33	37	15
100	38	26	30	17

break. Infection may extend to leaf blades, particularly in susceptible varieties (41) (Plate 10.5).

High humidity and temperature favor ShB, and high tillering modern rices favor it by creating a humid microenvironment within the crop canopy. High N fertilizer rates also favor ShB by increasing stand density and tissue susceptibility (4). At IRRI, increasing N from 20 to 120 ppm increased incidence of ShB-infected tillers from 28 to 77%. N source did not affect disease incidence (21).

Glume discoloration

GlD is caused by several fungi, including *Sarocladium attenuatum, Helminthosporium oryzae, Curvularia* sp., *Alternaria* sp., *Leptosphaeria* sp., *Fusarium* sp., *Diploidiella* sp., and *Nigrospora* sp. (13, 30, 41) (Plate 10.6). Grain-feeding rice bugs encourage fungal attack. G1D is a serious constraint to upland rice production in Africa (13); it also occurs in Brazil (9). GlD causes incomplete grain filling and substantial yield losses. When several grains or whole panicles are affected early, losses can be 50% (43).

GlD starts as brownish specks on the seed coat that often are surrounded by darker margins. Lesions become progressively darker, turning tan, pink, and then dark brown. Black, sooty grains often are found among lighter-colored grains. The disease may be limited to a few grains, but sometimes the whole pedicel, including the rachis, is discolored (41).

High humidity, especially at ripening, favors GlD. Dry weather discourages the disease (13).

Narrow brown leaf spot

NBLS, caused by *Cercospora oryzae* Miyake, is a minor disease of upland rice that occurs in Brazil and some West African countries (1, 9, 41). NBLS produces long, narrow brown leaf streaks parallel to the leaf axis. Lesions sometimes develop on sheaths and glumes (30). Symptoms usually develop at flowering (41).

False smut

FSm, caused by *Ustilaginoidea virens* (Cooke) Tak., is of minor importance in West Africa (1, 41). It develops after flowering in place of rice grains, replacing them with a mass of powdery spores that can reach 1 cm in diameter. At first, the agglomerate is yellow, then orange, then yellow-green or greenish black. Generally, only a few grains within a panicle are infected (30).

Sheath rot

ShR, caused by *Sarocladium oryzae* (Sawada) Gams and Hawksworth, is a minor disease in some upland rice areas in West Africa and Asia (1, 20, 41). Symptoms are greyish brown spots, sometimes with brown margins and grey centers, on the uppermost leaf sheath enclosing young panicles. Panicles remain within the sheath or only partially emerge. Spikelets are only partly filled or rotten and empty. The disease is often accompanied by stem borer infestation.

BACTERIAL DISEASES

Few bacterial diseases attack upland rice, although BLS, caused by *Xanthomonas translucens* (Jones, Johnson, and Reddy) Dowson f. sp *oryzicola* (Fang et al) Bradbury, sometimes occurs in Asia and West Africa (1, 20). The organism attacks parenchymatous tissue between leaf veins and is confined to interveinal spaces in its early stages. It may enter the leaf through stomates or through wounds, usually caused by storms (7).

Young lesions are easily recognizable. BLS produces transparent streaks that are easily seen when infected leaves are held up to light. Droplets of yellow bacterial. exudates form on these streaks. Later the lesions dry and become brown and opaque. From a distance, infected fields look orange. BLS causes only localized damage (30).

VIRUS DISEASES

Virus diseases are not a major problem in upland rice because there are few insect vectors. HB occurs in Latin America, pale yellow mottle in West Africa, and RTV in Asia (1, 20, 26, 41).

Hoja blanca

HB is not as widespread as Bl in Latin America, but it causes serious losses in some areas. HB is transmitted by planthopper *Sogatodes orizicola* (Muir). White or chlorotic stripes develop on rice leaves or leaves turn completely white. Plants are stunted and have poorly filled spikelets (32).

Pale yellow mottle

Pale yellow mottle was identified in West Africa in 1976 (42). It occurs in Sierra Leone, Liberia,, Ivory Coast, and Nigeria, and has caused serious losses at the experimental farm of the Rice Research Station in Rokupr, Sierra Leone, and in Kenema district in the Eastern Province. Occurrence is sporadic (44).

Pale yellow mottle is transmitted mechanically and by insects of the genus *Chaetocnema,* of which *C. zea* has been identified (41). From a distance, infected fields look yellow. Symptoms are linear chlorotic mottles on leaves that coalesce into broken or continuous pale green to yellowish streaks up to 10 cm long. Later, whole plants become light green and then pale yellow. Severely affected plants are stunted (Plate 10.7).

Tungro

Of the virus diseases that infect lowland rice, only RTV damages upland rice in Asia (20). De Datta (7) reviewed RTV damage to lowland rice in many South and Southeast Asian countries. Data for upland rice, however, are lacking.

RTV is transmitted by leafhoppers *Nephotettix malayanus, N. nigropictus* (Stal), *N. parvus, N. virescens* (Distant), and *Recilia dorsalis* (Motschulsky) (25). Symptoms include stunting, yellow leaves, and slightly reduced tillering. RTV infection shortens leaf sheaths and blades and internodes. Yellowing usually starts from tips of the leaves. The color may vary from light yellow to orange- or brownish yellow. Yellow leaves, and occasionally green leaves, develop irregularly spaced dark brown blotches. Young leaves usually are mottled with pale green to whitish spots, the pattern of which varies from mosaic to stripes of various lengths running parallel to the veins. Grains usually are covered with dark brown blotches.

NEMATODES

Several nematode species attack upland and lowland rice (10, 11, 35, 36) and other crops. Important species differ with location.

Rao and Prasad (35) identified *Pratylenchus indicus* as a potential polyphagous nematode of upland rice in Cuttack, India. Fields had patches of yellow plants within 15 d of germination. One week later, leaves wilted and dried and plants were dead 40-50 d after germination. Roots of infected plants had surface lesions with necrotic cells in the cortex. Fofie and Raymundo (10) isolated six species of nematodes at the upland experimental farm of the Rokupr Rice Research Station in Sierra Leone (Table 6), where upland rice had been continuously cropped since 1974. The exact effect of nematode infestation on rice growth and yield was not identified, however.

White tip, caused by *Aphelenchoides besseyi,* is the most important nematode-caused disease in Sierra Leone. Leaves of infested plants become white or chlorotic. The white areas become disfigured, discolored, and tattered. Infected plants are stunted, lack vigor, and produce small, short panicles with few spikelets. Plants have distorted glumes and high sterility (41).

Pratylenchus sp., *Meloidogyne* sp., and *Helicotylenchus* sp. are three most common nematodes in Nigeria. Preliminary studies show that infested plants are stunted, show general chlorosis, and have poor tillering (31).

Table 6. Parasitic nematodes in continuously cropped uplands at the Rice Research Station in Rokupr, Sierra Leone (10).

Nematode species	No. litre $^{-1}$
Pratylenchus sp.	262
Helicotylenchus sp.	174
Rotylenchulus sp.	178
Criconemoides sp.	115
Tylenchus sp.	67
Aphelenchus sp.	39

DISEASE CONTROL STRATEGIES

Disease control strategies range from host resistance to cultural, physical, and regulatory methods to chemical control. Adopting an appropriate strategy depends upon available technology such as resistant varieties and effective pesticides and cultural techniques and farmer capacity to purchase and use the technologies. Upland rice production suffers from both lack of technology and farmers' inability to buy inputs for disease control.

Controlling fungus diseases

Fungus diseases can be controlled by planting resistant varieties, following suitable cultural and sanitary practices, and applying chemicals.

Resistant varieties. Planting resistant varieties is the least expensive and safest method of disease control. For upland rice, resistant varieties are important because farmers cannot afford fungicides. Moreover, fungicides seldom are available where upland rice is grown. Breeding methods to develop disease-resistant varieties are described in Chapter 5.

Several varieties that have good Bl resistance have been identified in Latin America, West Africa, and Asia. They include ROK16, IR145, IR5853, IR198-1-2, IR112 8235-84, IR9669-Se1., IR8235-194, IR9559-1-2-3, IR5931-81-1-1, IR12979-24-1-1, IRAT13, IRAT104, IRAT133, IRAT142, IRAT144, IRAT146, IRAT160, IRAT161, IRAT162, IRAT165, IRAT166, IRAT169, IRAT184, ITA132, ITA135, ITA183, ITA208, ITA233, ITA234, TOx95-5-1-1-1, TOx728-1, SEL IRAT194/1/2, M18, OS6, Moroberekan, IAC164, IAC165, and CIAT ICA5 (1, 4, 9, 23, 41).

IRAT146, IRAT162, IRAT166, IRAT168, ROK 16, CICA8, and Ratna have BS resistance (1, 4, 23, 41). Varieties with good LSc resistance include ROK1, ROK2, ROK3, ROK15, IR9671-14-6-8, IRAT146, IRAT165, ITA183, OS6, M202, Du 135, Moroberekan, Pesoda, (36-153, Batatais, and Ratna (1,4,41,49) (Table 7). No variety with ShB resistance has been identified (20, 21).

Varietal mixtures can be used to slow disease infection, particularly of *P. oryzae,* which has several races. Varieties in a mixture should have similar

Table 7. Reaction of recommended upland rice varieties to 4 major diseases in Sierra Leone (41).

Variety	Reaction[a] to			
	Blast (leaf and neck)	Brown spot	Leaf scald	Pale yellow mottle[b]
ROKl	M to S	S	R	S
ROK2	M	M	R	S
ROK3	M to S	S	R	S
ROK15	M to S	S	R	s
ROK16	R	R	M to S	R

[a] R = resistant, M = moderate, S = susceptible. [b] Based on seedling reaction following inoculation by finger rule method.

agronomic characters but different sources of disease resistance. At IRRI, IR54, IR1905-81-3-1, IR442-2-58, and a mixture of all three were evaluated for B1 resistance. The mixed crop had equal B1 incidence as single varieties or even less. Random mixed planting was better than row-by-row mixtures (22).

Regulatory and cultural controls. Regulatory and cultural controls minimize infection by keeping hosts and pathogens apart by time, space, or biological barriers. They are the least expensive of all disease control methods.

Regulatory controls separate infection sources and host plants by space. These controls are extremely important when a particular disease does not occur in a country or in an area within a country. Because inoculum normally moves with planting materials, strict adherence to quarantine laws minimizes disease infection. Quarantine is particularly important because most fungus diseases of upland rice are seedborne (27).

Cultural disease control is manipulation of agronomic practices to minimize disease incidence and severity. A complete knowledge of relations between rice phenology and pest biology, and especially of the most vulnerable period of the pest's life cycle, is necessary. Timing of treatments is the key to success in cultural control. Almost all cultural practices used in upland rice production — timing of planting and harvesting, fertilizer application, tillage, weed control, and cropping system — affect disease development (20).

By adjusting planting date, peak infection period can be avoided. In monsoon climates, early plantings usually have high disease incidence because of high humidity and temperature during crop growth. In a trial at the Central Agricultural Experiment Station in Suakoko, Liberia, LSc incidence was higher in rice planted on 13 Jun than in that seeded on 23 Jun (49) (Table 8). In Senegal, varieties such as Dourado Precoce suffer less B1 if they mature at the end of wet season. If they are planted to mature earlier, B1 infection can be very high. Sowing date should therefore be adjusted so maturation coincides with the probable end of wet season (12).

Table 8. LSc incidence on rice varieties seeded on different dates and with different fertilizer application and spacing, Central Agricultural Experiment Station, Suakoko, Liberia (49).

Varietal group	Lines (no.)	Seeding date	Disease score[a]				
			0 NPK		40-40-40 kg NPK		Mean
			30-cm spacing	15-cm spacing	30-cm spacing	15-cm spacing	
Resistant[b]	4	13 Jun	2.3	2.8	3.0	3.0	2.9
	23	23 Jun	1.2	1.1	2.8	2.9	2.0
Moderately susceptible[c]	66	13 Jun	4.4	4.4	5.7	5.8	5.0
	12	23 Jun	3.3	3.4	5.4	5.7	4.7
Susceptible[d]	30	13 Jun	5.8	6.1	7.3	7 2	6.6
	10	23 Jun	5.7	5.4	7.0	7.1	6.3
Overall mean	100	13 Jun	4.8	4.8	6.1	6.1	5.4
	56	23 Jun	2.9	2.a	4.6	4.8	3.9
LAC23 (check)	6	23 Jun	2.7	3.0	4.5	5.0	3.8

[a]Scale of 1 to 9. [b]Score: 1-3. [c]Score: 4-6. [d]Score: 7-9.

