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FOREWORD

This is the report of the second International Upland Rice Conference, held 4-8 March 1985 in Jakarta, Indonesia. The first one was held in October 1982 at Bouaké, Ivory Coast, to review available information and current research on upland rice improvement. Bouaké participants recommended that future research be directed toward components of the upland rice environment, rather than upland rice in general.

The Upland Rice Intercenter Research Coordinating Committee (URIRCC) was established in 1983 in response to that recommendation. The Committee promotes collaboration among rice research workers on a bilateral, regional, and worldwide scale, and organizes a triennial International Upland Rice Research Conference. Member institutes are the International Center for Tropical Agriculture, Colombia; the International Institute of Tropical Agriculture, Nigeria; the International Rice Research Institute, Philippines; the Tropical Agronomy Research Institute (IRAT), France; the Brazilian Agricultural Research Corporation (EMBRAPA); and the West Africa Rice Development Association, Liberia.

The Jakarta Conference was organized by the URIRCC and the Agency for Agricultural Research and Development of Indonesia. The Conference was divided into four technical sessions: 1) characterization and classification of upland rice growing environments, 2) integrated upland rice farming systems, 3) biological stresses with emphasis on blast disease, and 4) ecological, social, economic, and technical issues of preproduction testing and production. Research priorities and strategies recommended by working groups corresponding to the sessions are an integral part of this book. The book was edited by Frank J. Shideler with the assistance of Ms. Corazon V. Mendoza.

M. S. Swaminathan
Director General

Characterization and classification of upland rice growing environments

PHYSICAL ASPECTS OF UPLAND RICE ENVIRONMENTS (An Introductory Statement)

L. R. OLDEMAN and T. WOODHEAD

The Upland Rice Research Inter-Center Committee, formed in April 1983, and composed of representatives of CIAT, IITA, IRAT, IRRI, and WARDA, decided in 1983-1984 to establish a task force on characterization and classification of upland rice environments, because

> ". . . from papers presented at meetings on upland rice in Brazil, France, the Philippines, and more recently at Bouaké, Ivory Coast, it is clear that upland rice researchers are acutely aware of the great ecological diversity by the general term *upland rice.* The need to define the target area of any work on upland rice is a first necessity, if research is to remove the constraints in that area . . ." (URRIC, 1983).

The range and complexity of upland rice environments are such that varietal improvement and management studies to boost production and enhance stability of the crop's farming systems should be directed toward components of the upland rice environments rather than upland rice itself. Upland rice is cultivated under growing season rainfall ranging from less than 1000 to more than 2000 mm. In many areas the rainy season may be interrupted by a short dry spell, known as a *veranico* in Brazil, that can cause severe drought stress. Landforms for upland rice vary from low lying valley bottoms (with occasional high water tables) to undulating and steep sloping lands with high runoff and lateral water movement. Soils on which upland rice is cultivated range from highly fertile volcanic soils (Ochric Andosols), alluvial soils (Eutric Cambisols), and Vertisols, to highly weathered infertile soils, such as the Acrisols that occupy large upland rice areas in Southeast Asia. Upland rice is grown on deep soils of high water-holding capacity as well as on shallow soils of low water-holding capacity (that may nonetheless have high clay content). In the soils of the *cerrado* region in Brazil, where

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upland rice is a major crop, soils have extremely low CEC values, high P fixation, and high levels of exchangeable Al.

Moreover, although many thin top soils have reasonable fertility under natural vegetation, upland rice yields on those soils often decline drastically after one or two crops. The decline results from combined effects of erosion, rapid depletion of nutrients, and drought stress resulting from shallow rooting.

Development of improved rice varieties and new technologies and their adoption by farmers will be aided if physical aspects of the upland rice-growing environments can be described, synthesized, and inventoried. Such synthesis and classification of upland rice environments are needed to define research priorities, identify homologues for technology transfer, and assist with the analysis and interpretation of upland rice trial networks. However, as was stressed repeatedly during a working group meeting on characterization and classification of upland rice environments in Goiania, Brazil, such classification should not become rigid.

Physical components of upland rice environments, and physical environments, in general, are elements from the three systems: climate, soil, and physiography. They supply and regulate, directly or indirectly, water, energy, and nutrient inputs to the crop. If supply of any input is outside the levels critical to the crop, action should be taken. Farmers have two basic options: they can adjust their cropping system or their choice of variety to the prevailing elements of the physical environment, or they can adjust certain elements of the environment to the needs of the crop. To provide farmers with proper advice, the physical aspects and their interactions should be carefully inventoried and interpreted.

A systems approach, particularly with regard to water availability, is appropriate. Input of water is from the atmosphere (as rainfall), from the soil (as water released from the soil and possibly as a groundwater contribution), and through the influence of the physiography of the terrain (runoff water). Water leaves the system through evapotranspiration, through percolation, and through runoff to lower-lying areas. A dynamic water balance gives information on water availability to the crop during each phase of the growth cycle.

The key variable in such a water balance is rainfall. Fortunately, relatively dense networks of rainfall stations exist and rainfall data are often abundantly available. However, data are generally reported as long-term averages of weekly, 10-d, or (most frequently) monthly totals. Water balances can be calculated using monthly time increments, but they have more applicability if they are calculated using rainfall expected at a specific level of confidence rather than through average monthly totals. Known correlations between average and expected rainfall totals should be exploited. The balance calculations should allow for effects of dry spells during the growing season; the probability of such occurrences might be assessed through Markov model analyses.

In characterizing physical aspects of upland rice environments, consideration should be given to constraints caused by excesses as well as by deficits in water and nutrients. Similarly, limitations set by temperature and irradiance should be assessed. In the tropical highlands and at higher latitude, low temperature leads to lengthening of the phenological stages, and may cause sterility or incomplete exsertion of panicles. Seasonal totals of irradiance may also be too low for maximal production of upland rice since the crop is cultivated during the cloudy rainy season. Moreover, upland rice is often grown under trees (coconuts), so that irradiation is further reduced.

An upland rice environment characterization and classification should deal with the following aspects:

- nutritional constraints (toxicity and deficiency);
- physiographic and soil physical constraints (slope, erodibility, infiltration rate, water release, soil temperature);
- water availability and air temperature suitability for the growing season, and
- irradiance during the growing season.

These physical aspects are to be discussed in subsequent papers of this International Upland Rice Conference. The first session shall address the constraints of adoption of improved technologies for four major upland rice environments in three different continents. Subsequently, presentation will discuss soil nutritional, soil physical, and available water constraints. The session's final paper will review some recent approaches to classifying upland rice environments.

The physical environment has influence also on the weeds, insects, and diseases of upland rice. Germination and growth of weeds, or rice, are affected by soil-water content and potential. Rice blast, the most important and widespread disease in upland rice, is both climate- and soil-related. Session III of this conference is devoted to blast and other biological stresses. Understanding of the effects of the physical environment on blast epidemiology will be fostered if there is collaboration between mycologists and physical environment researchers.

UPLAND RICE ENVIRONMENTS IN INDONESIA AND THE FITNESS OF IMPROVED TECHNOLOGY

A. SYARIFUDDIN K., M. SUDJADI, F. A. BAHAR, and I. G. ISMAIL

Upland rice is grown in rainfed, naturally well-drained soils with bunded or unbunded fields, and without surface water accumulation (5). Nearly all upland rice in Indonesia is grown this way.

Upland rice production is only about 6% of the national total (Table 1) but covers about 14% of the rice lands in Indonesia (Table 2). Estimated yields of upland rice are lower than those of other rice cultivation systems, particularly irrigated paddy rice. Therefore, although the upland rice direct contribution to the national rice economy is of lesser importance, when distribution of population and transportation conditions in Indonesia are considered, upland rice becomes important in some areas. Many remote areas, especially those without irrigation, depend on upland rice supplies. Moreover, many upland transmigration areas (old, new, or upcoming) lack irrigation systems and are in undulating zones with Oxisol and Ultisol soils.

Many modern rice varieties are poorly adapted to upland environments (3). Environmental classifications, as outlined by Garrity (3), are for research design and extrapolation. This paper compiles environmental information about upland rice growing areas in Indonesia and classifies them as proposed by Khush (5).

UPLAND RICE GROWING AREAS IN INDONESIA

Increased population and limited land base has resulted in more permanent cultivation of upland rice. Most underutilized lands have been converted to paddy or planted to perennial crops and only a few areas are continuously planted to upland rice. Shifting cultivation is only used now in remote areas of the outer islands (14, 15). Many shifting cultivation lands have turned to grass (*Imperata cylindrica*) and shrubs. Much of this land is for transmigration use and for planting to food crops, including upland rice commonly grown in intercrop combination with corn and cassava. Some upland rice is also grown on river levees.

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Table 1. Upland rice and total rice production in Indonesia (in thousand tons of dry rice).

Year	Upland rice		Total
	Production	% of total	
1978	1,599	6.2	25,771
1979	1,551	5.9	26,652
1980	1,659	5.6	29,652
1981	1,785	5.4	32,774
1982	1,808	5.4	33,584

Source: (1).

Table 2. Upland rice and total rice harvested areas in Indonesia (in thousand hectares).

Year	Upland rice		Total
	Production	% of total	
1978	1,231	13.8	8,929
1979	1,128	12.8	8,803
1980	1,181	13.1	9,005
1981	1,191	12.7	9,382
1982	1,116	12.4	8,989

Source: (1).

Several types of systems involving upland rice occur in Indonesia (14,15):

1. Shifting cultivation; limited to remote areas of outer islands.
2. Permanent cultivation; as part of upland cropping systems.
3. Permanent cultivation; on river levees, limited.
4. Temporary intercropping; with young perennial trees.

All provinces in Indonesia grow some upland rice (Table 3). In several, nearly a third of the total harvested rice area is upland rice and the crop is an important source of farmer income. Upland rice production, as a rice supplier, has importance in some provinces (Table 4). Upland rice production is high in Lampung, North Sumatra, West Java, and South Sumatra (Table 4). In harvested area, it is important in Lampung, West Kalimantan, South Sumatra, North Sumatra, and East Nusatenggara (Table 3).

Sumatra

Table 5 designating upland rice harvested areas indicates that most is grown in the mountains and associated piedmont and peneplain zones (15). Major soils in these regions are Ultisols and Oxisols (15, 18). These regions also have long rainy seasons (8, 15).

Table 3. Upland rice and total rice harvested area in different provinces of Indonesia, 1982.

Province	Upland rice		Total rice
	Area (ha)	% of total	
Aceh	11,437	4.5	255,645
N. Sumatra	92,050	16.3	566,136
W. Sumatra	12,723	4.2	299,902
Riau	44,457	34.7	128,195
Jambi	18,704	12.1	154,107
S. Sumatra	96,461	26.7	361,827
Bengkulu	25,823	33.8	76,426
Lampung	124,956	41.7	299,763
Jakarta	232	1.6	14,106
W. Java	95,241	5.3	1,797,745
C. Java	39,622	3.0	1,321,263
Yogyakarta	41,675	29.3	142,044
E. Java	70,869	4.8	1,473,560
Bali	4,278	2.5	169,761
W. Nusatenggara	15,229	6.2	245,101
E. Nusatenggara	73,411	55.4	132,560
W. Kalimantan	114,992	38.4	299,783
C. Kalimantan	43,090	36.8	117,094
S. Kalimantan	34,711	11.5	303,133
E. Kalimantan	48,693	53.0	91,944
N. Sulawesi	16,639	21.7	76,799
C. Sulawesi	29,180	29.5	98,986
S. Sulawesi	22,753	4.5	509,283
S. E. Sulawesi	24,444	66.5	36,741
Maluku	13,468	95.6	14,084
Irian Jaya	717	33.9	2,112

Source: (1).

Java

West Java, East Java, and Yogyakarta have relatively large upland rice areas (Table 3). In Yogyakarta, the crop is grown on hilly soils of recent volcanic origin where rainfall is good (13). Some upland rice is also grown on ditch and dike farmland. In the sorjan areas, soils are good and sufficient soil moisture is supplied from rainfall or shallow ground water.

In other parts of Java, upland rice is grown in hilly areas with gentle to steep slopes, with or without terraces, and poor to slightly good soils (16). Rainfall is generally sufficient for upland rice although rainfall is usually less in the eastern areas (16).

Kalimantan

Upland rice occupies about half the rice areas of some provinces in Kalimantan, especially in East Kalimantan (Table 3). Similar to Sumatra, upland rice in Kalimantan was formerly in shifting cultivation, but now it is more permanent as transmigration and resettlement programs have developed.

Table 4. Upland rice and total rice production in different provinces of Indonesia, 1982.

Province	Upland rice		Total rice (t)
	Production (t)	% of total	
Aceh	19,534	2.2	867,446
N. Sumatra	172,778	0.9	1,834,709
W. Sumatra	21,807	1.9	1,131,448
Riau	67,308	22.6	297,469
Jambi	27,981	6.6	426,687
S. Sumatra	155,399	16.0	968,296
Bengkulu	43,228	20.1	214,519
Lampung	208,427	24.3	875,055
Jakarta	395	0.8	49,235
W. Java	175,748	2.4	7,431,497
C. Java	75,841	1.3	5,774,064
Yogyakarta	70,843	12.9	548,984
E. Java	141,015	2.0	7,051,258
Bali	6,567	0.9	734,755
W. Nusatenggara	24,884	2.8	884,273
E. Nusatenggara	96,903	35.1	275,775
W. Kalimantan	158,344	25.0	632,818
C. Kalimantan	58,559	26.3	222,523
S. Kalimantan	55,052	7.4	738,793
E. Kalimantan	75,912	41.0	185,005
N. Sulawesi	24,421	9.4	257,258
C. Sulawesi	40,969	17.2	237,592
S. Sulawesi	34,494	1.9	1,854,466
S. E. Sulawesi	35,322	49.4	71,437
Maluku	12,391	89.3	13,881
Irian Jaya	931	22.0	4,234

Source: (1),

Table 5. Upland rice harvested areas in Sumatra (1000 ha).

Area	Shifting cultivation	Intercropped with young perennials	Permanent cultivation	Total
Western coastal strip	–	2	7	9
Mountain zone	13	75	51	139
Piedmont zone	13	30	80	123
Peneplains	28	53	109	190
Eastern lowlands	1	4	1	6
Western island chain	11	1	–	12
Eastern islands	–	7	1	7
Total	66	172	248	486

Source: (14, 15).

Upland rice area soils of Kalimantan are generally poor (17). Good upland rice is grown in the floodplain which is enriched by flooding nearly every year. Rainfall is sufficient for upland rice (9).

Table 6. Upland rice yield (t/ha) at different locations; provincial average and research plots range.

Location	Provincial[a] average	Research plot[b] range
West Sumatra	1.7	0.2 - 3.7
Riau	1.5	0.4 - 4.7
South Sumatra	1.6	0.3 - 3.8
Lampung	1.7	0.5 - 5.1
West Java	1.8	0.2 - 3.2
Yogyakarta	1.7	1.2 - 5.4
Southeast Sulawesi	1.4	0.5 - 5.2

[a]Source: (1). [b]Sources: (4, 10, 11, 12, 13, 20).

Sulawesi

In terms of area, upland rice in Sulawesi is smaller than in Sumatra, Kalimantan, and Java. However, it occupies 20-60% of the rice area in the three provinces other than South Sulawesi (Table 3). Shifting cultivation has almost disappeared.

Upland rice is grown on undulating areas with generally poor soils (19). Rainfall is sufficient except in some areas of central and Southeast Sulawesi (7).

Bali and Nusatenggara

Upland rice is only important in East Nusatenggara, where it occupies 55% of the rice area (Table 3). It is grown on gentle and relatively steep slopes. Soils are poor (19), but rainfall is sufficient (9).

IMPROVED TECHNOLOGIES AND FITNESS TO INDONESIA

Upland rice yields only about one-third as much as paddy rice, the provincial average ranging from 0.9 t/ha in Maluku to 2.0 t/ha in East Java (1). The actual yield range, however, is much wider while the range on research plots is also large (Table 6). Low yields (0.2-1.2 t/ha) are usual from plots lacking chemical inputs, especially on podzolic soils. Chemical inputs (fertilizers, lime, and pesticides) on podzolic soils result in higher yields (up to 5.2 t/ha).

Low input technologies have been developed for acid soils with low activity clays with upland rice in Indonesia. The first 2 to 3 yr after opening the land, only from 0 to not more than 40 kg/ha of N is needed. Higher N rates usually induce blast and reduce yields. Although many farmers do not use fertilizer on newly opened land, it is recommended that at least 50 kg/ha of triple superphosphate (TSP) be applied in the row with rice seed. Recommendations for continuously cropped lands is 60-90 kg/ha of N (depending on the N status in the soil and rice blast problems) annually along with 50 kg/ha of TSP applied with the seed. As much as 100 kg/ha of TSP is recommended where improved varieties have been identified and

farmers wish to have high input, year-round cropping systems. In all cases crop residues must be returned to the soil. Rates are modest compared to those commonly used for lowland rice.

Many improved management practices for upland rice, such as seeding rates, spacing, fertilizer practices, weeding, tillage, soil ameliorations, have been accepted (4, 10, 13). However, use of the technologies are constrained by blast disease. Yield variations caused by different environmental factors are also confounded by blast.

Data from experiments and farmer fields show that many improved technologies are applicable to upland environments. Farmers who plant upland rice early, and avoid blast disease, often obtain high yields with improved varieties and cultural practices. Preliminary results show that with early planting it is possible to reduce blast infestations. In Sumatra, for example, the recommendation is to plant upland rice before the end of October and use N rates between 60-90 kg/ha to control blast.

Weeds are a major problem for upland rice. Rice varieties which have droopy leaves and are fast growing in the seedling stage are needed so that the ground is shaded faster and weed growth suppressed.

UPLAND RICE ENVIRONMENTAL CLASSIFICATION

The effects of environment on yield have been blurred by biological factors such as blast disease.

Yields are low and data to support classification of upland rice environments are insufficient. However, to satisfy the first objective of classification (3), the system proposed by Khush (5) is sufficient.

The relative importance of the different classification factors for Indonesia are as follows:

1. Unfavorable upland with long growing season (LU). This class covers most upland rice areas in Sumatra, Java, Kalimantan, Sulawesi, Maluku, and Irian Jaya.
2. Favorable upland with short growing season (SF). This class covers East Nusatenggara and parts of Java and Sulawesi.
3. Favorable upland with long growing season (LF). This class is limited to small areas of Java, Sulawesi, and Sumatra.
4. Unfavorable upland with short growing season (SU). This class is also limited in parts of Southeast Sulawesi, East Nusatenggara, and East Kalimantan.

This classification needs further verification and development of detailed subclassifications. The length of the rainy season (in excess of 3 mo) is not so important. The variability of the rainfall within that rainy period is more important. Furthermore, the favorableness of the land is more dependent upon the responsiveness of the land to management (for example, fertilizer, green manure, soil conservation) than to inherent soil fertility alone.

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UPLAND RICE ENVIRONMENTS IN BRAZIL AND THE FITNESS OF IMPROVED TECHNOLOGIES

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Upland rice represents up to 70% of Brazil's total rice production, which covers about 5 million ha. The average yields are low (1.2 t/ha) and fluctuate highly from year to year.

Although drought is mainly responsible for the unstable and low yields, the soils' low natural fertility and water-holding capacity, diseases, insects, and weeds are other important constraints. In the midwest region where upland rice is mainly concentrated, rice is grown for 1 or 2 yr after clearing of the *cerrado* vegetation; then it is replaced by pasture. In general, rice is planted in extensive areas with low input levels. The soil is not adequately prepared, limed, or fertilized.

Objectives of this paper are to: 1) characterize environments in which upland rice is grown; 2) develop a preliminary agroclimatic classification; and 3) show how use of environmental knowledge can help generate technologies.

UPLAND RICE ENVIRONMENTS

Physical environment

Soils. The most important groups of soils in states where upland rice is grown are: Yellow-Red Podzol (YRP), Latossolo Roxo (LR), Dark-Red Latosol (DRL), Yellow-Red Latosol (YRL), and Quartz Psamments (QP). According to a survey of the soils of Brazil (5) these soils cover between 40 and 90% of the area of those states (Table 1).

The analysis of the main chemical properties of the DRL, YRL, and YRP, which are the most important types of soils in which upland rice is grown, indicates generally that natural fertility is low and decreases drastically with depth. This is the principal reason that root growth is confined to the superficial soil layers where the organic matter is relatively higher. All these soils have extremely low levels of available P and rice and other crops can grow only when phosphate fertilizers are applied.

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Table 1. Estimated area and percentage of the main groups of soils[a] in the most important upland rim-producing states of Brazil.[b]

State	Estimated area (million ha) of								
	TRE	PBA	YRP	LR	DRL	RL	YRL	YL	QP
Maranhao			6.2 (10%)				7.2 (22%)	4.3 (13%)	4.9 (15%)
Goiås			8.4 (13%)	3.9 (6%)		11.0 (17%)	16.2 (25%)		5.2 (8%)
Mato Grosso		4.4 (5%)	9.7 (11%)		7.9 (9%)		13.2 (15%)	25.5 (29%)	8.8 (10%)
Mato G. do SuI			2.1 (6%)	3.9 (11%)	9.8 (28%)				8.4 (24%)
Rondonia			7.3 (30%)				4.4 (18%)	4.6 (19%)	1.7 (7%)
Minas Gerais			8.8 (15%)	2.3 (4%)	14.1 (24%)		17.6 (30%)	2.3 (4%)	2.9 (5%)
Sao Paulo	0.7 (3%)		8.2 (33%)	3.5 (14%)		5.9 (24%)	3.2 (13%)		1.2 (5%)
Parana	3.4 (17%)		2.4 (12%)	3.0 (15%)		2.8 (14%)			

[a] TRE = Terra roxa estruturada, PEA = Podzol Brunno Amarelo, YRP = Yellow-Red Podzol, LR = Latossolo Roxo, DRL = Dark-Red Latosol, RL = Red Latosol, YRL = Yellow-Red Latosol, YL = Yellow Latosol, QP = Quartz Psamments.
[b] Source: (5). Area estimated planimetrically from the soil maps.

Table 2. Chemical and physical properties of a Yellow-Red Podzol profile.[a]

Horizon	Depth (cm)	Texture (%)			pH		Exchangeable cation (meq/100 g)				ECEC[b]
		Sand	Silt	Clay	H_2O	KCl	Ca	Mg	K	Al	
Ap	0 - 14	64	16	20	5.7	4.4	2.6	0.4	0.18	0.0	3.2
A_2	14 - 30	53	15	22	5.0	3.7	1.0	0.1	0.03	0.4	1.5
II B_{21t}	30 - 45	43	13	44	5.1	3.8	1.3	0.2	0.04	0.7	2.2
II B_{22t}	45 - 88	36	21	43	5.3	3.8	1.0	0.5	0.02	1.0	2.5
II B_{3t}	88 - 108	40	25	35	5.1	3.5	1.0	0.2	0.02	1.7	2.9
II C_1	108 - 130	42	27	31	5.1	3.4	0.8	0.3	0.03	2.4	3.5
II C_2	130 - 147	44	32	24	5.2	3.5	0.6	0.4	0.04	2.3	3.3
II C_3	147 - 190	48	34	18	5.2	3.3	0.8		0.03	4.1	4.9

[a] Source: (6). [b] Effective cation exchange capacity: SCa, Mg, K, AI.

An analysis of YRP (Table 2) indicates that even at the Ap horizon, rich in organic matter, the level of exchangeable cations is low. Also, the effective cation exchange capacity (ECEC) is quite low and, consequently, the saturation with Al^{3-} represents a considerable percentage of the exchange complex, even though the level of the exchangeable Al^{3+} is not high. Except in YRL, whose concentration of exchangeable Al^{3+} on the superficial horizons (2.0 meq/100 g) can be considered high, the lack of exchangeable

cations, as in the other soils, makes the A1 saturation high. In these soils, nutrient deficiency, rather than high exchangeable Al^{3+}, seems to be the main constraint to root growth. The mineral and chemical characteristics, excessive drainage, and extremely low water-holding capacity of the QP constitute serious limitations to agriculture. These soils should be kept in their natural condition by avoiding deforestation.

Water availability. The estimated water availability (in millimeters of water per centimeter of soil) for the main groups of soils are: YL and QP = 0.6 mm/cm, LR = 0.9 mm/cm, YRP = 0.95 mm/cm, YRL = 1.01 mm/cm, and DRL = 1.02 mm/cm.

According to USDA classification (17), the YL and the QP are classified as soils with low water availability (<6 mm/cm) and the remaining YRL, DRL, PL, and YRL are considered as having medium water availability (0.6-1.2 mm/cm). Generally, in most of cerrado soils, two-thirds or more of the available water is retained between 0.1 and 1 bar, independently of their clay content (14).

Soil management. Despite low natural fertility of Brazilian soils, it has been shown that, except in QP, an upland rice yield of 4-5 t/ha can be obtained through adequate soil management.

The main objective of soil management is to promote deeper root growth by eliminating the Al^{3+} and other toxic elements and by increasing the fertility of the subsoil. It can be accomplished either by application of lime and fertilizers or by deep plowing or increasing the movement of the Ca, Mg, and other nutrients to deeper layers of the soil. Calcium moves faster when applied as $CaCl_2$ or $CaSO_4$ than when used as $CaCO_3$ (3). However, nutrients with low mobility such as phosphates, can be incorporated only through deep plowing. Deep plowing can also promote a deeper root system, helping to assure higher yields in upland rice (16).

Classification of soils as favorable and unfavorable for rice cultivation should be based on natural fertility levels as well as on management practices.

Climate. Despite the fact that temperature, solar radiation, and other meteorological factors can be constraints to upland rice production, we will discuss only aspects related to rainfall and simulated water balance of the crop.

Rainfall. In Brazil, rainfall is the most important meteorological factor for upland rice and drought is a problem (4). Drought causes great yield decreases, especially if it coincides with the reproductive stage of the crop because of these factors: 1) low to medium water-holding capacity of the cerrado soils, 2) shallow root system, and 3) high evapotranspiration.

Water balance for upland rice. Most studies of agroclimatic zonation for upland rice in Brazil use the monthly water balance of Thornthwaite and Mather (1,11). The method, despite showing interesting differences among regions, does not permit adequate interpretation of water stress caused by dry spells. For this reason, the agrometeorological research program at Centro Nacional de Pesquisa de Arroz e Feijao (CNPAF) evaluated results

of the water balance for 80 localities of Brazil and established a preliminary agroclimatic classification.

Characteristics of the model. The model developed by Forest and Kalms (8) was used in the study. It calculates, for a 5-d period, an index of the plant water needs expressed by the ratio ETr/ETm (real evapotranspiration/ maximum evapotranspiration). It also estimates drainage and irrigation needs.

Real evapotranspiration is estimated by Eagleman's equation (2) adapted by Franquin and Forest (9), considering the climatic demand of water (ETm) and water availability in the soil. ETm is obtained by multiplying potential evapotranspiration (ETp) by the crop coefficient (Kc), appropriate for each phenological phase of the crop. The model considers the maximum amount of available water in the soil that can be used by the root system. This parameter is designated by "Reserve Utile" (RU). Greater details of the model may be obtained in the publications of Forest (7) and Forest and Kalms (8).

Data used and simulations executed. Daily rainfall data for periods greater than 20 yr were used for most locations. These data were checked, using the regional vector methodology (12). Potential evapotranspiration and crop coefficient data were those of Hargreaves et a1 (10) and Kalms (13), respectively.

Three hypothetical levels of RU were established: 30 mm represented low, 50 mm medium, and 90 mm high level of available water in the soil that can be extracted by a root system.

In general, upland rice has the greatest concentration of roots, and consequently, the greatest uptake of water and nutrients, in the superficial layers (20-30 cm) of the soil (15). Assuming a water availability of 1 mm/cm soil, the RU would correspond to 20 or 30 mm. The 30-mm RU was used. On the other hand, results by F. N. Reyniers at CNPAF/EMBRAPA (pers. comm.) has shown that in well-prepared, adequately limed, and fertilized soils, roots can extract water at depths of 1 m or more during a dry spell. The 90-mm RU was selected to represent the maximum water availability to the crop. The 50-mm RU was considered an intermediate level.

During the cycle, three steps were followed: 1) simulation of the water balance to choose the best planting date, 2) simulation with three levels of RU for the best planting date, and 3) frequential analysis of the ETr/ETm values. In all simulations a short-cycle (110 d) variety was used.

Preliminary classification. Using the results of the water balance, a preliminary agroclimatic classification was developed considering the frequential analysis (8/10 yr) of the ratio ETr/ETm during the cycle.

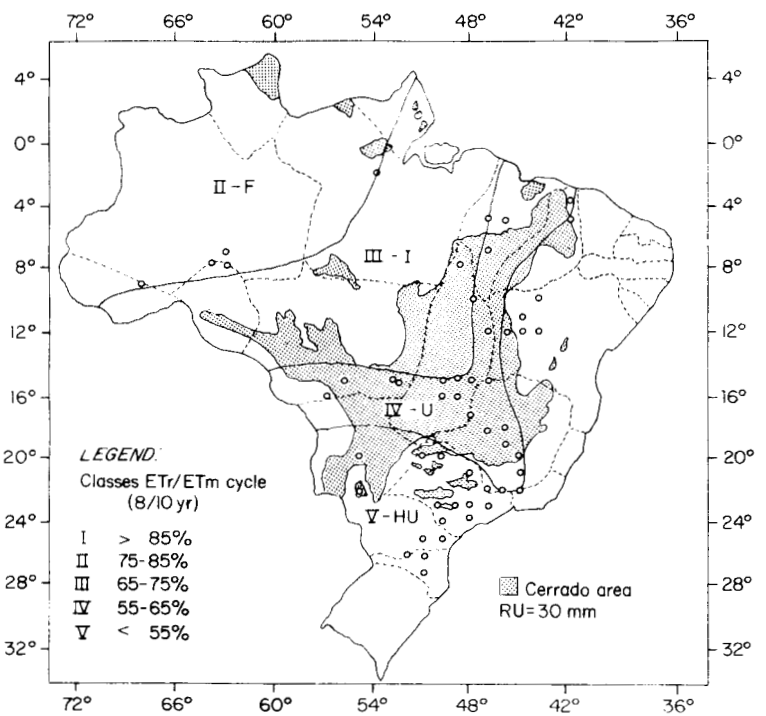
Five classes were established: 1) highly favorable – HF (ETr/ETm > 85%); 2) favorable – F (ETr/ETm > 75 to 85%); 3) intermediate – I (ETr/ETm > 65 to 75%); 4) unfavorable – U (ETr/ETm > 55 to 65%); and, 5) highly unfavorable – HU (ETr/ETm < 55%).

These classes represent situations in which the risk due to drought varies from very low (highly favorable) to very high (highly unfavorable).

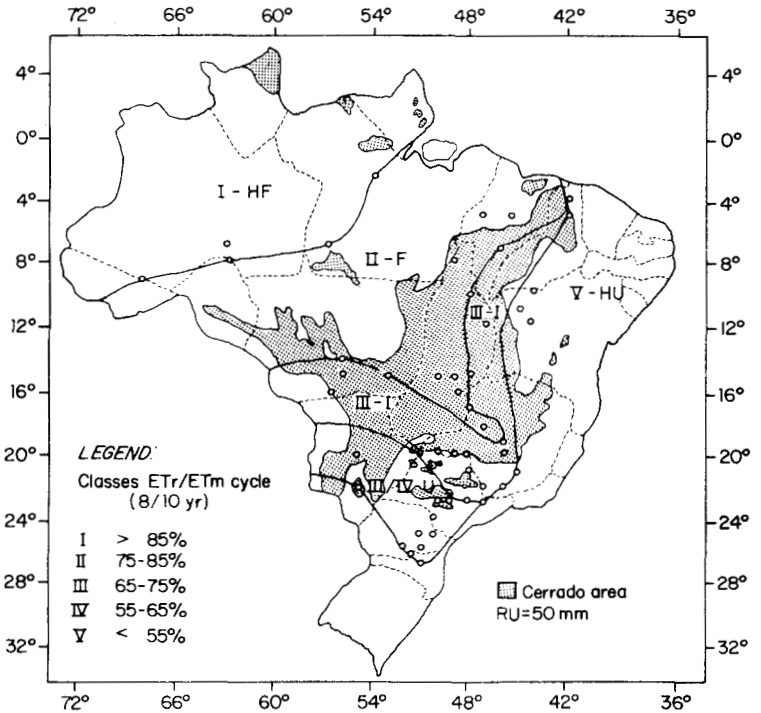
Results of this classification, shown in Figures 1, 2, and 3, point to the great influence of RU value.