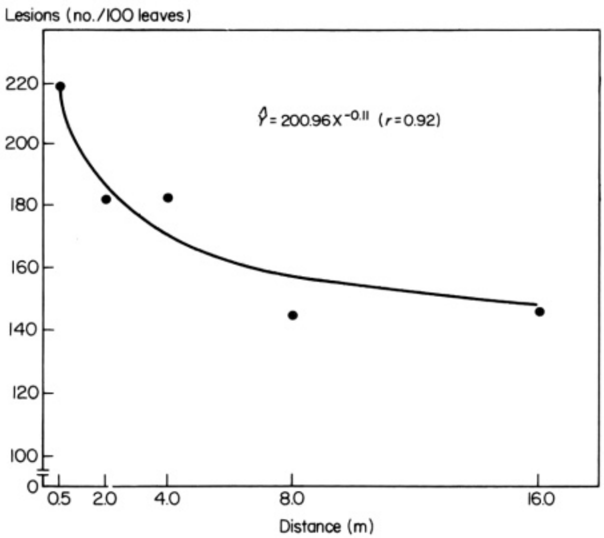
Wide row spacing also inhibits B1 infection (33, 34, 47) (Fig. 6) by reducing the buildup of dew in the crop canopy. Wide spacing also may check inoculum movement. In Brazil, upland rice usually is planted at wide row spacing. Ribeiro (47) studied B1 infection at 10-, 20-, and 30-cm row spacing and found that B1 infection was least at 30-cm spacing. Virmani and Sumo (49), however, found that LSc incidence was only slightly affected by spacing (Table 8).

Applying fertilizer increases disease severity because of the vigorous foliage growth that provides landing space for inoculum and increases humidity in the crop microenvironment. This may be why farmers in the Brazilian cerrado, where B1 and drought are major problems, apply very little N. De Faria et a1 (8) studied B1 development in Goias, Brazil, on IAC47 at 0, 15, 30, 45, and 60 kg N ha^{-1} . Leaf, neck, and panicle B1 increased with N level (Fig. 7). With more than 15 kg added N ha^{-1} , B1 and drought substantially decreased grain yield. Carefully balanced application of NPK, silica, and other micronutrients, however, may effectively reduce BI incidence and severity (6). Virmani and Sumo (49) found that LSc infection on susceptible and moderately susceptible lines increased with 40-40-40 kg applied NPK ha^{-1}.

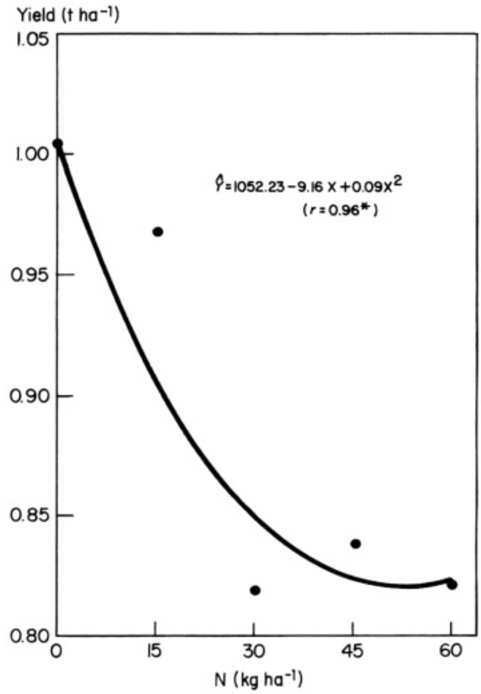
Weed control and interrow cultivation reduce weed competition and humidity within the crop canopy. Weed-free crops withstand disease and insect pest incidence better than weedy crops.

Harvesting time is critical for quality seed production. Rice should be harvested immediately after ripening. If a crop weathers in the field after seeds have matured, many seeds become diseased. When they are planted they spread fungus diseases, most of which are seedborne (27).

Cropping system influences pest and disease incidence (see Chapter 5) in several ways. Most upland rice, is not continuously cropped, but is grown in association, rotation, or relay with other crops. Continuous rice cropping



6. *Pyricularia oryzae* dissemination from infection source in upland rice (34).



7. Relation between N level and upland rice yield (8).

encourages soil sickness, which probably is caused by fungi that inhabit rice roots (29).

When no rice is grown for several months of the year, it is difficult for disease inoculum to survive. Ventura et al (48) found that nematode populations declined in upland rice-based cropping systems. Researchers assume that intercropping nonhost plants with rice is a barrier to inoculum movement and thus reduces the spread of disease. Disease severity also is reduced because inoculum that falls on a nonhost plant does not develop. There are no published data, however, to support these assumptions.

Chemical control. Two chemical controls for fungus diseases have been evaluated — seed treatment and fungicide spray on standing crops. Success rates vary, particularly for Bl control (8, 14, 15, 16, 17, 18, 21, 23, 27, 30, 31). Fungicides are expensive, and applying them may only be justifiable where disease appears in epidemic form and where large yield gains can be realized.

Seed treatment is the most effective Bl control for 30-40 d after planting. Several seed dressings have been evaluated for B1 control at IRRI. Among them, systemic fungicides CGA 49104 (50% WP) and PF 389 JF 5816 (50% WP) performed very well. PF 389 JF 5816 dry powder or slurry at 20 and 40 g kg^{-1} seed and CGA 49104 at 8 g kg^{-1} seed provided 95-100% B1 control for 8 wk after seeding. Tricyclazole (75% WP) at 5.3 g kg^{-1} seed and thiophanate-methy1(70% WP) at 20 and 40 g kg^{-1} seed were moderately effective. PF 389 JF 5816 and thiophanate-methyl generally were more effective at higher than at lower rates (21). Benomyl

(50% WP) at 40 g formulation kg^{-1} seed controlled ShB most effectively for 7 wk after seeding (18).

Seed dressing is widely used for fungus disease control in West Africa. It is inexpensive and protects young plants from parasites. In some cases, seed dressing may be phytotoxic and should not be done 3 wk before seeding. Several fungicides, including systemic thiabendazole and carbendazim and nonsystemic thiram, maneb, mancozeb, and captafol, are available in West Africa (30).

Fungicides are sprayed to control Bl in parts of Asia and South America where epidemic conditions and high yield potential make sprays profitable (30). Mancozeb, benlate, fentin hydroxide, and blasticidin-S sprays effectively control B1 in Nigeria (2). In Brazil, spraying upland rice with tricyclazole [5 methyl-1,2,4-triazolo (3,4-b) benzothiazole] helped control B1, but not stackburn (27). Two sprays of benomyl at 250 g ha^{-1} , however, did not control B1 in Goiania, Brazil (8).

At IRRI, benomyl 50 WP at 1.0 kg formulation ai ha^{-1} sprayed 7 times at weekly intervals beginning at early booting effectively controlled GlD. The sprays also protected the crop from NBLS, Bl, ShR, and ShB. CGA 49104, a systemic seed treatment formulation for B1, did not control BS (23). Preliminary studies in Nigeria indicated that benlate, blasticidin-S, triphenyltin acetate, ditholan, mancozeb, and tricyclazole were promising for BS control (31).

Controlling bacterial diseases

Bacterial diseases are of minor importance in upland rice production except in parts of South and Southeast Asia where monsoon rains are heavy. The effectiveness of chemical controls are limited by heavy rains, therefore varietal resistance is the most important way of controlling bacterial diseases. At IRRI, thousands of rices are screened each year for resistance to bacterial diseases, and breeders work to incorporate resistance into new varieties (22). Because pathogens vary, however, varieties do not remain resistant indefinitely, and new sources must be continually identified.

Chemicals such as Cu and Hg and antibiotics have been used to control bacterial diseases. Acetyledene dicarboxamide has been used as spray with streptomycin (300 ppm) and cupric oxide (7).

Controlling virus diseases

Virus diseases can be controlled by planting resistant varieties and by eliminating vector insects. Of thousands of entries tested at IRRI, only about 0.2% have RTV resistance. Habiganj DW8, Gam Pai 30-12-15, and Pankhari have more RTV resistance than many other varieties (22). In Latin America, CICA7, CICA9, Iniap 415, Iniap 7, Donato, and Canilla have HB resistance (5). In West Africa, many traditional varieties are resistant to pale yellow mottle (30). In Sierra Leone, modern variety ROKl6 has resistance (41).

Eliminating vector insects is the best way to control mild virus outbreaks. Most insecticides kill insects several hours after application, by which time they already have transmitted the virus. Ou (32) found that soaking rice seed in carbofuran prevented RTV infection for up to 30 d after emergence. Insects died when they fed on the seedlings.

Controlling nematodes

Nematodes can be controlled by cultural and chemical methods and by planting resistant varieties. N fertilizer favors nematode development. Fortuner and Memy (11) found that planting rice early decreased *Hirschmanniella* sp. populations. In Japan, rotating rice with soybean reduced *Heterodera elachista* population.

Hot water and fungicide seed treatments can effectively control nematodes (32). Treating seeds with hot (52-53°C) water for 15 min reduced nematode infection and did not injure rice seeds. Seed nematodes also may be killed by soaking seeds in cool water for 8-12 h, heating them in 55° C water for 15 s, soaking in 50° C for 15 min, soaking in cool water for 5 min, and drying them.

Seed fumigation with methylbromide at 16.5 g m^{-2} for 6 h effectively controlled nematodes, but some rices may be sensitive to the treatment. Ou (32) found the following controls were successful: 25% parathion dust, 50% dimeton, or carbon dust at 28 g kg^{-1} seed; soaking seeds for 12 h in a 1:1000 mercuric chloride solution; Agronaa dust at 28 g kg^{-1} seed; and soaking seeds for 24 h in 1:200 to 1:400 of a 20% emulsion of ethyl thiocynate or dipping them for 24 h in a 1:100 to 1:500 concentration of active ingredient of methyl thiocynate or butyl thiocynate. Treating soil with nematicide such as carbofuran can be effective (30). Some nematode-resistant varieties have been identified (11), and should be used where possible.

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CHAPTER 11

Insect Pest Management

Upland rice usually is grown as a single-season crop that occupies fields for only 4-5 mo a year. In the remaining months, fields may be planted to other upland crops or remain fallow. Insect pests are seldom a major problem in upland rice. Upland rice systems prevent population buildup of insects that feed only on rice, such as brown planthopper (BPH), green leafhopper (GLH), yellow stem borer (YSB), and gall midge (GM) (23). Other factors that limit insect buildup are long, harsh dry seasons, technology that favors low plant density, slash-and-burn shifting cultivation, and use of tall land races that have insect, disease, and drought resistance.

LOSSES TO INSECT PESTS

The actual upland rice yield losses caused by insect pests are variable and difficult to determine. Yields of upland rice are lower than those of lowland rice, especially in unfavorable areas, and an insect attack sometimes may cause more damage to upland than to lowland rice.

In Asia, the low yield losses to insects may be due to low crop density (23). In Thailand, yield losses to diseases and insects between 1976 and 1980 ranged from 1 to 13%, averaging 5% (25), but it was noted that loss assessment was imprecise at low productivity levels. A 20% yield loss in a crop that yields 1 t ha^{-1} often cannot be quantified using a randomized complete block design with 4-6 replications.

Yield losses range from a modest 14% to a high 30% in West Africa (1,7), and average about 29% in Brazil (11). In Brazil, *Elasmopalpus lignosellus* (Zeller) and *Tomaspis* (= Deois) *fluvopicta* (Stal) damage seedlings and may make it necessary to replant large areas.

Most upland rices are tall and leafy and can tolerate more than 50% defoliation (23). A study in Goiania, Brazil, with leaf caterpillar *Spodoptera frugiperda* Smith on 1AC47 and IAC25 showed that vegetative stage defoliation did not decrease productivity, and might slightly increase yield. Severe defoliation during reproductive stage hampered flower development and reduced productivity (30).

MAJOR INSECT PESTS OF UPLAND RICE

Major upland rice insects in Asia include grasshoppers. armyworms (AW), leaffolders (LF), and rice bugs and soil pests such as ants, termites, white grubs, soil cricket, root beetles, and snout weevil. Seedling maggots and beetles also cause problems (23). In Africa, major upland rice insects are SB, including stalk-eyed fly, termites, AW, mole cricket, and sucking bug (2, 44) (Table 1).