Considering an intermediate level of KU (50 mm), a greater part of the northern region is classified as highly favorable (Fig. 2). The favorable region includes practically all of Goiás state (except its southern and northeastern areas), the central area of Minas Gerais, north of Mato Grosso, all of the state of Maranhão (excepting the southeastern part) and the larger part of Pará and Rondõnia. The intermediate class involves the south and northeast of Goiás, south of Mato Grosso, north of Mato Grosso do Sul, the south and north of Minas Gerais, north of São Paulo, west of Bahia, and Piaui. Areas located in the south of Mato Grosso do Sul, south and southeast of São Paulo, Paraná and Santa Catarina belong to a class which can be considered either as intermediate or unfavorable. The remaining locations of the northeast, represented by the three stations of Bahia (Fig. 2), are considered highly unfavorable.

Using the 30-mm (Fig. 1) and 90-mm (Fig. 3) RU values instead of 50 mm, areas in each class change considerably. The greatest part of the cerrado area would be considered intermediate or unfavorable if the 30-mm RU value is used. On the other hand, with RU of 90 mm a greater part of this area would be classified as favorable or highly favorable.



1. Preliminary agroclimatic classification for upland rice in Brazil using a short-cycle (110 d) variety and the 30-mm RU.



2. Preliminary agroclimatic classification for upland rice in Brazil using a short-cycle (110 d) variety and the 50-mm RU.

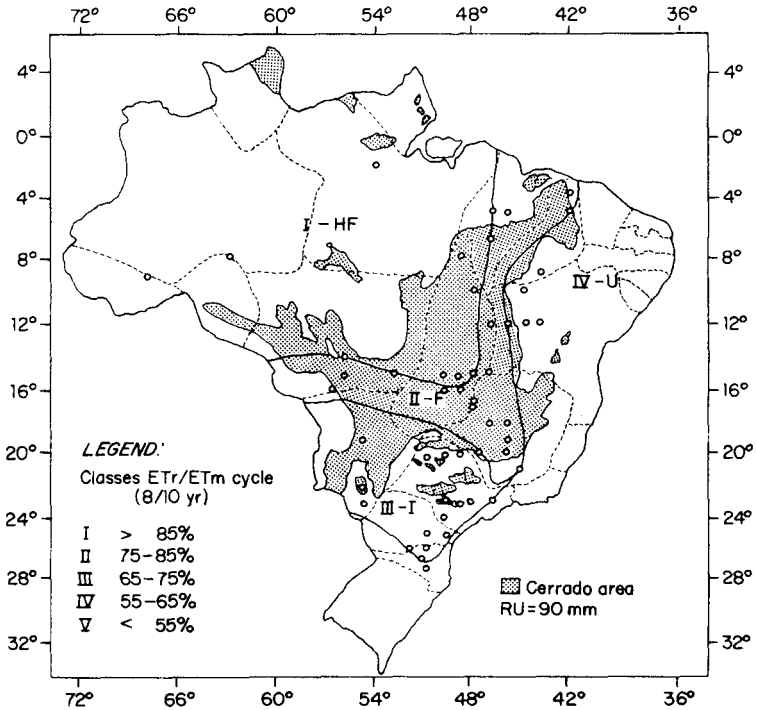
This classification based on hypothetical RU values, although preliminary, may help orient research by characterizing the relative importance of some parameters of the environment on crop performance. Results clearly show that one way to reduce the risk of drought stress in the northeast, south, and southeast regions, and in some areas of the midwest region, would be through increase of RU by soil or plant management. In northern regions, the emphasis should be on aspects other than drought. It is emphasized that, despite the northern region's classification as favorable or highly favorable, deforestation should be avoided in areas considered inadequate for annual crops.

This classification can be improved by determining the real RU values in different regions of the country.

Biological environment

Diseases, insects, and weeds constitute the main biological stresses of upland rice. In this paper, only problems of the midwest region are reported.

Blast (*Pyricularia oryzae*), the principal rice disease, is responsible for serious losses in the states of Goiás and Mato Grosso do Sul and in the



3. Preliminary agroclimatic classification for upland rice in Brazil using a short-cycle (110 d) variety and the 90-mm RU.

cerrado area of Mato Grosso. In the northern part of Mato Grosso, where rainfall is more abundant and night temperatures are high, the main problems are glume blight (*Phoma sorghina*), leaf scald (*Rhynchosporium oryzae*), and grain infection caused by *Helminthosporium oryzae.*

Several species of insects cause yield losses in upland rice. The incidence of *Syntermes* spp. is higher in deep and well-drained soils with low humidity, and previously planted with rice, sugarcane, or pasture grasses. *Elasmopalpus lignosellus* are more damaging in dry years, mainly in light-textured soils. In years of abundant rainfall (40 or more continuous rainy days), the high incidence of *Deois flavopicta* results in significant losses. Its natural habitat is pasture and it often migrates to rice.

In newly opened areas, weeds are not a serious problem for upland rice. However, after the second year they increase and cause losses of 50% or more, depending on rainfall distribution. The most important weed species in the midwest region are *Digitaria sanguinalis, Cenchrus echinatus, Cynodon dactylon,* and *Brachiaria plantaginea* (grasses); and *Acanthospermum australe, Ageratum conyzoides, Acanthospermum hyspidum, Amaranthus spinosus, Bidens pilosa, Commelina* sp., and *Sida* spp. (broad leaves).

SUITABILITY OF IMPROVED TECHNOLOGIES

Knowledge of distinct environments can help develop research guidelines to generate appropriate technologies. The changing research priorities of the Brazilian Upland Rice Breeding Program are cited as a typical example.

Until a few years ago, research was directed at breeding varieties adapted to areas with erratic rainfall distribution. Drought resistance was the main research objective. Significant progress has been made with traditional germplasm. With the upland rice shifting toward the north where rainfall is more plentiful, existing varieties were unsuitable because they lodged severely. Thus, current breeding objectives have been altered to obtain nonlodging, high-yielding, and medium-statured varieties.

Table 3 shows the performance of five upland rice varieties at two fertility levels in regions with distinct rainfall regimes (favorable and unfavorable).

The variety GA 3383 has intermediate height and moderate tillering capacity. The others, except IAC 164, which has less decumbent leaves, have similar characteristics as the traditional upland rice varieties. In unfavorable localities most varieties, including GA 3383, failed to lodge even in fertile soils. On the other hand, where the rainfall was favorable, despite increased height, grain production was not higher on the fertile soil than on the infertile soil. However, GA 3383 yielded higher in fertile soils of the favorable region, probably because of lower lodging and better use of solar energy as a function of its ideotype. The variety IAC 164 also was fairly resistant to lodging.

The results suggest the need for developing plant types suitable for distinct environments.

In the current breeding program, the germplasm is being evaluated under different environmental conditions. In 1984, four varieties — CNA 108,

Table 3. Production, plant height, and lodging scores of 5 upland rice varieties at 2 levels of soil fertility in regions with favorable and unfavorable rainfall.

	Infertile soil			Fertile soil		
	Production (kg/ha)	Ht (cm)	Lodging (1-9)	Production (kg/ha)	Ht (cm)	Lodging (1-9)
Unfavorable region[a]						
GA 3383	21 35	83	1.3	4042	94	1.5
CNA 791059	2064	100	1.2	4392	120	1.2
IAPAR 9	21 32	103	1.5	4360	117	1.0
IAC 164	21 12	105	1.0	4654	122	1.5
IAC 47	2062	106	1.2	3785	123	2.0
Favorable region[b]						
GA 3383	2059	104	1.0	4296	112	1.4
CNA 791059	1935	131	3.0	3160	139	3.5
IAPAR 9	2630	130	3.0	3451	136	3.9
IAC 164	2426	130	1.0	3806	138	1.2
IAC 47	2216	138	3.0	3260	140	3.7

[a]No. of observations: 13 for infertile soil, 12 for fertile. [b]No. of observations: 15 for infertile soil, 17 for fertile.

CNA 791048, CNA 104, and GA 3383 — were released. These varieties should contribute to increasing yield and yield stability of upland rice in the next few years.

CONCLUSIONS

Drought is the most limiting factor in upland rice production in Brazil. Low natural fertility and water-holding capacity of the soils plus low level of inputs by farmers in most rice-growing areas, contribute to low average grain yields.

The preliminary agroclimatic classification suggests that the percentage of area considered unfavorable can be greatly decreased if the amount of water extracted by the root system of the crop is improved. Soil management may be effective in promoting deeper root growth either by removing the soil compaction (deep plowing) or by increasing the fertility of deeper layers of the soil. However, it involves major changes in the traditional system used by farmers.

Biological constraints caused by diseases (mainly blast), insects, and weeds can also be a serious problem to upland rice.

Knowledge of the physical and biological environments is useful for generating appropriate technologies for distinct environments. Therefore, studies to better understand influences of physical and biological factors on upland rice yields should be encouraged.

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UPLAND RICE ENVIRONMENTS IN INDIA AND FITNESS OF IMPROVED TECHNOLOGIES

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About 6 million ha are in upland rice out of a total 39 million ha of rice area in India. Average upland rice yield is only 0.6 t/ha. Recent efforts indicate the yield can be improved two- to threefold by adopting latest production technologies. Some integrated management practices to improve upland rice production include raising suitable short-duration varieties, row seeding, controlling weeds by the stale seedbed technique, timely and split application of nitrogen (N), intercropping with an appropriate pulse crop such as mung or red gram, moisture conservation for the succeeding crop by harvesting early rice before receding monsoon, opening the land to receive moisture, and seeding a legume/oil seed crop in rabi season.

About 143 million ha of cultivable land in India include 108 million ha under rainfed agriculture, such as dry lands without irrigation resources constituting about 70% of arable land. Rice, India's main cereal crop, is cultivated on 39 million ha with a total production of 59 million of clean rice. Upland rice is grown on about 6.15 million ha which produce 4.0 million.

Upland rice (dryland rice) refers to rice grown on level or sloping fields that may or may not be bunded. Rice fields are invariably plowed to open in summer, then are leveled and prepared for seeding under dry conditions or with moist soil. Areas under upland rice in India are indicated in Table 1.

UPLAND RICE ENVIRONMENT

Upland rice in India usually refers to early-maturing rice (80-110 d duration) raised during kharif (wet) season under rainfed conditions in the high lands. Fields may or may not be bunded. Because of topography and high porosity, soils do not impound rainwater even for short periods of 2-3 d. Upland rice is also called autumn rice because the crop is direct seeded under dry conditions in May-June and remains in the field until

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harvest in September-early October. Upland rice has different names in different parts of the country: *ahu* in Assam, *aus* in West Bengal, *beali* in Orissa, *kuari* in eastern Uttar Pradesh, *gora* in Bihar, and *modan* in Kerala.

Depending on total rainfall, the uplands are broadly divided into 3 categories: 1) high rainfall areas (1100-2000 mm), 2) moderate rainfall areas (800-1100 mm) (Fig. 1), and 3) hilly terrain or *jhum* land with shifting cultivation (9). The northeastern upland areas, parrs of West Bengal, Orissa, and Kerala make up most of the first category while the remainder is in the second category (portions of Uttar Pradesh, West Madhya Pradesh, Gujarat, and most of the areas lying east of western ghats). The *jhum* is an ancient and unproductive system, mostly in hilly terrains in the northeastern region of the country. Rice yields in the first group are low because of soil nutrient problems and short periods of moisture stress. In the second group, periodical moisture stress ranging from 3 to 10 d caused by erratic rainfall or early cessation of monsoon becomes a major limiting factor for optimizing yields.

Nutrient status

Nutritional status of upland soils in India have been reviewed by Patnaik and Nanda (10). Nutritional problems adversely affecting rice growth and yield are:

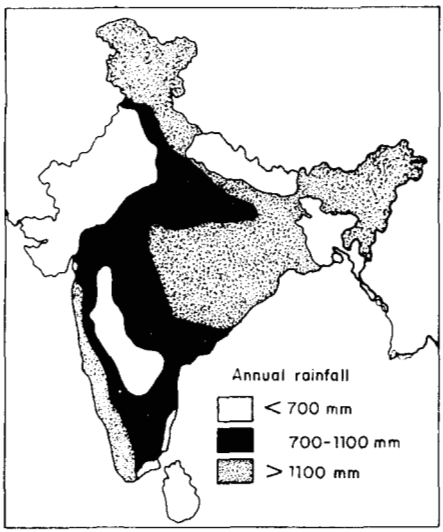
- low native fertility and availability of nitrogen;
- iron deficiency because of highly oxidized soil that becomes severe in soils of neutral and alkaline pH and thereby causes iron chlorosis as in the Deccan plateau;
- phosporus deficiency resulting from high fixiation particularly in acid soils of hilly terrains;
- silica deficiency, which adversely affects protection against disease and insect pests; and
- aluminum (AI) and manganese (Mn) toxicity in strongly acidic soils.

Moisture status

Moisture for sustained plant growth depends on rainfall distribution and

Table 1. Area under rainfed upland rice in different states of India.

State	Area (million ha)
Andhra Pradesh	0.21
Assam	0.54
Bihar	0.51
Kerala	0.03
Madhya Pradesh	0.84
Maharashtra	0.50
Orissa	0.85
Tamil Nadu	0.18
Uttar Pradesh	1.65
West Bengal	0.84
Total	6.15



1. Drought-prone rice areas (700-1,100 mm annual rainfall) in India (2).

duration. Daily rainfall is actually more critical than monthly or annual rainfall. High variability of rainfall distribution is indicated by the high coefficient of variation (60-100%) in most of the country with the exception of west coast, northeast region, and Assam (8). More than 75% of total rainfall occurs during June-September. Onset of the monsoon and its cessation varies (2). The length of rainy season in different regions of India is indicated below.

Region	*Length of rainy season*
Northeastern region	125
Eastern region	120
Southern region	130
North and Western region	85-90

Analysis of rainfall data over an 80-yr period shows that during July-August (which covers the tillering and reproductive phases of upland rice), duration of breaks in rainfall varied from 3 to 21 d (Table 2) with an average of 3.8 d in July and 4.5 d in August. However, breaks of 10 continuous days and longer are only 10% of the total in July and August, hence varieties tolerant of 10-d drought spells may be adequate for most drought-prone uplands.

IMPROVED PRODUCTION PRACTICES

Improved technologies for upland rice have been studied far less than those for lowland rice. However, recently evolved management practices helped increase upland rice yield 2-3 t/ha compared to normal yield of less than 1.0 t/ha (3).

Table 2. Number of breaks in monsoon rain in 80 yr in India (2).

Duration (d)	Breaks (no.)		
	Jul	Aug	Jul-Aug
3–4	28	25	2
5–6	10	12	–
7–8	8	9	1
9–10	3	4	–
11–12	2	3	1
13–16	1	1	–
17–21	1	1	1
Total	53	55	5

Varietal choice

An approach for successful upland rice production would be to select a variety with a life span well within the monsoon duration. Generally, varieties for uplands should mature in 80-100 d for ripening by the time monsoon recedes at the end of September. Built-in tolerance for drought spells is essential in such varieties (6,7). Among cultivars recommended for upland, Akashi and Rasi in Andhra Pradesh and Karnataka, Kiran in Bihar, Annapurna and MW 10 in Orissa, Sattari in Madhya Pradesh, and Saket 4 in Uttar Pradesh have gained popularity even in drought-prone areas.

AGRONOMIC PRACTICES

Sowing time

Sowing is generally decided by the onset of monsoon. More specifically where premonsoon rains are adequate for land preparation, direct seeding of upland rice in early June as soon as cumulative rainfall reaches 55-60 mm is desirable to ensure uniform and adequate plant population (14). Seeding between 13 and 23 June in eastern Orissa and in the first week of July in Varanasi are advantageous to yield.

Seeding practice

Seeds are broadcast on dry or moist soil and a ladder is dragged to cover the seeds with soil. Sowing seeds behind the plow is also practiced by some farmers. Drilling in rows 20 cm apart facilitates interculture. Sowing seeds with well-rotted cowdung is superior to sowing with farmyard manure and helps retain moisture better even with scanty rainfall soon after sowing.

Sowing seeds treated with chemicals such as Na_2HPO_4 (358 ppm for 6 h and drying back to normal moisture) ensures uniform germination and seedling stand even under longer dry spells soon after germination. A minimum seed density of viable 200 seeds/m^2 (about 60 kg seed/ha) was found beneficial to ensure at least 300 panicles/m^2 (14). A seeding rate up to 100 kg/ha is considered useful in certain agroclimatic conditions in Uttar Pradesh (1).

Weed management

Severe weed infestation is a major constraint which causes up to 90% yield loss (12). Grain yield loss from unchecked weed growth was more (71%) in a short cultivar (CR 222-MW-10, 80 cm height), than in a semitall (CR 237-1, 120 cm height) cultivar (50%).

Generally, hand weeding is done if seed has been planted in the tradtional broadcast method. However, with the introduction of row sowing, mechanical weeding with simple hand hoe followed by hand weeding inside rows is possible. With the advent of chemical weed control, effective postemergence herbicides have been recommended. However, the major constraint for large-scale adoption of chemical weed control is its prohibitive cost for the small marginal farmer. Stale seedbed preparation has been found more effective and economical in partially eliminating weeds (Table 3).

The stale seedbed practice consists of repeated plowing with premonsoon showers, leveling, allowing weeds to emerge after the first soaking rain in late May or early June, smothering the germinated weeds 2 wk later by shallow plowing, followed by leveling and row sowing of paddy seed with adequate moisture. Applying preemergence herbicide such as butachlor or thiobencarb even at half to a third of the recommended dose (1.0-1.5 kg ai/ha) 6-7 d after sowing helps eradicate subsequent weeds (Table 3). Thus, herbicide use can be minimized by using the stale seedbed technique.

Fertilizer management

In the traditional broadcasting seed method, practically no fertilizer is applied because farmers fear that the nutrients will be used by the weeds instead of being available to the rice crop. With the introduction of row sowing and the use of mechanical or chemical weed control methods, applying N - 50% of total incorporated into the soil 3 wk after sowing (after thorough weeding) and the remainder in 2 splits, i. e., at 6 wk after sowing (maximum tillering) and at booting - has been recommended for higher tiller sustenance, optimum grain number per panicle, and high grain yield (Table 4) (11, 3, 15).

Table 3. Effect of weed control by the stale seedbed technique on yield of rice variety CR222 and MW10.

Treatment	Yield (kg/ha)		
	Nonstale seedbed	Stale seedbed	$\frac{\text{Stale}}{\text{Nonstale}} \times 100$
Hand weeded check	2650	3333	126
Weed check	0780	0940	121
Thiobencarb (1.5 kg ai)	2130	2959	139
Thiobencarb (3.0 kg ai)	3854	3203	112
Thiobencarb 1.5 kg + 1 hand weeding	3228	3276	101
Mean	2309	2740	120

Source: G. B. Manna and B. T. S. Moorthy (unpublished).

Table 4. Effect of management of low N input on grain yield for direct-seeded upland rice (15).

N applied (kg/ha) at				Grain yield (t/ha)[a]	Response per kg N
Sowing	20 DAS	45 DAS	Panicle initiation		
0	0	0	0	1.29	—
0	15	10	5	2.19	30.0
0	15 (i)	10 (i)	5	2.44	38.2
0	10 (i)	10 (i)	10 (i)	2.31	34.2
0	15 (i)	10 (i)	5 (i)	2.72[b]	40.5

[a]Data for 4 yr (1973-76). [b]Tested for 3 yr only. DAS = d after sowing, (i) = incorporated.

Large-scale adoption of the stale seedbed technique provides conditions ideal for applying fertilizer even at sowing because the superficial weeds are smothered by the technique. Such initial basal application of N fertilizer combined with P and K helps early seedling vigor, stand establishment, and rapid coverage of the field by the rice foliage with consequent reduction in weed population. With availability of high-yielding, early-maturing upland rices and prospects of adopting timely weed control, a level of 30-40 kg N and 15-20 kg each of P_2O_5 and K_2O is adequate for a 2.5 to 3.0 t/ha yield.

Cropping system

In upland rice areas where water limitation is a major constraint, intercropping rice preferably with legumes may be an insurance against rice crop failure due to erratic rainfall (Table 5). In normal years, rice yield in an intercropping system is as good as a pure crop of rice and a legume. Intercrop combination of rice (Var. CR222-MW10 of 105-d duration) + red gram (T21 of 155-d duration) gave a 155% higher gross monetary return than a sole crop of rice in coastal Orissa and Chotanagpur regions (3,4,5).

In sequence cropping, an early-maturing rice variety as a pure crop or intercrop with green gram (maturing along with rice) is harvested at the recession of monsoon, and the land is plowed when the last soaking rain is received. The system helps assure a good amount of moisture to sustain a normal crop of mustard, gram, lentil, and safflower.

Jhum cultivation

Jhumming or shifting cultivation is primarily prevalent in the northeastern hill regions. The essential features are selecting a jungle site on a hill slope, clearing and burning the jungle, and growing a mixture of essential crops, such as rice, by dibbling. The area is abandoned after 2 yr of cultivation as the Jhumias shift to another site. They come back to the same site after 6-10 yr — the jhumming cycle. Agriculturally, jhumming is an unproductive farming system where fertile top soil is removed without replacement. Advanced technology, including use of fertilizers and implements, cannot be practiced. Recent efforts have used a model land use concept as an

Table 5. Grain yield (kg/ha) of crops under different intersequence croppings (4).

Treatment	Mean of 4 yr (1981-84)	
	Sole	Intercrop
Rainy season crops		
Rice (sole), unprotected	201 8	–
Rice (sole), protected	2824	–
Green gram (sole)	325	–
Red gram (sole)	1142	–
Rice + green gram (2:1)	1514	250
Rice + green gram (3:1)	2251	202
Rice + green gram (4:1)	2345	142
Rice + red gram (4:1)	2414	999
Winter season crops		
Horse gram (one irrigation)	1788	
Horse gram (rainfed)	1179	
Black grain (one irrigation)	433	
Black gram (rainfed)	281	

Test crop varieties and duration: Rice : CR 222-MW 1o (105 d), green gram: Hyb. 12-4 (65 d), red gram: T 21 (155 d), Hose gram: (local) (90 d), blackgram : T 9 (100 d).

alternative to jhumming. The top third of the slope is left for forestry to prevent erosion, the middle third for horticultural crops, and the bottom third lor food crops after suitable bench terracing. Several short-duration rice varieties (Pusa 2-21, Pusa 33) have been introduced into the system of food crops by the technology developed by the ICAR Research Complex for northeastern hill region.

Insect and disease management

The common insect pests in the uplands are termites at seeding, parasitic nematodes at seedling stage, stem borer and mealybug at vegetative stage, gundhibug at flowering, and cutworm at harvest. Among diseases, brown spot, blast, and sheath blight are common. Applying 40 kg/ha of benzene hexachloride (BHC) 10% dust to the soil at seeding for termites; spraying with quinalphos, chloropyrifos, or monocrotophos (0.5 kg ai/ha) in two rounds at weekly intervals for stem borer; and spraying phosphamidon (0.25 kg ai/ha) for mealybug and endosulfan or DDVP (0.5 kg ai/ha) in the evening cutworms are effective. Spaying edifenphos or carbendazim (0.1%) for blast, carbendazim or BHC (0.1%) for sheath blight, and mancozeb (0.25%) for brown spot is recommended.

Fitness of technologies

Based on this discussion technologies that can easily be adopted by small and marginal upland rice farmers especially in eastern and northeastern regions of India are:

- Replacing existing traditional rice varieties with newly evolved high-yielding, early-maturing (80-110d) varieties. Some varieties have built-in tolerance for periodical soil drought and soil nutrient problems.
- Proper germination and stand establishment by sowing seeds after about 60 mm cumulative rainfall and treating the seeds with sodium phosphate solution for early seedling vigor and drought tolerance.
- Drilling seeds in rows (15-20 cm spacing) using combined seed and fertilizer drill for easy interculturing and fertilizer placement in moist soil.
- Integrated weed control by adopting the stale seedbed technique and use of preemergence herbicides.
- Timely fertilizer application and incorporation into moist soil to prevent leaching.
- Timely plant protection measures especially for stem borer and leaf blast.
- Double cropping (rice + red gram [4:1] or rice t mung [3:1]) in drought-prone areas. Even in normal years double cropping is more economical than monocropping.

STRATEGIES FOR RAINFED UPLANDS

Because of meager upland rice yields, the National Commission of Agriculture suggested diverting 6 million ha of upland rice to low-risk and more remunerative dry crops. However, recent research illustrates potential of these areas to produce average yields of 2.0 t/ha or more by adopting available technologies.

However, to stabilize yield in these problem areas and to further enhance yield potential, the following strategies are indicated:

- Replacing existing traditional varieties with recommended newly developed suitable early-maturing varieties according to rainfall duration (80-110d) and intensifying seed production programs for timely supply of quality seed.
- Using suitable drills and simple interculturing equipment to facilitate row seeding, mechanical weeding, and fertilizer placement.
- Producing more effective postemergence herbicides on commercial scale for use in integrated weed management, and widespread adoption of the stale seedbed technique.
- Popularizing appropriate cropping systems, with rice as an intercrop or a suitable sequence crop for maximum land utilization and economic returns.
- Runoff water harvesting by storing it in small farm ponds for irrigation and exploitation of underground water for rational irrigation.
- Consolidating and bunding rainfed uplands for better water retention and improved productivity.
- Bench terracing the lower third of the sloping portion in jhum areas for growing recommended short-duration rice varieties.

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UPLAND RICE ENVIRONMENTS IN NIGERIA AND THE FITNESS OF IMPROVED TECHNOLOGIES

T. L. LAWSON and K. ALLURI

The environments in which upland rice is and can be produced in Nigeria span fourdistinct agroclimatic zones: perhumid, humid, transition (humid/subhumid), and subhumid. They are diverse and offer a fair degree of flexibility in choice of technologies, but each must be properly targeted to specific areas if its potential is to be realized.

Present production areas are delineated into four characteristic zones:

- a southwestern production zone with bimodal rainfall and moisture cycle;
- a southeastern zone with a more dependable but excessive rainfall;
- a northern zone with best insolation regime but with comparatively short, unimodal moisture cycle; and
- an east central zone with probably the best combination of insolation and rainfall regimes.

Upland rice is the dominant rice ecology in West Africa. In view of the socioeconomic structure of upland rice farmers, upland rice will continue to assume importance in the foreseeable future.

The increasing prominence of rice as a staple food in the West African subregion has led to increased importation of the commodity (13,14,15,16). The phenomenon has been even more spectacular in Nigeria, buoyed by the relative affluence the country has experienced during much of the period. Imports in this case increased from 342 000 t in 1976-78 to more than 600 000 t in 1982 (47).

The need to increase local production has become extremely crucial with the recent import restrictions which have made the commodity more scarce as demand increased sharply. Never has the opportunity for serious efforts in improving rice production in Nigeria been as great as it is now. This need has been strongly felt and enunciated in various policy statements (36).

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Historically, increase in production of rice, as is the case with other crops, implies increase in cropping area (7,8) and, to lesser extent, in yield per unit area.

This paper examines the Nigerian environment globally and assesses the fitness of different areas to upland rice technologies, the most dominant production system in the country.

UPLAND RICE AREAS AND THEIR ENVIRONMENTS

The largest proportion of upland rice in Nigeria is grown in the southwestern part, including the states of Ogun, Ondo, and Bendel (36). A second area of production is south of the Benue River in southwestern Gongola state which occupies the east-central part of Nigeria bordering the Republic of Cameroon (Fig. 1). In addition to these main producing areas, upland rice is also reported to be produced in southeastern and northern Nigeria, in areas where tidal and inland valley swamp rice is the dominant form of production (36).

Upland rice may derive its water supply partly (i.e., at least for short periods) from phreatic nappes. Such ecology is also considered as upland in this paper, along with the strictly upland type grown in well-drained soil. Given the recent wide ranging definition of upland rice used by Huke (19) as "rice grown in fields that are not bunded, are prepared and seeded under dry conditions, and depend on rainfall for moisture," this consideration is appropriate.

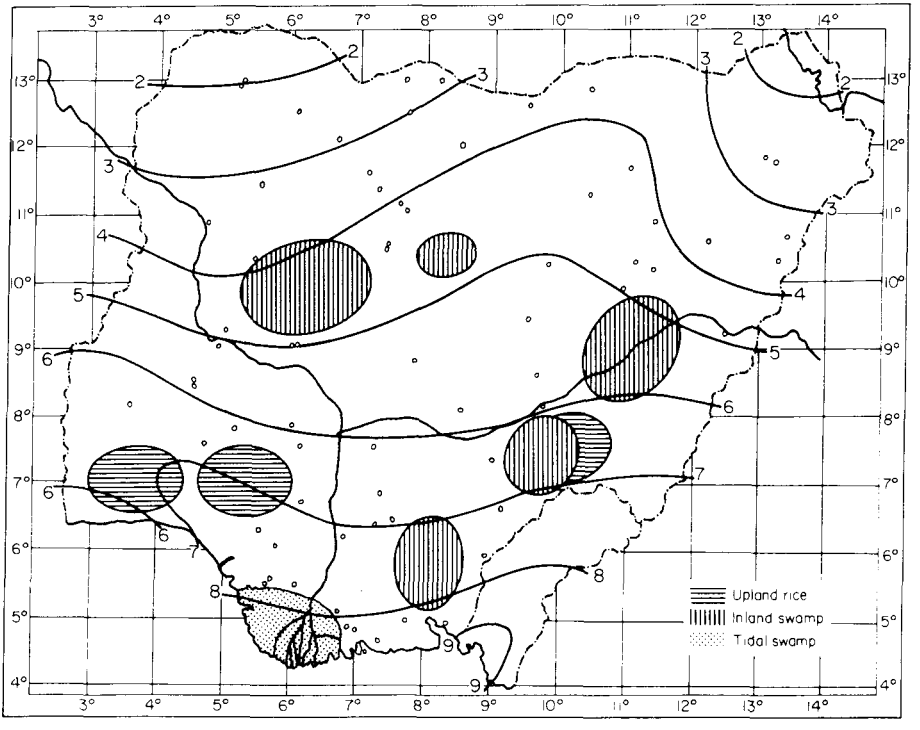
Upland rice production in Nigeria ranges from latitude 11°N down to the coast, and thus from the subhumid to the perhumid regions.

Southwestern and southeastern production areas

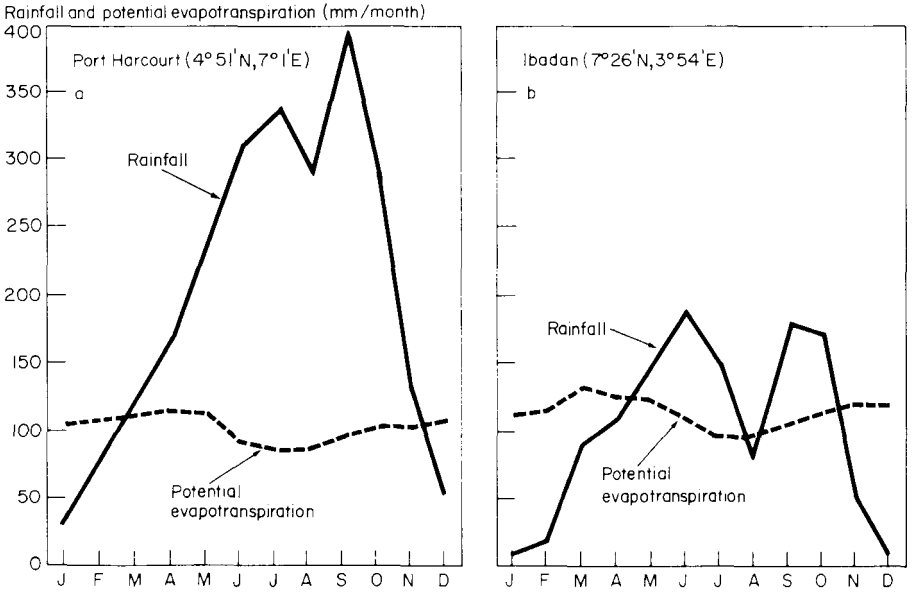
Moisture conditions. The southwestern production areas (Fig. 1) are marked by a bimodal rainfall and moisture cycle (Fig. 2B) which gradually fades into a single moisture cycle in the southeastern areas with no change in the rainfall pattern (33). Annual and seasonal rainfall increases correspondingly from the southwest to the southeast (Fig.2A, B) where the annual total reaches an extreme of more than 4000 mm at Calabar. In comparison, in the southwest, Ibadan and Ondo receive on the average 1270 mm and 1570 mm of rainfall, respectively, spread over 7 mo.