In Latin America *Elasmopalpus lignosellus* and *Blissus leucopterus* (Say) frequently occur on upland rice, but cause serious damage only during prolonged drought (6). White grub and planthopper *(Sogatodes)* also attack upland rice. In the central western region of Brazil, subterraneous termites, thrips, rice stink bugs, leafhoppers, planthoppers, spittlebug, AW, lesser cornstalk borer, SB, rice beetle, and cutting ants sometimes cause damage. Beetles cause important damage in Maranhão and Para States, and panicle borer *Neobaridia amplitarsis* recently damaged rice in Mato Grosso (11).

Stem borers

Several SB infest upland rice fields in Asia, Africa, and Latin America (1, 6, 10, 11, 14, 17, 24, 26, 28, 34, 36, 45). SB commonly found in South and Southeast Asia include *Chilo suppressalis* (Walker), *Scirpophaga incertulas* (Walker), *Sesamia inferens* (Walker), *Chilo polychrysus* (Meyrick), and *Scirpophaga innotata* (Walker).

In West Africa, important SB include *Maliarpha separatella* (Rag), *Chilo zacconius* (Blesz), *Diopsis thoracica* (West) (Plate 11.l), and *Sesamia calamistis* (Hampson). In Latin America, primarily Brazil, the primary SB are lesser cornstalk borer *Elasmopalpus lignosellus* and *Diatraea* species.

SB damage rice in two ways from seedling through reproductive stage.

- *Deadhearts.* During the vegetative stage, SB larvae bore into and feed on leaf sheaths, causing broad, longitudinal, whitish areas at feeding sites. Central leaf whorls do not unfold; they turn brownish and dry. Lower leaves

Table 1. Major upland rice insects in Africa (44).

Insect	Status[a]		
	Upland	Lowland	Irrigated
Maliarpha separatella	x	xx	xx
Chilo zacconius	x	x	xx
Chilo diffusilineus	xx	x	x
Chilo partellus	xx	x	x
Scirpophaga spp.	x	xx	xx
Sesamia spp.	xx	x	x
Diopsis spp.	x	xx	xx
Nymphula depunctalis	-	xx	xx
Orseolia oryzae	-	xx	xx
Nephotettix spp.	x	xx	xx
Epilachna similis	xx	x	x
Spodoptera spp.	xx	x	x
Gryllotalpa africana	xx	-	-
Aphids	x	-	-
Termites	xx	-	-

[a]xx = abundant, x = present but not abundant, - = not present.

remain green and healthy. The affected tillers dry without bearing panicles (Plate 11.2).

- *Whiteheads.* During reproductive stage, particularly after panicle initiation, SB cut the growing plant parts and panicles dry, causing serious yield losses. The empty whitish panicles are called whiteheads (Plate 11.3).

Leafhoppers and planthoppers

Leafhoppers and planthoppers usually are not major upland rice insect pests. However, GLH *Nephotettix* sp. and BPH *Nilaparvata lugens* Stal attack upland rice in the Philippines (14, 20, 36). In Brazil, several leafhoppers, including *Exitianus obscurinerves, Balclutha* sp. *Hortensia* sp., *Graphocephala* sp., and planthopper *Sogatodes oryzicola* Muir damage upland rice (11). *S. oryzicola* transmits hoja blanca virus.

Generally, leafhoppers feed on leaves and upper plant parts and planthoppers feed on lower plant parts. Both suck sap and plug the xylem and phloem. A small infestation during early growth can reduce tiller number, plant height, and general vigor. After panicle initiation, the same population can cause a high percentage of unfilled grains.

Armyworm and cutworm

Several AW and cutworm species — *Mocis latipes, Spodoptera frugiperda* (Smith), and *S. litura* (F.) — attack upland rice in Brazil (11, 30), West Africa (1), Malaysia (10), Bangladesh (26), and India (35). They are more important in upland than in lowland rice because they pupate in the soil (35). AW may destroy seedlings and detach panicles. Swarming caterpillars *S. mauritia* Boisduval cause severe seedling damage and sometimes defoliate rice. Young cutworm caterpillars eat only soft, new leaves. Mature caterpillars can devour whole plants.

Grain sucking insects

Several grain sucking insects cause serious rice losses. Rice bug *Leptocorisa* sp. damages upland rice in India, Bangladesh, and Malaysia (10, 24, 28, 40) and rice stink bug *Oebalus* sp. damages it in Brazil (11). Chinch bug *Caenoblissus pilosus* causes damage in Papua New Guinea (16).

Rice bug nymphs and adults feed on developing grains, causing them to remain empty or only partially filled. Partly damaged grains have an off-flavor (35). Nymphs are more destructive than adults. Stink bug nymphs and adults feed on rice at milk stage. Infestation at late dough stage may cause broken grains and reduce milling quality.

Rice mealy bug

Rice mealy bug *Brevennia rehi* Lindinger is a serious pest, particularly during drought, in northern India and Bangladesh (22, 23, 35). Nymphs and adult females frequently feed in colonies of thousands. They suck sap from rice stems, which causes stunting and curled leaves. With heavy infestation, either no panicles form or they are not fully exserted. Whole plants may dry. Damage is in patches because nymphs have limited migratory ability.

Rice leaffolder

Rice LF *Cnaphalocrocis medinalis* (Guenee) attacks upland rice in tropical Asia, including Bangladesh (22, 26), where it damages the aus crop. The caterpillars fold leaf blades into tubes and feed on the green tissue within them. Usually, only one caterpillar is found within a fold. Infestation discolors leaves, and reduces general plant vigor and photosynthetic ability.

Seedling fly

Seedling fly *Atherigona oryzae* (Malloch) infests rice in parts of Asia (22), and is an important pest in Orissa, India, and Java, Indonesia (39, 45). Maggots feed on main shoots and burrow into the base of stems and growing tips, causing deadheart symptoms and stunting. The insect causes most problems at early crop growth.

White grub

White grub (toy beetle) *Leucopholis irrorata* (Chevrolat) feeds on the roots of many crops grown in well drained soil. It damages upland rice in the Philippines (3, 19), Indonesia (45), and Latin America (6). It also attacks maize and sorghum (19).

Grubs live in the soil and attack the root system and the bottom of plants, especially young plants, causing stunting and wilted patches in the field. At harvest, damaged plants have almost no root system and can be easily pulled by hand from the soil. Figure 1 shows the population dynamics of white grub in Batangas, Philippines.

Termites

Several termite species damage upland rice in West Africa and Brazil (5, 11, 34). The most destructive in Nigeria is *Macrotermes* sp.; that in Brazil, *Syntermes* sp. Young plants are cut off at the ground, covered with soil, and eaten. On newly cleared land, damage may be considerable (5).

Other insect pests

Upland rice also is sporadically damaged by thrips *Frankliniella rodeos* Moulton, ladybird beetle *Aulacophora similis* Olivier, rice beetles *Diabrotica speciosa* and *Chaetocnema* sp., cutting ants (*Acromyrmex* sp.), aphids (*Oryopeia hirsuta* Baker), and scarabaeid beetle *Heteronychus liuderes* Redtenbacher (11, 33, 34, 35, 40).

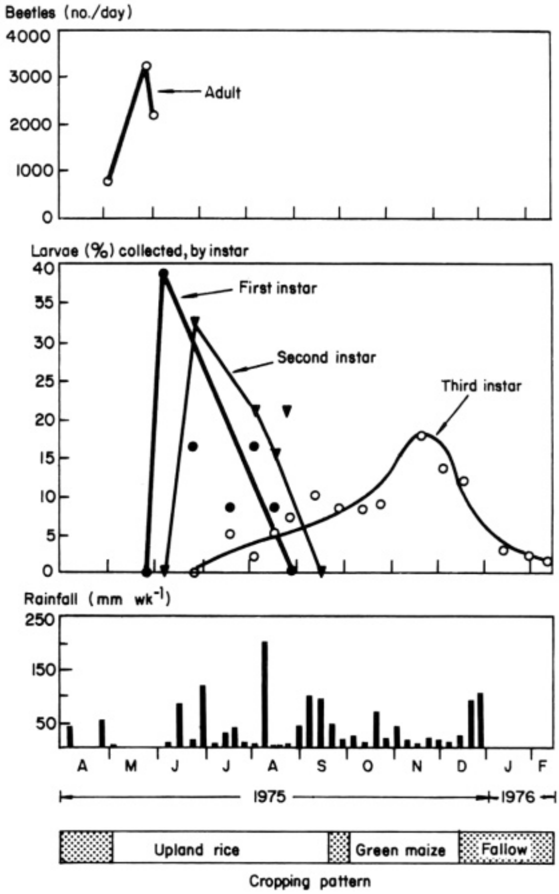
CONTROLLING INSECT PESTS

Upland rice insect pests can be controlled by resistant varieties, insecticide application, cultural practices, and biocontrols. Integrated pest management that considers local ecology may be the most efficient and economical approach.

Resistant varieties

Planting resistant varieties is the safest and least expensive way of controlling insect pests. Most upland rices are traditional, tall varieties with long, wide leaves and thick stems. They are more susceptible to SB damage than moderate tillering

1. Population dynamics of adult white grub *Leucopholis irrorata* (Chev.) and 3 larval instars in 3 farmers' fields in Batangas, Philippines(19).



semidwarfs (32, 35). Martins et al (32) found that in Brazil hairy-leaf genotypes suffer less SB damage than other varieties.

IITA has identified several rices with resistance to stalk-eyed fly, which is a major pest in West Africa (Table 2) (18). Among them, TOs5827, TOs3213, and TOs285 had less than 2% fly infestation. Sources of resistance to African SB, African white borer, and African pink borer also have been identified (2, 18) (Table 3).

In Brazil, traditional IAC47 and Pratao were more susceptible to SB *Diatraea saccharalis* F. than modern varieties P733-B4-5, CICA4, and IR841-3-2-3 (Table 4). BKN6652-249-1-1 had more resistance (14% dead plants) than Catetao (33% dead plants) under natural lesser corn stalk borer *Elasmopalpus lignosellus* infestation in Goiania, Brazil (13). Damage was most serious 2 mo after rice emerged (Fig. 2).

At IRRI, breeding lines are regularly evaluated for resistance to striped SB *C. suppressalis,* LF *Cnaphalocrocis medinalis,* and GLH *Nephotettix* sp. Several resistant lines have been identified (21). In Bogor, Indonesia, several upland rices

Table 2. Twenty varieties selected for resistance to stalk-eyed fly *D. thoracica* in mass screening of 988 rices, IITA, 1982 (18).

Designation	Source	Infestation[a] (%)
TOs 5827	Liberia	1.2
TOs 3213	Ivory Coast	1.8
TOs 285	USA	1.8
TOs 372	Indonesia	2.0
TOs 3212	Ivory Coast	2.2
TOs 5792	Liberia	2.2
TOx 916-6-1-101-2	IITA	2.4
TOg 6390	Liberia	2.5
TOs 272	USA	2.8
TOs 5677	Nigeria	2.9
ITA121	IITA	3.1
TOs 5267	Ivory Coast	3.3
TOs 657	USA	3.3
TOs 373	Indonesia	3.3
x.2. D. T.	Vietnam	3.4
TOx 936-153-5-33	IITA	3.5
TOs 663	Nigeria	3.5
TOs 5734	Liberia	3.6
TOx 891-212-2-102-1-1	IITA	3.6
TOg 6481	Liberia	3.8

[a]Infestation ranged from 1.2 to 66.7% in the mass screening test.

Table 3. Sources of resistance[a] to insect pests of upland rice in Africa (2).