Few, if any, stations in the southwestern areas of production receive a mean monthly rainfall of 200 mm, the minimum amount postulated by Brown (6) to be needed in the growing season for an upland rice crop. In addition, the lower rainfall in these areas coupled with irregularities in the rains considerably increases the potential for intraseasonal drought spells. But for the dependence on phreatic nappes to meet part of the water requirement, upland rice production in the area would hardly be possible.

By contrast, the higher rainfall in the southeastern growing areas lessens to a considerable extent the effects of rainfall irregularities (34) and provides a comparatively better moisture regime for the crop. This is apparently enhanced by the presence of phreatic nappes.



1. Predominant Nigerian upland and swamp rice growing areas and mean duration of the wet season (P ⩾ ETP). Information on rice areas from (36).



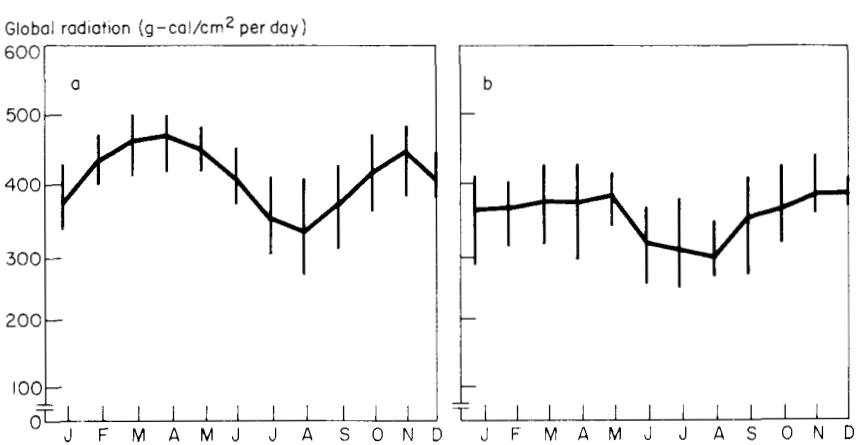
2. Mean monthly rainfall and potential evapotranspiration at Port Harcourt (4°51'N, 7° 1'E) (a) and Ibadan (7° 26'N, 3° 54'E) (b). Rainfall data are from Nigerian Meteorological Services.

Solar radiation. Solar radiation (insolation) in both the southwest and southeast production areas (Fig. 3A, B) are suboptimal because of cloudiness or long periods of precipitation, particularly during growing seasons. The mean monthly percentage of possible sunshine received in Ibadan (southwest) and Port Harcourt (southeast) in Table 1 illustrates the low global radiation reaching the crop in these areas. It also shows the unfavorable association between higher rainfall and better moisture regime in the southeast with a poorer light climate.

Temperature and humidity. Air temperatures in both areas are moderately high and limited in range. Mean minimum temperatures are among the highest for the country, with average values generally above 20°C, (Table 2). Daytime soil temperatures are rather high (about 40°C), particularly at the beginning of the rainy season. However, they fall within a reasonable range during the rainy and cropping season, fluctuating between 30 and 36°C in the southwest, lower in the southeast.

Humidity and dew. High humidities prevail in both areas during the rainy season. Even in the dry season, relative humidities average above 90% at night, with a tendency toward saturation in the early morning hours (31) resulting in frequent fogs and mists. Surface dew occurs year-round, persisting for long periods ranging from 12-16 h on vegetative surfaces (33).

Soil resources. Most soils in the southwestern region have developed on pre-cambrian basement complex (29). They are relatively course in texture with poorly graded surface horizon and often with gravel layers at shallow depths. They are generally poor in organic matter content and inorganic colloidal fraction, and have a low moisture-holding capacity (29). In the southern portion of the area, parent materials of sedimentary origin give rise to deep soils with considerably improved physical properties (29). They are, however, generally less fertile (42).



3. Monthly mean global radiation and its variability at a) Ibadan and b) Onne, Port Harcourt. Source: (30).

The southeastern areas are dominated by Ultisols and Oxisols of the kaolinitic and siliceous groupings (26). Soils in the Niger delta area to the extreme south typically consist of fine sand or silt loam of low permeability and low pH (4.5-5.0). Further inland on the floodplains, clay loam to clayey soils of equally low pH predominate (4). Beyond this zone are soils derived mostly from the basement complex (25).

East-central and northern production areas

Moisture condition. The annual moisture cycle in the east-central areas of production is monomodal despite a bimodal rainfall regime (Fig. 4A) similar to conditions farther south (Fig. 2A) but much lower in amount. Most rain is concentrated in the 6-mo period of positive moisture balance with 3 of the months receiving amounts in excess of 200 mm. Moisture conditions would thus appear more conducive to upland rice than in the southwestern production zone. As in the two southern production areas a partial dependence on phreatic nappes during the cropping season seems evident in this zone, with swamp rice partially overlapping the upland rice area south of the Benue River.

The northern production zone is characterized by a truly monomodal rainfall and moisture cycle (Fig. 4B). With 4 continuous months of rainfall exceeding 200 mm each month, it nominally satisfies the rather stringent requirement for upland rice postulated by Brown (6).

Rainfall in the northern zone is irregular starting late or ceasing early which, in effect, shortens the favorable moisture cycle. There appears to be a heavier dependence of phreatic nappes in the production system in this region (Fig. 1).

Solar radiation and temperature. Insolation in the east-central production zone (Fig. 5) is higher than that in the southwestern and southeastern areas and compares favorably with that in the northern zone (30).

Temperatures are higher, the mean maximum air temperature ranging from 29.6 (August) to 36.0°C (February) in Makurdi, and between 26.8 (September) and 34.9° C (March) in Kaduna. Kaduna registers the coolest night temperature of all stations (Table 3).

The east-central and northern production areas are also marked by lower mean relative humidity values compared to the two previous areas in the south. Daily maximum values are comparable during the cropping season when they rise above 90%. The correspondingly lower daytime values contribute to higher evaporative demands.

Table 1. Percentage of possible sunshine at Ibadan (7°26'N, 3° 54°E) and Port Harcourt (4° 57'N, 7° 1'E). [a]

Station	J	F	M	A	M	J	J	A	S	O	N	D
Ibadan	56	59	53	49	49	41	24	19	25	45	58	59
Port Harcourt	45	51	39	40	40	27	20	20	17	29	39	47

[a] Adapted from (17).

Table 2. Daily mean maximum and minimum temperature at Ibdan (7° 26'N, 3° 54'E). Ondo (7° 6'N, 4° 50'E) and Port Harcourt (4° 51'N, 7° 1'E).[a]

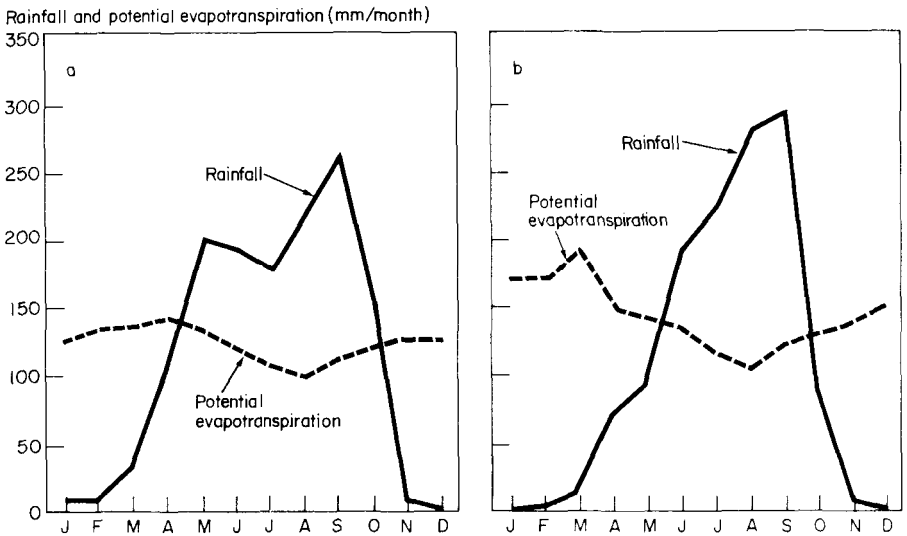
Station		Temperature (°C)											
		J	F	M	A	M	J	J	A	S	O	N	D
Ibdan	Max	32.3	34.1	33.5	32.2	31.2	29.6	27.8	27.2	28.5	29.7	31.3	31.9
	Min	20.9	21.9	22.5	22.3	21.7	21.6	21.2	20.7	21.2	21.2	21.6	20.7
Ondo	Max	31.3	32.9	32.2	31.2	30.3	28.9	27.1	26.7	27.8	29.1	30.7	31.0
	Min	21.7	22.3	22.5	22.2	21.4	21.4	21.1	20.7	21.2	21.2	22.0	21.6
Port Harcourt	Max	31.6	32.6	32.0	31.6	31.0	29.1	28.0	28.1	28.8	29.6	30.6	31.3
	Min	20.8	21.4	22.3	22.4	22.6	22.1	21.8	21.8	22.0	21.9	21.8	20.8

[a] Source: Nigerian Meteorological Service. Lagos (pers. comm.)

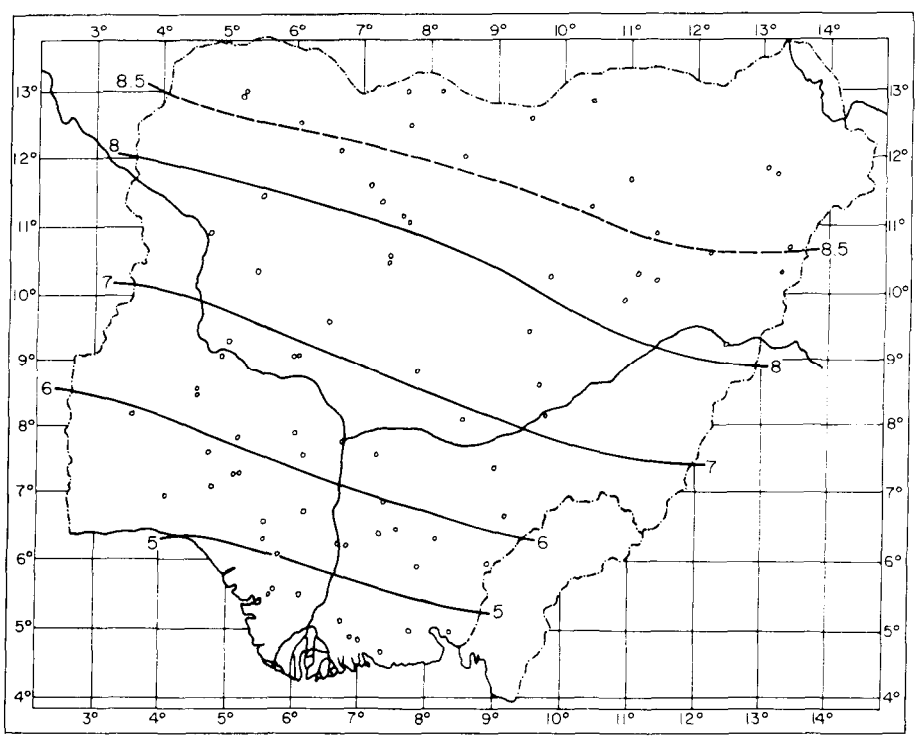
Table 3. Mean daily temperatue (°C) at Makurdi (7° 44'N, 8° 32'E) and Kaduna (10° 36'N, 7° 27'E), Nigeria.[a]

Station		J	F	M	A	M	J	J	A	S	O	N	O
Makurdi	Max	34.4	36.0	35.9	34.1	32.2	30.7	29.7	29.6	30.0	31.5	32.8	33.6
	Min	18.3	21.0	24.1	24.1	23.1	22.2	22.2	22.2	21.9	21.8	20.3	17.1
Kaduna	Max	27.9	33.4	34.9	34.3	32.0	29.6	27.6	26.9	26.8	31.2	34.1	31.8
	Min	15.2	16.8	20.4	21.9	21.2	19.8	19.5	19.4	19.2	18.7	15.6	13.4

[a] Source: Nigerian Meteorological Service, Logos (pers. comm.).



4. Mean monthly rainfall and and potential evapotranspiration at (a) Makurdi (7°44'N, 8°32'E) and (b) Kaduna (10° 36'N, 7°27'E). Rainfall data are from Nigerian Meteorological Services.



5. Nigerian yearly mean sunshine hours (h/d). Source: Nigerian Meteorological Services 1961, Meteorological Note No. 18, Bright Sunshine.

Winds. Winds in all four upland rice growing areas identified are generally light except during thunderstorms when strong gusts are frequently observed (30). Although gusts are more frequent in the south, they tend to be more violent in the north.

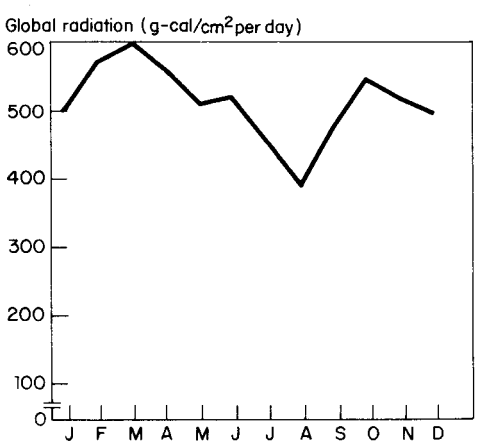
Soil resources. Soils in this region are also of dominant kaolinitic type clay. To the northeast, they are derived mostly from basement complex; south of there, these soils are in many cases shallow and stony. Deeper soils derived from sandstone predominate farther south and west along the Benue River (39). To the west between Kaduna and the River Niger, Luvisols separated by dissected land with predominant Lithosols predominate. Farther west of the Niger, shallow and stony soils derived from basement complex again become dominant.

In general, these soils are low in organic matter and in available soil moisture reserve; they are also readily prone to soil compaction (27, 32). Nitrogen and P content are low, while K content tends to be variable, usually higher on the basement complex soils (26, 39). Sulfur, Zn, and B deficiencies are common, notably on the sandy and siliceous soils, and CEC is largely low.

Extreme northern production areas

Farther north of the present upland rice growing areas, the moisture cycle becomes too short (Fig. 1) to support the crop. The only rice culture in this region, according to Oni and Ikpi (36), is floating and irrigated rice which benefits from the much higher insolation (Fig. 5, 6).

Based on the preceding discussion, present upland rice growing areas practically encompass the potential growing areas of the country.



6. Mean monthly global radiation at Samaru (30).

DESIRABLE ATTRIBUTES OF UPLAND RICE ENVIRONMENT

Rice, like any other crop, gives the highest yield when environmental factors favor the best expression of its genetic potential. The many detailed physiological studies of the crop throughout the years not only have brought into focus various aspects of the environment that best suit the development and yield of the crop, but have also provided guidelines to breeders in their continuing attempt to raise the inherent genetic potential of the available materials. In this perspective, efforts at improvement of upland rice must be considered relatively recent.

Moisture requirement. Although rice has been referred to as a semiaquatic crop, it is evident that its real requirement in terms of moisture is not so much the presence of free or standing water but rather the availability of nonlimiting regular moisture, regardless of the direct or immediate source of such supply.

Light and temperature requirement. Dry matter production and yield of rice have been conclusively shown to be strongly affected by solar radiation (11, 38, 41, 43). Yield not only increased with total radiation received during the growing season but was also found to depend on insolation during the reproductive and ripening phases of the crop (9, 40, 46).

By contrast, low temperatures prolong growth duration, and at extreme values (about 15°C) may also induce sterility (18, 44). Owen (37) reported daytime temperature of 30° C with night time minima of 20° C for overall optimum performance of IR8. Other available evidence suggests temperatures of the same order for other varieties (44, 45).

Relative humidity and winds requirements. The direct relationship between evapotranspiration and dry matter production (10) suggests that moderate values of relative humidity and winds, which result in corresponding values of evaporative demand, should ensure balance between water uptake and water loss by the relatively short-rooted rice crop in a given environment and promote high yields (30). High wind speeds cause mechanical damage to the plant and induce the spread of diseases; in combination with low humidity, they may induce rapid moisture loss and desiccation.

IMPROVED TECHNOLOGIES AND THEIR FITNESS

The fitness of a technology to an environment depends on the extent to which it overcomes or provides answers to the limitations of that environment. Table 4 summarizes the physical factors of the Nigerian environments as they affect the rice crop and the improved technologies required to fit upland rice to these environments. The technologies may be broadly divided into two groups: those associated with varietal improvement and those based on cultural and crop management practices.

Varietal improvement technologies. The paramount problem of drought in upland rice environments created the need for drought-resistant varieties. In recognition of the merit of the thick and deep rooting systems of upland-

Table 4. Physical environment of Nigeria, its effect on crop growth, and technologies required to fit upland rice to the environment.

Environmental factor	Region	Environmental constraint	Effect of the constraint	Technology required
Rainfall	Southwest	Irregular	Intermittent drought	Drought-tolerance varieties Soil water retention by minimum tillage and mulch
	Northern	Short duration	Drought at the beginning or at the end of crop growth	Drought escape (early maturity) Time of planting
	Southeast	Excessive	Excessive leaching and low pH	Varietal tolerance for soil acidity Nutrient management
Soil	All	Physically poor	Erosion, low water- and nutrient-holding capacity	Agronomic practices and adapted varieties
	Southeast	Chemically poor	Low fertility	Agronomic practices and adapted varieties
	All regions at the beginning of the rains	High temperature	Poor germination	Heat tolerance and cultural practices to minimize the damage compatible crop architecture
Solar radiation	Southeast, southwest	Low	Low crop photosynthesis	Time of planting
Humidity	Southeast	High	High incidence of fungal diseases and insect pests	Varietal resistance, integrated control measures
Wind	All regions	High speed (occasional)	Lodging	Varietal resistance

adapted varieties, major efforts have been made to combine this character with the high yielding ability of new but unadapted varieties. Selection for root traits at seedling stage, followed by confirmation at adult plant stage, is practiced at IITA (3). Ayotade (5) and other studies (22) have demonstrated that IRAT 110, IRAT 133, IRAT 144, IRAT 146, ITA 116, ITA 150, ITA 165, ITA 235, and ITA 257 are outstanding compared to the local farmers' variety OS 6 (FARO 11) for drought resistance.

Selection for early maturity to escape drought has led to the development of IRAT 110, IRAT 133, IRAT 144, ITA 120, ITA 150, and ITA 257. The varieties mature in 90-110 days.

Droopy leaf uses solar energy more efficiently when the leaf area is small (45), as is usually the case in the uplands. On the other hand, the incidence of diseases such as leaf scald is more in droopy-leaved plants. So, extremely droopy-leaved plants may not be desirable. In the southeastern and southwestern Nigeria where cloud cover is excessive and radiation comparatively low, selection has been for intermediate-statured plants with droopy lower leaves and erect upper leaves. The improved varieties ITA 117, ITA 119, ITA 141, and ITA 303 with these traits appear compatible with the environment and therefore potentially better yielding.

The prevailing high humidity and long periods of favorable temperatures in the southeast favor several fungal pathogens and insect pests. More important among them are blast, grain discoloration, and stem borers. Varietal improvement made against these constraints are reported elsewhere in this workshop (2, 24) and the improved varieties substantially obviate these indirect environmental hazards.

Tall, traditional varieties prone to lodging during storms suffer from serious yield losses. Successful combination of short plant height from improved varieties and sturdy stem from traditional upland varieties have produced new sturdier varieties resistant to lodging and therefore better-suited to the main rice-growing areas. The promising varieties identified by NCRI (5, 12), and IITA (21, 22, 23) are resistant to lodging.

Varietal screening against high soil acidity at Onne in the southeast (1,22, 23) identified ITA 116, ITA 117, ITA 118, ITA 141, ITA 235, ITA 305, ITA 307, TOx 936-81-1-4, IRAT 104, and IRAT 170 as more acid tolerant and therefore better suited to that zone.

Varietal differences in the ability of the seeds to germinate at 40° C have been reported (20). TOx 95-8-1-5, a breeding line from IITA, showed greater tolerance to high temperatures than the adapted upland types OS 6 and Moroberekan.

For upland rice cultivation in Nigeria, considerable varietal improvement technologies are now available. Specifically, early-maturing varieties with good levels of drought, blast, and lodging resistance for northern Nigeria and varieties with tolerance for acid soils and resistance to major diseases and lodging in southeastern Nigeria are available.

Cultural and crop management technologies. The use of mulches is an important cultural practice to control extreme soil temperature, increase soil moisture reserve, and prolong the period of moisture availability (28).

Studies have shown that rice response to N is up to 40 kg/ha in the southeast (23) and up to 60 kg/ha in the southwest (12, 23). These studies indicate response to P up to 20 kg/ha and no response to added K in southwest Nigeria. Studies (21) under field conditions at Ikenne in southwest indicated a low P requirement for upland rice. When compared with 0 and 60 kg P/ha, no response to added P was observed in southeast Nigeria (Alluri, unpubl.). Fagade (12) observed no yield response to N from 0 to 60 kg/ha, to P from 0 to 40 kg/ha, and to lime from 0 to 1.0 t/ha in the coastal plains in southeast Nigeria. Studies with Onne soil (21) indicated the need for a balanced application of various nutrients - N, P, K, Ca, Mg, and Zn for crop growth. Small amounts of Ca (100 kg/ha) were beneficial as a nutrient but large amounts (1.0-2.0 t/ha) to correct the low pH was not necessary.

Shifting cropping cycle relative to the moisture cycle should be effective in increasing yield particularly in the southeastern region. A sample survey in Bendel State, southern region (35), showed that planting is traditionally done in April at the beginning of the period with positive moisture balance. The crop reaches maturity and is harvested in August when insolation is at a relative minimum. Because the August minimum in rainfall in this area is not pronounced, moisture levels usually remain adequate. However, occasionally, as in 1981, drought could occur in July/hugust.

Farm grain yields in Bendel State (35) are low, 0.5-0.8 t/ha, because of poor cultural practices such as old varieties, low seed rate (15-40 kg/ha), and insufficient weed control and fertilizer application. Experimental trials conducted in Ubiaja, Bendel State (21), showed that high grain yields of 5.0 t/ha were possible by adopting improved varieties of about 120 day maturity. With good management and when planted in June, the rice plants are at vegetative stage during July/August to avoid possible low light and drought stress to coincide with critical reproductive and ripening stages.

Upland rice is usually planted in all the regions first year after bush clearing and sometimes, by fewer farmers, again in the second year. There is a need to develop economically viable environment management technology for upland rice cultivation year after year by adapting suitable varieties, crop rotation, and appropriate soil and fertility management practices.

SUMMARY AND CONCLUSION

Upland rice environments in Nigeria show a fair degree of diversity, ranging from the perhumid to the subhumid zone of the country. None of these environments appears inherently ideal for the crops. However, considerable improved technologies are now available which can be properly targeted to achieve viable levels of production. For example, early-maturing varieties with good levels of drought resistance will fit the conditions in the north whereas disease-resistant varieties adapted to acid soils provide the necessary genetic resources for the excessive rainfall areas of southeastern Nigeria.

The main problem area is the southwest where drought stress occurs intermittently and the period of occurrence may vary from year to year. Even here, however, varieties that are drought resistant can already afford sow measure of protection against the evident risk.

Complementing some of these varietal attributes with appropriate cultural practices should considerably increase upland rice production in Nigeria.

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AN OVERVIEW OF UPLAND RICE IN THE WORLD

TRAN VAN DAT

ABSTRACT

Upland rice occupies about 20.4 million ha or 14% of the world's cultivated rice area and is grown mostly on poor soil with erratic rainfall under shifting or permanent cultivation or as a pioneer crop depending on socioeconomic levels. Physical constraints (drought stress, soil erosion, and fertility deterioration) and biological constraints (weeds, birds, diseases, insects) combine with socioeconomic problems, account for low average grain yield at the farmer level. Fundamental physiological features of upland rice should be studied to shed more light on the work in varietal improvement and agronomy. Better upland rice farming systems must adapt to local environments as substitutes for slash-and-bum shifting cultivation practices. Subsistence living leaves little margin for risk taking. A new approach is needed to convert unfavorable upland rice culture to a more favorable one whenever possible. Essential to an upland rice development scheme is an integrated method covering national policy reorientation, developing adaptable technology packages, and more effective extension work to improve farmers' socioeconomic conditions.

Upland rice (or dryland rice) grows on about 20.4 million hectares (Table 1), about 14% of the world's rice area. Although it is less important in world rice production, the production of upland rice is crucial to the agricultural economy of many countries, particularly in tropical Africa. Grain yields average about 1 t/ha as a result of many serious biological, socioeconomic, and cultural problems.

Most upland rice is grown on poor soil with uncertain rainfall distribution, by poor farmers using traditional methods (except in a few Latin American countries which partly mechanize upland rice), with low or no inputs under either permanent or shifting cultivation. In the last decade

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Table 1. Estimated upland rice area and production in the world.

Region	Area (thousand ha)	Production (thousand t)	Yield (t/ha)
Africa	2047 [a]	1023	0.50
Asia	11593 [b]	11593	1.00
Latin America [c]	6724	8820	1.10
World	20364	21436	1.05

[a] From (28). [b] From (11). = From (5).

research has been directed toward upland rice but production has not improved accordingly. This probably means that the research technology has not adapted well to diverse environments of upland rice, or is not socioeconomically accepted by farmers, or the technology transfer is ineffective. This paper attempts to review current upland rice production, analyze some major constraints, and outline a brief strategy for developing upland rice. Upland rice is defined as rice grown in rainfed, naturally well-drained soils with bunded or unbunded fields without surface water accumulation (16).

UPLAND RICE PRODUCTION AND ITS TREND

Accurate information concerning area and production of the world's upland rice is not reported because the crop is grown in remote areas and scattered throughout countries.

Upland rice environments are generally classified into four categories:

1. Favorable upland with long growing season (LF), occupying about 11% of the world's upland rice area,
2. Favorable upland with short growing season (SF), occupying about 25% of the world's upland rice area,
3. Unfavorable upland with long growing season (LU), occupying about 38% of the world's upland rice area, and
4. Unfavorable upland with short growing season (SU), occupying about 26% of the world's upland rice area.

In Asia, upland rice occupies 11.6 million ha or 53% of the world's upland rice area. Of this, India has 6 million ha, Indonesia has 1.13 million ha, and Indochina has 1.24 million ha (Table 2) (14). These countries cover 73% of total upland rice in Asia. Grain yield in this region varies from 0.5 to 2.0 t/ha.

In Africa, upland rice has a more important role in rice production. It is planted on about 2.0 million ha representing 40% of the total area.

The contribution of upland rice to total regional rice production is more important in Latin America and the Caribbean countries than in Asia although production is less. Upland rice occupies 6.72 million ha or 76% of the total area planted to rice and produces 7.6 million t of paddy or 47% of the total in 1982 in this part of the world (Table 3) (5).

Table 2. Estimated rice area in major cultural types by country in South and Southeast Asia (11).

Country	Area allocated (thousand ha)						Total
	Dryland	Deepwater	Irrigated[a]		Rainfed		
			Wet season	Dry season	Shallow (0-30 cm)	Intermediate (30-100 cm)	
South Asia							
India	5,973	2,434	11,134	2,344	12,677	4,470	39,032
Bangladesh	858	1,117	170	987	4,293	2,587	10,012
Pakistan	–	–	1,710	–	–	–	1,710
Sri Lanka	52	–	294	182	210	22	760
Nepal	40	53	261	–	678	230	1,262
Bhutan	28	–	–	–	121	40	189
Total	6,951	3,604	13,569	3,513	17,979	7,349	52,965
Southeast Asia							
Burma	793	173	780	115	2,291	1,165	5,317
Thailand	961	400	866	320	5,128	1,002	8,677
Viet Nam	407	420	1,326	894	1,549	977	5,573
Kampuchea	499	435	214	–	713	170	2,031
Laos	342	–	67	9	277	–	695
Malaysia	91	–	266	220	147	11	735
Indonesia	1,134	258	3,274	1,920	1,084	534	8,204
Philippines	415	–	892	622	1,207	379	3,515
Total	4,642	1,686	7,685	4,100	12,396	4,238	34,747
Grand total	11,593	5,290	21,254	7,613	30,375	11,587	87,712
%	13	6	24	9	35	13	

[a] Double-cropped areas are counted twice.

In 1984, world paddy production reached 465 MT and 16 MT more than the previous year, mainly from the developing countries of the Far East (7). Production in the other regions remained less changed. This represents the trend of rice production in the world for the last 10 yr (Table 4). Rice production in Africa, Near East and Latin America, and Caribbean countries increased slightly for the same period. These regions are still major rice importers. The decline in rice production in developed countries is temporary and reversible due to national imposed rice policies such as restrictions on rice production in Japan and recent acreage reduction in the United States due to strong competition from developing countries for rice in the world market.

Rice demand in the future will follow the same trend as in the past for Latin America and the Near East, but will be higher in both Asia and Africa (7). Asia accounts for about 90% of the world's total rice production and consumption. For Africa, this is explained by the population growth and its dietary shifting from traditional staple food to rice, especially in urban areas. Because water resources, land availability, and investment capital are limited and population rapidly increases, farmers are forced to accelerate rice production by exploiting existing forests and savannas to meet their needs. Although some areas planted to upland rice could be planted to other

Table 3. Area, production, and yield of rice in Latin America, 1981-82 harvest (5).

Country	Area (thousand ha)[a]			Production (thousand t)			Yield (t/ha)		
	Irrig.	Upland	Total	Irrig.	Upland	Total	Irrig.	Upland	Av
Argentina	110.0	–	110.0	400.0	–	400.0	3.6	–	3.6
Belize	1.2	2.2	3.4	3.5	4.3	7.8	2.9	2.0	2.3
Bolivia	0.5	58.2	58.7	1.3	91.4	92.7	2.6	1.6	1.6
Brazil[b]	740.6	5897.8	6638.4	2747.6	5890.4	8638.0	3.7	1.0	1.3
Chile	37.0	–	37.0	131.2	–	131.2	3.5	–	3.5
Colombia	345.9	107.4	453.3	1754.9	161.0	1915.9	5.1	1.5	4.2
Costa Rica	2.0	70.3	72.3	12.2	189.8	202.2	6.1	2.7	2.8
Cuba	130.0	–	130.0	496.9	–	496.9	3.8	–	3.8
Ecuador	72.4	62.8	135.2	282.5	127.2	409.7	3.9	2.0	3.0
El Salvador	–	13.9	13.9	–	50.1	50.1	–	3.6	3.6
Guatemala	–	15.4	15.4	–	33.3	33.3	–	2.2	2.2
Guyana[b]	86.4	35.2	121.6	259.2	52.8	312.0	3.0	1.5	2.6
Haiti	31.7	10.5	42.2	190.0	30.1	220.1	6.0	2.9	5.2
Honduras	6.0	28.1	34.1	27.0	75.2	102.2	4.5	2.7	3.0
Jamaica	1.5	–	1.5	4.5	–	4.5	3.0	–	3.0
Mexico	96.4	110.6	207.0	366.9	219.7	586.6	3.8	2.0	2.8
Nicaragua	22.3	19.5	41.8	90.5	48.1	138.6	4.1	2.5	3.3
Panama	6.0	98.2	104.2	24.5	193.1	217.6	4.1	2.0	2.1
Paraguay	21.3	11.0	32.3	61.8	19.8	81.6	2.9	1.8	2.5
Peru	120.2	40.3	160.5	595.6	80.6	686.2	5.0	2.0	4.3
Dominican Rep.	100.0	3.1	103.1	258.1	4.0	262.1	2.6	1.3	2.5
Surinam[b]	35.7	–	35.7	150.0	–	150.0	4.2	–	4.2
Uruguay[b]	68.0	–	68.0	381.0	–	3810.	5.6	–	5.6
Venezuela	60.0	140.0	200.0	240.0	350.0	590.0	4.0	2.5	3.0
Total	2095.1	6724.5	8819.6	8479.2	7620.9	16100.1	4.0	1.1	1.8

[a] Blank space indicates no planting. [b] Data are from Brazil and Uruguay (1980-81), Guyana (1977-78), and Surinam (1979-80).