African striped borer	
Taichung 16	TOs 2513
PR403	Ratna
ITA6-20-1-Bp1	Malagkit
IR503-1-91-3-2-1	Sung Song
PR325	SML 81B
H8	
African white borer	
ITA6-4-2	
IR1168-76[a]	
IR1561-38-6-5[a]	
ITA7-7-2[a]	
TKM6[a]	
African pink borer	
W1263	INJ171
Taichung 16	INJ146
SML 81B	Sikasso
Stalk-eyed fly	
IR579-160	ITA6-22-22Bp-1
Tx52-2-4	E. L. Gorpher
IR523-1-218	IR1561-38-6-5
Iguape Cateto	Huang-Sengoo
Leuang 28-1-64	Td 10A
DNJ171	Magoti
Ctg 680	C5565
IR589-53-2	Saconodo Brazil
ITA6-16-7-Bp-3	

[a]Moderately resistant

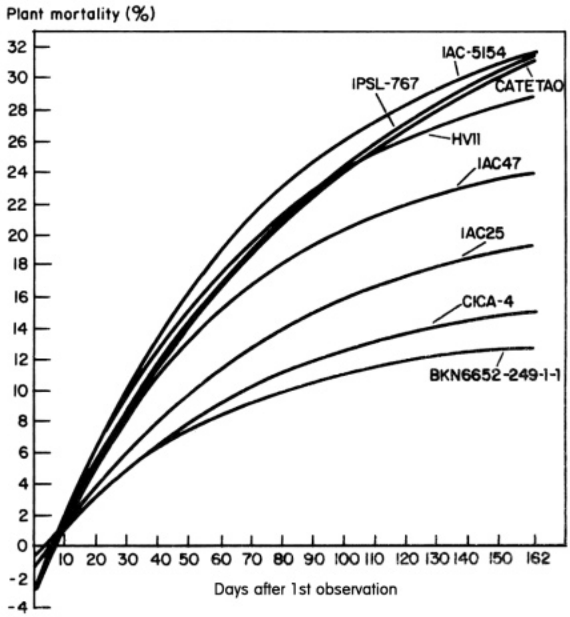
Table 4. Reaction of upland rice varieties to stem borer damage (32).

Variety	% tillers attacked
P733-B4-5	3.7
CICA4	4.4
IR841-3-2-3	6.0
P738-97-3-1	6.1
IR665-4-5-5	10.6
Kanan	12.7
IAC25	19.0
Perola	19.6
Catetao	21.5
Bicó Ganga	24.6
IAC47	25.9
Pratao	26.5
D. M. S. (Turkey 5%)	8.9

were screened for resistance to seedling fly *Atherigona exigua* Stein under natural infestation. Arias, from India, had least damage and local Gama 61 had the most (42).

Chemical control

When insect-resistant varieties are unavailable, insecticides usually are applied to control insect pests. Insecticides, however, are expensive and need careful handling because they are toxic to humans and animals. The low yield potential of upland rice and economic conditions limit insecticide use.



2. Cumulative average percentage of dead plants per *E. lignosellus* worm in cultivars and lines of rice after 162 d (13).

There are two kinds of commonly used insecticides.

- Contact insecticides are applied on foliage and kill insects by contact. They are easily washed away by rain, and should be applied at the insects' most vulnerable stage.
- Systemic insecticides are applied to rice plants or soil, are absorbed by plant parts, and travel throughout the plant tissues. They kill insects as they feed on the plant and are not easily washed away by rain. They also have longer residual effect than contact insecticides.

Common insecticide formulations are dusts, wettable powders, emulsifiable concentrates, and granules.

- Dusts may consist of a toxic agent only, of a toxic agent and an active diluent that serves as a carrier, or a toxic agent and an inert diluent such as talc or clay (8). They are not popular in Asia because they are expensive, bulky, require protection against inhalation, and are readily washed off plants by rain (29).
- Wettable powders (WP) look similar to dust but contain a wetting agent and are applied as liquid sprays. They must be agitated before application. WP are bulky and have short shelf life when opened; therefore manufacturers are shifting to emulsifiable concentrates.
- Emulsifiable concentrates (EC) are oil-based liquid formulations with high insecticide concentration. They are a mixture of insecticides, solvents, and emulsifiers that make them easy to mix with water and have wetting and sticking agents to help them cover and adhere to plants. EC are the least expensive insecticide formulations. They can be applied as foliar sprays at any crop stage, are not bulky, are easily transported, and store well. They are, however, hard to apply in upland rice areas because they must be mixed with water (29). They are easily washed from plants by rain.
- Granular (G) formulations consist of free-flowing grains of inert materials mixed or impregnated with an insecticide. They are extremely bulky, but can be applied by hand without special equipment. They are more expensive than EC but are more persistent.

Insecticides are applied to soil, seeds, or foliage.

Soil application. Applying insecticides to the soil controls soil insects and protects young plants. Efficacy decreases as plants grow older. Soil insecticide usually is applied before planting, It can be sprayed on the soil and incorporated, or granular insecticides can be placed in furrows with the seed and covered. Rice roots absorb systemic insecticides, which protect against foliage insects.

Several soil-applied insecticides have been tested for upland rice. Pathak and Dyck (36) found furrow placement of carbofuran, chlordimeform, acephate, and gamma BHC+MTMC, at 2 kg ai ha^{-1} provided good BPH control for 50 d after seeding. Carbofuran, propoxur, AC 64, 475, phentriazophos, and thiadiazinthion were effective against GLH, and carbofuran controlled LF.

In Thailand, carbofuran applied before planting in furrow bottoms at 1 kg ai ha^{-1} and carbosulfan sprayed in furrows before planting or after seedling emergence in furrows at 330 g ha^{-1} were evaluated as insect controls. Carbofuran effectively controlled flea beetle with 99% plant survival versus 77% in untreated plots. Carbosulfan furrow application gave 98% survival. Both chemicals also controlled field ants (25).

In Batangas, Philippines, lindane 6 G and diazinon 10 G each at 1 and 4 kg ai ha^{-1} were evaluated for control of white grub. The insecticides were broadcast in furrows and covered 7 d later. Soil samples to 20-cm depth taken after rice harvest showed that lindane gave 100% control at both application levels. Diazinon was not so effective. In another trial chlordane 75 EC at 1 and 4 kg ai ha^{-1} and dieldrin 50 WP at 2 kg ai ha^{-1} were jetted into furrows with a knapsack sprayer without the disperser nozzle. Chlordane gave 90% control at 1 kg and 100% control at 4 kg ai ha^{-1} . Dieldrin gave 99% control (3, 19). Lindane at 1 kg ai ha^{-1} provided the most inexpensive control, costing \$37.70 ha^{-1} for 100% control, and \$9.40 for 90% control. For 99% control, dieldrin cost \$31.24 (19).

In Indonesia, treating soil with BHC 6 G at 2.0 kg ai ha^{-1} before planting controlled white grub and seedling fly (45). In Brazil, soil and seed treatments with several insecticides were evaluated for controlling soil pests such as termite and lesser corn stalk borer. The higher initial plant stand obtained with treatment was not reflected in grain yield because increased tiller number encouraged blast infection (31).

In Nigeria, lindane G at 2 kg ai ha^{-1} effectively controlled *Diopsis* and lepidopterous borers. Diazinon and chlorfenvinphos were best against Diopsis and lindane was best against lepidopterous borers (34).

Seed treatment. Seed treatment is aninexpensive way of protecting young rice plants from insect pests, but only lasts for 30-40 d after seeding, after which foliar spray is necessary.

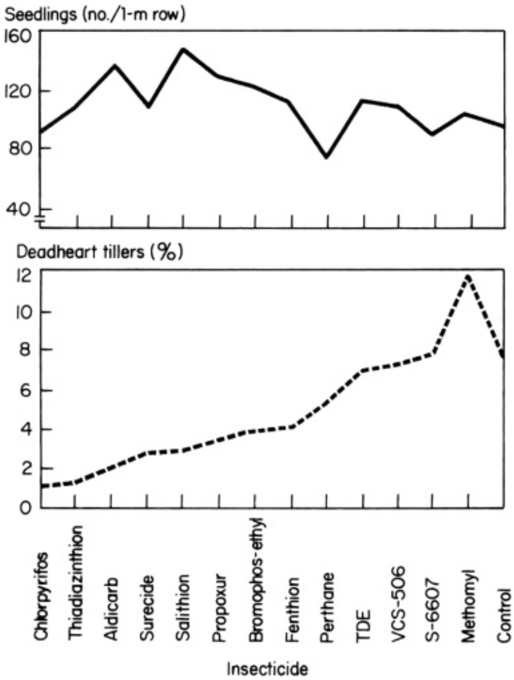
De Souza and Ramiro (9) evaluated chlorfenvinphos 25% WP (25% ai), aldrin 40% WP (27% ai), and an equal mixture of the two at Minas Gerais and São Paulo, Brazil. Chlorfenvinphos and the mixture were tested at 6.7 g kg^{-1} seed and aldrin was tested at 6.7 and 10 g kg^{-1} seed. Treated plots had higher plant stand than untreated plots, but grain yield was not significantly different.

Pathak and Dyck (36) compared 13 insecticides for controlling SB in upland rice during early growth. At 13 d after seeding, all 13 compounds were effective against SB; at 29 d after seeding, plants treated with chlorpyrifos, thiadiazinthion, aldicarb, cyanofenphos, salithion, and propoxur had significantly fewer dead-hearts than the control plants (Fig. 3).

Seed treatment with systemic insecticides such as carbofuran can be used to control soil insects, including seedling maggot (23). Seed treatment effectively controls GLH during early rice growth but is not effective later in the season (19). In Thailand, carbofuran seed treatment at 1% ai controlled BPH for 30 d after seeding (25).

Foliar spray. Applying foliar spray is a convenient way of controlling grasshoppers, AW, LF, and other insects that attack plants at vegetative and reproductive stages. It often is ineffective against insects, such as SB, that feed inside the plant (20). Contact insecticides generally are used in foliar application.

Foliar sprays often are ineffective because rain washes them from plants (10).



3. Stem borer protection 29 d after seeding with different insecticide seed treatments at 2 kg/ 100 kg seed (36).

Additionally, spray volume is important under upland conditions because water is scarce. Foliar application with high-volume knapsack sprayers is impractical. Low-volume and controlled droplet applicators developed for other crops should be used to spray insecticides on upland rice. Ultralow volume and controlled droplet applicators use only 1 litre of water ha^{-1} (23).

Several foliar sprays have been used to control upland rice insects. In the Philippines, three and six sprays of parathion, TEPP, or toxaphene control SB, LF, and rice bug. In a laboratory study, parathion followed by TEPP killed rice bug and LF and SB larvae. Toxaphene was not effective (38). Pathak and Dyck (36) found that 0.05% foliar spray of compounds such as chlordimeform, metalkamate, acephate, and monocrotophos at 15-d intervals controlled BPH and LF (Table 5). For effective BPH control, the sprayer nozzle should be aimed at the center of the plant.

Several insecticides were tested at different Philippine sites to identify appropriate crop stages at which protection should be applied. At all sites except IRRI, furrow application of carbofuran increased seedling density. Seed pest protection increased yield at Pili (Table 6). Insecticide application before panicle initiation reduced LF damage at all sites and SB damage at IRRI. A foliar application of monocrotophos at 20-d intervals effectively controlled LF, GLH, and whitebacked planthopper at IRRI (20). At three sites in Batangas and IRRI, continuous protection significantly increased yields. These results suggest that inexpensive insecticides are needed to protect upland rice (19). Only 1 foliar insecticide application, as necessary, is recommended to control grasshoppers,

Table 5. Control of hopperburn and leaffolder damage in upland rice IRM-2-58 with foliar sprays of 0.05% ai insecticide applied at 25d intervals[a] (36).

Insecticide	Hopperburned area (%) at 70 d	Leaffolder damage[b] at 57 d
Chlordimeform	0 a	0.9 a
Metalkamate	0 a	3.4 bc
Acephate	0 a	0.5 a
Monocrotophos	la	0.5 a
BPMC	8 ab	4.6 de
Chlorpyrifos	17 abc	0.5 a
Fenthion	28 abc	3.6 bcde
Fenitrothion	39 bcd	3.5 bcd
Endosulfan	51 cde	4.5 cde
Azinphos ethyl	76 de	2.8 b
Cyanofenphos	90 e	0.6 a
Untreated control	42 bcde	4.8 e

[a] Any two numbers followed by the same letter are not significantly different at 5% level. [b]On a 0-5 scale; the larger the number, the greater the damage.

AW, and LF because they are relatively unimportant pests of upland rice (23).

Comparison of insecticide application methods. Insecticide application methods should be compared to determine their relative and economic effectiveness. Eight application methods were compared at Bukidnon Settlement, the Philippines, in 1980 wet season (Tab1e 7). Application method did not significantly affect grain yield. The recommended practice of incorporating 1 kg carbofuran 3 G ai ha^{-1} mixed with fertilizer before seeding and spraying carbaryl85 WP at 0.75 kg ai ha^{-1} produced 4.6 t rice ha^{-1}, which was comparable to complete control. *Scirpophaga incertulas* and *S. innotata* were dominant insects, but there were small populations of rice root aphids and rice bugs (1 5).