Table 4. World rice area and production, 1974-83 (6).

Region	Area (thousand ha)				Production (thousand mt)				
	1974-76	1981	1982	1983	1974-76	1981	1982	1983	1984
Africa	4,420	4,880	4,915	4,925	7,955	8,436	8,902	8,551	
Asia	126,691	129,307	125,710	130,469	316,031	374,574	384,811	417,135	
Latin America	7,461	8,231	8,190	7,119	13,897	15,590	17,555	14,856	
Others	2,027	2,631	2,470	1,960	9,622	13,214	12,196	9,285	
World	140,599	145,049	141,285	144,473	347,505	411,814	423,464	449,827	465,700[a]

[a] Preliminary.

more profitable crops, a considerable area of upland rice is expected to remain or even expand in Africa (to the detriment of forests), often mainly for socioeconomic reasons. Although any technological improvement in upland rice will benefit many poor farmers and contribute substantially to their social welfare, its production will not improve world rice production significantly unless the average yield is remarkably above farmers' actual yield level.

UPLAND RICE PRODUCTION SYSTEMS

It is convenient to define upland rice production systems depending on the power resources and its cropping sequences. Depending on the size of their farms and their resources, upland rice farmers use different farming systems ranging from hand tool cultivation to draft animals to power mechanization under different crop intensity levels. Based on crops, three distinct major upland rice cropping systems are used by world farmers: shifting cultivation, permanent cultivation, and pioneer cultivation. Shifting cultivation occupies 88% of total upland rice area in West Africa. In other countries such as Thailand, Vietnam, Laos in Asia, and Peru in Latin America, most upland rice is also planted under shifting cultivation. Permanent cultivation of upland rice is practiced in many Asian and Latin American countries while pioneer cultivation is concentrated in Latin America (Brazil).

Shifting cultivation

Shifting cultivation is a first step in agricultural development and evolution which according to Greenland (8) consists of four phases:

Phase 1 — simple shifting cultivation (dwellings and cultivation area shift together),
Phase 2 — recurrent cultivation (cultivated area shifts more frequently than dwellings with maybe many field types),
Phase 3 — recurrent cultivation with continuously cultivated plots (always many field types), and
Phase 4 — continuous cultivation.

In general, man prefers a settled mode of living to a wandering one. The existing shifting cultivation in the world is evidence of socioeconomic problems in particular regions or countries.

The shifting cultivation is primitive and practiced in remote areas. Farmers bush, burn, and clear a piece of land for a rice crop planted alone or associated with other crops such as maize, yam, beans, cassava, and plantain. They continue from 1 to 3 yr until they note a decline in soil fertility and weed and pest invasion. They abandon the land and return to previously abandoned farm land or they start cropping on other available virgin land. The fallow period, which depends on soil type and demographic pressure, may last from 3 to 20 yr under bush fallow or forest fallow to permit soil fertility restoration. In a tropical forest, the rate of litter decomposition is

rapid, from 50-500% annually (21), and the average rates of per hectare nutrient return in litter from three African forest locations, reported by Nye and Greenland (23), are 184 kg N, 6 kg P, 73 kg K, 142 kg Ca, 47 kg Mg, and 12.5 t dry matter. The magnitude of nutrient availability for the next cropping after fallowing depends on litter, vegetation biomass, and burning efficiency. Sulfur and nitrogen are lost after burning; the other elements remain in the ash (22).

Shifting cultivation has its merit: minimum disturbance of soil structure, naturally rapid regeneration of soil nutrients, maintenance of soil fertility, and low-cost control of weeds and pests if properly practiced. The system, however, results in low agricultural productivity and production because no new technology is used and land exploiting capability is physically limited. Exposed bare soil in early years of fallow may result in severe soil erosion and degradation.

Permanent upland rice cropping systems

With increasing population density and decline in land availability for agricultural exploitation, cropping becomes more intensive, the crop frequency is high, and the fallow phase is reduced or eliminated. To maintain an intensive cropping system to meet vital food consumption for their households, farmers have to use inputs from animal manure, organic matter, chemical fertilizers, and pesticides. The use of these inputs, particularly chemicals, is far less than the recommended rates because of cost. The draft animal used in this system is common in Asia. Partial or high mechanization in upland rice is also practiced in Latin America, especially in Brazil. The permanent upland rice-based cropping system is characterized by more orderly intercropping, relay cropping, and sequential cropping with a limited number of crops planted in each field, at one time, and with more uniform crops (22). Continuous annual cultivation of upland rice on fertile soil was developed in the Philippines and Indonesia. In Indonesia, with favorable rainfall, upland rice is intercropped with early-maturing maize in the early rainy season then with cassava a month later or a second maize crop. The most concentrated continuous upland rice growing is in the savanna of central-west Brazil (4, 14).

Pioneer cultivation

Pioneer cultivation is an extensive cropping system in which upland rice is grown as the first crop after land clearance prior to grass or interplanted with young tree crops, such as coffee or citrus (13). It is predominant in Brazil but rare in Asia and Africa.

UPLAND RICE PHYSICAL ENVIRONMENT

The physical environment of upland rice is characterized by climate and soil conditions.

Climate

Upland rice production depends totally on natural weather, especially rainfall which is uncontrollable. The average grain yield of the crop, therefore, is not expected to increase spectacularly like irrigated rice particularly in regions with short and bimodal rainfall season. Increased upland rice production in the world, if any, is mainly due to an area expansion rather than yield, at least in the near future. In practice, farmers need to know a good short- and long-range weather forecast in a particular region to avoid a dramatic drought risk. However, such forecast is seldom available or reliable on any upland crops in developing countries.

Rainfall. Upland rice grows under a wide range of rainfall. Rainfall may vary from 700-800 mm in Sahelian areas to 4,000 mm in forest areas. Critical aspects of rainfall are amount, intensity, duration, spatial distribution, and reliability throughout the year. In Asia, the monsoon brings humid air causing heavy rainfall, which ranges from 1,500 to 3,500 mm. Dry spells frequently occur during the growing season. In Vietnam, Laos, and Thailand, rainfall is erratic usually during July-August. The rainfall in those regions starts about May and ends about October. The Philippines, which is usually affected by tropical cyclones, has unimodal rainfall at Malaybalay in Bukidnon, Mindanao, and bimodal rainfall in Davao (3).

Rainfall is the prevailing factor in African rice production, particularly in upland rice. The climate varies greatly from Sahelian to tropical. The harsh and diverse climate slows upland rice production in Africa. The annual rainfall ranges from 500-700 to 4,000 mm. The erratic precipitation frequently occurs in East Africa and in the semiarid areas. Abundant rainfall favors upland rice in Central and West Africa. Different models of rainfall are also present. The northern part of West Africa has monomodal rainfall, characterized by irregularities of the start or end of rains; the southern area of West Africa has bimodal rainfall often remarkably reduced at the middle (July-August) of the rainy season starting from March/April to October (19). Drought may occur any time during the growing season and is a permanent menace to African farmers.

Mean annual rainfall in Latin America ranges from 1,400 mm in Goiania, Brazil, to 4,800 mm at Puerto Cortes and Costa Rica. There is high probability and severity of dry spells during the growing season in unfavored areas (18). An annual rainfall of 1,000 mm with 200 mm/mo is adequate for upland rice in this region (1).

Temperature. Temperature is related to latitude, altitude, and rainfall patterns. The temperature of most regions in Latin America, Asia, and Africa is relatively favorable to upland rice, except in some high-altitude areas where the temperature drops 5.2°C per 1,000 m increase in altitude. Minimum and maximum temperatures average 20 and 30°C for Latin America, 20 and 32° C for Southern Asia, and 18 and 35°C for Africa. The optimum temperature for maximum rice photosynthesis is about 25-30°C. Soil temperature may be more important for upland rice in terms of water absorption, evapotranspiration, and root development in soil profile.

Upland rice, if broadcast, may suffer from high soil temperature at the start of the rainy season if the rain does not start.

Solar radiation. Solar radiation plays a central role in spikelet formation, grain filling, and ripening as well as in the rice plant's water and nutrient uptake. The total radiation is affected by seasonal changes of rainfall distribution and day length. For example, the increase in rainfall along with a decline of day length in August and September in the Philippines causes a pronounced drop in total radiation by 313 cal/cm^2 per day (24). Generally, rainfed rice cultivated during the rainy season receives a total radiation ranging from 380 to 420 cal/cm^2 per day in tropical regions. Compared with irrigated rice cultivation in dry season, this will represent a 20-30% reduction in total radiation. This is probably a cause of generally lower grain yields of rainfed rice in humid tropical regions. Low solar radiation is, however, less adverse to upland rice than drought stress. In many cases, shading may improve rice growth and increase grain yield because it conserves soil water and makes photosynthesis per unit of light more efficient under rainfed conditions (30).

Relative humidity. A seasonal variation in relative humidity follows seasonal changes of rainfall. It may reach 80-95% in wet tropics and drop to 20-30% in dry regions. High relative humidity determines duration of seed viability in storage and favors development of some fungus diseases.

Evaporation and evapotranspiration. Evaporation is related to total radiation, temperature, vapor pressure, and wind speed. It may vary from 3 to 5 mm/day in the wet season to more than 6 mm/day in the dry season in the tropics (24).

Soil

In general, many upland rice soils are well-drained, more acid, and contain low amounts of basic cations. Because of erosion and leaching, soil fertility declines rapidly with fast decomposition of organic matter and important loss of fine and soluble mineral elements. Nitrogen and P deficiencies are widespread and Al and Mg toxicities are fairly common.

In Asia, upland rice is mostly on flat or gently sloping soils in India and Bangladesh but mainly on hillsides where slopes exceed 8% in southeast Asia, especially in Vietnam, Laos, and Thailand.

Upland rice soils in most parts of Africa have low available water-holding capacity due to coarse textures, often kaolinitic, and with severe nutrient deficiencies and Al and Mg toxicities (12, 15).

The soils of tropical America are Oxisols, (Ferrasols) (34%), Ultisols (22%), Inceptisols (Cambisols, Gleysolsj (l6%), Alfisols (12%), Entisols (Fluvisols, -Lithosols, Regosols) (8%), and other soils which occupy small areas (26).

MAJOR CONSTRAINTS IN UPLAND RICE PRODUCTION

The major constraints commonly observed in upland rice production are either physical (drought stresses and soil problems), biological (diseases, insects, birds, rats, and weeds), or socioeconomic.

Physical constraints

Drought stresses are responsible for seasonal yield fluctuations of upland rice while poor soil is a main cause of low yield.

Drought stresses. Moisture stress is the primary limiting factor in the growth and yield of upland rice. Stansel (27) estimated that for world rice production, moisture stress would be changed by ± 8% if the estimated rainfall changes by ± 15% whereas in upland rice production a 15% decline in rainfall would result in 30% reduction in production but only 3% decline in world rice production. Generally, soil moisture stress occurs in rice when 50% of total available soil water is depleted.

Rice is particularly sensitive to water stress at the reproductive stage or from 20 d before to 10 d after heading (20). Pollination is most affected by drought stress (10). However, drought which can occur during the growing season in a region of uncertain rainfalls may cause a decline in grain yield or may destroy a crop if it coincides with any sensitive stage of crop growth from germination to before physiological maturity.

A difference of 1 or 2 wk earlier or later in sowing can lead to the success or failure of upland rice in a particular year. The same happens if rainfall ends 1 or 2 wk before the physiological maturity.

An improved upland rice variety in the present concept has some plant characteristics that are intermediate between modern irrigated rice and the traditional variety, for example, moderately long and droopy leaves, moderate height, moderate tillering ability, and moderate recovery ability (2). In drought-prone areas, early-maturing varieties are desirable with a root system that is characterized by La1 et a1 (17) as follows: deep root system; higher root mass, particularly when grown at high soil moisture; greater root diameter; few but stronger roots for deeper penetration, and lodging resistance; a larger cross-section area to have large root volume; a higher root-shoot ratio for better water absorption and uptake.

Hybrid rice may be a genetic source to provide better plant traits, especially a root system that can effectively tolerate drought. According to Yap and Chang (29) rice heterosis may be more important under rainfed conditions than under irrigated conditions.

Use of early-maturing varieties and early planting may help upland rice crops escape drought stress due to early rainfall cessation. Soil moisture conservation becomes crucial for upland rice cultivation in the drought-prone areas. It can be improved by reducing water runoff losses and evaporation, and by increasing infiltration rate, soil's water-holding capacity. A rice variety that grows rapidly and covers bare soils quickly in the early growing season is not only able to effectively compete with weeds but also enhances the soil moisture conservation through reduction in evaporation, rainfall intensity, and water runoff.

Some cultural methods to conserve soil moisture may relieve adverse effects of drought on upland rice crops. Minimum tillage, bunding, weeding, reasonable plant density with respect to both water stress and weed infestation, and mulching practices in which crop residues will be incorporated into soils are commonly recommended for upland farmers. Finally,

a good knowledge of local meteorology, particularly of the frequency, duration, and probability of dry spells and soil water budget in each cultivated area, would benefit farmers in regions where irrigation facilities are inadequate.

Soil problems. Upland rice prevails in the tropical areas, where fertility declines rapidly under improper soil management. Clearing and uncontrolled burning, slope cropping, climate, and inherent soils, in addition to human intervention, account for soil erosion and soil fertility deterioration.

Deforestation for arable land uses causes changes in soil temperatures that influences soil microorganisms and organic matter. This also reduces soil moisture content by formation of surface crust.

The main principle for soil erosion control is to provide a continuous vegetative cover to diminish rainfall intensity and water runoff. Fast-growing crops, including cowpea, soybean, pigeon pea, and other legumes, may be good companion crops for rice.

Improvement may be made in shifting cultivation by introducing efficient, stable cropping systems such as mix cropping, relay cropping, and intercropping, to ensure subsistence of farmers through increasing crop productivity in low input production systems. A system of alley cropping recently developed by IITA in Nigeria is a good alternative to shifting cultivation. In this system, food crops (rice, maize, cassava) are grown in alleys formed by hedgerows of leguminous shrubs or trees. However, more studies should evaluate legumes that grow fast and are suitable to various environments. Also, it is necessary to design sufficient incentives to transfer this soil and water conservation technology to the poor upland rice farmers.

Liming can improve many acid soils. Adding organic matter to well-drained soils with green manure, farmyard manure, crop residue, and compost would improve soil structure. Chemical fertilizers, which are recommended to compensate for nutrient loss, would not be economic for farmers who grow upland rice with a high risk of crop failure due to uncertain rainfall.

Biological constraints

Upland rice usually suffers more seriously from biological constraints - problems of insects, diseases, rodents, birds, and weeds - than irrigated rice.

Diseases. Major fungal diseases, such as blast (*Pyricularia oryzae*), leaf scald (*Rhynchosporium oryzae*), brown spot (*Helminthosporium oryzae*), and dirty panicles are common in Africa, Asia, Latin America, and the Caribbean countries. In addition, eye spot (*Drechslera gigantea*), and the recurrent hoja blanca are also threatening diseases in Latin America and the Caribbean countries. Sheath rot exists in Africa. On upland rice, water stress, soil problems (acidification, sandy soil, low water-holding capacity, and soil nutrient imbalance) aggravate disease epidemics.

Insects. Stem borers are common on upland rice everywhere. Termites, ants, *Elasmopalpus lignosellus, Blissus leucopterus, Phyllophaga* spp., the *Sogatodes* planthopper, an insect vector of the hoja blanca virus, are

widespread in many areas of Latin America and the Caribbean countries (18). Whitebacked planthopper, root-knot nematodes, and leaffolders are common in Asia. Termites and white grubs *Heteronychus* spp. are more serious in Africa.

Other pests. Rodents and birds are probably the most serious pests on upland rice. Serious damage from birds, especially from *quelea* spp. is well documented in Africa. Migratory birds are also severe in Central America, Colombia, and Venezuela (1).

Weeds. Weed infestations are more severe in upland rice than in wetland rice because of lack of submergence that depresses weed population. Shifting cultivation in forest regions has few problems the first year but after that weed infestation reduces yields. Weed problems also contribute high production costs which small farmers cannot support.

The increasing population pressure tends to intensify shifting cultivation and not to diminish it as forestry scientists and ecologists would advise. Because of the scarcity of land suitable for wet rice cultivation and inherited land tradition in Africa and Asia, farmers must move to available forest areas although they are isolated and suffer from lack of services and minimum necessary conveniences. However, they may enjoy more freedom and independence in their work (25). The demographic pressure is an indirect cause of land deterioration because farmers extend the cropping periods and shorten soil fallow necessary for fertility restoration. When the population density exceeds 25 persons/km^2, shifting cultivation, deforestation, and land degradation are bound to occur (9).

UPLAND RICE RESEARCH AND DEVELOPMENT STRATEGY

Except in rare mechanized schemes, upland rice is not concentrated over large areas like wetland rice. It is scattered throughout a country, especially in remote areas including hills, mountain sides, forests, and savannas where land is still available to farmers. Many farmers are poor, they lack communication, health facilities, education. Improving upland rice production is consequently not a simple task of using technical approaches alone to solve such a complex problem. An integrated approach including socio-economic components becomes crucial in mobilizing multidisciplinary efforts to support such an improvement. Unfortunately upland rice research and development schemes until now are mainly restricted to a simplistic technical or vegetal approach.

Upland rice research

To be more practical and acceptable to farmers, research on upland rice must be oriented toward:

- grain yield stability and intensification of cropping systems aimed at maintaining soil fertility, controlling soil erosion and weeds,
- minimizing the risk of crop failure due to the erratic rainfall, and
- the different methodologies for the four great categories of upland rice described earlier.

More fundamental physiological aspects. It seems that not much fundamental profound work on these aspects of the rice plant has been done under dryland conditions. More specific work on the role of amino acids, soluble nitrogenous compounds, enzymes kinetics, and particularly preheading stored carbohydrates with their remobilization under drought stress should be studied. The energy expense for drought resistance, particularly drought avoidance, should be studied quantitatively since many drought resistance features cause negative impacts on grain production.

Varietal improvement. It would provide valuable genetic resources for varietal improvement programs if more effort were directed toward extending and analyzing for better utilization, and collecting local upland rice varieties, particularly in African regions. Since upland rice environment varies from one place to another, a research program for this crop should aim at a specific environmental condition. A clear-cut description of plant ideotype should be made for different environment categories. Effective selection criteria for both dry matter and physical, biological, and socio-economic constraints should be developed.

Hybrid seed has great potential in rice production for both dryland and wetland rice cultivation. Hybrid rice may be used for upland cultivation under favored conditions.

Environment improvement. Climate and soil are two major factors that directly influence upland rice production.

- *Climate.* A good stand establishment is required for a good upland rice harvest. Therefore, seedling vigor, seeding rate, and planting date must be studied for each region.
- *Soil.* Research should focus on tillage conservation, green manure, organic matter, live mulch crop, and cropping patterns, especially alley crop in which fast growth legume tree is intercropped, aimed at soil and soil moisture conservation. The study must also be directed to soil nutrient use efficiency, especially nitrogen and phosphorous, and their loss mechanism. Indigenous sources of fertilizers such as farmyard manure, compost, and legume crops deserve to be developed. Studies on soil acidification, nutrient deficiency (P, N, Zn, Fe, S, Si, . . .), toxicity (Al, Mn, . . .), and practical correction methods should be included.

Crop protection. Effective, low-cost, and nonpolluting crop protection technology and the integration approach for main biological problems — weeds, birds, major diseases (blast, leaf scald, leaf spot, hoja blanca, bacterial diseases, etc), and insects (stem borer, termites, nematodes, etc) — under different farming systems must be generated.

More power to better practice upland rice farming systems. In the local farming system, research efforts should focus on:

- improvement of traditional cropping systems in terms of productivity and soil and moisture conservation,
- developing more productive and profitable upland rice-based cropping systems or other alternatives to shifting cultivation,

- studies on crop rotation, interplanting, relay cropping with fast growth legumes or other crops aimed at soil and moisture conservation, anti-erosion and farmer profits, and
- studies on response of various cropping systems to different input levels and technologies, and identifying the most economic cropping pattern with minimum crop risk.

Long-term studies on upland rice-based cropping systems in particular areas outside research stations will make findings more realistic and easily acceptable to local farmers.

Upland rice development

An appropriate development scheme for upland rice would require the following:

- National policy reorientation. The local government must give reasonable priority to both research on relevant technology and development for upland rice;
- Characterization and detailed zonation for upland rice cultivation;
- Effective upland rice extension program. With emphasis on small farmers, upland rice extension would need new strategies and appropriate methodologies so that it could extend its coverage and actually reach more small upland rice farmers.
- Socioeconomic improvement. Improved socioeconomic conditions in rural areas would facilitate and encourage efforts in upland rice development in developing countries.

CONCLUSIONS

The world average upland rice yield has been stagnant at 1 t/ha for a long time. The majority of farmers still practice traditional farming systems characterized by low-cost inputs and manual work, and improper soil management has led to soil erosion and degradation in many parts of the world. Even the present emphasis on making research more relevant to the upland rice crop has made limited progress in production improvement. More serious efforts must be devoted to generating a new technology adaptable to local upland rice conditions and implementing the multidisciplinary approach in favor of small-scale farmers to increase upland rice production.

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MORPHOLOGICAL CRITERIA FOR STUDY OF LOWLAND VALLEY SUITABLE FOR RAINFED RICE

M. RAUNET

Except for specific problems of mangrove and floating rice cultivations, two types of rice cultivation opposed in water regime and the necessary amount of management works will be considered here. On the one hand is strictly pluvial rice (javanica types), watered only by rain, cultivated on naturally well-drained land, and that does not require specific preparation (except perhaps to prevent erosion). On the other hand is irrigated rice with controlled flooding regime (indica types), which requires carefully prepared and constantly maintained hydroagricultural works.

These two types of rice cultivation are contradistinctive because of their edaphic requirements, cultivation methods, and varieties. Strictly pluvial rice mainly depends on rainfall distribution, soil water-holding capacity, and root penetration — factors determining its water supply. Pluvial rice under well-drained conditions is also sensitive to an excessive exchangeable aluminum content, and, therefore, to soil acidity. Other problems include control of blast (pyriculariosis), weeds, and erosion. Maintaining fertility is a constant concern; crop rotation, amendments, and soil tilling must be carefully combined for each type of environment.

Irrigated rice requires favorable environmental conditions (sufficient water and flat, level zones, usually on river plains), heavy investments, constant maintenance by motivated farmers with good technical knowledge, competence, and ancestral traditions. These criteria are rarely found all together in Africa.

The sociocultural and natural conditions of Africa today are not always favorable for these two main types of rice cultivation. However, rice cultivation on valley-floors with little land preparation retains benefits from certain traditions that should be improved and extended. The valley floors, the small valleys and depressed axes, which in Africa form the elementary drainage system of the deep weathered rock, represent a large surface area (estimated at 1.3 million km^2) and combine hydropedological conditions favorable for rice cultivation.

DAP/IRAT, B.P. 5035, Montpellier, France.

In intertropical regions, termed "valley bottoms," are the flat or concave bottoms of vales, small valleys, and floodable gutters. They form the elementary drainage axes encased in the thick, weathered rocks of the "peneplaned" crystalline basements. The valley bottoms are specific and essential land units in tropical environments. They are the main axes of convergency for surface waters, hypodermic flows, and groundwaters contained in the thick weathered mantle, and fed by rains. As opposed to usual river valleys, valley bottoms make up a large proportion of the upstream drainage network. Their soils are waterlogged or submerged for a large part of the year by groundwater and surface runoff.

Regions with annual rainfall of less than 1100 mm, which is considered insufficient for strict pluvial rice, could grow rice in the valley bottoms.

As opposed to strict pluvial and irrigated rice cultivation, valley bottom rice cultivation is more difficult to define exclusively. In hydrological terms, valley bottoms vary greatly in direct rainfall, groundwater, runoff, and the overflow of the streams. The contribution of groundwater varies little over a long time. One predominant characteristic of a valley bottom is the intricate nature of water regimes.

In examining the concept of valley bottom rice cultivation it is necessary to make a comparative geographic study concerning the structure genesis and hydrological functioning of the main families of small valleys in Africa and Madagascar.

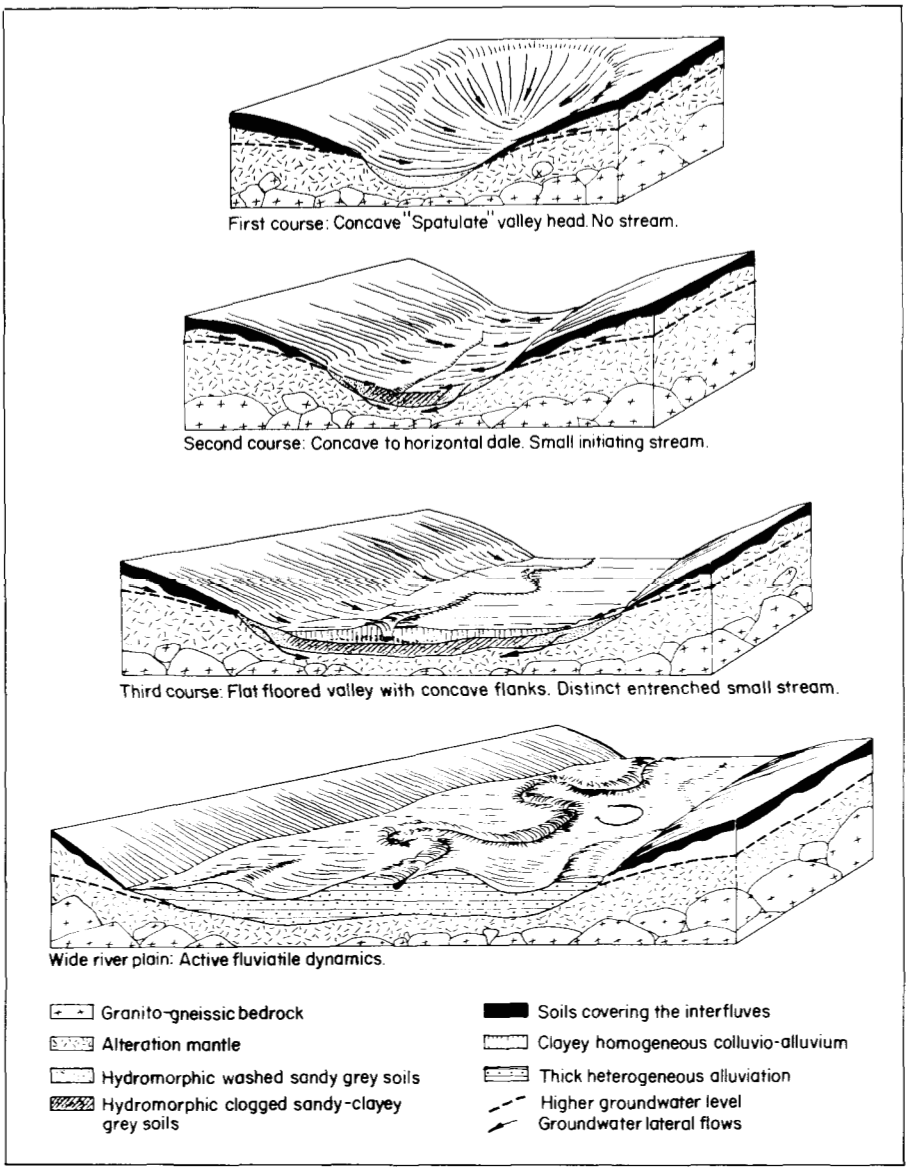
This structural analysis will aid us in determining general laws concerning the pedological and hydrological particularities of small valleys on the scale of the African continent. The aim is to exploit natural hydrological regimes to the maximum and to avoid unadapted or too expensive works.

GENERAL CHARACTERISTICS OF VALLEY BOTTOMS

Intertropical environments with rainfall between 700 and 2000 mm, drained by small valleys, possess a mantle of thick weathered products. This mantle is only a few meters thick in dry regions, and up to 40 m thick in humid regions. This weathered material is the seat of groundwater, which is discontinuous and temporary in dry regions and usually continuous and permanent in humid regions. During the year, in relation to the distribution of rainfall, the upper part of the groundwater is subject to vertical fluctuations and lateral flow. It converges in the nearby valley bottoms where it may outcrop. From upstream to downstream, and transversely, a valley bottom system is generally differentiated as shown in Figure 1.

First course

The top upstream part (short in a dry region and long in a humid region) of a transverse concave profile with no clearly defined stream usually widens into a "spatulate" or "amphitheater" form. Soils are sandy, the weathered rock is near the surface. Groundwater outcrops freely in the rainy season and flows laterally downstream. Genetically these upstream parts are being gradually



1. Tropical valleys. Schematic morphopedological differentiation upstream to downstream.

depressed because of the physicochemical departure of matter. On the one hand, there is selective hypodermic drawing-off (washing) of the fine particles of kaolinitic alterites through which the very mobile upper groundwater passes when converging at these places.

There is also a slow downstream movement by flowage of this section of alterations during washing, because of the destabilizing and mobilizing action of the circulating groundwater.

Second course

Still upstream in relation to the total network, the second course is marked by a lessening of transverse concavity. The transverse profile becomes horizontal in the center, the flanks remaining distinctly concave. A slight channel caused by the concentration of flow becomes apparent. Soils become clayey-sandy and there is a lack of alluvial deposits. Washed material has become clogged by clayey colloid particles that come from courses upstream. Flanks are subjected to washing and flowage. Groundwater continues to outcrop and flow on the concave edges, helping to flood the center of the gutter, where this same general groundwater remains confined beneath the clogged clayey-sandy material. In the axis of the valley bottom are two sheets of saturating free groundwater: deep groundwater, located in the granito-gneissic regolith, and floodwater, the two separated by material varying in its degree of impermeability. This clogged level is distinct in dry regions, and less so in humid regions. Its formation is also linked to the longitudinal slope of the valley. The greater the slope, the less the clogging.

Third course

The valley widens and its transverse profile becomes distinctly horizontal in the third course. A definite stream can be observed, embedded 1 to 2 m and sometimes bordered by small levees. Alluvial upbuilding is now observable, with a fairly homogeneous loamy-clayey texture, covering a sandy-gravelly base, all lying on granito-gneissic weathered rock that is only slightly reworked (earlier flowage) and is often clogged. The degree of clogging of this suballuvial material is more or less accentuated depending on the particular morphoclimatic and lithological environment. It has a considerable effect on the hydrological regime of the valley bottom (confining groundwater contained in arenaceous alteration), therefore on rice cultivation.

The valley bottom alluvium is a decantation deposit beneath graminaceous strata, allowing the spread of a sheet of fairly calm water resulting from the overflow of the stream fed from surface runoff and outcropping of groundwater. On the edges of the river flat, the valley may still exhibit concave fringes. Here soils are washed and sandy, because of outcropping of groundwater lying beneath the interfluves.

Groundwater contained in the weathered material that covers the landform, converges in the valley and circulates in suballuvial material. In addition, there is usually perched groundwater lodged in the actual alluvial upbuilding. Its fluctuation is linked to the flow of the stream, which goes through the valley. In relation to the upstream courses, the hydrological regime becomes more complex in function of the origin of supply (direct rainfall, runoff, floods, general groundwater, perched groundwater) and space-time differences. At the height of the wet season, these waters cannot be distinguished, saturating materials and flooding the valley.

PASSAGE TO THE TURBULENT RIVER VALLEY

These river plains are suited to development of a type of rice cultivation quite different from that of the valley bottoms. As opposed to the case of the latter, the adaptation of rice cultivation to the natural hydrological regime is impossible without considerable costly hydroagricultural works. They belong to irrigated rice cultivation and do not enter this study.

The foregoing model constitutes a structural axis of reference from which modalities and associations of basic components of the main families of African valley bottoms will be distinguished.

The appearance of alluvial upbuilding from the head of the network is a variable characteristic depending on the family considered, but essential to identify for rice cultivation, because the soils are better for crops than elsewhere. The same applies to the extension of the concave sandy flanks usually prized for phreatic rice cultivation. This fringe may be negligible in one type of valley or considerable in another. Another distinguishing criterion is the extent of the clogged clayey-sandy level beneath the alluvial upbuilding. Depending on the type of association with sandy flanks (width, slope, and relative altitude of the latter), this characteristic may be advantageous or disadvantageous.

The nature of the interfluves also provides important information about the hydrological regime: thickness of the weathered rock, the nature of the soils above them, the relative altitude of summits and valley bottoms, plant cover and shape of the slopes, are all determining factors. Another factor is drainage rate of groundwater, linked to relative altitude and the situation of the landscape in relation to the general base level.

TYPE 1 VALLEY BOTTOM: SUDANO-SAHELIAN
(Rainfall: 800-1100 mm)

Environments and specific characteristics

Type 1 valley bottoms are in Sudano-sahelian or similar regions with rainfall between 800- 1100 mm. They drain landscapes with slight slopes (less than 3%) and differences in altitude. Natural vegetation is sparse, shrub savanna (Combretum or Acacia). This landform has wide undulations, is shaped on alteration materials several meters thick, which are usually relics of a more humid climate. Depending on degree of truncation, the soils which now lie above this weathered material are either kaolinitic ferruginous clays (plinthite) that are hardened or gravelly or soft or they may be Vertisols, Planosols, or sandy Regosols. They are usually characterized by compacting, clogging, or discontinuity at slight depth, and are not filtering. Rainwater tends to run off laterally. The waters thus have a lateral washing action with the frequent creation of discontinuities. In these environmental conditions, the alterite groundwater is not well supplied, and is thus discontinuous and temporary.

The valley bottoms are only slightly entrenched, with gentle longitudinal slopes. They begin as depressed vales, widening into concave spatulate valleyheads. They have washed sandy soils or clogged sandy-clayey soils with no linear cuts, and seasonal outcropping of groundwater. Downstream are wider valleys (more than 200 m) with a transverse horizontal profile, built up by colluvio-alluvium from one to several meters thick, and cut to a depth of 1 to 3 m by a small intermittently flowing stream. Deposits are usually clayey (sandy-gravelly at the base) and highly structured. They lie on clogged sandy clay formed in the unreworked or slightly reworked weathered material (regolith).

The hydrological regime of floods is characterized by slight influence of groundwater, and by an abrupt flow regime. In the height of the rainy season, groundwater only outcrops in the upstream parts of the valley. Further downstream, once the soils of the interfluves are quickly saturated, flow is irregular and is linked to the unstable rainfall regime. Floodwater may disappear a few days after the rain has stopped. In the axis of the valley bottom, two types of free saturating groundwater are distinguished: regolith groundwater beneath the alluvial upbuilding more or less confined by suballuvial clogged clay, and perched groundwater (or *alluvium groundwater*), lodged in the alluvial clayey upbuilding and its base gravels. The latter is fed by overflow from the stream and flows which converge from all sides toward the valley. At the end of the rainy season, these groundwaters remain for several months, then gradually dry up.

Consequences for rice cultivation

These types of environment, with an annual rainfall of less than 1100 mm, and slightly pervious soils with low water-holding capacity (high lateral water loss), make strict pluvial rice cultivation impossible. Attention should therefore be turned to the valley bottoms.

These valley bottoms function as wide upfilling gutters with relatively sudden and sporadic variations in water level following violent storms, rather than as calm places where water is maintained at a slight depth, where there is regular seepage and dripping of groundwater. In these types of environments there is considerable wash and flow, to the detriment of deep percolation, which feeds the groundwater. We cannot count too much on perennial continuous groundwater at the foot of slopes to compensate for lack of rainfall. It is necessary to take maximum advantage of surface runoff: reducing its violence by diffusing and controlling it, improving the soil absorption rate to favor percolation, thereby filling the soil reservoir and feeding the perched groundwater lodged in the alluvial upbuilding. The aim is to build up sufficient water reserves to compensate at any time for a break in rainfall of 10 to 15 d, which often occurs in Sudano-sahelian Africa.

Valley bottom rice cultivation in dry regions requires hardy varieties able to resist sudden variations in the water regime. Usually sown as strict pluvial after soil preparation, it must go through an early critical stage totally dependent on rains, thus it must be extremely resistant to drought. At the

same time it must rapidly become strong and cover the soil to resist asphyxia and the violent sweeping due to the concentration in the valleys of the first storm rains, during which period graminaceous plants are dry or burned and therefore not covering.

Once this critical period (usually June and July) has passed, the rainy season sets in, and growth develops. The water regime is relatively stable until the end of July. The rice then requires thorough weeding. From the end of July, 2 mo after the start of rains, the soil is saturated; the small valleys are abundantly fed by surface and hypodermic flow, groundwater outcrops in the sandy heads of the valley bottoms, and streams acquire their maximum volume and overflow. The rice is usually flooded by a sheet of water varying in depth of up to 1 m, closely linked to the storm regime, which regulates the flow regime. Groundwaters, which act as a buffer in more humid regions, have little action here because of the level nature of the landscape, the small amount of weathered material, and an almost generalized clogging of suballuvial material that confines the groundwater.

The rice may be subjected to great stress in August either because of immersion by floods, which are abrupt, heavy, and prolonged; or because of dry periods caused by breaks in rainfall of a week or more, frequently at the height of the rainy season.

The root system, more or less adapted to a flood regime, is usually shallow and slightly developed; thus a drought in the upper 25 cm of soil is harmful.

Rice must be selected to resist drought, fluctuating floods, brief immersion, and lodging. It must also have a good tillering rate and be resistant to blast. This ideal variety has yet to be found. Some traditional African varieties with medium to low yield (1-2 t/ha) combine some of these criteria (Gambiaca).

To improve and control these natural conditions, rational development requires small works, well adapted to the particular course and its catchment area. We distinguish the upstream courses from those downstream.

The upstream courses

Upstream courses are concave and slightly depressed, less than 200 m wide, with no channels or alluvial deposits. They have sandy soils, and no violent flow. They usually drain catchment areas of less than 5 km^2. Farmers like these sandy gray soils for their food crops (other than rice) because they are easy to work. Usually large buttes (50-80 cm) are formed to prevent waterlogging by groundwater. Water only begins to flow freely at the surface 1 or 2 mo after the rains start. Rice sowing in strict pluvial conditions is therefore particularly dangerous on these soils that have a low water supply. Even at the height of the rainy season the groundwater may disappear, and in any case fluctuates rapidly. The gray soils of the dry zones are therefore much less suited to phreatic rice cultivation than the gray soils of zones with more than 1100 mm rainfall, which are genetically comparable to them. The possibility of catching runoff by means of a system of dikes, is limited because of the small size of the catchment area, the low water-holding

capacity of the gray soils, and the dikes themselves, which are made of sandy material.

Thus, as a rule, the water regimes of these valley heads cannot be substantially improved, which makes them unsuitable for risk-free rice cultivation.

The downstream courses

Downstream courses are flat, more than 200 m wide, with colluvio-alluvial upbuilding, and cut by a winding stream. They have relatively fertile clayey soils, and are subjected to frequent floods. They drain catchment areas of 5 to 50 km^2. Beyond 50 km^2 are the vast river valleys whose development for rice cultivation requires much greater works, and which are outside this study. In relation to soils of the interfluves, these courses have a much greater agricultural potential than the gray soils at the valley heads. Extreme hydrological regimes (passage of too much instant water or drying of the root system if there is insufficient rain) may be envisaged by checking the strength of the flow, its infiltration, and even temporarily retaining it for release later in the dry season.

The two extreme types of works (both in size and cost) that may be considered are dikes and total storage dams:

The dike system. Dikes 30-50 cm high are equipped with small outlets, and are built along contour lines to form an open system. They are usually placed to catch the maximum of normal runoff, letting pass the more violent flow. The advantage of these systems is simplicity and low cost (less than US$450/ha). However, experience shows that, used alone, these dikes have limited utility; they are inadequate during a break of more than several days in rainfall. In addition they require constant maintenance, as they are easily ruptured by heavy flow when the catchment area is greater than 10 km^2. Lastly, the drainage by the central stream is not consistent with the desired result, which is the storage of water thus filtered in the alluvial upbuilding. It has often been observed in Africa that artificial straightening and digging of the channel, to prevent overflow, only aggravates harmful drainage in the dry periods. A system of effective dikes should be accompanied by a series of bulkhead gates across the stream that could be closed as soon as the water level fell. The use of dikes alone is recommended only in the valley bottoms with no distinct central channel, on clayey soils, and when the catchment area is less than 10 km^2.

Total storage dams. Dams more than 3 m high, made of gabions or laterite blocks equipped with outlets, could store the maximum surface runoff and redistribute it downstream in a controlled manner. To be profitable, these dams require an integrated hydroagricultural development for irrigated agriculture in the dry season. In Africa, farmers cannot construct, maintain, and manage these dams themselves. The cost often exceeds $2250/ha. A further disadvantage is that the reservoirs submerge large upstream areas of the best land on both sides of the valleys. Experience shows that these large dams are useful for only a few years after their construction, because of the

farmers' lack of motivation and maintenance.

We suggest that large dams in the Sudano-sahelian valley bottoms present more disadvantages than advantages. For improvement of valley bottom rice cultivation alone, far more modest works must be considered.

An optimum system is one that would check floodwater, limit damage to works, condemn a minimum of good land, store only enough water to irrigate for 2 wk, and ensure a good distribution of flow while controlling the floodwater. It would combine a system of dikes and small dams at intervals along the valley bottoms. The dams would be relatively small, approximately 2 m high. They should be equipped with a central concrete spillway at the thalweg level, and lateral outlets for heavy floods. Emptying works would restitute water to downstream plots when necessary. Between the dikes, the valley bottom is divided into leveled floodable plots bordered by dikes and open to the nearby valley sides to catch runoff. Plots upstream from the dam may be flooded by the rising ofthe reservoir water; downstream plots may be irrigated. Dikes are constructed with channels that enable water to circulate from one basin to another. The cost of such works would be approximately $450-$1200/ha. They require certain technical knowledge and maintenance, but within the farmers' capabilities.

TYPE 2 VALLEY BOTTOM: SUDANO-GUINEAN
(Rainfall 1100-1400 mm)

Environments and specific characteristics

A valley bottom system specific for the West African Sudano-guinean regions will have annual rainfall of 1100- 1500 mm. The typical landscape, on a granito-gneissic basement, is monotonous undulations of long, rectilinear valley sides, with a 3-8% slope often capped with fragmented ferruginous rocks. The valley sides are of hardened plinthites (kaolinitic mottled clay) and therefore exhibit carapace or subsurface ferruginous gravels. Beneath this plinthite, weathering continues for a depth of 10-20 m before reaching bedrock. It serves as an aquifer for permanent groundwater that fluctuates seasonally in a thick layer (5-10 m below the top of the interfluve).

Natural vegetation is sparse forest or shrub savanna. Soils are typical leached, gravelly, or carapaced, usually characterized by a sandy or sandy-gravelly texture in the upper 10-100 cm, and below by plinthite that is often carapaced. In this type of environment, rainwater mostly infiltrates (runoff is less than 1% beneath natural vegetation). When absorption capacity of the mantle of weathered rock is exceeded (rise of the groundwater about 3 mo after start of the rainy season) a hypodermic flow causes lateral washing of the soil (which is thus enriched in sand), then runoff.

Valley bottoms are usually not as wide (less than 200 m) and form a denser network than the Sudano-sahelian type. They also are more entrenched (20-40 m difference in level with the interfluves). From the air, their network exhibits a characteristic segmented pattern, formed by rectilinear sections of constant width, making definite angles between them.

The valley heads (widened into spatulate form) and highest upstream parts of the valley bottoms have concave profiles, a marked longitudinal slope and sandy nonalluvial soils (washed plinthite).

Flooding of the valley begins long after start of the rainy season and is determined by previous filling of all the aquifers.

The suballuvium water table, linked to that situated beneath the interfluves, is usually permanent. However, the perched groundwater inside the alluvium, separated from the former by the deep impermeable level, is exhausted in the dry season because it is drained by the stream, which itself dries up.

Consequences for rice cultivation

This type of valley bottom has characteristics between those of Type 1 (Sudano-sahelian) and Types 3 and 4 (East African dambos and humid regions). Water and hydrological regimes are better than drier region Type 1 valley bottoms. The higher rainfall, greater entrenchment of the valley bottoms, greater depth, and perviousness of the weathered rock of interfluves all make possible permanent groundwater which ensures a better hydrological coverage that is more effective in checking the heavy flow in the valleys and alleviating periods of drought in the wet season.

Compared with the Type 4 (humid region) valley bottoms, Type 2 valley bottoms are less affected by groundwater. It outcrops only briefly, and its rise is hindered by the suballuvial clogging; soils are never peaty. In relation to Type 3 (dambos), these valley bottoms are narrower. The lateral gray-soiled sandy band is much narrower; moreover, a clayey alluvial upbuilding, covering the vertic or clogged level, is generalized. Irrigated rice cultivation with complete water control is usually not possible in these valley bottoms.

Valley heads and lateral fringes

These valley heads, less than 1 km long, are dominated by catchment areas of less than 2 km^2. They have a fairly wide concave profile, distinct slopes, and no cuts. The washed soils are sandy and nonalluvial. There is no violent flow; groundwater seeps steadily, with a time lag of 1 to 2 mo in relation to the rainy season.

The soils, rich in sand, are often poor and not productive in strict pluvial conditions. But for rice, their fertility is revaluated when they are traversed by lateral flows, renewed and aerated, because of the swelling of the alterite groundwater. This aspect was observed in Senegal, on soils that seem genetically comparable, by Bertrand (1), Ganry (3), Haddad and Seguy (4), and Siband (5). As long as they remain exclusively sandy (white sand) without showing underlying clogged clayey-sandy level characters, these soils do not require building of dikes. Once rooting is established, so that its capillarity compensates for breaks in rainfall, the groundwater must remain less than 100 cm below the surface. This is the case for the gray soils of the Sudano-guinean regions with rainfall of more than 1100 mm. The problem on these sites is to determine the most suitable sowing date for each

situation. To overcome the bad water distribution at the start of the rainy season, one technique is to observe the rise of the static level of the water table and to sow in consequence. Late sowing has the disadvantage of leaving the soil exposed to erosion for a long time. Erosion is particularly dangerous on these poorly structured sandy soils. Another disadvantage is that these soils when waterlogged and before being completely covered by the rice, are particularly prone to weed proliferation (*Cyperus, Imperata*). In favorable conditions, sites with gray soils can produce 2 crops a year, in particular two rice cycles if the temperatures permit, which is often the case in Sudano-guinean fields below 500 m in altitude.

The upstream courses

This part is between the sandy valley heads (gray soils or white sands), widened into spatulate form, and the downstream courses with clayey upbuilding cut by a stream. They are at least 100 m wide, their transverse profile is fairly concave without a clear-cut stream. Soils are sandy on the edges, but are clayey-sandy and clogged in the center. They hinder rise of groundwater as well as infiltration of water, and therefore favor the formation of perched groundwater in the rainy season (fed by lateral flows).

These courses are usually less than 1 km in length and the catchment areas 2 to 10 km^2. The centers of the vales have a different water regime that requires different rice cultivation practices. The capillary rise is more difficult to exploit, and the groundwater does not directly outcrop from below. It is a lateral (and upstream) outcropping that contributes to the circulating floodwater of this central part of the gutter.

The difficulty will be the maximum retention of this water to prevent the soil from drying out during breaks in rainfall. This course is the most unfavorable of the valley bottoms. Sudden variations in the water regime have a most harmful effect, and the rice is most vulnerable to these types of stress and their consequences, which are the interruption of mineral supply and increased sensitivity to pyriculariosis. Compared with alluvial soils further downstream, soils here are poor and compacted. Because of clogging, they transmit water slowly and are thus confined and nonaerated (as opposed to the sandy gray soils). Roots are poorly developed and shallow, which accentuates the harmful effect of frequent abrupt succession of flooding and drying. Drying of the soil to a depth of 20 cm is sufficient to affect the rice. To improve this situation, a system of dikes (30-40 cm high) must be built, open to the flanks of the valley bottom. At the same time physical quality of the soil and its water absorption capacity must be improved.

The downstream courses

Generally wider (more than 100 m), downstream courses are transversely horizontal, with a slight longitudinal slope, and with alluvial upbuilding. The soils are more fertile than elsewhere and have a small, well-channeled winding stream. These courses are the most important and valuable parts of

the Sudano-guinean valley bottom network, and may be up to 10 km long. Their catchment areas are less than 75 km^2.

These courses are sporadically flooded 1-2 mo after start of the rainy season, the time required to fill the aquifer of the catchment area. At this time the hypodermic flow and runoff on the valley sides becomes active, and groundwater outcrops upstream and on the edges of the valley bottoms. All these waters converge, cumulating their volume and their effects in the alluvial courses where the streams overflow. The alluvial upbuilding, which lies on clogged sandy clay, also contains groundwater which is fed or drained by the stream, depending on the season. This aquifer may feed the upper part of the soil by capillarity. This soil usually has excellent physical qualities for this water movement as it is loamy-clay porous, and lacking sandy lenses. Once rice is well established, at the height of the wet season, the drying out of the soil is not usually a problem as is the case for the upstream clogged clayey-sandy soils. The stream bed should not be straightened or dug out, however, as this would reduce groundwater and nullify its beneficial effect. Materials for dikes, built to prevent overflow, must not be obtained by scraping the bottom of the channel.

The improvement may, in semiintensive conditions, necessitate a system of irrigation drainage in leveled, floodable plots surrounded by dikes. Water could be stored, if its volume is sufficient, through direct intakes at the rear of vertical lift gates barring the channel. Small storage works (less than 3 m high) could also be constructed across the valley bottom.

TYPE 3 VALLEY BOTTOM: EAST AFRICAN DAMBOS
(Rainfall: 1000-1500 mm)

Environments and specific characteristics

The type 3 valley bottoms, known as "dambos" (Swahili vernacular), are characteristic of east and southeast African environments. Lying on a granito-gneissic basement, they have an annual rainfall of 1000-1500 mm. This is what geomorphologists call the "African surface," situated between 800 and 1400 m altitude. The landform is composed of wide convexo-concave undulations, whose dips form the dambos that are wide valley bottoms. Natural vegetation is usually tree savanna *(Brachystegia).* Soils of the interfluves are ferrallitic, and lie on thick-weathered rock containing permanent and fluctuating groundwater.

The action of termites that build domes several meters high is important for soil morphology.

Dambos are wide, and appear to be only slightly entrenched in the landscape. They have flaring concave flanks, steeply sloped (up to 5%), and have sandy gray soils where, for the greater part of the year, there are lateral flows of the upper part of the shallow or outcropping groundwater. Dambos, that are usually several hundred meters wide, tend to widen into vast plains that may be considered veritable planation surfaces in formation, giving the impression of gradually encroaching on the red soils. The line between the

wide convexity of valley sides with red soils, and the concavity of the gray-soiled dambo, is often marked by an alignment of large closely spaced, dome-shaped termitaria (2-4 m high).

Sandy gray soils of the concave flanks

In relation to the other valley bottom families, the dambos, the gray soils spread considerably and may cover half of the surface area. They are characterized by definite slopes (up to 6% upstream), so are not in danger of flooding. However, there is free outcropping of aerated groundwater with rapid lateral circulation. In the rainy season, food crops other than rice usually are not successful on these sites. Only maize can be grown with reasonable success if artificial drainage is provided.

In the dry season the water table does not fall below 2 m, and fluctuates in the upper 50 cm in the wet season 1-2 mo after the start of the rains. An important factor to consider downstream is the gradual montmorillonitic enrichment of the kaolinitic mottled clay (plinthite), lying beneath the upper sandy level, and the simultaneous appearance of a sharp discontinuity separating the two materials. This differentiation hinders the vertical rise of the deep groundwater in the wet season, and its capillarity in the dry. Consequently and paradoxically, the dryness of the soil at the end of the dry season is more accentuated (on the same transect line) in a position further downstream of the gray soil glacis. For rice cultivation, it is worse to sow too early downstream than upstream, where the capillarity of the rising water table may more quickly and effectively take over from the rains and compensate for their irregularity at the beginning of the season. In any case, an early date of sowing is not necessarily desirable on these soils. If planting is delayed at the beginning of the wet season, it is usually easy to recuperate after the end of the rains because the water table remains at less than 1 m from the surface for several months. In high regions, at relatively low latitude in east Africa, consideration must be given to thermic constraints, which may make it impossible to overlap too far into the dry cool season. However, other crops such as fodder or wheat may be considered in the dry season.

When the crop is established and the groundwater has swelled sufficiently, the rice is rooted in a sandy layer saturated almost permanently by circulating water that is relatively aerated. Rooting in aerated hydromorphic conditions is better than in confined hydromorphic conditions. This special type of hydromorphy is beneficial for rice cultivation. Experience has shown that in Casamance in Senegal, on comparable "gray soils" (2), rice yield is always higher than that on neighboring well-drained soils in strictly pluvial conditions. Even without fertilization, yield is often satisfactory (about 2 t/ha). With adequate fertilization (especially P), the potential may be tripled. Moreover, on these soils yield with rice-on-rice remains satisfactory for several years without crop rotation.

Disadvantages of this type of hydrological regime include

- *Vulnerability to erosion.* Slopes are usually steep (up to 6% upstream)

and the soils have low structural stability. As long as plant cover is not assured, they are particularly vulnerable to surface flows, especially when waterlogged by outcropping groundwater. Simple conservation techniques must then be used. These include contour tilling, use of varieties with good tillering, manuring, regular regeneration by legume fallow for at least 1 yr, and green manure crops in the dry season (when the capillary rise has occurred). In mechanized rice cultivation, heavy machinery and too frequent cultivations must be avoided. Construction of bench terraces along the contour lines may be considered if gutters and channels, which could reduce the groundwater (desirable for other crops), were not created.

- *Another disadvantage of this type of environment.* Even worse under dambo conditions than under strictly pluvial conditions, is the invasion by weeds of the *Cyperus* type. These weeds find ideal conditions for proliferation and are often difficult to eradicate.

The farther we descend in latitude (but still remaining in the dambo region), the more rainfall is reduced (1500 mm in west Kenya and 1000 mm in south Zimbabwe). Thus, more attention must be given to short cycle varieties and sowing dates. An increase in altitude results in lengthening of the cycles, making it impossible to have two cycles.

Clayey soils of the central trough

Water and hydrological conditions are completely different here, and permit flooded rice cultivation. Usually all other crops are excluded, except under special conditions in which a central stream is sufficiently entrenched to ensure natural drainage of the Vertisols, that are in a narrow strip on either side of the channel.

Flooding is ensured here, mainly by lateral flow from the sandy flanks of the dambo. It is usually no deeper than 40 cm, because of a fairly clear longitudinal slope. This flow is always late (at least 1.5 mo) in relation to the start of the rains, but once it has begun it is relatively steady.

These troughs are usually suitable for rice cultivation in classical rice fields, that is in leveled and partitioned floodable plots surrounded by dikes. These plots are fed by a network water supply that maintains a fairly regular depth of water. Dambo floors are usually sloped enough to ensure a gentle flow from one plot to another. In the dambos, the absence of sudden arrival of water (as opposed to what happens for Type 1 and Type 2 valley bottoms) is favorable for this type of rice cultivation. The irregularity of rainfall is lessened here, both in periods of violent downfalls and drought.

The change from a regime of irregular supply of rainwater, into a regime of regular and widespread recharge is because of the depth and absorptive capacity of the interfluve materials and also the size of the rechargeable area composed of gray soils.

Transplanting is possible when special sites may be flooded or irrigated, and therefore lend themselves early to creation of nurseries on the edges of perennial streams, or near permanent ponds, for example. This type of rice

cultivation requires excellent preparation of the plots; leveling, plowing, harrowing before muddling, then transplanting. Regular aquatic conditions make it possible to greatly reduce the weed constraint. This type of rice cultivation is still little known in east Africa, where the dambos offer considerable potential. A fairly good technical level is required for water control and soil preparation.

TYPE 4 VALLEY BOTTOM: THE HUMID REGIONS
(Rainfall greater than 1400 mm)

Environments and specific characteristics

Type 4 of Humid Region valley bottoms characterizes areas with more than 1400 mm average annual rainfall. Natural vegetation is either dense evergreen forest, or tree savanna, or a forest-savanna combination. The purest landform is the half-orange type, with steeply sloping, convex hills separated by flat, deeply entrenched valley bottoms enclosing (up to 50 m).

The reliefs, on granito-gneiss, are underlaid with deep, ferrallitic weathered rock (sometimes more than 40 m thick), terminated by thick red (or ochre) soils, that are homogeneous and filtering. A stoneline or gravel sheet (quartz or ferruginous gravel), separates them from unworked weathered rock (plinthite or rotten rock). When plinthite exists it favors percolation of rainwaters because of numerous elongated small, pit-like alveoles or cavities.

As opposed to what has been observed in drier regions, the soils have not undergone much truncation or deterioration from above (because of washing, clogging, and discontinuities, for example), which would hinder good, deep percolation of waters. Runoff and hypodermic flow are practically nonexistent. Groundwater is always present and well supplied. Except that discontinuities may result from differential weathering and lithology, the phreatic surface more or less follows the considerable differences in landform level. These characteristics enable groundwater to outcrop systematically (or to remain at a shallow depth in the dry season) in the valley bottoms, because of a constant hydrodynamic rebalancing. The absence of runoff on the valley sides eliminates the possibility of violent runoff in the small valleys, with their harmful flushing effect as opposed to valley bottom regimes of Types 1 and 2.

The valley bottoms usually have flat floors, and meet the convex valley sides rather abruptly. They may have a steep longitudinal slope (up to 5% in Madagascar). Their width (20-30 m) has no relation to the size of the catchment area. The valley bottom, on the other hand, widens considerably at its head (a deeply encased amphitheater), then has successions of constrictions and lobes, adapted to the lithology of the basement. The valley bottoms, in the upstream branches of the network, are not cut (absence of streams); groundwater is permanently subsurface. The soil is peaty on the surface, sandy in depth, and is rarely clogged. There is almost permanent waterlogging at the floor of the valley, but no real confinement, because

longitudinal slope and hydrostatic pressure of the groundwater permit a permanent flow downstream. The permanent circulation of waters, added to the absence of seasonal desiccation, prevents formation of montmorillonitic clay in this type of valley bottom (as opposed to valley bottoms of the preceding types).

Between their peaty parts, and the true river plains with more abrupt regimes, the downstream branches of the networks widen (usually more than 200 m), and are cut by a stream. They are built up with organic clay or loam, which indicates calm conditions of decantation of fine particles, but which hinder the accumulation of pure peat. These soils are flooded in the rainy season. They are never dry, although the groundwater may descend to a depth of 1 or 2 m in the dry season.

Consequences for rice cultivation

In contrast to Type 1 valley bottoms, those of this humid region family are exposed neither to risks of dry soil, nor to violent flow. Here the danger is excess water. The soil almost never dries out. Control of excess water from the vertical rise of the groundwater, and the reclamation of often peaty soils are the rice cultivation conditions of the valley bottoms in humid regions.

When farm use is considered, the hydrological system can be subdivided into a peaty upstream part, with no alluvial deposits or individualized stream, and a less peaty downstream part, with clayey deposits in calm conditions with small streams. Next come the typical river plains and valleys which, because of size and function and the amount of development they require, are not included in the valley bottom category.

Upstream parts of the network

The true valley bottoms, in the strictest sense are the upstream parts with heads widening into amphitheaters, 10 to 50 m wide with no clear stream cut, with peaty soils on the surface on top of sandy soils, that are almost permanently waterlogged. The catchment area is between 4 and 10 km^2, and the network is often dense with an antler appearance. Groundwater outcrops permanently, and waterlogs the thick, spongy, loose peat. Use of this type of valley bottom depends on the difficult control of this water, on the reclamation of the peaty-on-sandy soils, and sometimes on laborious clearing beforehand (Raphias etc.). Aquatic rice cultivation, the only type possible, cannot rely entirely upon the natural hydropedological conditions. It is necessary to first create a stable support for crop cultivation and rooting, and to improve and regulate, as far as possible, the hydrological regime of flooding.

Relying completely on vertical fluctuation of the water table is dangerous, because it exposes the rice to frequent variations in water depth. Stable soil and surface flood control are closely linked. Burning the peat is not usually a good solution, because this technique lowers the topographical surface, only making control of the water level more difficult. Another technique, actively practiced and controlled by peasants of the Malagasy highlands, is covering

the peat or its mixture with clayey amendments, destined to create stable soil and to proof the floor of the valley. Dikes separating the rice fields into plots, are constructed to maintain water at a fairly constant depth. The covering clay comes from the scraping of ferrallitic weathered material from the lower parts of the nearby lateral sloping valleysides. At the same time this practice enables the peasant to widen his rice field slightly, and to straighten the edges of the valley bottoms by sharp vertical embankments. In Madagascar, the plowing, muddling, leveling and trampling of the rice fields before each crop year, then the covering by water, contribute to gradual proofing, which progressively improves. Thus, it is possible to confine the water table by preventing it from rising vertically to the surface in the axis of the valley bottom, and it continues as underflow. At the surface, on the leveled partitioned plots, perched groundwater with a controlled depth (10-20 cm) can be maintained. It flows by steps from one rice field to another, controlled by the opening or closing of the dikes. Usually these small works are accompanied by the digging of drains on the edges of the valley bottom to capture the lateral flow of the groundwater and to redistribute it in the rice fields. It is therefore possible to obtain perfect control of the water, as is the case for irrigated rice cultivation. Such a technique, to produce satisfactory results, requires a clear longitudinal slope of the valley bottom, so that there will be a sufficiently rapid circulation and renewal of the floodwater downstream. This type of environment, thus controlled, is as well suited to flooded and transplanted rice cultivation with fairly high yields.

The practice and success of this type of rice cultivation depends on sociocultural motivations, aptitudes, and traditions, as well as on the role that rice, in relation to other crops, is likely to play in the economy of the land. In Africa, the development of these types of valley bottoms is still uncommon, unlike in Madagascar (Asian heritage traditions), where rice is the staple diet, and rice field is the object of particular care.

Downstream parts of the system

After several junctions of peaty valleys, the humid region valley widens (usually more than 50 m), and a small permanent stream with calm overflow becomes more definite. The soils remain fairly rich in organic matter, but lose their peaty appearance. They are usually semiorganic loamy soils with buried peaty horizons, then sand.

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SOIL NUTRITIONAL ASPECTS WITH A VIEW TO CHARACTERIZE UPLAND RICE ENVIRONMENTS

A. S. R. JUO and P. A. SANCHEZ

Because of its semiaquatic nature and shallow rooting depth, the rice plant grown under upland conditions is subjected to water and nutrient stresses. Studies show that growth and yield of upland rice are inferior to lowland or flooded rice. Upland rice generally has shorter and fewer tillers, higher sterility, reduced plant height, and delayed flowering. In a review article, Yoshida (14) concluded that moisture stress and nitrogen deficiency are important factors limiting the growth and yield of upland rice.

Unlike other crops, the world's upland rice cultivating areas are expanding primarily because of social and climatic reasons rather than the soil fertility. In countries such as Indonesia, Philippines, Thailand, Sierra Leone, and Liberia where rice is a major staple food, upland rice is generally grown in areas with favorable rainfall but with heavily leached, infertile soils. Thus, even when water supply is adequate, nutrient management becomes the most important factor for increasing upland rice production.

Soil characteristics

Upland rice cultivation is in both humid and subhumid tropical regions. Major upland soils of these regions have low effective cation exchange capacity, low nutrient reserve, and low available water-holding capacity. Properties and classification of some typical upland rice soils are provided in Table 1.

Traditional practices of upland rice cultivation by small-holding farmers, such as in Sierra Leone, are 3-5 yr of bush fallow, followed by 1-2 yr of cultivation. Upland rice is often intercropped with pearl millet or cassava. Increased and sustained upland rice production on these marginally suitable soils in the high rainfall tropics with priority research for improving soil management practices is needed.