Economic analysis of three treatments (Table 8) showed the recommended practice yielded 4.6 t ha^{-1} - 1.1 t ha^{-1} over the control — giving a net benefit of \$136 ha^{-1} versus \$93 for the alternative practice. The alternative practice, however, had a slightly higher benefit to cost ratio (15).

Cultural control

All cultural practices directly or indirectly influence insect populations. Most upland rice is grown in drought-prone areas and usually only one crop is harvested each year. The rest of the year land is fallow or planted to another crop. Often, rice is mixed or relay-cropped with other upland crops. These practices reduce insect pest infestation.

Plowing immediately after harvesting rice incorporates stubble in the soil and kills eggs and adult insects, thus reducing insect carryover to the next crop. In Goiania, Brazil, incorporating rice stubble soon after harvest decreased *D. saccharalis* and *E. lignosellus* buildup (12).

The adverse effect of seed and seedling damaging insects can be reduced by dense planting, which also controls weeds. Proper insecticide application and lower seeding rates can produce the same benefits.

Table 6. Effect of insecticide treatment on upland rice seedling density, insect damage, and grain yield[a] (19).

Treatment			Seedling density (no. m-row^{-1})		Leaffolder damage[b] (grade)	Whiteheads (%)		Yield (t ha^{-1})			
Carbofuran granules in furrow (2 kg ha^{-1})	Monocrotophos weekly spray (0.06%)	Methyl parathion weekly spray (0.06%)	Cale	Pili	San Pedro	Cale	IRRI	Cale	San Pedro	IRRI	Pili
Seeding	Seeding to heading	Flowering to maturity	96 a	-	1.5 a	1.1 a	4.0 a	3.5 a	3.6 a	2.9 a	
-	Seeding to heading	Flowering to maturity	51 b	-	2.0 a	2.9 b	4.5 a	2.4 c	3.4 a	2.3 ab	-
-	Panicle initiation	Flowering to maturity	54 b	-	4.0 b	2.9 b	7.2 b	3.0 abc	3.2 ab	2.8 ab	-
	to heading	Flowering to maturity	53 b	-	4.5 b	2.3 b	7.3 b	3.2 ab	2.5 b	2.5 ab	-
Seeding	-	-	-	57	-	-	-	-	-	-	1.4
Untreated control		-	52 b	25	4.0 b	3.0 b	7.2 b	2.7 bc	2.7 b	2.1 b	1.0

[a] Rice variety was Dagge at Cale, Kinanda at San Pedro, C22 at IRRI, and Bursiging Puti at Pili. In a column, any two means followed by the same letter are not significantly different at the 5% level. [b] Rated on a scale of 0-9: 0 = no damage, 9 = most severely damaged. Observation was at 60 d after seeding.

Table 7. Effect of different insecticide application methods on upland rice plant stand, grain yield, and insect damage (C171-136)[a] (15).

Treatment[b]	Plant stand per 1-m row	Root aphid infestation (%)	Stem borer damage (no. per 10-m row)		Leaffolder damage (%)	Rice bugs (no. per 10-m row)	Yield (t ha^{-1})
			Deadhearts 45 DE[c]	Whiteheads			
1	120	.27	4.5	0.0	1.68	13.3	4.67
2	105	4.9	22.5	3.3	2.98	13.3	4.60
3	115	2.08	16.7	13.3	3.57	20.0	4.53
4	125	6.8	8.9	11.7	1.19	14.7	4.20
5	112	12.5	7.2	6.7	2.89	11.7	4.23
6	126	9.68	51.0	36.7	4.43	26.7	3.55
7	116	0.89	5.2	10.0	1.22	20.7	4.61
8	117	1.7	11.0	13.3	2.78	16.7	4.26

[a]Average of 3 farmers' field. No significant difference on treatment yield (ns). CV 12.67%. [b]Treatment 1 = complete controi: a) bendiocarb seed treatment of 1 kg ai/kg seed; b) monocrotophos 1 kg ai/ha at 15, 25, 35 DE; c) 1 kg chlorpyrifos/ha at 45, 55, 65, 75 DE; d) 1 kg monocrotophos at 7-d intervals (beginning after flowering, 3 sprays). 2 = omit 1a. 3 = omit 1b. 4 = omit 1c. 5 = omit 1d. 6 = untreated. 7 = recommended practice: 1 kg carbofuran 3G plus fertilizer, soil incorporated; 1 kg carbaryl/ha at premilking stage and 7 d later. 8 = alternative practice: 0.5 kg ai carbofuran 3G/ha + fertilizer and 1 kg carbaryl 85 WP/ha at premilking stage and 7 d later. [c]Days after emergence.

Table 8. Cost and return analysis of insect control methods with granular and foliar insecticide for upland rice C171-136 (15).

Treatment[a]	Yield[b] (t ha^{-1})	Insecticide cost ($ ha^{-1})	Net return from insecticides ($ ha^{-1})	Benefit:cost[c]
6	3.5	-	-	-
7	4.6	47.20	136	3.89
8	4.3	30.00	93	4.12

[a] For treatment explanation, see footnotes to Table 7. [b] Price of rice minus P1.30/kilo (14% moisture content). Treatment yield minus yield from untreated multiplied by price of rice minus cost of insecticide. US$1 = ₱ 7.50. [c] Treatment yield loss from untreated multiplied by price of rice divided by insecticide cost.

Synchronizing planting dates also limits insect population development. Fortunately, most upland rice is planted simultaneously just after rains begin.

Fertilizer management also influences insect populations. Applying high levels of N leads to luxuriant growth that attracts leafhoppers and planthoppers and increases humidity in the canopy, which favors other insects. Judicious P and K application strengthens plants and helps them withstand insect attacks. In an experiment in Brazil, applying 64.5 kg P and 41.5 kg K ha^{-1} reduced insect populations and increased grain yield (Table 9). Applying 7.5 kg Zn ha^{-1} also reduced *E. lignosellus* infection (Table 10) (12).

Table 9. Insect damage in upland rice with and without applied P and K[a] (12).

Variable	Without P and K	With P and K[b]
Insects (no./5-m line)		
Hemipterans	45.9 a	54.1 b
Planthoppers	53.9 b	46.1 a
Coleopterans	55.8 b	44.2 a
Elasmopalpus sp. worms (no./20 litres of soil)	42.7 a	57.3 b
Dead tillers (no./ *Elasmopalpus* sp. in 5 m^2)	53.2 b	46.8 a

[a] In a row, values followed by different letters are significantly different at 5% level of probability by f test. Data related to population and insect damage are presented as percent distribution. [b] P at 64.5 kg ha^{-1}, K at 41.5 kg ha^{-1}).

Table 10. *E. lignosellus* damage to upland rice with and without applied Zn[a] (12).

Variable	Without Zn	With Zn (7.5 kg ha^{-1})
Dead tillers (no./lesser corn stalk borer in soil and plant sampling)	57.7 b	42.3 a

[a] Values significant at 5% level of probability by f test. The data are presented as percent distribution.

Biological control

In the broadest sense, biological control includes planting resistant varieties, modifying insect habitats, and applying pheromones and growth inhibitors. In a narrow sense biological control includes the encouragement of natural enemies of insect pests and release of sterile male insects (37). The following are necessary to effectively use natural enemies to control insect pests:

- a thorough knowledge of the bioecology of the insect pests to be controlled. including the times when they are most vulnerable to attack;
- an understanding of the economics of pest damage relative to acceptable population thresholds; and
- an understanding of population dynamics of insects on all crops within a system that will permit quick solutions that bring damage within acceptable economic level.

Three types of insect enemies are being studied: parasites, predators. and pathogens. Research also is progressing on sex pheromone identification and mating disruption (21). *Bacillus thuringiensis* has been found toxic to 3d and 4th instars of AW larvae. Many spiders are known to prey on BPH (8).

There is almost no information on the use of bioagents to control insect pests of upland rice. In Batangas, Philippines. Barrion and Litsinger(4) found that LF was the most important upland rice insect; however, there were very few larvae within folded leaves because ants preyed on them. One *Diacamma* sp. worker ant could transport about 10 LF larvae per hour from plant to tunnel.

Integrated pest management

A single approach to insect pest control may not always be best on a long-term basis. Insects develop resistance to insecticides and new biotypes evolve to attack resistant varieties. Continuous use of insecticides may harm the environment and kill natural enemies, thus changing minor pests to major pests.

An integrated, ecological approach that is being developed uses a variety of control technologies within an agroecosystem to control insects, diseases, and weeds. Systems analysis, including modeling. simulation, and optimization. will play an important role in developing integrated pest management (IPM) methodology.

A systems approach to pest management includes population surveillance, a population dynamics model to help predict future pest populations, a plant damage model that reflects plant-pest interaction, a decision making model for control tactics, and an evaluation model to determine the effectiveness of controls (27). IPM can involve one or all pests that affect a crop.

Smith and Apple (41) described IPM components.

- Identify diseases, insects, weeds, etc. that must be managed within an agroecosystem.
- Define the management unit of the agroecosystem.
- Develop a pest management strategy.
- Establish economic injury thresholds. (An economic injury threshold is the pest population level that reduces crop value more than the cost of controls.)
- Develop reliable monitoring and predictive techniques.

- Evolve descriptive and predictive models.
- Overcome socioeconomic barriers to establishing IPM systems.

IPM systems are being developed for lowland rice, where insects are a major problem. IPM may have limited applications in upland rice, where insects do not yet cause major problems.

OTHER PESTS

Rodents, birds, and large animals such as monkeys, deer, and pigs also damage upland rice crops.

Rodents

Rodents, particularly rats, substantially damage upland rice. Because upland rice fields have no standing water, rats can easily build large burrow systems. They eat rice seeds and seedlings, gnaw tillers, damage plants, and feed on grain.

Although several rat species damage upland rice, little quantitative information is available on the losses they cause. In Sierra Leone, where cutting grass or crane rat *Thryonomys swinderianus* Tem. damage is very important, a simulation experiment assessed rat damage by artificial defoliation of Nickaboi (110-115 d duration), Anethoda (130-135 d), and Baanyalojopoin (140-145 d). Half, two-thirds, or all leaves were removed before, during, or after tillering. All varieties had marked compensatory tillering. Yield increased when plants were defoliated during tillering but decreased when foliage was removed after tillering, especially in shorter duration rices. Total defoliation reduced yields most (43). When rats gnawed tillers, others emerged and matured late, which also reduced yield.

Rats can be controlled by rat fences or other barriers, poison bait, and burrow fumigation. At IRRI and other experiment stations in Southeast Asia, electric fences are used to control the rats. They are quite expensive, however, and not feasible for upland rice conditions.

Poison baiting with sodium fluoroacetate and zinc phosphide controls rats well before panicles emerge. When natural food is available, baiting is ineffective. Sealing burrow openings, placing Celphos tablets in burrows, and fumigating burrows may provide effective control after panicle initiation.

Birds

Birds cause considerable damage to upland rice shortly after seeding and from flowering onward. In Asia, *Ploeus,* parakeets, Munia, and sparrows are the most serious pests (8, 10). Noisemakers are used to scare away birds. Planting rice in large areas to mature at the same time reduces bird damage.

Mammals

Upland rice fields near forests are damaged by monkeys, deer, and pigs. In Malaysia, monkeys *Macaea nemestrina* and *M. irus,* Sambhur deer *Cervus unicolor,* barking deer *Muntiacus muntjok,* and pig *Susbarbatus barbatus* once caused great damage. They became less of a problem when shotguns became available to farmers (10, 28).

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CHAPTER 12

Economics of Upland Rice Production

Most upland rice is grown on small, subsistence farms with few purchased inputs. Labor is substituted for capital, and most production is for family consumption. Market forces, therefore, are not an important factor in deciding what production technology to adopt. An exception to this rule is Latin America, where upland rice is grown on large mechanized farms. On those farms, human labor is of less importance and market forces have more influence on technology decisions.

Traditional upland rice farms are more diversified than lowland farms. On upland farms, rice usually is one component within a cropping system that includes several crops grown after or with rice. Labor use for upland rice is more evenly dispersed through the growing season than in lowland rice, and investments in fixed capital, such as irrigation systems, have less potential for increasing upland rice production.

CONCEPTS

An understanding of basic concepts is needed before addressing the economics of upland rice production.