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Table 1. Properties of some well-drained soils where upland rice is grown. (IITA soil data bank).

Depth (cm)	Particle size (fine earth) (%)		Gravel (Whole soil) (%)	pH (H_2O)	Exch. cations (meq/100 g)				CEC effective (meq/100 g)
	Sand	Clay			Ca	Mg	K	(Al+H)	
Oxic Paleustult, Bouake, Ivory Coast									
0-15	59	30	23	5.0	2.5	0.8	0.7	1.2	5.4
15-35	30	43	60	4.6	1.5	0.4	0.4	2.1	4.6
Plinthic Paleudult, Suakoko, Liberia									
0-13	76	18	30	4.5	0.7	0.2	0.4	0.7	2.2
20-53	72	20	47	4.1	0.2	0.1	0.1	1.2	1.8
Typic Paleudult, Onne, Nigeria									
0-15	67	18	0	4.3	0.3	0.1	0.1	2.3	2.9
30-45	67	28	0	4.3	0.2	0.02	0.02	2.2	2.5
Typic Paleudult, Yurimaguas, Peru									
0-5	58	19	0	4.2	0.2	0.2	0.1	3.0	3.6
16-25	40	28	0	4.3	0.1	0.1	0.04	4.6	4.9
Haplorthox, Itaituba, Amazonian Brazil									
0-30	2	83	0	5.2	0.6	0.6	0.2	4.7	6.4
30-55	2	86	0	5.0	0.2	0.1	0.07	2.0	2.6

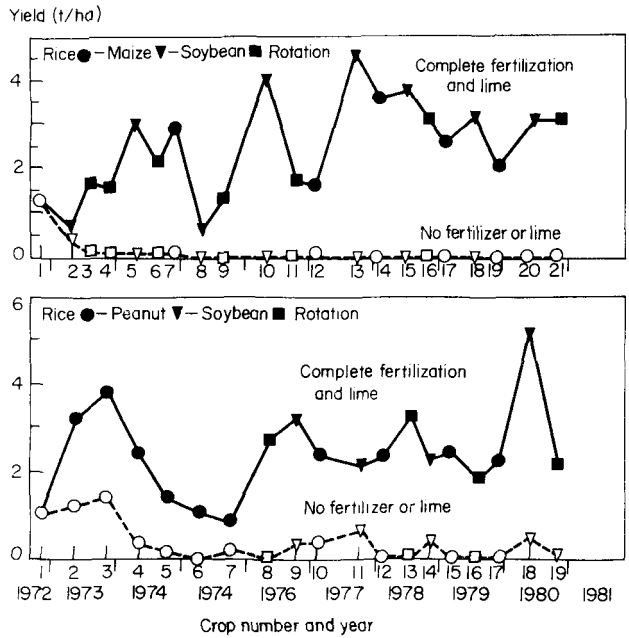
NUTRIENT MANAGEMENT

A continuous cropping experiment of upland rice in an acidic Ultisol began at Yurimaguas, Peru, in 1972 in an attempt to show that chemical input (fertilizers and lime) would sustain yield under continuous rice monoculture (10). However, upland rice grain yield declined drastically after the third crop despite lime applications and complete fertilization including N, P, K, Mg, S, Zn, Cu, B, and Mo (Fig. 1). After the seventh continuous cropping of upland rice, the trial was changed into an upland rice - peanut - soybean rotation. Upland rice yield was maintained thereafter at respectable levels (above 2 t/ha) throughout the 10 cropping seasons (Fig. 1).

Results from these Peruvian trials indicate that continuous production of upland rice can be achieved on strongly weathered soils in the high rainfall tropics with adequate fertilization and crop rotation (10).

Use of nitrogen

Although N is the most limiting nutrient for upland rice in highly weathered soils, few upland rice varieties have shown large yield responses to high levels of N applications. Nitrogen trials at IITA's high rainfall substation at Onne (rainfall 2400 mm/yr) show that most upland rice varieties respond to N applications up to about 90 kg N/ha. Higher N rates resulted in severe lodging and reduced yield. Maximum yield from these trials is usually 2-3 t/ha (8).



1. Long-term upland rice trials in rotation with maize, soybean, and peanut in a Typic Paleudult at Yurimaguas, Peru (TROPSOIL, NCSU, 1981).

Soil moisture

When soil moisture becomes a limiting factor, the interdependence of water and nutrient availability is illustrated by yield data of several upland and lowland rice varieties grown in an Alfisol toposequence at IITA's main station near Ibadan (rainfall 1200 mdyr). The relatively low rice yields under upland and *hydromorphic* conditions are attributed to N deficiency caused by periodic soil moisture stress (Table 2). Rice grown in soils that remain flooded or saturated during the growing season but are drained and become oxidized during the dry season gave highest yield for both upland and lowland varieties. Rice grown in valley bottom soils that remain flooded and strongly reduced throughout the year gave lower grain yield (Table 2).

Research on N and water-use efficiency for upland rice may be dealt with separately according to climatic and soil moisture conditions. In the high rainfall tropics, leaching of nitrate through the highly permeable Ultisols (Paleudults) and Oxisols (Haplorthox) may become a major problem. Split application of N at 90 kg/ha from 1 to 3 applications can reduce leaching losses of fertilizer N from 53% to 28% (1). Moreover, in acid soils, use of NH_4-form fertilizers is preferable to minimize leaching losses (7). This is because these strongly weathered acidic soils contain negligible nitrifiers unless high dosages of lime have been previously applied (1, 7).

In the subhumid or wet-dry tropics, soil moisture stress frequently occurs early in the growing season such as in Ibadan, Nigeria; Bouake, Ivory Coast;

Table 2. Effect of soil water regime on rice yield along a soil toposequence at Ibadan, Nigeria (8).

Water regime	Grain yield (t/ha)	
	Upland varieties[a]	Lowland varieties[b]
Freely drained	1.18	-
Hydromorphic[c]	1.57	1.50
Flooding during growing season	2.31	4.13
Continuous flooding	1.96	3.23

[a]Mean of 7 varieties. [b]Mean of 12 varieties. [c]Fluctuating groundwater table at shallow depth during growing season.

and the Campo Cerrado of Brazil. In these places, an increase in N use efficiency may be achieved by improving soil moisture availability through crop residue mulching and subsoil liming. The low water-holding capacity of the soil and the rapid drainage of excess water through the macropores allow only a small part of the rainwater to be used by the crop. Therefore, adequate growth and yield depend on frequent soil water recharge (8).

A possible solution to increase N and water-use efficiency for upland rice in subhumid regions is to carefully time fertilizer application and planting, and select deep-rooting varieties that use subsoil moisture more effectively during the dry spells. Chang et a1 (3) showed that two local upland rice varieties, Palawan and OS4, have deeper roots and are more branched. But these varieties have low yield potential and do not respond to high soil fertility.

The management of soil P, K, and micronutrients for most crops including upland rice is generally well established (4). The high P requirement of soils derived from ferromagnesian parent rocks and volcanic ash is also well known (9). Banding P fertilizer is essential to minimize fixation by soil. Using high rates of K also facilitates water uptake by plant roots and reduces transpiration loss (2).

Mg and Fe deficiencies

In acid soils, high levels of soluble and exchangeable Al can induce Mg deficiency in oats (6). Mg deficiency may also occur in upland rice grown in strongly acidic Ultisols and Oxisols with low exchangeable Mg contents. Field experiments are needed to determine whether Mg deficiency contributes to the low yield of upland rice grown in strongly acidic soils.

The occurrence of Fe deficiency (chlorosis) in upland rice grown in Alfisols and Oxisols in the subhumid or Cerrado regions is common despite relatively high content of the sparingly soluble total free iron oxides in the soil. A common practice to correct Fe deficiency is foliar application of 0.2% of ferrous sulfate or Fe-chelates. Published data on improvement of soil and water management practices to remedy Fe deficiency in the highly weathered Fe-rich soils are lacking.

Table 3. Soluble silica in some rice-growing soils. (A. S. R. Juo and A. J. Herbillon, unpubl.)

Soil	Depth (cm)	Soluble Si [a] (ppm)
Upland soils		
Haplorthox, Brazil	A	2.68
	B	1.36
Haplorthox, Zaire	A	1.36
	B	1.00
Plinthudult, Liberia	A	1.96
	B	1.18
Paleustalf, Nigeria	A	2.95
	B	1.48
Lowland soils		
Tropaquent, Nigeria	A	3.81
	B	10.43

[a] 0.01 *N* NaCl, 3 days equilibration. A = surface soil, B = subsoil.

Use of silicon

Silicon deserves special attention in rice cultivation. Although it is not an essential nutrient element for rice, it is well known for its beneficial effects on rice growth. These include maintenance of erect leaves, reduction of water loss, increase in oxidizing power of roots, and protection against diseases and insects (11, 13, 14). The use of basic slag as a source of Si to lowland rice is common in Japan, Korea, and Taiwan for soils containing relatively low levels of extractable Si (4).

The strongly weathered soils in the tropical regions have reached high degree of desilication (5). Soluble Si contents in these soils are generally five- to tenfold lower than in most upland soils in the temperate regions (Table 3). Research is needed to determine the effect of Si application on growth and yield of upland rice grown in the highly desilicated Oxisols and Ultisols of the tropical regions.

SOIL FERTILITY ASSESSMENT

Few tropical countries have detailed soil survey and mapping information at the family and series levels which are more useful for agronomic interpretations. The Fertility Capability Classification (FCC) system has been developed to fill this information gap (12).

The FCC system groups soils essentially according to their fertility limitations rather than soil quality. It deals with the chemical and physical properties of the surface (0-20 cm) and subsurface (20-50 cm) soils, The FCC system also attempts to bridge the gap between the subdisciplines of soil classification and soil fertility. It is an open-ended system consisting of a set of *condition modifiers.* To assess soil fertility for upland rice, the following condition modifiers or parameters are selected:

1. Textural type of surface soil (0-20 cm)—
   S = sandy top soils (loamy sands and sands);
   L = loamy top soils, <35% clay but not loamy sands or sands;
   C = clayey top soils, >35% clay;
   O = organic soils, >30% O. M.
2. Substrata textural type (20-50 cm)—
   S = sandy subsoil;
   L = loamy subsoil;
   C = clayey subsoil;
   R = rock, iron pans.
3. Condition modifiers (0-50 cm)—
   d = soil moisture stress because of frequent dry spells during the growing season;
   k = potassium deficiency, exchangeable K below 0.15 meq/100 g (varies somewhat with soil texture and clay mineralogy);
   i = phosphate fixation, standard P requirement >150 µg/g soil;
   e = low effective CEC, <4 meq/100 g soil;
   h = acidic, 10-60% exchange A1 saturation;
   a = A1 toxicity, >60% A1 saturation;
   b = basic reaction, pH >7.3.
   f = Fe deficiency (criteria to be determined).
   q = low soluble silica (criteria to be determined).
   s = salinity, EC in saturation extract $\geq$4 mmhos/cm.

Sanchez et al (12) interpret most of these condition modifiers.

By using the individual guides for each surface and substrata textural type and modifiers, it is possible to prepare composite interpretation guidelines for all the FCC units. Some examples follow:

LCeak = erosion or other removal of surface soil will expose undesirable clay-textured subsoil; drainage limited but favorable for upland rice; low ability to retain nutrients such as K, Mg, and Ca; N application should be split; root growth may be restricted because of high Al toxicity and application of a low rate of lime is recommended; K is needed initially at a high rate of 100-150 kg/ha for the first few seasons of cropping but exchangeable K level should be monitored to determine adequate rate for subsequent applications.

L = excellent soil with no major fertility constraints; N deficiency likely with intensive use.

The FCC system is relatively easy to apply because only a few laboratory measurements of surface soil samples are required. Moreover, it would be more useful to group a set of condition modifiers for each crop or group of crops because soil physical and chemical requirements for each crop species may differ considerably. For example, a “LC” soil would not be good for soybean or cowpea if drainage or temporary waterlogging is a problem. But the same soil would be suitable for upland rice.

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PROPOSALS FOR THE CLASSIFICATION OF AGROCLIMATIC SITUATIONS OF UPLAND RICE IN TERMS OF WATERBALANCE

F. FOREST and F.N. REYNIERS

True upland pluvial rice has been the object of multilocational experiments in West Africa. The Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) (Department of Food Crops of the Centre Internacional en Recherches Agronomiques pour le Developpement), in collaboration with the institutions of agronomic research in the countries of this region, has attempted to better understand the relationships between observed yield and climatic environment.

Regionally, productivity appears to be linked to the isohyets, but on a field scale it is impossible to link yield and rainfall.

To solve this apparent contradiction, IRAT developed a method that has been inoperation for several years. It is based on analysis of rainfall regimes in function of evaporative demand, water requirements, and the soil water reserve useful for roots. This method supplies standard indices of classification of the agroclimatic situations based on water balance of upland rice. These indices, correlated with the productivity observed in agronomic trials, have enabled estimation of this relationship.

Totally microcomputerized, this method functions with the BIP4 file. It could contribute effectively to a fuller understanding of the conditions required for better utilization of rainfall for upland rice cultivation.

The aim of the climatic characterization of the environment, set forth in this communication, is not only to classify the regional climatic risk for upland rice, but especially to supply growers with information about the yield they may expect from their land, and how they may achieve it by improving rainfall use.

On the physiological level, in particular, in view of variety selection for drought tolerance (16), the characterization of water deficits is essential. As Robelin (19) has shown, the relationship between real water consumption and crop requirements is a good means of estimating the deficits, and this leads to obtaining the water balance.

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On the agroclimatological level, the need for a simulated water balance model became apparent, particularly during the first years of the drought in the Sahel (5).

Perfecting of the simulation model began (7) with integration of the Eagleman function (4) and then it was gradually improved. The concept of critical periods proposed by Robelin (19) was applied successfully to upland rice (3, 17). A methodology of water balance for upland rice was established by Kalms et al (10) who measured the real or actual evapotranspiration (ETR) in situ. Finally, local analyses (6) showed a relationship between the ETR of upland rice and production.

This set of results led to establishment of the BIP4 water balance model, the testing of its validity, and its application.

BASES OF THE BIP4 MODEL

Principles of the water-soil-plant-atmosphere models

The first models of water-soil-plant-atmosphere relationships aimed at directing irrigation and using the potential evapotranspiration (ETP) as a reference (15).

For true upland cultivation, the aim of establishing a model is to characterize the optimum level of water requirements by comparing ETR and maximum evapotranspiration (ETM). To calculate ETR, the starting point is the water condition of the soil, which is subjected to random drought and moistening conditions. Calculation of the ETM is based on evaporative demand and the water requirements of the upland rice.

In situ relationships

Eagleman (4) set up a statistical model of relationships between the ETR-ETP ratio (ETR:ETP) and relative soil humidity (RSH). This link was established by measuring, in situ, climatic evapotranspiration and humidity of the soil obtained in multilocation experiments for several crops.

It corresponds to the following third degree equation:

$$ETR/ETP = A + B(RSH) + C\,(RSH)^2 + D(RSH)^3$$

$$\text{with } RSH\,(t) = \frac{HU\,(t) - HU\,(15\text{ atm})}{HU\,(0.3\text{ atm}) - HU\,(15\text{ atm})}$$

HU (t) = soil humidity at time t,
HU (15 atm) = soil humidity at 15 atm, and
HU (0.3 atm) = soil humidity at 0.3 atm.

The values of coefficients A, B, C, and D are calculated in function of ETP (in millimetres per day) by the following equations:

$$A = -0.050 + 0.732\ ETP \qquad r = 0.73$$
$$B = 4.97 - 0.661\ ETP \qquad r = 0.93$$
$$C = -8.57 + 1.56\ ETP \qquad r = 0.95$$
$$D = +4.35 - 0.880\ ETP \qquad r = 0.97$$

Estimating ETR:ETM

The next step calculates the ETR:ETM in function of daily rainfall, climatic demand, water requirements of the crop, and useful water in the soil. Because the aim of the BIP4 (Bilan Hydrique Pluvial, 4th version) model was to serve as a standard agroclimatic instrument of analysis and diagnosis for the cultivation system, it was necessary both to replace the ETP by the ETM and to simulate the useful soil water when it is not known.

Estimating ETM

The ETM of a crop may be estimated by means of two formulae:

$$ETM = K'c\ Ev\ Bac\ (class\ A)$$
$$ETM = Kc\ ETP$$

Measurement of the Ev Bac (class A) gives a good estimation of climatic evaporation during the rainy season (2) with an interannual variation coefficient of 10%.

Reference to the Penman mode of calculation is used for the ETP.

If these data cannot be obtained, simplified formulas such as the formula of Hargreaves for Latin America may be used.

Crop coefficients of upland rice were measured by Dancette (2) in Senegal and by Kalms (11) in the Ivory Coast, by Thornthwaite type evapotranspirometers. For the BIP4 model, the values of Table 1 were used. The high Kc (crop coefficients) values observed, with the maxima reaching 1.35, are explained by a high transpiration of upland rice in soil humidity conditions near saturation. In using Kc coefficients, allow a margin of error of 15% (8).

Table 1. Crop coefficients (Kc), in function of length of the rice cycle and its degree of development.

Days after sowing (DAS)	Length of cycle of the varieties		
	100 DAS	135 DAS	150 DAS
1 - 10	0,40	0,40	0,40
11 - 20	0,78	0,50	0,50
21 - 30	1,00	0,65	0,70
31 - 40	1,20	0,85	0,90
41 - 50	1,25	1,05	1,10
51 - 60	1,30	1,10	1,10
61 - 70	1,35	1,10	1,10
71 - 80	1,35	1,20	1,20
81 - 90	1,20	1,30	1,25
91 - 100	0,90	1,30	1,30
101 - 110		1,30	1,20
111 - 120		1,20	1,10
121 - 130		1,12	0,90
131 - 140		0,85	0,70
141 - 150			
Av (cycle)	1,07	0,99	0,96

The BIP4 model calculates an average value of the ETM for each site studied in conformity with results obtained by Peyremorte and Rosset (13), showing that this simplification involves only a slight error compared with variations in rainfall.

Estimating ETR. The RSH for the period of measurement must be known to calculate the ETR. In the BIP4 model ETR is calculated through the following relationship:

$$\text{RSH (t)} = \frac{\text{(water supply) + reserve (t - 1)}}{\text{RUR}}$$

t corresponds to one pentad of the cycle, and (t - 1) to the preceding one. Useful root reserve (RUR), in mm, defined as the maximum quantity of water available for the roots, corresponds to the depth of the moisture limit to its maximum value.

$$\text{RUR} = \text{HU (0.3 atm) - HU (15 atm)} \quad \text{Zrac da}$$

Zrac = maximum depth reached by roots
da = apparent soil density

Water supply during period t is equal to rains minus surface runoff and drainage.

Runoff is simulated, in the BIP4 model, by a decrease in rainfall when it reaches the triggering level as determined by the user.

Dr (drainage) is calculated by the relationship:

$$\text{Dr (t)} = \text{P1 (t) - RUR + Res (t - 1)}$$

P1 (t) = rainfall during period t.

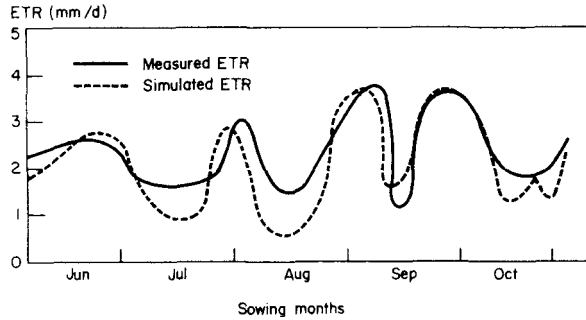
This calculation is made before calculation of the ETR.

Postdrought effect on ETR. After a dry period, when the soil becomes moist again, the ETR does not immediately return to its normal level (18). To account for this factor, the BIP4 model reduces the ETR 30% during the pentad period when rains resume.

Testing BIP4 model estimation of ETR. Measurement of the ETR, in situ, by the water balance of the soil and its estimation by the BIP4 model are highly correlated (6). The relative deviation is 10.7% for the complete cycle (Fig. 1). The lower ETR simulated indicated during dry periods is probably the effect of slight capillary rises (1 mm/d) not taken into account by the model.

However, analysis of numerous results, particularly those of Vauclin et al (22), indicates the BIP4 model estimates the ETR (cycle) within about 10% of the water balance in the soil.

Sensitivity of the BIP4 model. The effect on the ETR and ETM values of the 10% inaccuracy in evaporative demand, and 15% inaccuracy in the crop coefficients, mentioned above, was tested for a season of low or normal rainfall (Table 2). In relation to the accumulation of variations of the two



1. Comparison between real evapotranspiration, simulated and measured in situ. Data obtained with Iguape Cateto variety, Bouaké, 1978 (6).

Table 2. Sensitivity of real evapotranspiration (ETR) simulated rice 136 d, Bouaké.[a]

Situation		Deficit season (1978)			Satisfactory season (1974)	
Hypothesis		Sowing	ETMs	ETR (cycle)	ETMs	ETR (cycle)
kc ETP	–15% –10%	1-5/06	413 mm	280 mm	403 mm	391 mm
kc ETP	0% 0%	16/06	538 mm	291 mm	538 mm	444 mm
kc ETP	+15%	1-5/06	678 mm	297 mm	672 mm	474 mm
CV :	25%		25%	3%	25%	9%

[a] sowing date 5 Jun 1974. Useful root reserve = 50 mm. ETM = maximum evapotranspiration.

parameters, that of the ETR is smaller. The ETR:ETM is more sensitive to deviations from the average in a season of low rainfall than in a season of normal rainfall.

Before proposing a classification code based on standard indices, it is worthwhile to indicate their relationships with crop production.

ESTIMATING POTENTIAL YIELD AND EXPECTED YIELD

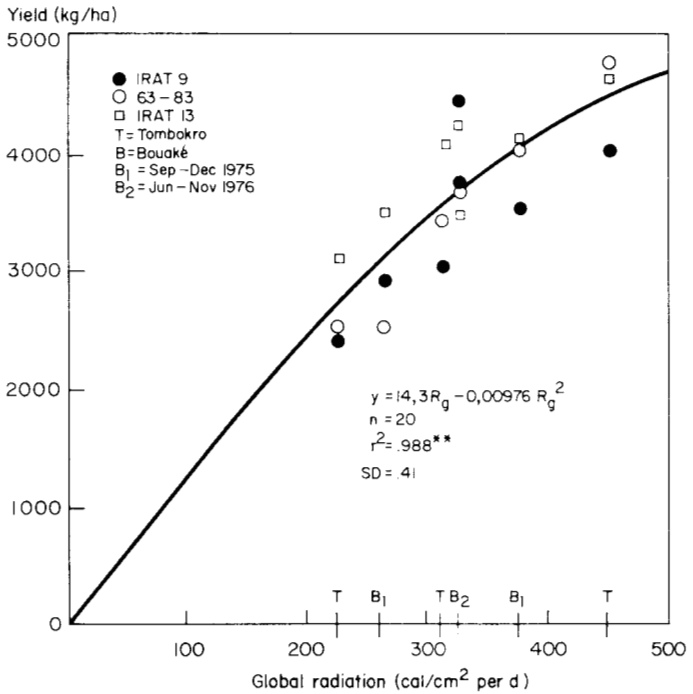
Potential yield

When water supply is not limiting, the productivity potential of upland rice depends on daily average global radiation (Fig. 2), a relationship established by Posner (14) in the Center Ivory Coast region.

The regression function is:

$$\text{Yield pot} = 14.3\ Rg - 10^{-3}\ Rg^2$$

Yield pot is potential yield, in kilogram per hectare, to the ETM.



2. Effect of average daily global radiation on upland rice production for 4 trials in Central Ivory Coast with 3 varieties. Cultures without water-limiting alimentation (14).

The regression coefficient is 98% for 20 pairs of measurements. Small deviations between varieties are relatively slight compared with the increase in productivity due to radiation.

To replace global radiation data by evapotranspiration data, the following relationship, established by Monteny et al (12), was used for a temperature of 30° C:

$$ETP = 8.2 \quad 10^{-3} Rg$$

where Rg = global radiation (cal/cm^2 per day).

If the two relationships are combined, the following may be proposed after simplification:

$$\text{Yield pot} = \text{Ivar ETM (cycle)}$$

Ivar is an index of varietal water productivity expressed in kilogram of grain per millimetre. It translates the water efficiency of the variety. It corresponds to what agronomists call varietal potential, but which they express in tons per hectare. Thus, the Moroberekan variety has an Ivar of 7 (3.5 t/ha) and IRAT 13 an Ivar of 11 (5.5 t/ha) for an ETM of 500 mm. These values were obtained under satisfactory fertilization conditions.

Considerable drainage beneath the roots causing leaching, may significantly reduce the Ivar. Forest and Kalms estimated the Ivar was reduced by half if drainage was 3 times the RUR for the first 50 d after sowing. It is therefore necessary to include drainage in classification indices formulated by the Dr-RUR ratio (Dr/RUR is the standard index of drainage for 1-50 d after sowing).

Expected yield

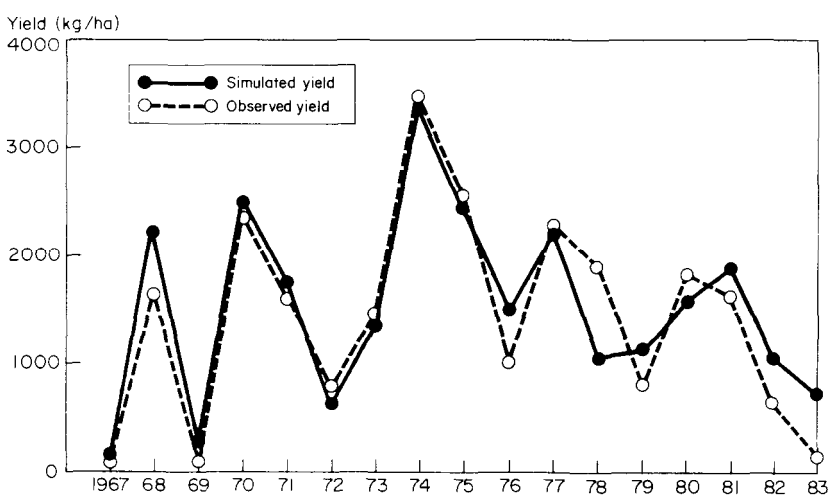
Yield results of long-term trials at Bouaké were compared with the ETR (cycle) and the ETR/ETM pc, which were estimated with BIP4. (ETR (cycle) is the standard index of real evapotranspiration of the cycle, in millimetres; ETR/ETM pc is the standard index relationship between real evapotranspiration and maximum minimum transpiration during the sensitive phase.) The resulting statistical relationship enabled calculation of yield exp (expected yield) in kilogram per hectare, to the ETR.

$$\text{Yield exp} = \text{Ivar ETR (cycle) ETR/ETM pc}$$

ETR/ETM pc corresponds to the minimum ETR/ETM during one of the critical phenological phases of the crop. The calculation method is explained below.

The comparison of yields simulated by this equation with those observed (Fig. 3) indicates a significant link with a correlation coefficient of 0.84.

This relationship must be tested for the regions in which it will be applied. However, it reinforces the value of the indices calculated by the BIP4 model to characterize the agroclimatic situations of upland rice.



3. Comparison of yields observed and simulated by the BIP-4 model. (Data obtained between 1967 and 1983 with OS6 until l974, then Iguape Cateto. Sown between 25 May and 20 Jun at Bouaké, (LC.), (66-80-80) NPK fertilization and RUR (Root water soil reserve) of 50 mm).

REGIONAL CLASSIFICATIONS

Standard indices

Regional classification of agroclimatic situations of upland rice must be based on standard indices that take into account the principal climatic and agronomic parameters. The ETM (cycle)[1], ETR/ETM (cycle), ETR/ETM pc, and Dr/RUR indices calculated by BIP4 seem satisfactory as standard indices.

Calculating standard indices

Standard indices are calculated by the BIP4 model using agrotechnical information:

- period of rice-sowing with a minimum rainfall threshold for soil preparation and sowing;
- RUR;
- division of the cycle into its principal phenological phases, which makes possible determination of the critical period;
- level of rains required to trigger runoff, then the rate of decrease; and
- the rate of decrease in the ETR after drought.

These standard indices are expressed for frequencies of 2, 5, and 8 yr out of 10.

ETR/ETM (cycle) and ETR/ETM pc relationships

Use of two standard indices, ETR/ETM (cycle) and ETR/ETM pc, complicates the classification. The comparison of these indices at Bouaké for the 1967-83 period, made possible establishment of this relationship:

$$\text{ETR/ETM (cycle)} = 0.54\ \text{ETR/ETM pc} + 0.44 \quad r = 0.90$$

Similar relationships were established later, also taking spatial variability into account. For the Ivory Coast, Figure 4 indicates the linear relationship

$$\text{ETR/ETM (cycle)} = 0.47\ \text{ETR/ETM pc} + 0.44 \quad r = 0.87$$

In Brazil, with five stations spread over a north-south axis of several thousand kilometres (21), the relationship is:

$$\text{ETR/ETM (cycle)} = 0.71\ \text{ETR/ETM pc} + 0.29 \quad r = 0.92$$

These relationships simplify the classification by using ETR/ETM (cycle), and the calculation formula of yield exp for the Ivory Coast, for example, becomes:

$$\text{Yield exp} = \text{Ivar ETR cycle ETR/ETM (cycle)} - 0.45$$

It must be noted that the expected yield varies with the square of ETR (cycle).

[1]ETM (cycle) is the standard index of maximum evapotranspiration.

Upland rice classification proposals

The proposed classification of agroclimatic situations is based on three major standard indices:

1. ETM (cycle),
2. ETR/ETM (cycle), and
3. Dr/RUR - 0-50 d after sowing.

The ETM index (daily average for the cycle, in millimetres per day) characterizes the energy potential of the environment and determines the crop potential.

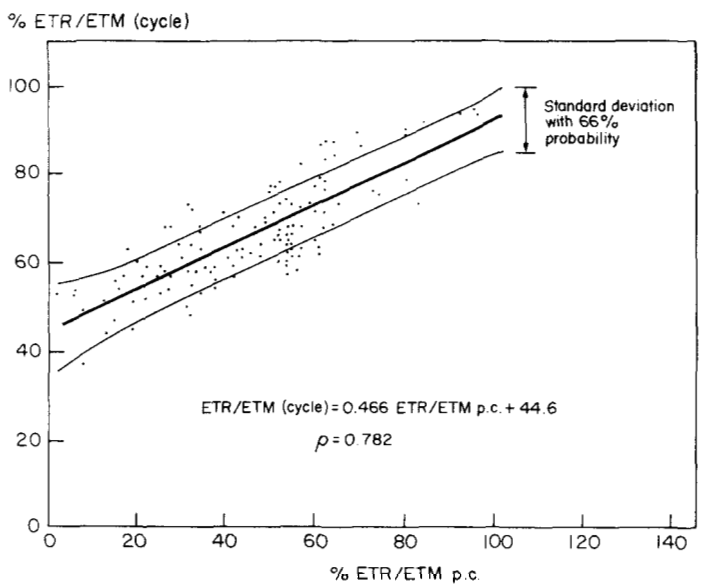
The ETR/ETM cycle index characterizes the satisfaction rate of water requirements for the crop and determines the expected yield for total dry matter.

The Dr/RUR index characterizes the drainage rate and determines leaching and fertility rate (value Ivar or Ivar/2).

These three indices have been used to distinguish classes of agroclimatic suitability proposed in Tables 3 and 4.

To the three standard indices of characterization of the agroclimatic situation, we may add the Ivar index (kilograms of grain produced per millimetre of ETM), which is characteristic of the water efficiency of the variety in nonlimiting fertilization conditions.

Beginning with these standard indices, after experimental testing of the yield exp equation, expected yield may be calculated.



4. Water need satisfaction during cycle (ETR/ETM cycle) and minimum water need satisfaction (ETR/ETM p.c.) comparison for different stations of Ivory Coast: Daloa, Bouna, Bouaké, Adiopodoume, Korhogo, with RUR (root useful reserve) of 50 mm. ETR = real evapotranspiration, ETM = maximum evapotranspiration.