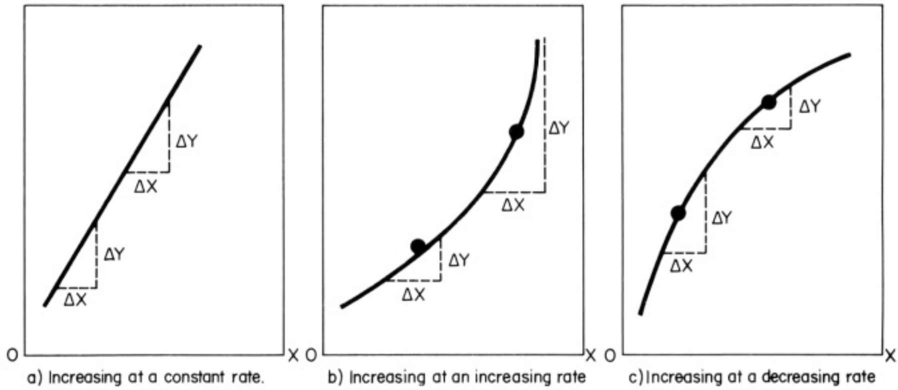
Production function

A production function, or response function, is a mathematical expression that describes the physical relationship between inputs and outputs. The relationship is expressed as

$$Y = f(X_1, X_2, X_3 - -Xn)$$

where Y is the output obtained as a result of using capital X_1, land X_2, and other inputs X_n. A farmer may change the relationship by increasing or decreasing one input, fertilizer for example, and keeping other inputs constant, or may simultaneously increase or decrease several or all inputs.

Rate of change in output can be described as slope, increment, or margin, which are used interchangeably when discussing productivity, cost, and revenue. The reaction of productivity to increasing one input while others remain constant is shown in Figure 1. The relationship can be constant, increasing, or decreasing marginal physical product (MPP). At constant MPP, each additional input level generates equal increments. At increasing MPP, each additional level of input



1. Production functions.

generates a higher level of output than the one obtained by the previous level of input. At decreasing MPP, each additional unit of input yields an incremental output less than that from the previous input increment.

Law of diminishing returns

The law of diminishing returns applies to many agricultural input-output relationships. It states that when successive units of one input are added to a fixed level of other inputs, a point will be reached when production increase from an additional input unit will decline (Fig. 2). At that point, total physical product (TPP) changes from increasing at an increasing rate to increasing at a decreasing rate. The MPP of diminishing returns may apply to crop production with variable fertilizer or water levels (4).

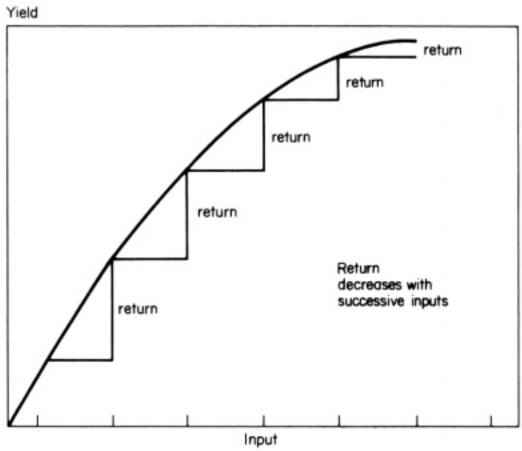
Profit maximization

Profit maximization is the behavioral rule often credited with determining farmers' actions. It says farmers will choose the production alternative that provides highest monetary profit. In developing countries, however, many farmers choose alternatives other than maximum profit; therefore profit maximizing alone will not predict farmer behavior (10). Still, profit maximization is a valuable concept.

Farmers must decide what commodities to produce, how much to produce, and how much of an input to use. For upland rice production, we assume that a farmer has already decided to produce a certain quantity of upland rice. Therefore, the farmer must decide how much of an input to apply for maximum profit. Profit maximization also determines the adoption of new technology.

Profit maximization can be explained negatively. Farmers will not increase inputs to levels that leave them economically worse off. They will apply additional inputs only as long as their economic status improves. Economic well-being will increase only as long as the added cost of another unit of input is less than the revenue generated. Added costs are called marginal costs and added returns are called marginal returns or benefits.

2. The law of diminishing returns.



Marginal analysis compares additional returns with additional costs that result from changes in outputs or inputs. The marginality principle states that, to obtain the highest possible profit, an additional input should be applied only if marginal return is greater than marginal cost. Net return is maximized when extra return equals extra cost.

Enterprise budgeting

Budgets are a simple and widely used technique in economic analysis. They can be prepared for each farm enterprise, which is a single farm commodity, such as upland rice. An enterprise budget allows evaluation of costs and returns of any production process. Comparing relative profitability of a new technology helps show how the farm can be more profitable. In enterprise budgeting, profit is earned if benefits exceed costs. If benefits are less than costs, loss is incurred. The difference between gross returns and variable costs is called the gross margin (return above variable costs). Gross margin measures the contribution of an enterprise to farm profitability (5). In constructing a budget, all production costs and revenue sources must be specified.

Costs. Costs are either variable or fixed. Fixed costs must be paid regardless of output level. They include depreciation, land taxes, and costs of irrigation. Variable costs are specific to a particular enterprise, such as upland rice production, and include wages for plowing, planting, weeding, harvesting and threshing; fertilizer and pesticide costs; and energy costs. Farmers can control or alter variable costs.

The total cost of each input is obtained by multiplying the quantity of inputs used by unit price. In small farm agriculture like upland rice, the real price of an input is not always easy to estimate because market price may deviate from farmers' cost. Generally, the effective price paid for most inputs is higher than the market price because of transport and handling charges. The latter should be included when estimating cost of production. The real price to the farmer is called opportunity price (5). Inputs provided by the farm family, such as labor, should be estimated at prevailing market prices.

Capital cost is the cost of borrowing money for crop production. It includes interest and related expenses such as the cost of negotiating a loan and risk premiums.

Land costs for farming differ. If the cost of farming land is not related to the crop, it is not included in the enterprise budget.

Returns. Several returns are used to compare the profitability of an enterprise.

Gross return is the value of the crop after paying in kind harvesting and rental costs (3).

Return above variable costs (RAVC) is obtained by subtracting total variable costs from gross returns.

Returns to specific factors are estimates of returns to scarce resources such as capital or labor. Most upland rice farmers are relatively poor. Thus, returns over cost of materials such as fertilizers and pesticides are very important. Return to a specific factor is computed as

$$\text{Returns to A} = \frac{\text{gross returns} - \text{cost of all other inputs}}{\text{cost of A}}$$

This can be written as

$$\frac{\text{return above variable costs} + \text{cost of A}}{\text{cost of A}}$$

Economic analysis of new technologies

In a simple crop enterprise, farmers often must decide if new cropping practices or patterns are more profitable than those currently in use. If a new technology is as profitable as or less than the existing one, the farmer will most likely reject it. A new technology should be economically evaluated before (*ex ante* evaluation) or after (*ex post* evaluation) it is released to farmers.

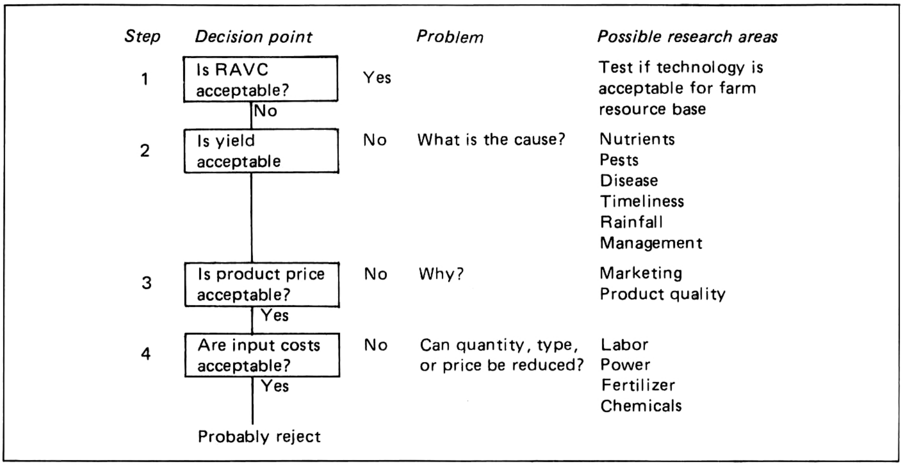
Banta and Jayasuriya (2) used RAVC to compare economic performance of new and dominant technology. For a farmer to adopt new technology, its RAVC must be at least 30% higher than that of the dominant technology. Figure 3 gives a set of decision points for evaluating a new technology. If RAVC is higher than 30%, further tests should be made to judge the technology's acceptability.

In addition to RAVC, Banta and Jayasuriya suggested using marginal benefit to cost ratio (MBCR) to compare the economic performance of new and farmers' technology. MBCR is computed as follows:

$$\text{MBCR} = \frac{\text{Added returns by shifting to new technology (NT) from farmer technology (FT)}}{\text{Additional costs incurred by shifting to NT}}$$

$$\frac{\text{Gross return of NT} - \text{gross return of FT}}{\text{Total variable costs of NT} - \text{total variable costs of FT}}$$

MBCR should be equal to or greater than 2:1 for new technology to be acceptable.



3. Decision analysis tor evaluating a new technology (2).

UPLAND RICE PRODUCTION

Most upland rice farmers maintain few records of inputs used and outputs produced, and published data on the economics of upland rice are scanty. It is. therefore, difficult to generalize the profitability of upland rice production in, different regions.

Labor utilization

Labor is a major input in upland rice production in most of tropical Asia and Africa. It is less important on mechanized farms in Latin America, where machines are used from land preparation through harvest. Family, hired, and exchange labor are used in upland rice production.

Njoku and Karr (9) recognized four sources of labor for upland rice in Sierra Leone:

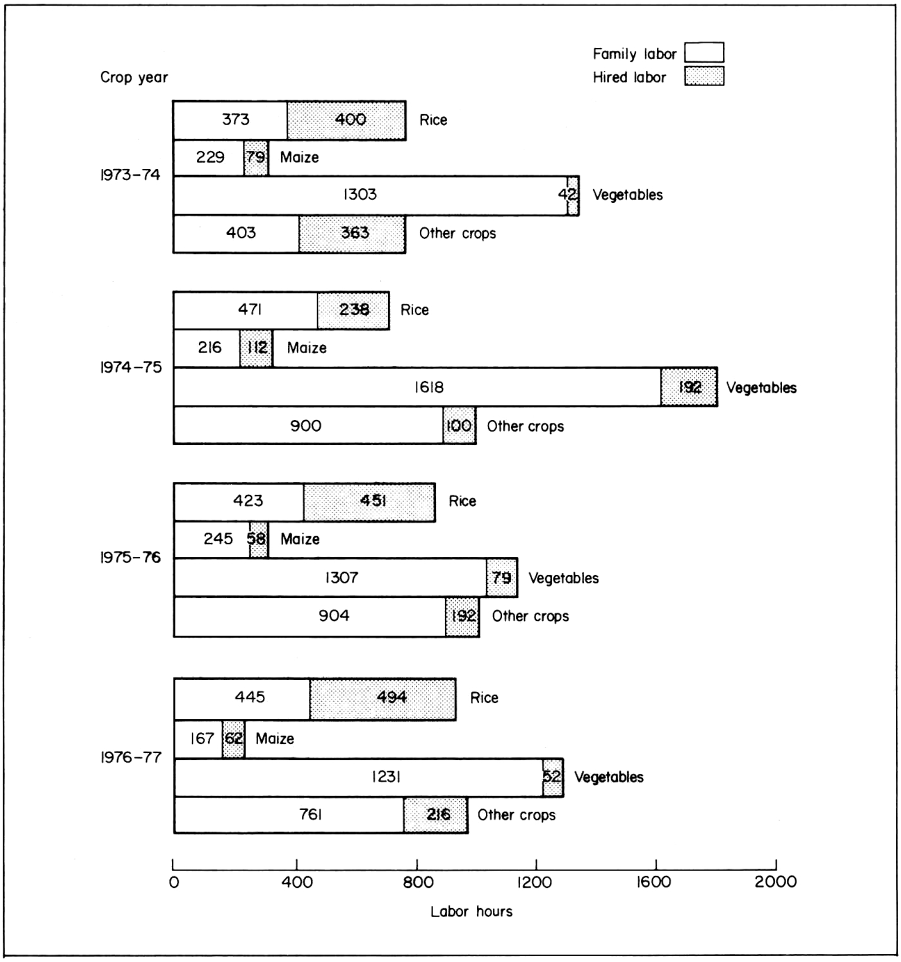
- Household or family labor.
- Communal labor, which is a complex of labor arrangements with varying rewards. It can be reciprocal or nonreciprocal. In reciprocal arrangements. farmers work together to perform specific operations for each other and receive no cash payment. The arrangement may or may not include meals. Farmers generally ask for the help of the others either as a group or as individuals.
- Gang labor, which is a refined form of communal labor. It is generally an association of young people who perform a wide range of farm operations in their communities. Gangs have a hierarchy of officers such as headman, treasurer. and musician. They work for their members by turns and are hired or asked to help by nonmembers.
- Hired labor is paid in cash and/ or kind, and laborers have one or two meals each day. Hired labor may be individual or group.

All four types of labor may be used on one farm at the same time.

Family labor is a major part of total labor used on small farms (5) and is particularly important on small, family-owned, upland rice farms in Asia and Africa. In Cale, Batangas, Philippines, family labor represented 48 to 66% of all labor used in upland rice production in 1973-77 (Fig. 4). Hired labor varied from 34% in 1974-75 to 52% in 1973-74 (12).

Table I shows the amount of hired and communal labor used in upland rice production in Njala, Ngesehun, and Sogbale in Sierra Leone. More hired labor is used for brushing and plowing than for harrowing. Hired labor for weeding ranged from 0 to 21%. In another survey in Sierra Leone, hired labor for upland rice production ranged from 11 to 26% (14).

Harvesting requires the most labor, followed by weeding (1, 12, 14, 15). Labor used for upland rice production in Cale, Batangas, Philippines for 1975-76 and



4. Labor h ha^{-1} by crop and by source, Cale, Batangas, Philippines 1971-77 (12).

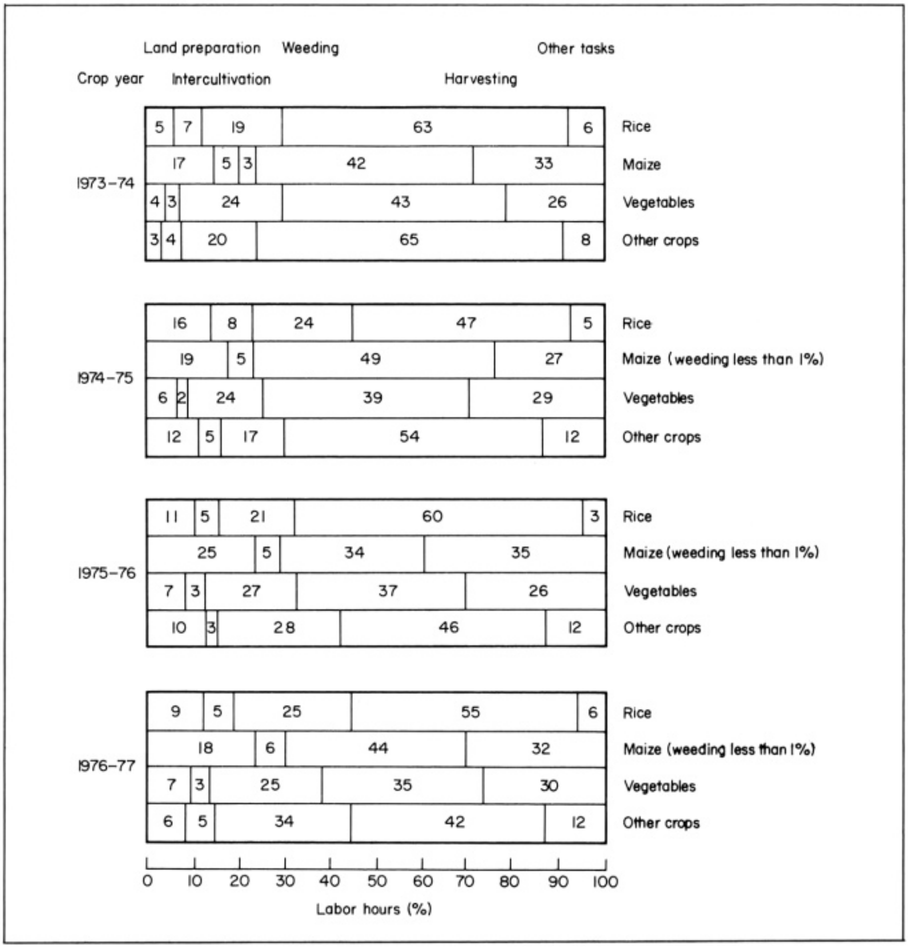
1976-77 is presented in Table 2. Harvesting required 385 to 439 labor h ha^{-1}, and weeding needed 186-244 h (1). Figure 5 shows a distribution of total labor hours for upland rice in the same locale for 1973-77. Harvesting required 47-63% of labor; weeding, 19-25%,; land preparation, 5-16%; intercultivation, 5-7%; and other tasks 3-6% (12).

Table 1. Communal and hired labor used for upland rice farm activities in Sierra Leone, 1979 (9).

Study area, tasks	Farms reporting (no.)	Farms hiring (no.)	Farms using communal labor (no.)
Njala			
Clearing vegetation	32	26	9
Felling	32	22	7
Burning and clearing	32	13	6
Plowing	32	31	3
Harrowing	32	5	6
Weeding	12	6	1
Ngesehun			
Clearing vegetation	38	26	7
Felling	38	17	4
Burning and clearing	38	8	2
Plowing	38	30	1
Harrowing	38	6	3
Weeding	6	0	0
Sogbale			
Clearing vegetation	16	15	1
Felling	16	16	1
Burning and clearing	16	10	0
Plowing	16	15	4
Harrowing	16	1	1
Weeding	7	3	0

Table 2. Labor utilization for upland rice production, Cale, Batangas, Philippines (1).

Farm operation	Labor h ha^{-1}	
	1975-1976	1976-1977
Plowing	61	58
Harrowing	12	9
Furrowing	15	14
Planting	6	4
Harrowing to cover seeds	7	7
Weeding	186	244
Harrowing for cultivation	16	16
Lithao for weed control	28	34
Fertilizer application	5	6
Subtotal	336	392
Harvesting	385	439
Threshing	137	130
Average	858	961

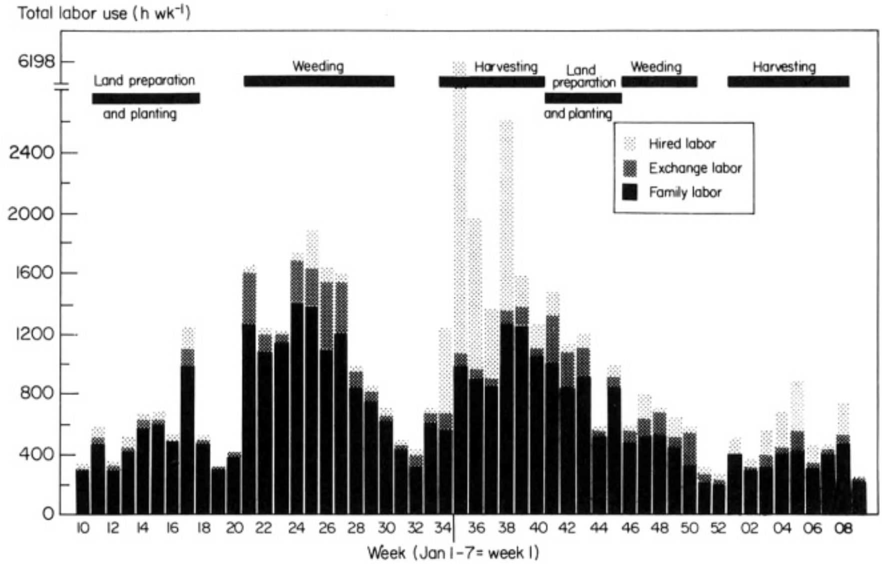


5. Percent of total labor h ha^{-1} for crop operations, Cale, Batangas. Philippines, 1973-77 (12).

In Cale, upland rice generally is not grown as a single crop, but is intercropped or rotated with other upland crops. Price and Barker (11) studied the time distribution of crop labor in 6 upland rice-based cropping patterns. About 44% of the land was double-cropped with rice - maize and 56% was planted to other patterns. There were two land preparation and planting periods, the second of which was most concentrated (Fig. 6). Weeding rice was the second highest labor peak. Harvest also produced a labor peak.

Tautho et al (15) assessed the upland rice productivity of three sets of upland rice farmers in Zamboanga del Sur, Philippines:

- participants in the Ministry of Agriculture and Food multiple cropping production program (MAF-MCPP);
- nonparticipants who grew improved varieties (IV); and
- nonparticipants who grew local varieties (LV).



6. Weekly labor use for major farming operations, 36 farm, Cale, Batangas, Philippines, 1975-76 (7).

An average 110 labor d ha^{-1} was needed to grow upland rice (Table 3). Total labor inputs were significantly higher for program participants (117 d ha^{-1}) and IV growers (106 d) than for LV growers (% d).

Land preparation, weeding, and harvesting required the most labor, each accounting for about 30 d ha^{-1}. Slightly more family labor was used for land preparation. Weeding labor used equal family and hired labor. Most harvesting and postharvest labor was hired. About 60% of all labor was hired: IV program participants hired the most and LV farmers the least.

Labor use for upland rice production in Sierra Leone is summarized in Tables 4 and 5. Production activities include clearing vegetation, felling trees, burning and clearing land, plowing, harrowing, weeding, bird scaring, harvesting, threshing, and winnowing (9). Weeding required the most labor, but harvest data were not included in the study. In another survey, Spencer (14) found that labor requirements for upland rice production in Sierra Leone varied from 156 to 286 labor d ha^{-1}. The most labor was used for harvesting and weeding in some regions, and for pest control and land preparation in others.

Costs and returns

Costs and returns of upland rice production in Cale, Batangas, Philippines, are shown in Table 6 and compared with other crops in Table 7. Averaged over 4 yr, gross return per hectare was $359. Return above variable cost was $211. Hired labor and fertilizers were the dominant cash inputs (12).

Compared to other crops and crop combinations, upland rice had relatively low gross and net returns, being only higher than maize. The return to cash inputs,

Table 3. Labor inputs (d ha^{-1}) for upland rice production in Zamboanga del Sur, Philippines, 1983 wet season (15).

Operation	Labor source	Labor input[a] (d ha^{-1}) Participant Improved variety	Nonparticipant Improved variety	Nonparticipant Local variety	All
Land preparation[b]	Family	20	22	20	21
	Hired	16	13	12	14
	Total	35 a	35 ab	32 b	35
Seeding	Family	5	5	6	5
	Hired	5	4	4	5
	Total	10 a	9 a	10 a	10
Fertilizing	Family	3	3	2	3
	Hired	5	1	1	3
	Total	8 a	4 b	3 c	6
Weeding	Family	12	15	15	14
	Hired	18	13	11	15
	Total	30 a	28 a	26 a	29
Spraying	Family	2	2	-	1
	Hired	-	-	-	-
	Total	2 a	2 a	- b	1
Preharvest	Total	86 a	78 ab	71 b	81
Harvest or postharvest	Family	1	1	2	1
	Hired	30	27	23	27
	Total	31 a	28 ab	25 b	28
Total	Family	43	48	45	45
	Hired	74	58	51	64
	Total	117 a	106 ab	96 b	109
Sample size		80	44	55	179

[a] Row means with the same letter are not significantly different by Duncan's multiple range test at the 5% level. [b] Includes labor of a plowman.

Table 4. Farm labor distribution in Sierra Leone, 1970 (9).