Table 3. ETM (cycle) standard indice for upland rice agroclimatic situation classification.

Class \ Criteria	ETM (cycle) mean (mm/d)
Very favorable	> 5
Favorable	4 - 5
Intermediate	3 - 4
Unfavorable	< 3

ETM = maximum evapotranspiration.

Table 4. ETR/ETM (cycle) and DR/RUR standard indices for upland rice agroclimatic situation classification.[a]

Class	ETR/ETM (cycle)	Coefficient of variation (%)	DR/RUR 1 - 50 DAS
Excess	0,85	8	>3
Very favorable	0,85	8	<3
Favorable	0,75-0,85	15	
Intermediate	0,55-0,75	25	Not
Drought prone	0,55	40	applicable

[a]ETR = real evapotranspiration, ETM = maximum evapotranspiration, DR = drainage, RUR = useful root reserve, DAS = days after sowing.

AGRONOMIC APPLICATIONS OF THE BIP4 MODEL

A major advantage of the standard indices chosen and the simplicity of their calculation by the BIP4 model is that they permit evaluation of the principal agronomic factor impacts of rainfall use.

Choice of cycle length and sowing date

The simulation by BIP4 of the cycle lengths and sowing dates enables eliciting the response of standard indices to these two factors. To choose optimal agroclimatic situation, three factors must be considered:

1. the optimal use of the rainy season, with the possible consideration of a succeeding crop;
2. the maximum value of the standard index ETR/ETM pc; and
3. the minimum value of the drainage indices for the first 4-6 wk after sowing.

This approach, employed for the Ivory Coast, confirmed previous results (9) for the center region: average cycle of 135 d and sowing date at the beginning of June.

Even more useful for the west central region of Brazil, this approach clearly indicated that the importance of the sowing date had previously been neglected.

Observations in the center Ivory Coast region (6) and in Cameroon (20) on the drop in productivity for a wet year may be explained in part by the standard index Dr/RUR at the beginning of the cycle. This quantification of drainage could result in improvements in the choice of the sowing date and fertilization procedure.

Influence of useful water reserve

The rice producer's aim is to maximize his net income. This depends on rainfall risk in the so-called semiarid regions. The first applications of the simulation of water balances show that the determining factor of yield over which the farmer has control was the maximization of the usable water reserve for rooting (RUR).

In many cases, the RUR is lower than that permitted by the pedological profile. This reduction has two harmful consequences from the water point of view: first, in a rainy period, the risk of having a surplus water index greater than 3 × RUR increases, for a given rainfall rate; and second, in a dry period, as the contribution of the soil reserve is reduced, the ETR inevitably falls along with the yield. Table 5 shows the estimated effects of the RUR on production.

Two major obstacles for maximum rooting are often identified as:

- soil compactness, which, if shallow, causes radiated rooting limited to 15-20 cm (RUR = 30 mm), or,
- chemical toxicity (particularly Al toxicity), frequent in upland rice cultivation on acid soils and which inhibits root development in a manner not yet fully understood.

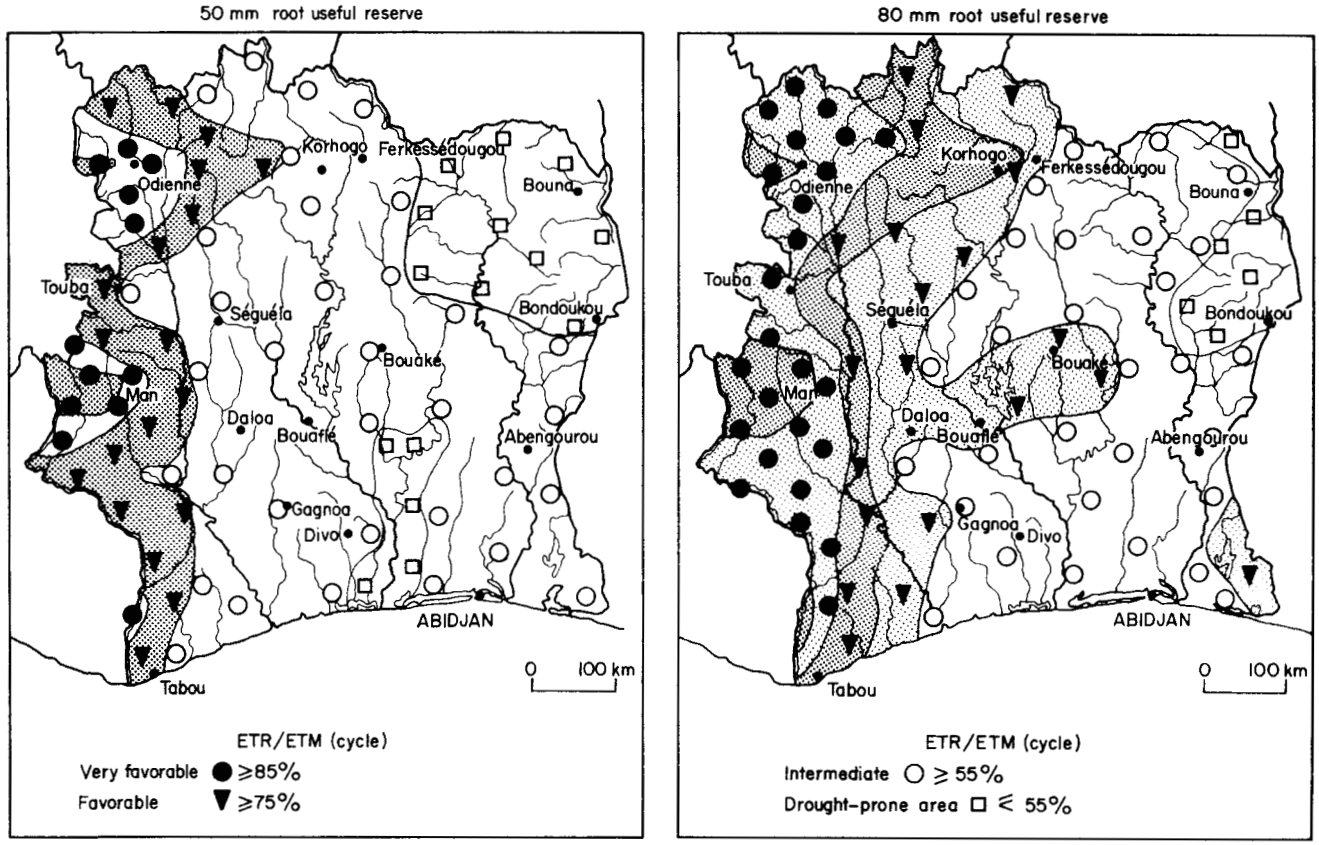
A rough estimate of the useful water reserve may be obtained by using the relationship with clay-loam content (1).

The knowledge of the maximum used reserve (RMU), and the in situ analysis of rooting to determine the RUR, constitute one priority for future research. To be useful, the research must be at the crop systems level, taking into account interactions among soil preparation, useful reserve, root dynamics, and chemical balance.

The initial phase of strategy is to simulate, using the BIP4 model, the effect of different RUR on the standard index ETR/ETM in different localities. This procedure was used for the Ivory Coast (Fig. 5) and the degree to which climatic risk depends on this factor was evident.

Table 5. Expected yield in function of useful root reserve (RUR). Example of Oxisol soil in Bouaké, Ivory Coast.

Soil texture	Used depth	RUR	ETR/ETM (cycle)	Yield expected (kg/ha)
Coarse	70 cm	50 mm	0,55	1080
Medium coarse	80 cm	80 mm	0,70	1890
Fine/medium	100 cm	100 mm	0,80	3000



5. Upland rice agroclimatic aptitude for Ivory Coast. Comparison between 50 and 80 mm of root useful reserve.

CONCLUSION

We consider that the method of regional climatic characterization for upland rice, which has been proposed and justified, can be put into practice and through use can better be adjusted to the different environments.

Its advantage is twofold: 1) the proposed indices better explain yield fluctuation than the former indices, and 2) in a relatively simple and sure manner it enables taking into account natural environmental characteristics and the main parameters of farm situations.

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TOWARD A CLASSIFICATION SYSTEM FOR UPLAND RICE GROWING ENVIRONMENTS

P. G. JONES and D. P. GARRITY

Upland rice is usually characterized by dry soil preparation and direct seeding into fields that are generally unbunded. The critical distinguishing characteristic of upland rice is that surface water accumulation does not occur for any significant time during the growing season. As a consequence of this definition of upland rice, and of the highly varied hydrological characteristics of this crop, upland rice has often been relegated to a single undifferentiated position in schemes of rice classification (8).

In view of the diverse and harsh environmental conditions of upland rice, both in Asia and the Americas, considerable interest has been shown in classifying the growing environments for this subset of the rice crop. This paper explores theoretical and practical aspects of such a classification and reports on progress made toward this goal in IRRI and CIAT.

Who is the classification for?

Environmental classification in a crop context has a large range of potential end uses. Important among these are

1. defining broad-scale research priorities,
2. identifying homologous areas for technology transfer,
3. assisting in siting and interpreting multilocation trial networks,
4. identifying recommendation zones for extension work, and
5. assisting in specific regional development and planning.

Each of these uses requires different degrees of subdivision, from only a few in (1) to many in (5).

The user's list would tend to be national or international research policy makers at the top; rice scientists and breeders in the central part; and extension workers and field agronomists at the most detailed end. In general the International Agricultural Research Centers (IARC)s would be specifically interested in the first three items, whereas national programs would have an interest in all types of usage.

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Does this mean we must have a different classification for each end use? Of course not. The consequence of these remarks is that the classification must be hierarchical. At its upper levels it must subdivide rice environments into broad but useful and recognizable categories. At each level the categories should be subdivided to provide the increased accuracy for the given task.

Two basic methods are used to develop a crop environmental classification. The first is to proceed from a detailed knowledge of the crop's physiology and pathology and to define a matrix of factors that completely classifies all possible rice environments, whether they exist in the real world or not. This tends to become unwieldy as many combinations of variables are added to the matrix. A proportion of these combinations may not actually exist and, even if they do, may account for insignificant areas of the crop. Nevertheless, if kept to a relatively simple level this approach has its merit. After constructing the classification schema, the environmental types described by it should be mapped, at which stage the classification may be compared with actual rice distribution and verification achieved.

The second method is to take an inventory of the cultivated area of the crop and inspect the environmental variation existing in the crop target area. The environmental classification is then imposed upon the inventory data to put it into a usable, easily understood form. This approach is the inverse of the first, and is basically that chosen by both IRRI and CIAT.

The situation as at Bouakè

IRRI first produced an inventory-based approach to upland rice classification (4). Using the dot maps of rice area distribution of Huke (1982) and overlaying FAO Soil Maps (2, 3) and climate maps (Garrity, unpubl.) an inventory of nearly 4000 sites was constructed. Each site represented 3000 ha of upland rice. The data were presented by imposing a simple two-way classification. The main climatic variable considered was growing season, divided into long and short. The soils were ranked into an inherent fertility scale and for the purpose of the classification divided into fertile and infertile.

At the time of the Bouakè meeting, studies in CIAT had not advanced to a full inventory. Nevertheless an investigation of eight representative upland rice regions (13), indicated that season length was probably not a major determinant in Latin America, but that rainfall reliability was an important factor.

Developments

The CIAT approach to upland rice inventory is embodied in a preliminary study for the Andean region presented in part by Jones (9) and more completely in Jones (10). The inventory consisted, not unlike Huke (7), of taking all available information from surveys, census, bank lending information, and other sources, and assigning upland rice cultivation to specific areas. Satellite imagery was used to specifically locate the areas. Unlike the

study of Huke, the result was an inventory of microregions and not a dot map. Since the hectarage of rice in each microregion was known the resulting inventory serves the same purpose as that of Garrity (4).

No attempt was made to construct a comprehensive classification of the environments, but tabulation of the inventory results necessitated some classification by environmental variables. One of these was the probability of severe soil water stress during the crop cycle, another was inherent fertility. Table 1 shows the inherent fertility scale modified slightly from that of Garrity (4). The results of tabulating the inventory against these factors (Table 2) showed conclusively that drought stress probability was an important classifying factor, and that this was independent of soil fertility.

The study confirmed our previous impression that growing season length was not a major factor in the region but Table 3 shows that it cannot be completely neglected. The criterion is more liberal than used by Garrity (4) in that it only requires that daily precipitation exceed evapotranspiration.

These results, taken with those of Garrity (4), show conclusively that at least three important factors must be taken into consideration in classifying upland rice environments: growing season length, moisture sufficiency during the season, and the inherent soil fertility.

Garrity and Agustin (5) proceeded to develop and apply a three-factor classification system as follows:

Table 1. Areas sown to upland rice in the Andean region grouped by inherent fertility status.

Inherent fertility status rating		Soil mapping unit	Area sown (ha)
2	Be	Eutric Cambisols	20
3	Je	Eutric Fluvisols	44900
	Lo	Orthic Luvisols	520
	Vp	Pellic Vertisols	10940
	Ve	Chromic Vertisols	9450
4	Ne	Eutric Nitosols	1100
	J	Unspecified fluvisols	20400
5	Gm	Mollic Gleysols	50
	Ge	Eutric Gleysols	39600
	We	Eutric Planosols	8400
6	Bd	Dystric Cambisols	21800
	Ao	Orthic Acrisols	13240
7	Lf	Ferric Luvisols	69580
	Nd	Dystric Nitosols	4570
	Lp	Plinthic Luvisols	11040
	Gh	Humic Gleysols	7620
8	Fo	Orthic Ferralsols	75
	Fx	Xanthic Ferralsols	110

Modified after Garrity (4).

Table 2. Areas sown to upland rice in the Andean zone classified by fertility class and probability of 7 dry days in the second month of the cropping season.

Inherent fertility class	Probability				
	0 - 0.4	0.4 - 0.6	0.6 - 0.8	0.8 - 1.0	Total
			Hectares		
2+3	8820	16100	20000	20300	65300
4	3000	9400	5900	3300	21500
5	3000	10100	28000	4300	45000
6	0	10500	7200	17400	35100
7	58000	7500	27000	800	93000
8	200				
			Percentages		
2+3	13	25	31	31	100
4	14	44	27	15	100
5	7	22	62	9	100
6	0	30	20	50	100
7	62	8	29	1	100
8	100	0	0	0	100

After Jones (10).

Table 3. Areas (hectares and proportion) of upland rice in Andean region classified by growing season length.

Humid days[a]	Area	
	Hectares	Percentage
Less than 50	21900	9
50-100	8090	3
100-150	136900	57
150-200	44700	19
200 plus	29600	12

[a]Number of consecutive days on which precipitation exceeds potential evapotranspiration.

Growing season length. Growing months were defined as those with evaporation (15) exceeding precipitation by 20%. (Note that this is not in conflict with CIAT studies since Penman evaporation estimates were used which are often underestimated by 10-20% by Thornthwaite). The scale of growing months was divided into less than 4 months, 4 months, and 5 or more months. This followed the reasoning that if a region had less than 4 full growing months a serious growing season constraint was indicated requiring extremely short season cultivars. With 5 or more months there is no restriction as to maturity type. The intermediate zone (4 months) would be restricted to earlier maturity types but not necessarily with a serious maturity restriction.

Moisture sufficiency during the season. Estimation of the probability of drought stress from present worldwide information is difficult. CIAT

studies use a stochastic modeling procedure based on Markov chain models and the comprehensive climate data base SAMMDATA (11). However, significant investment is required to extend this beyond the Americas. Garrity and Agustin devised an empirical scheme to estimate the relative favorability of the moisture sufficiency during the growing season for a site based on soil texture, slope, growing season length, and precipitation. Moisture sufficiency classes were assigned according to the cumulative sum of the four determinants of soil and rainfall factors. The calculation method is shown in Table 4.

Upland rice sites are classified into:

1. Highly drought prone (HDP)
2. Drought prone (DP)
3. Intermediate (I)
4. Favorable (F)

The schema is illustrated in Figure 1. It has the useful property of being easy to calculate directly from the FAO Soil Map legend using the slope classes and texture in combination with rainfall data.

Inherent soil fertility. The numerical scale of Garrity and Brinkman (6) was replaced by the Fertility Capability Classification (FCC) of Sanchez and Buol (l4). The FCC is based on quantitative topsoil and subsoil parameters directly relevant to plant growth. These parameters are mainly derived from the class limits of the *Soil taxonomy* (16) and the legend of the *FAO soil map of the world* (1). The FCC modifiers used are in Table 5.

Thus the table of possible qualifiers for an upland rice ecosystem stands as:

Growing season	Water balance	Soil fertility constraints
S (Short)	HDP	e (Low CEC)
M (Medium)	DP	a (Al toxicity)
L (Long)	I	i (P fixation)
	F	b (Basic reaction)
		s (Shallow soil)
		f (Fertile)

It is proposed that these be combined in a triadic form, thus: (S HDP i) = Short season, High probability of water deficit, P fixation problems. Another example: (L DP aie) would mean Long growing season, Drought-prone, Al toxicity, high P fixation and low cation exchange capacity. This yields a classification with 72 potential taxons, although some combinations will be unobservable.

Climatic variables may be calculated on the basis of long-term climatic normals and generalized soil data as in Garrity and Agustin (5) or preferably, if data exist, by more exact methods of stochastic simulation and daily water balance.

For general purposes, a system of 72 potential classes may be overly fragmented. Therefore, the water balance may be aggregated with only two

Table 4. Numerical values used for classifying moisture sufficiency during the growing season based on soil water retention potential and rainfall regime for upland rice, South and Southeaat Asia.

Soil water retention potential				Rainfall regime			
Texture	Value[a]	Slope (%)	Value[a]	5 mo. rainfall	Value[a]	Length of growing season	Value[a]
Fine/Medium	1.0	0- 8	1.0	High to very high (>1500 mm)	1.0	Long (5-12 mo)	1.0
		0- 30	0.8			Medium (4 mo)	0.6
		8- 30	0.6			Short (0-3 mo)	0.3
		8->30	0.4				
		> 30	0.2	Medium (1200-1500 mm)	0.8	Long	0.8
						Medium	0.5
Medium/Coarse	0.6	0- 8	0.9			Short	0.2
		0- 30	0.6				
		8- 30	0.4	Low (1000-1200 mm)	0.5	Long	0.6
		8->30	0.3			Medium	0.4
		>30				Short	0.2
Coarse	0.3	0- 8	0.8				
		0- 30	0.5	Very low (<1000 mm)	0.2	Long	0.3
		8- 30	0.4			Medium	0.2
		8->30	0.2			Short	0.1
		> 30	0.1				

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

SOIL WATER RETENTION POTENTIAL	Soil Textural Class	Slope Class (%)	RAINFALL REGIME: Long Growing Season (5-12 mo) Rainfall (mm)				Medium Growing Season (4 mo) Rainfall (mm)				Short Growing Season (0-3 mo) Rainfall (mm)		
			>1500	1200-1500	1000-1200	<1000	>1500	1200-1500	1000-1200	<1000	1200-1500	1000-1200	<1000
	Fine/Medium	0-8	692	341	148	45	64	1030	277	123	72	242	255
		0-30	144	89	35	13		207	21	15	62	83	209
		8-30	796	265	134	81	59	312	54	30	6	125	286
		8->30	196	165	58	51	12	186	46		44	56	86
		>30	774	456	189	104	11	34	67	46	32	72	189
	Medium/Coarse	0-8	201	5			15	18					
		0-30	30	168	48	59		72	131	11	51	18	43
		8-30						3					
		8->30											
		>30											
	Coarse	0-8	58	27	15	3		671	70		17	66	28
		0-30	23	43	6		28	3					
		8-30	6	9				128	17		29	65	12
		8->30	3	18	3	11		127			7	28	
		>30											

Legend:

Moisture Sufficiency				
Favorable	Intermediate	Drought-prone	Highly drought-prone	No upland rice area

1. Moisture sufficiency during the growing season as a function of rainfall regime and soil water retention potential, and the distribution of upland rice areas (in thousand ha) in South and Southeast Asia.

classes as DP (including both DP and HDP) and F (including F and I), and the soil fertility constraints may be aggregated into two classes as Adverse (including e, a, i, b, and s) and Fertile (including f). This simplification enables the major environments of the upland rice crop to be described by 12 major classes.

Nonetheless as a complete classification of upland rice environments, the system contains shortcomings:

(1) Significant climatic variables are left out. These include radiation and temperature as direct effects on crop growth apart from their influence on evaporation.

(2) Soil physical characteristics enter only as a factor of water balance and not directly as, for example, in erosion risk.

It is not difficult to think of further factors which are lacking. Adding these will expand the scope of the classification. However, additional factors may create confusion in practical application of the system.

Table 5. Fertility Capability Classification System modifiers used for upland rice.

	Modifier	Criteria	Interpretation
e	Low cation exchange capacity (CEC)	Applies to plow layer or surface 20 cm: CEC <4 meq/100 g soil by sum of bases + KCl ext. Al (effective CEC), or CEC <7 meq/100 g soil by sum of cations at pH 7, or CEC <10 meq/100 g soil by sum of cations + Al + H at pH 8.2	Reflects less gradual N release, more exacting N management low ability to retain nutrients against leaching, mainly K, Ca, and Mg.
a	Al toxicity	Applies within 50 cm of the soil surface: >60% Al-saturation of the effective CEC, or >67% acidity saturation of CEC by sum of cations at pH 7, or >86% acidity saturation of CEC by sum of cations at pH 8.2, or pH <5.5 in 1:1 H_2O except in organic soils where pH must be <4.7.	Al toxicity will occur; soil test for P deficiency recommended.
i	High P-fixation by iron	Applies to plow layer or surface 20 cm: % free Fe2O3/% clay = >0.15 and >35% clay, or hues of 7.5 YR or redder and granular structure.	Potential Fe toxicity requires high level of P fertilizer or special P management practices.
b	Basic reaction	Applies within 50 cm of the soil surface: Free $CaCO_3$ (effervescence with HCl); or pH >7.3.	Calcareous soils; high pH may induce Fe deficiency.
S[a]	Shallow soils	Lithic soil mapping units of the FAO-UNESCO Soil Maps.	
i[a]	Fertile	No major soil constraints	

[a] Added to FCC system for purposes of this study.

Toward the classification

The aim of a crop environment classification system is to subdivide the environmental range into units that minimize genotype environment interaction within classes at each level of the hierarchy. Schemata for the classification may be invented *ad libitum* but the one that will serve best must be drawn from actual crop response, and yet retain sufficient simplicity of description to be useful in scientific discourse at whichever level is chosen.

A large amount of data on crop response exists in regional and international yield trial results of IRRI, CIAT, and national programs. These data should enable testing the level of variation within taxa of a proposed classification. Two main problems with this approach are first, the data are dispersed and the consolidation will take time and much good will; and second, there is scant likelihood of finding uniform variety sets to span the trials.

Currently, work at CIAT offers a possibility that the second obstacle may be surmountable. An algorithm has been developed (12) for clustering of sparse matrices. This algorithm has accurately clustered observations drawn from test populations even when up to 75% of the data values have been deleted at random. This lifts the normal restriction that each variety must appear in every trial and, given sufficient overlap of common varieties, will allow us to group trial environments based on varietal response.

CONCLUSION

Inventories of crop production environments now exist for Asia and certain parts of Latin America. To extend these to cover the remainder of the upland rice growing areas of the world is an urgent next step. These inventories serve as a testbed for proposed classification schemes. The factors of season length, probability of water stress, and soil fertility limitations are basic to any classification. Addition of other factors and the structuring of the resultant classification must take careful account of the crop response.

Classifying the inventory should proceed in the same manner as classification in plant taxonomy. Objects are fitted into the existing classification until one is found that will not fit. At that time the classification is modified. The schema of plant taxonomy was not invented without close reference to the actual specimens. It is not a theoretical construct but has been iteratively derived by many scientists over many years.

We now have the environmental specimens in the shape of our inventories. We have an increasing body of information on genotype environment interaction. Let us now accept as a rough guide the work to date and start examining closely the individual environments as they interact with germplasm.

Rather than inventing over and over again new classification schemata we may now enter a cycle of investigation and publication to work toward a consensus, and toward a classification.

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Integrated upland rice farming systems

A. Present and emerging farming systems

UPLAND RICE FARMING SYSTEMS

R. A. MORRIS

More so than in rainfed lowland rice-based farming systems, rainfed upland rice-based farming systems should be examined in the context of competitive crops. Although the Bouaké Workshop regarded upland rice as that grown on rainfed naturally well-drained soils, without surface water accumulation, normally without phreatic water supply, and normally not bunded (9), in this paper, the issues of phreatic water supply are not regarded so restrictively. However, the phreatic supply should not be the predominant water source for transpiration. Where the phreatic water component is dominant, upland rice should have a strong advantage over other annual crops. Upland rice would rarely be the only crop fit for cultivation on a field commonly regarded as suitable for upland rice. Whereas the compound word *rice-based* is appropriate to describe rainfed lowland rice cultivation where climatic, terrain, and edaphic conditions combine to demand that rice, and virtually only rice, be cultivated during the wet season, an environmentally dictated constraint that only upland rice be cultivated probably does not operate. Many other crops are cultivated in association with upland rice.

DIVERSITY AND OTHER CROPS

With respect to the issue of competition for cultivated area, Elston (7) examined the occurrences of crops that are cultivated across the West African rainfall gradient. According to Elston, West Africa has a simple climatic system in which rainfall changes regularly with latitude. As the length of the rainy season (defined as the period when rainfall exceeds PET) increased, the number of crops cultivated changed (Fig. 1). Furthermore, he found characteristic changes in the mixes of crops (Fig. 2). The relative importance of rice increased as the rainy season lengthened. Although a component of this rice was cultivated on flooded fields, it is reasonable to

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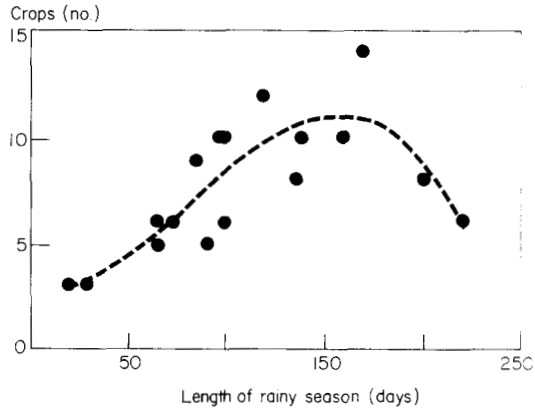
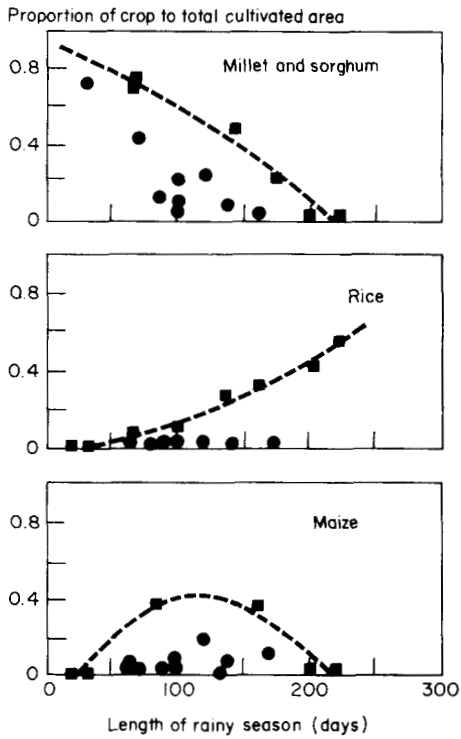
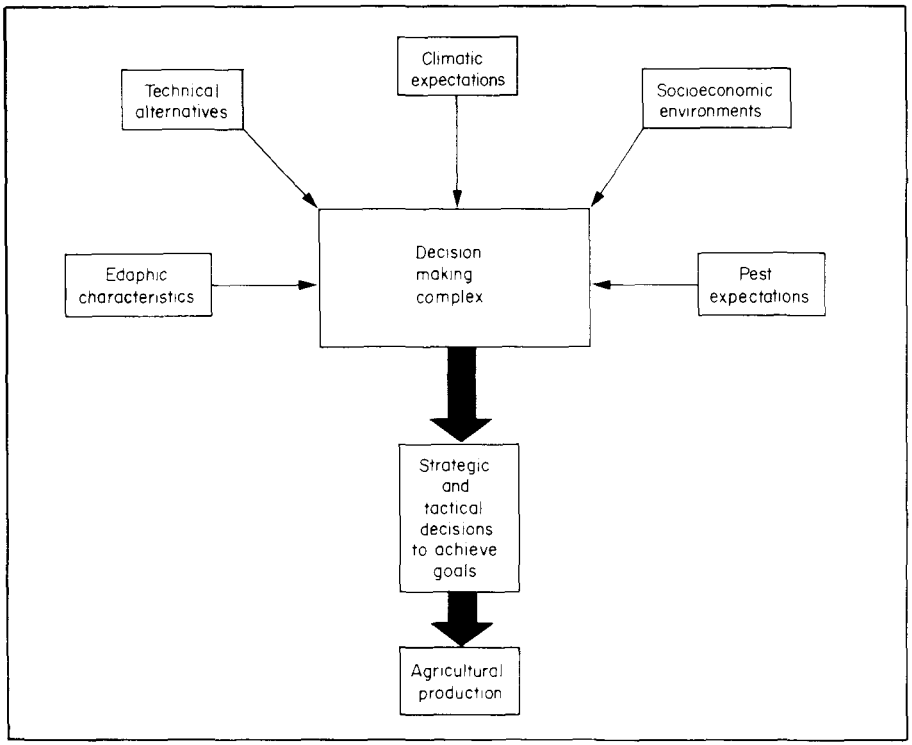


1. The number of crops grown in West Africa is a function of the length of the rainy season in days, plotted as the duration of the period when rainfall exceeds potential evaporation (7).



2. The relative importance, as a fraction of the total cultivated area, of millet and sorghum, rice, and maize in West Africa plotted against the length of the rainy season (7).

assume that in West Africa, the flooded component was not great, especially when the wet season duration was under 150 d. From Figure 3, one comes to the unsurprising conclusion that the competitiveness of rice increased as the length of the wet season increased, at least for the maximum wet season length reported by Elston. One also recognizes that in Elston's study, rice was not cultivated at many locations regardless of wet season length.



3. Climatic expectations, socioeconomic environments, pest expectations, and edaphic characteristics influence the technical alternatives selected by the decision making complex of a farm. These alternatives are incorporated into the field activities undertaken to achieve farm goals.

CATEGORIES OF UPLAND FARMING SYSTEMS ON WHICH RICE IS CULTIVATED

With respect to the characterization of farming systems in which upland rice is cultivated, papers presented at the Bouaké workshop (12) are interesting. Virtually all overview papers written by the NAR and IAR centers and by authors reporting on regional upland rice cropping systems, explicitly or implicitly, stated that the environmental conditions under which rice was cultivated were diverse, that other crops were grown before or after rice, were intercropped with rice, or competed with rice (exceptions were reported from Latin America), and that cultural practices were varied (3, 8, 11, 12, 14, 15, 17, 18, 24, 28). For a subject so complex, a comprehensive report on "Upland Rice Farming Systems," as the title the author was assigned might suggest, has not been attempted in this paper. For detailed descriptions of the diverse upland rice farming systems found in tropical environments, readers are referred to the proceedings of the Bouakè workshop, this workshop, and other sources. Rather than listing data and stating facts, this paper will discuss upland rice farming systems in a more general manner.