Task, study area	Farms (no.) requiring given days for each activity 2-7 d	7-10 d	11-13 d	14-16 d	Total farms
Clearing vegetation					
Njala	2	22	7	1	32
Ngesehun	0	24	12	2	38
Sogbale	0	10	3	3	16
Total	2	56	22	6	86
% of total	2	65	26	7	100
Felling					
Njala	14	14	1	3	32
Ngesehun	7	27	3	1	38
Sogbale	7	6	1	2	16
Total	28	47	5	6	86
% of total	32	55	6	7	100

Continued on opposite page

Table 4 continued

Task, study area	Farms (no.) requiring given days for each activity				Total farms
	2-7 d	7-10 d	11-13 d	14-16 d	
Burning and clearing					
Njala	13	15	2	2	32
Ngesehun	17	19	2	0	38
Sogbale	7	8	1	0	16
Total	37	42	5	2	36
% of total	43	49	6	2	100
Plowing					
Njala	0	13	17	2	32
Ngesehun	0	24	13	1	38
Sogbale	0	13	3	0	16
Total	0	50	33	3	86
% of total	0	58	38	4	100
Harrowing					
Njala	3	16	9	4	32
Ngesehun	0	16	18	5	38
Sogbale	0	10	4	2	16
Total	3	41	31	11	86
% of total	3	48	36	13	100
	2-16	17-20	21-23	24-27	
Weeding					
Ngala	0	7	4	1	12
Ngesehun	0	3	3	0	6
Sogbale	1	3	1	2	7
Total	1	13	8	3	25
% of total	4	52	32	12	100

Table 5. Number of upland farms, total area, and average labor used per hectare for selected activities, Sierra Leone, 1970 (9).

Task, study area	Farms reporting (no.)	Total area (ha)	Workdays ha^{-1}	
			Average	Range
Njala				
Clearing vegetation	32	35	21	9-35
Felling	32	35	16	7-40
Burning and clearing	32	35	16	7-37
Plowing	32	35	25	17-37
Harrowing	32	35	23	1240
Weeding	11	12	50	47-59
Ngesehun				
Clearing vegetation	38	55	23	17-37
Felling	38	55	18	12-35
Burning and clearing	38	55	16	7-30
Plowing	38	55	24	17-37
Harrowing	38	55	26	17-37
Weeding	6	5	47	44-54
Sogbale				
Clearing vegetation	16	24	23	17-40
Felling	16	24	17	15-40
Burning and clearing	16	24	16	9-27
Plowing	16	24	21	17-32
Harrowing	16	24	25	20-37
Weeding	7	8	47	35-62

Table 6. Costs and returns[a] per hectare for 35 rice farms, Cale, Batangas, Philippines, 1973-77 (12).

Item	Crop year				All years	
	1973-74	1974-75	1975-76	1976-77	Mean	SD
Farms (no.)	33	33	31	29	33	2
Total area (ha)	27.74	27.86	22.06	22.52	100.18	3.19
Mean area planted (ha)	0.84	0.84	0.71	0.78	0.78	0.06
Cash costs ($)						
Material costs						
Pesticides	[b]	-	-	-	[b]	
Fertilizer	18	31	32	38	29	9
Other[c]	-	-	0.14	-	[b]	
Subtotal	18	31	32	38	29	8
Hired labor	74	42	72	79	66	15
Marketing	-	-	[b]	-	[b]	
Total cash costs ($)	92	76	104	117	96	17
Total variable costs ($)[d]	131	126	164	181	148	23
Gross returns ($)	380	234	407	442	359	91
Returns above cash cost ($)[e]	288	158	304	324	264	75
Returns above variable cost ($)[f]	248	108	243	261	211	72
Returns to labor ($)[g]	0.50	0.30	0.40	0.40	0.40	0.0
Returns to cash ($)[h]	1.70	0.88	1.50	1.50	1.40	0.30

[a] Converted at the rate of P7 = $1. [b] Less than P1.00. [c] Includes cost of seeds and other materials. [d] TVC = total cash cost + imputed cost of family labor. [e] RACC = gross return – total cash costs. [f] RAVC = gross return - total variable cost.

[g] $$\text{RTL} = \frac{\text{gross returns - total material cost}}{\text{total labor h}}$$

[h] $$\text{RTC} = \frac{\text{gross return - hired labor cost}}{\text{(total material cost + cost of marketing)}}$$

Table 7. Four-year average economic returns[a] per hectare of various crops on 35 farms in Cale, Batangas, Philippines, 1973-77 (12).

Item[b]	Rice	Maize	Vegetable	Other crops
4 yr $\bar{x}$ area planted (ha)	25.045	22.91	10.92	4.18
			Dollars	
Gross return				
$\bar{X}$	359	245	881	483
SD	91	44	283	94
Return above cash cost (RACC)				
$\bar{X}$	264	182	721	375
SD	75	27	234	72
Return above variable cost (RAVC)				
$\bar{X}$	211	155	553	274
SD	72	24	234	60
Return to labor (RTL)				
$\bar{X}$	0.40	0.66	0.50	0.44
SD	0.08	0.10	0.12	0.06
Return to cash (RTC)				
$\bar{X}$	1.40	0.60	0.85	1.00
SD	0.35	0.17	0.60	0.83

[a] Converted at the rate of P7 = $1. [b] RACC = gross returns - total cash cost; RAVC = gross returns - total variable cost;

$$\text{RTL} \quad \frac{\text{gross returns - total material cost}}{\text{total labor hours}}$$

$$\text{RTC} = \frac{\text{gross returns - hired labor cost}}{\text{(total material cost + cost of marketing)}}$$

however, was highest for rice, averaging \$1.40, which implied that relative to other crops, farmers used fewer cash inputs for rice. Vegetables had the highest gross return, return above cash cost, and net return per hectare (12).

Ramos et al (13) surveyed farm management in major Philippine upland rice growing areas, including southern Tagalog, central Mindanao, western Mindanao, Bicol, and southern Mindanao. Farms were grouped as low, medium, or high yielding. Total costs (TC) of producing upland rice for all sampled provinces averaged \$168 ha^{-1} and gross net returns (GR) averaged \$139 ha^{-1}. Variable costs totaled \$144 ha^{-1}, of which \$60 was cash and \$84 was noncash. Fixed costs were \$25 ha^{-1} (Table 8).

In another upland rice production survey in Zamboanga del Sur, Philippines, Tautho et al(15) found the gross margin of owner operators was higher than that of tenants, and that farmers who grew improved varieties had higher gross margins

Table 8. Costs and return[a] of producing upland rice by yield group, 1981 (13).

Item	Low[b] yield	Medium[c] yield	High[d] yield	All farms
Farms reporting (no.)	93	212	95	400
Av area (ha)	2.26	1.0	1.04	1.30
Yield per hectare (t)	0.47	1.01	2.09	1.01
		Dollars		
Variable costs	84	158	240	144
Cash costs	29	62	119	60
Hired labor	18	38	73	36
Food for laborers	2	5	5	4
Fertilizer	4	10	27	11
Chemicals	0.50	2	6	2
Transport cost	0.10	0.40	0.90	0.35
Seeds	5	6	6	6
Noncash costs	54	96	121	84
Landlord share	5	12	31	13
Harvester's share	7	15	20	13
Seeds	1	5	10	4
Unpaid labor	41	63	59	54
Fixed costs	16	27	38	25
Depreciation	2	4	9	4
Interest on capital	9	17	25	15
Interest on crop loan	2	2	0.30	1.50
Land tax	2	3	3	3
Others	0.20	0.60	1	0.60
Total cost	100	185	278	168
Total returns	60	145	297	139
Return above cash costs	30	83	178	80
Returns above total variable costs[e]	(24)	(13)	57	(4)
Net returns[e]	(41)	(40)	19	(29)
Return cost-ratio[f]	0.59	0.78	1.07	0 83

[a]Converted at the rate of P8.20 = \$1. [b]0.700 t ha^{-1} and below. [c]0.701 to 1.000 t ha^{-1}. [d]1.501 t ha^{-1} and above. [e]Values in parentheses are negative profit.

[f]Return-cost ratio = $\frac{\text{gross returns}}{\text{total cost}}$

than those who grew traditional varieties. On a cash cost basis, gross margin ranged from \$63 to \$190 ha^{-1} (Table 9).

Table 9 further shows that the benefit-cost ratio (return per dollar invested) exceeded 2 for owner-operators, with a maximum of 2.8 for those who grew local varieties. The benefit-cost ratio of tenants was close to or less than 2, which often is regarded as the break-even return on capital invested that is necessary to make new technology attractive to farmers. On a full-cost basis. the benefit-cost ratio was lower than 2, and more so for farmers who grew local varieties.

In Orissa, India, researchers evaluated the benefits of new technology over conventional upland rice farming practices (Table 10) (8). By adopting new

Table 9. Estimated gross margin for 6 upland rice production systems, Zamboanga del Sur, Philippines,[a] 1983 (15).

Item	Tenure status[b]					
	Participants		Nonparticipants			
	Improved variety		Improved variety		Local variety	
	Owner (38)	Tenant (38)	Owner (25)	Tenant (18)	Owner (36)	Tenant (18)
Gross benefits (\$)	336	267	311	227	170	130
Variable costs (\$)	178	190	182	149	100	95
Nonlabor input[c]	109	116	115	77	40	41
Labor inputs	69	74	67	71	61	54
Gross margin (\$/ha)						
Cash cost basis	190 a	111 b	165 a	117 b	109 b	63
Full cost basis	158 a	78 b	129 a	78 b	69 b	35
CV (full cost)	50	85	64	95	87	127
Return per \$ invested						
Cash cost basis	2.31	1.71	2.13	2.06	2.80	0.18
Full cost basis	1.89	1.41	1.71	1.53	1.69	1.37

[a] Numbers in parentheses indicate sample size. [b] Values were converted at the rate of P11 =\$1. Row means with a common letter are not significantly different at 5% level by Duncan's multiple range test. [c] Includes interest on cash costs.

Table 10. Statement of costs and returns ha^{-1a} for rice production with improved versus traditional technology (8).

Item	Improved technology	Farmer technology	Change over farmer technology
Yield (t ha^{-1})			
Grain	4.3	0.9	+ 3.33
Straw	6.0	2.5	+ 3.50
Cost of cultivation ha^{-1} (\$)	160	123	+ 37
Gross return ha^{-1} (\$)	580	136	+444
Net return ha^{-1} (\$)	419	13	+406
Expenditure t^{-1} (\$)	37	129	- 92
Net return per rupee spent (\$)	0.33	0.01	+ 0.32

[a] Converted at the rate of Rs 7.90 = \$1.

Table 11. Management practices, productivity, and costs and return[a] analysis of farmer's direct-seeded rainfed aus rice at Alimganj cropping system research site, Rajshahi district, Bangladesh, 1980 (6).

Item	Local variety		Modern variety[b]			
	Hashikalmi	Dharial	BR1	BR3	BR9	Purbachi
Sample number	6	4	3	2	4	1
Seeding date range	10-17 May	13-17 May	10-1 3 May	10-1 3 May	10-1 7 May	10 May
Av N-P-K rate (kg ha^{-1})	3-19-33	41-17-25	92-19-16	64-21 -32	72-24-27	42-25-0
Hand weeding frequency (range)	24	2-3	3-5	3-5	3-5	2
Farmers (%) who used insecticide	0	0	33	100	50	100
Av field days	89	86	113	138	115	100
Av grain yield (t ha^{-1})	2.3	2.2	2.8	3.2	2.2	2.5
Grain yield (kg $d^{-1} ha^{-1}$)	25.62	25.49	25.19	23.15	19.36	24.77
Grain yield range (t ha^{-1})	1.9-3.0	1.8 -2.8	2.4-3.3	3.0-3.4	2.1 -2.3	-
Av production cost ($ ha^{-1})	146	155	234	218	187	176
Production cost range ($ ha^{-1})	119-217	143-172	187-296	180-257	188-220	-
Av net return ($ ha^{-1})	31 3	256	348	435	268	290
Net return range ($ ha^{-1})	164-403	189-369	291-453	428-442	247-303	-
Benefit-cost ratio	3.14	2.65	2.48	2.99	2.44	2.64

[a]Exchange rate used: Taka 15 = $1. [b]First introduced at the site.

technology, farmers obtained a net profit of \$321.20 (\$1 = 10 rupees) ha^{-1}, compared to conventional technology where the net profit was only \$10.50 ha^{-1}. A 1980 agroeconomic monitoring study at the Bangladesh Rice Research Institute cropping systems research site in Alimganj in Rajshahi District evaluated direct seeded upland rice. Modern BR1, BR3, BR9, and Purbachi were introduced and compared with traditional Hashikalmi and Dharial. Management practices and costs and returns are shown in Table 11. The production cost of modern varieties was 35% higher than that of the local varieties, and the grain yield of modern varieties was 9 to 40% higher. Average net return ranged from \$268 for BR9 to \$435 for BR3. The benefit-cost ratio varied from 2.44 for BR9 to 3.14 for Hashikalmi (6).

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