Farming systems in which upland rice is cultivated can be categorized as:

- Swidden, subsistence orientation
- Semipermanent primitive, subsistence orientation
- Traditional peasant, subsistence orientation, incipient market orientation
- Semimodern, market orientation
- Modern, market orientation
- Frontier, market orientation

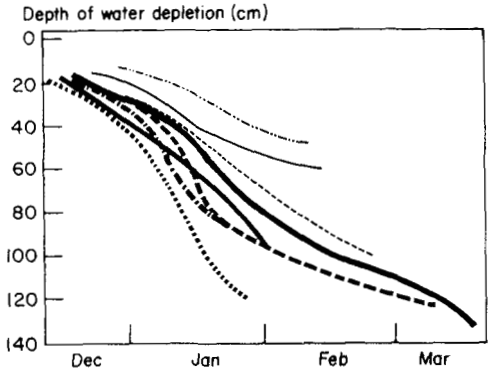
Gonzaga et a1 (10) describe swidden and semipermanent primitive systems in eastern Luzon, the Philippines. McIntosh et a1 (18) describe traditional peasant systems. Martinez (16) describes modern systems in Latin America. EMBRAPA (8) describes frontier rice (rice cultivated for a few years after land cleaning prior to establishment of improved tropical pastures). The contrasts among these systems are many in number and enormous in magnitude. Grain yield is one simple contrast: 0.4 t/ha was reported by Gonzaga et a1 (10) in a swidden cultivation system in the Philippines and 4.5 to 5.5 t/ha was reported by Martinez (16) in modern cultivation systems in Colombia. Heterogeneity within each category is also substantial. Conditions that foster farming systems with vastly different characteristics are important to recognize (Fig. 3). One way to increase the productivity of a system is to develop technical alternatives which are more gainful than those in present use but which also satisfy an important condition: farmer acceptability.

That the upland systems are diverse with respect to the environmental determinants and cultivation practices is important to recognize, but many technical problems are common to more than one system. The working groups at Bouaké listed research needs by problem areas which, if addressed, would increase our understanding of farming systems in which upland rice is cultivated and generate improved technology for the farmers who operate those systems.

ADVANTAGES AND DISADVANTAGES OF RICE IN UPLAND FARMING SYSTEMS

Roots

When its roots are in an aerobic environment, rice is often at a disadvantage with respect to other species. Most rices are shallow rooted and unable to extract water and nutrients deep in the soil profile. Angus et a1 (2) compared six crop species grown with and without irrigation. Without irrigation, neither IR36 nor UPL Ri5, which are some of the few modern upland rice varieties adopted by farmers in the Philippines, developed root systems as deep or extracted as much soil water as the species well adapted to the rainfed conditions of the experiment (Fig. 4, Table 1). Apart from a weaker ability to remove water from the soil, rice exhibited greater yield reduction than other crop species when water was limiting.



4. Changes in depth of the root zone for rainfed dryland crops, as determined from the onset of water extraction at a given depth. ———, ground-nut; -----, maize; -·-·-·- soya bean, ·····, cow-pea; -----, sorghum; ——, mung-bean; ▬, rice C-171-136; -·-·-, rice IR36. (2)

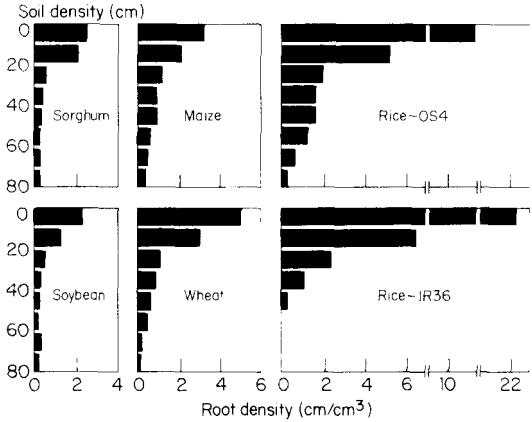
Table 1. Total water use and seed yields of rainfed and irrigated crops cultivated during the 1978-79 dry season, Los Baños, Philippinas (2).

Crop	Water use		Seed yield	
	Rainfed	Irrigated	Rainfed	Irrigated
	mm		t/ha	
Mungbean	238	263	1.23	1.44
Cowpea	268	253	1.28	1.33
Soybean	198	263	0.64	1.10
Peanut	364	361	1.11	2.57
Maize	258	324	2.57	4.07
Sorghum	293	324	3.28	4.76
Rice (UPL Ri7)	205	406	0	3.58
Rice (IR336)	198	450	0	2.56

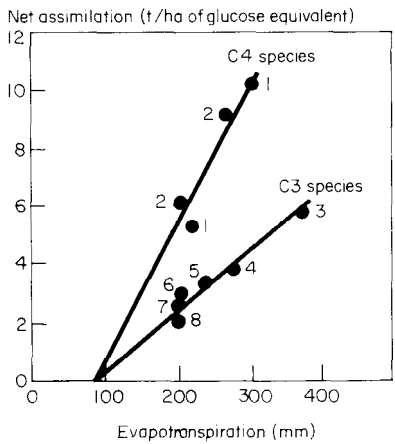
Yoshida and Hasegawa (20) compared root densities of 2 upland rices and 4 other species (Fig. 5). OS4 exhibited a deeper rooting habit than IR36. Furthermore, the rooting density of OS4 to 60 cm was greater than that of other species, suggesting that it has the "plumbing" needed to extract water from deeper in the profile. From a field study in West Africa, however, Moormann et al (19) postulated that soil water below 30 cm contributed very little to the growth and development of a locally adapted upland rice variety. Although the issue of comparative water removal from the profile by an OS4-type rice and alternative crop species requires further examination, it does appear that most upland rices are at a disadvantage when compared to other species.

Carbon assimilation pathways

Unlike a number of tropical cereals and several important forage grasses, the carbon assimilation pathway of rice is of lower efficiency and less yield can be expected from the transpiration of an equal quantity of water. This is illustrated by Figure 6 which shows that for an equal quantity of



5. Vertical root distribution of 4 upland crops and 2 rice varieties (29).



6. Net assimilation of 8 rainfed dryland crops expressed as the glucose equivalent of the major organic constituents carbohydrate, protein, and lipid) in relation to total water use. Regression lines fitted through the data represent the C3 and C4 species; the common X-intercept, 87 ± 19 mm, represents the mean soil evaporation for all crops. The slopes of the lines represent transpiration efficiencies of the two groups C3 = 2 · 2 ± 0.27 g/m² per mm; C4 = 4.9 ± 0.62 g/m^2 per mm). 1 = sorghum, 2 = maize, 3 = groundnut, 4 - cowpea, 5 = mungbean, 6 = rice C-171–136, 7 = soya bean, 8 = rice IR36 (2).

evapotranspiration, net assimilation by C4 crops was greater than by C3 crops. Moreover, upland rice did not use as much soil water as the other C3 pathway plants, although net assimilation per unit water used was not greatly different. The susceptibility of rice to reproductive stage drought stress prevented grain development.

Mineral nutrition

By comparison to grain and forage legumes which have effective symbiotic fixation systems, upland rice must depend on soil or fertilizer, and perhaps associative fixation, to meet its N requirement. Fertilizer N can be applied to exploit the yield potential of improved cultivars (5, 6). At current N fertilizer prices in the Philippines, however, the cost of the 120 kg N/ha needed to increase grain yield from 0.8 to 3.0 t/ha, a moderately good response, is $96/ha. This is a substantial sum for a farmer whose income from land, labor, and capital may be less than US$750/yr.

By comparison to lowland rice which has mineral nutrition advantages conferred by the soil reduction process (22) and a more assured water supply, upland rice may be at another disadvantage. N uptake from the NO_3-N pool presumably predominates when rice is cultivated on aerobic soils. In lowland rice cultivation, N uptake from the NH_4-N pool presumably predominates. NO_3-N must undergo assimilatory reduction, which requires 0.33 mol glucose/mol NH_4 produced (23). For a 4 t/ha rice crop yield, N uptake is approximately 60 kg/ha (27). If most N enter as nitrate and nitrate reduction primarily occurs in the roots, then the equivalent of 0.25 t rough rice/ha will be used in assimilatory nitrate reduction, assuming that 1.35 kg glucose is required to produce 1 kg of rough rice (20).

Per unit costs of producing rice by upland and lowland cultivation. Cost and return data of rice produced on upland and lowland farms under the same climatic environment illustrate the comparative advantage lowland rice often has in the market place over rice produced in a traditional peasant upland farming system. Mean yield of irrigated lowland rice in the Bukidnon Settlement Project, the Philippines, was 4.3 t/ha in 1979 (1). The unit variable cost labor (labor and materials) of producing 1 t rough rice in this lowland area was US$34. The unit cost of producing traditional upland rice was US$115/t of rough rice. Mean yield was 0.8 t/ha. When traditional upland rice technology was replaced by improved technology, yields increased to 2.8 t/ha, but variable costs increased by US$59/ha, making the unit cost US$55/t, which was still not competitive with unit production costs of lowland rice grown in a nearby irrigation system. Wage costs for these calculations, however, were obtained by survey. In practice, members of a farm family may not be able to obtain those wages, in which case the assumed wage rates would be too high, and the estimated unit cost of production would also be high. In this area, upland rice is primarily grown for subsistence but some is sold locally. It is obviously not possible to generalize about comparative advantages of upland versus lowland systems but it does seem reasonable that because mineral nutrition is more favorable and risks of drought stress are generally lower in lowland systems, rice from upland systems will find stiff competition from rice produced in lowland systems. There are, however, cases where upland rice competes in the market with lowland rice (16, 26).

Why rice?

Given these disadvantages why is rice included in upland farming systems? Figure 3 suggests that many factors must be considered. In the market-oriented systems, profitability relative to other crops must be important. For the subsistence-oriented systems, traditional taste preferences and social customs must be important matters. In Asia, traditional tastes and food security cannot be ignored. From discussions with villagers and examinations of past studies, Penny and Singarimbun (21) concluded that the Indonesian concept of *cukupan* was a workable test of poverty for

anthropology studies. According to Penny and Singarimbun, "If a farmer is *cukupan* he will be happy. If he can produce some 900 kg of (milled) rice, plus what he can get from his house-garden, he will be *cukupan* and happy". With 900 kg of rice, a family can eat rice two or three times a day.

The comparative ease with which rice can be stored without insect and disease damage is an important factor. In remote areas of the humid tropics where modern storage facilities are not common, ease of storage is important for both food security and seed preservation.

TRADITIONAL PEASANT SYSTEMS

Of the six upland farming system categories, the traditional peasant category is probably the most important in terms of the number of families which rely on it for food and cash income. Rices cultivated in these systems are tall traditional types with characteristics similar to those described by Chang and Vergara (4). Because the soils on which most traditional peasant systems are found are infertile (9), nutritional disorders (deficiencies, toxicities, imbalances) are common on upland rice. Drought stress is another production hazard. Farmers have learned to cope with weeds and to not overextend the area cultivated with crops that do not compete well with weeds. Rice blast becomes severe when attempts are made to increase yields. Insect and vertebrate pests are also hazards, but pressures differ over environments and years. Cash inputs are uncommon in traditional peasant systems. Various forms of intercropping are used in many traditional peasant systems.

Using economic criteria, Jodha (13) concluded that intercropping was superior to monocropping and was used to achieve multiple objectives. Furthermore, farmers used intercropping to exploit the biological potentials of crop mixtures while increasing returns, creating new employment opportunities, reducing labor input peaks, simultaneously satisfying cash and food crop cultivation requirements, and minimizing the risks caused by too little or too much water. Although Jodha found that indigenous intercropping systems were highly complex, he cautioned that scientists should not try to generate equally complex new intercropping arrangements. He advocated satisfying a few key objectives, such as profitability and stability, without ignoring other objectives. He also presented evidence that intercropping technology is equity-biased because it benefits resource-poor farmers more than resource-rich farmers.

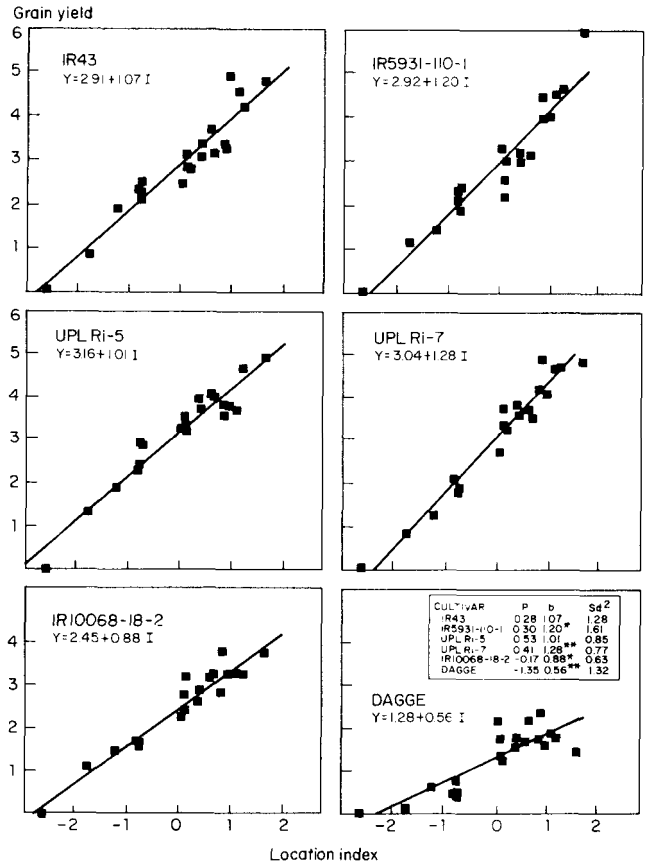
Can grain legume - rice intercropping be used to shift traditional peasant systems in which upland rice is cultivated toward greater market orientation, but without sacrificing food security? Snaydon and Harris (25) discussed the biological mechanisms that farmers can exploit by intercropping to achieve the multiple objectives described by Jodha. Snaydon and Harris' classification of mechanisms is presented in Table 2. At least three of these mechanisms are important in grain legume - upland rice intercrops and should enable farmers to exploit two frequently limiting factors, water and nitrogen, more fully.

Table 2. Classification of possible mechanisms, involving more effective use of environmental resources, that could lead to greater production from intercropping than from sole cropping (25).

1. Intercropped species compete only partially for limiting resources.
   (a) Same limiting resource, but different sources:
      (1) partially different times of use (i.e., semiconcurrent crops);
      (2) partially different zones of use (i.e., different root or shoot zonation);
   (b) different limiting resources:
      (1) same requirement met by different resource (e.g. N_2 and NO_3 for legumes and nonlegumes);
      (2) different requirements (e.g., light, various mineral nutrients, water).
2. Intercropped species compete wholly; the most productive component is most competitive and the outcome of competition is unpredictable.
   (a) The environment is spatially variable (i.e., mosaic environment).
   (b) The environment lis temporally variable (i.e., seasonal and year-to-year).

Several upland rices or lines have yield potentials that are greater than most farmers will achieve in most years even if supplied with modest input levels (Fig. 7). Yields of the better cultivars do not differ at the dry end of the spectrum. They are all low, suggesting that strategies to minimize the incidence of drought are important. To achieve even modest yields (3 to 4 t/ha) N uptake must increase. Acid-tolerant cowpea-rhizobium materials with short duration and determinant growth habit have been developed at IITA. Can improved rice and cowpea cultivars be combined into a mixture that farmers who cultivate rice on acid upland soils will accept?

At IRRI, research has been initiated on grain legume-upland rice intercropping as a strategy to improve N availability to rice and associated crops, reduce late drought stress on rice, and increase protein availability and cash income. In this research, mixtures of short duration, short statured, determinant acid-tolerant legumes and intermediate statured, 120- to 125-d rices are being emphasized. Mechanisms that Snaydon and Harris described which should be exploited by intercropping these species are a) partially different times of resource use (crop duration), b) partially different zones of resource use (rooting depths), and c) same requirement met by different resources (soil and symbiotically fixed N). A fourth mechanism, which according to Snaydon and Harris applies where intercrops compete wholly, may also be exploited even though the condition of "wholly competitive" is not fully met. Because weather is variable, favoring the legume in some years and rice in others, water and N should be used more complete over years, but the output mix will change according to how the crops exploit annual differences.

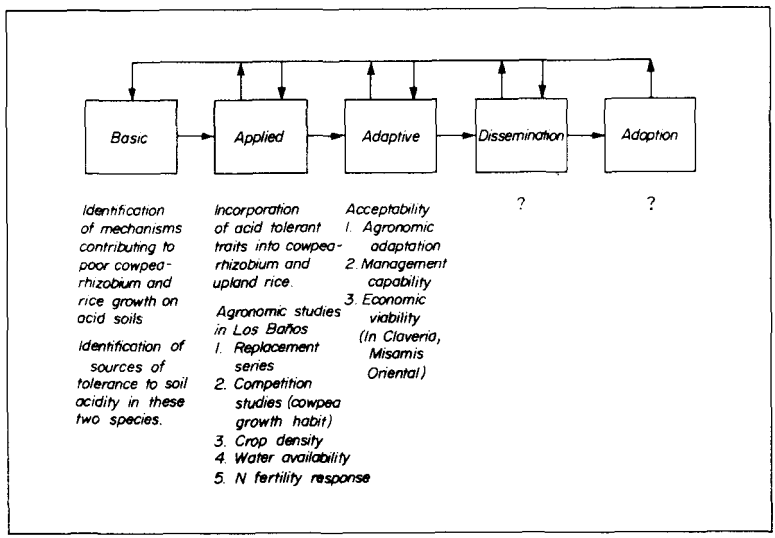


7. Stability analyses of 6 upland rice cultivars planted on seven 1983 WS dates under three irrigation regimes. I is environmental index, P is phenotypic index, b is stability index, and Sd^2 is squared deviations from regression, IRRI.

Figure 8 summarizes the continuum starting from basic studies to adoption. We have begun with genetic materials that were developed elsewhere, presumably after crop tolerance to acidity was identified by basic research and breeding programs exploited the tolerances.

In 1983, a series of agronomic experiments were started in Los Baños with the objective of identifying cowpea cultivars with growth habits compatible with UPL Ri5 and testing for intercropping sensitivity to important management variables (e.g., crop ratios). Initial agronomic adaptation trials were planted on acid soils (pH 4.0 to 4.5) in June 1984 at Claveria, Misamis Oriental, the Philippines.

More agronomic experiments are in progress in Los Baños. Soils have been brought to Los Baños so that the nature of the soil limitations can be



8. Cowpea-rhizobium combinations and rices have been bred for tolerance to disorders encountered on acid upland soils. Cowpea-rice intercrop combinations are being tested at an experiment station and in an on-farm research project. Should the tests be encouraging, results will be passed on for dissemination over a wider area.

more clearly pinpointed in laboratory and greenhouse studies. In the coming wet season, we will continue with adaptation studies in Claveria and begin to test the capability of farmers to cope with management requirements. As progress is made, economic viability will be examined. If tests prove encouraging, we will collaborate with the Ministry of Agriculture and Food on technology specification and identification of domains of adaptation.

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ECONOMIC ANALYSIS OF UPLAND RICE PRODUCTION IN INDONESIA: CASE IN RIAU, SUMATRA

S. ARIFIN, A. DJAUHARI, A. RACHIM
and Y. MOROOKA

Both lowland and upland rice are of paramount importance in the national economy of Indonesia, occupying more than one-third of the total arable land and providing the staple food for most of the population. However, until recently rice production has been insufficient to meet domestic requirements and substantial quantities of rice (between 1 and 2 million t) were annually imported from the mid-1970s to 1980 (1).

Domestic procurement of rice has gradually improved. For example, BULOG (the National Logistics Agency) data show that planned rice imports for 1982-83 were reduced from 506,000 t to 69,000 t because of adequate stocks at the end of 1981. This amount was 16% larger than that for 1981-82, which was the lowest import since Pelita I (4).

To meet increasing needs of the country's large and growing population (160 million in 1984 with a 2.3% annual growth rate), government food policy has emphasized rice, particularly in well-irrigated lowland areas through several intensification programs (Bimas, Inmas).

Agricultural intensification has played an important role in national efforts to increase food production. Bimas (Mass Guidance), for example, is built around three principles: first, participating farmers are encouraged to use modern production practices; second, noncollateral credit is made available to obtain a package of inputs; and third, technical assistance is provided by extension agents.

Modern technology over the past 15 yr has had a significant impact on the rice sector (2). Although modern varieties have been widely adopted throughout the country, this has taken place largely in the lowland areas. Consequently, substantial areas with upland conditions or at high elevation have not fully benefited from the new technology. Such areas account for most untapped agricultural potential in Indonesia, and have been targeted for transmigration of small-scale or landless farmers in Java.

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Food production in Indonesia is characterized by the concentration of population and production in Java, and the rapid growth of the population. Java accounts for only 7% of the total area of the country, but has about 60% of the total population. Hence, 60% out of Indonesia's 17.4 million farm householders cultivate less than 0.5 ha of farm land, and 5% are landless farmers (3). The government is attempting to solve the problem of uneven distribution of population through its transmigration program. This aims at moderating the population pressure in Java and expanding the agricultural production area outside Java.

Especially for small-scale farmers who live in the less developed areas, upland rice plays a major role for home consumption and as a cash crop. This paper reviews trends in upland rice production at both national and regional levels in Indonesia since 1950, and considers some farm-oriented economic problems encountered during the period. A socioeconomic case study of upland rice farming in Riau, Sumatra, in 1982-83 is also described.

OVERVIEW OF UPLAND RICE PRODUCTION

Location of producing areas

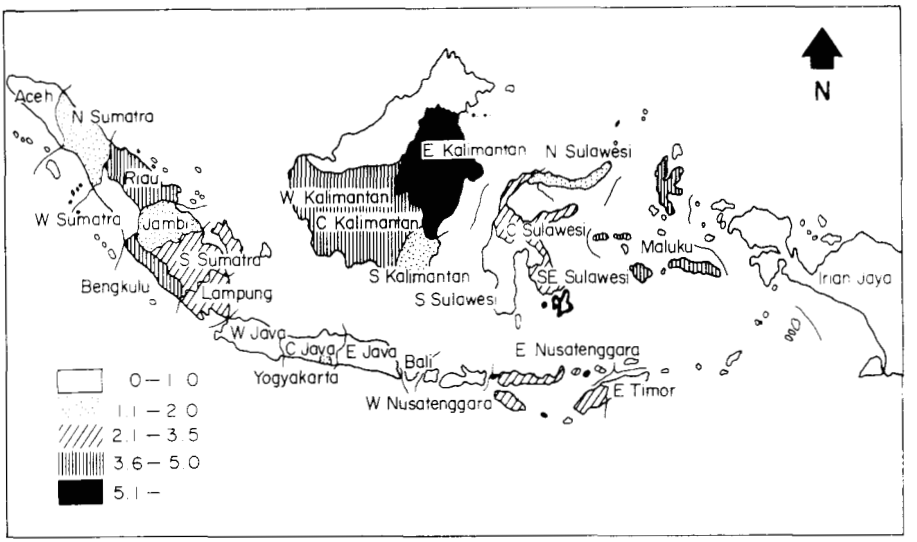
Figure 1 shows the location quotients for upland rice production, by province, of Indonesia. The location quotient is a statistical measure of the extent to which a particular economic activity is comparatively over-represented or underrepresented in the economy of a region, compared to its representation in the economy as a whole. Because the area of arable land is different in each province, the rates of concentration of certain crops are also diverse. Provinces with more arable land may have more potential for upland rice production than those with less arable land.

Of the 27 provinces, East Kalimantan has the highest location quotient, followed by a group consisting of Central and West Kalimantan, Maluku, Riau, and Bengkulu. Lampung, Central Sulawesi, and South Sumatra have quotients approaching those of this group. During 1980-82, the average harvested area of upland rice was 13% of about 9 million ha of all rice cropping types, but the majority of such upland was outside Java. About 6% of the 24 million t of milled rice produced each year was grown in these upland areas.

Infrastructure such as irrigation, drainage, farm roads, and other transportation facilities are not yet well developed in upland areas, especially outside Java. In 1980, the irrigated area was about 5.4 million ha, or 28% of the total of 19.5 million ha of arable land (12). The irrigated area could be increased 2.2% each year, but such expansion will be costly. This suggests that most arable land will remain as rainfed land or dryland. In this connection, attention is now being focused not only on lowland rice, but also on upland rice.

Trends of upland rice production

Rice production in Indonesia has undergone a transformation since the

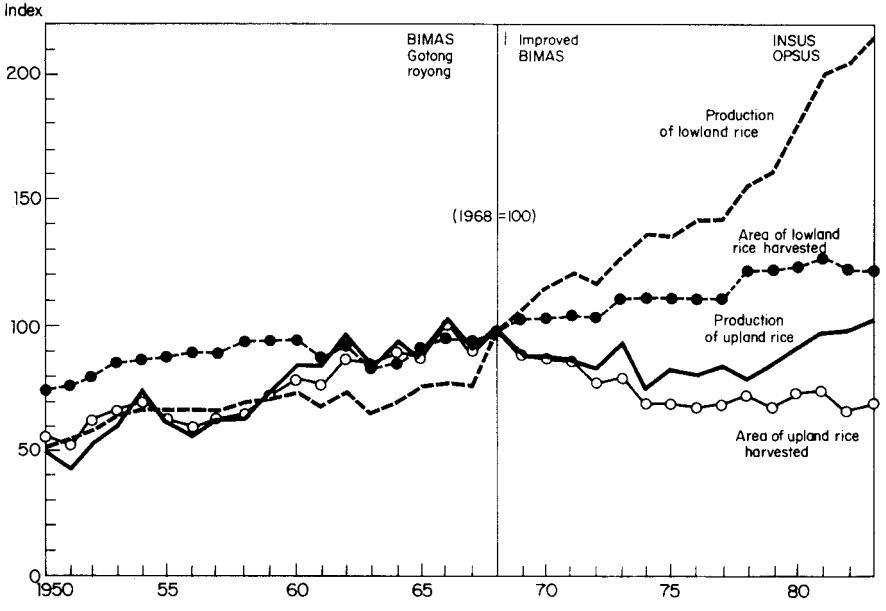


1. Classification of location for upland rice cropping in Indonesia, 1980-81. Location quotient by province:

D.I. Aceh	0.52	South Kalimantan	1.27
North Sumatra	1.95	East Kalimantan	6.03
West Sumatra	0.37	Central Kalimantan	4.56
Riau	3.74	South Sulawesi	0.33
Jambi	1.51	Southeast Sulawesi	2.33
Bengkulu	3.56	Central Sulawesi	3.27
South Sumatra	3.23	North Sulawesi	1.09
Lampung	3.32	Bali	0.26
D.K.I. Jakarta	0.23	West Nusatenggara	1.65
West Java	0.60	East Nusatenggara	0.65
Central Java	0.21	East Timor	-
D.I Yogyakarta	1.35	Maluku	3.82
East Java	0.24	Irian Jaya	0.19
West Kalimantan	4.45		

mid-1960s as new technology was adopted and intensification programs implemented by the Government (11). Figure 2 shows changes in the harvested area and production of upland rice compared with those of lowland rice from 1950 to 1983.

Before 1968 increases in production of both lowland and upland rice had depended mainly on increases in the area harvested (Fig. 2). However, this changed drastically, particularly for lowland rice, after the first Five Year Plan (Pelita) began in 1968. Since the mid-1960s, new technology has made a major contribution in the form of modern rice varieties, inorganic fertilizers, rehabilitation and expansion of the infrastructure, and improved management practices. Because of higher yields and cropping intensification, the supply of rice was significantly improved, while the expansion of area has been slow or negative in the case of upland rice. Upland rice has had a tendency similar to lowland rice in terms of production, although the decoupling of production from area has not been as remarkable.



2. Changes in upland and lowland rice production and area harvested, Indonesia, 1950-83. Sources: (8, 9).

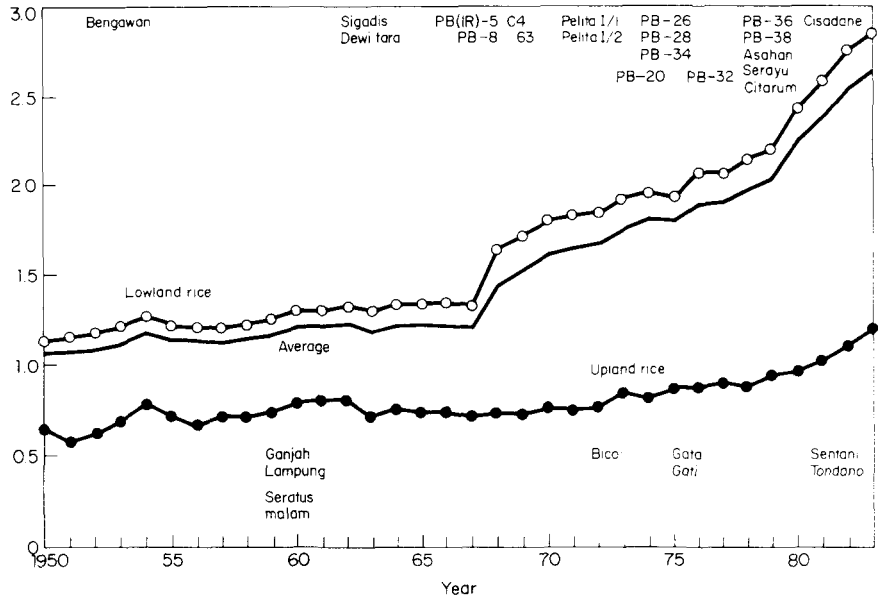
Figure 3 indicates yield increases of upland and lowland rice since 1950. Upland rice yields have increased from about 600 kg/ha to 1,200 kg/ha during the last 30 yr. The yield difference between upland and lowland rice has grown from two to three times in the same period. Upland rice is often cultivated on small-scale farms and depends heavily on weather, timeliness of rains, and natural hazards such as droughts, floods, insects, and diseases. In addition, uncertainty has existed at the farm level in the supply of some key inputs, including fertilizer and pesticides. Combined, these factors restrain upland rice yield increases.

UPLAND RICE IN RIAU

Profile of research site

Riau is an agricultural province on the east coast of Sumatra. In 1982, 156,000 ha in this province were cultivated for food crops. Of this total, lowland rice accounted for 54% and upland rice 29%. Upland rice is highly valued as a cash or commercial crop by upland farmers in transmigration areas. The average yield of milled rice grown on upland in 1981-83 was 975 kg/ha.

The study was in March 1983 at Pasir Pangarayan I, about 200 km northwest of Pakanbaru, the capital of Riau. This site opened in the early 1980s. The physical, social, and economic infrastructures are relatively new, only 50% of the total land has been cultivated. In this area, food crops such as



3. Changes in upland and lowland rice yield (milled rice), Indonesia, 1950-83, for different varieties. Sources: (8, 9).

upland rice, maize, cassava, sweet potato, peanut, mungbean, and soybean are cultivated in several cropping systems. Poultry raising is also a major farm enterprise.

For a farm management survey on upland rice, 200 farmers were randomly sampled, with the same number of respondents in two separate blocks in the research site. The survey on upland rice farming was part of the cattle distribution project in this transmigration area. The main objective of the project was to provide additional power source for farmers. Because cattle were distributed to participants in this project only 6 mo before this survey, the effects were not yet significant. The survey period was 1 yr from April 1982. Results of the survey are summarized in Table 1.

Upland rice and cropping patterns

Figure 4 shows the planting and harvesting period for upland rice, and the monthly rainfall pattern in Riau. De Datta et al state that in upland rice farming, 100 mm/mo precipitation, distributed evenly, is preferable to 200 mm/mo which all falls in 2 or 3 days (7). As shown, rainfall in Riau is relatively evenly distributed compared with that in other provinces where wet and dry seasons are clearly distinguished.

Figure 4 also indicates how the area planted and harvested of upland rice was distributed throughout the year (5). Of 45,300 ha, 61% of the upland rice was planted in September, 17% in August, and 9% in October. Of the 44,500 ha of upland rice harvested, 90% was harvested between January and

Table 1. Summarized survey results for upland rice farming at Pasir Pangarayan I, Riau, 1982-83.

Item	Pasir Pangarayan I			Remarks
	Block I	Block II	AV	
1) Sample farmers (no.)	80	120		Total: 200
2) Yield (kg)	1,298	1,155	1,212	Unhulled rice
3) Land (ha)	0.63	0.51	0.56	Area of upland rice harvested
4) Current inputs (kg/ha)				
Seeds	33	31	32	
Chemicals	1.4	2.4	2	Powder
Fertilizers				
Urea	179	40	– [a]	8 samples
TSP	155	198	180	
Manure	650	457	–	4 samples
5) Labor inputs (h/ha)				
Family labor				
Land preparation	351	– [b]	351	44 work days (WD)
Others	459	–	459	57 WD
Hired labor				
Labor preparation	130	–	130	16 WD
Other	147	–	147	18 WD
Animal				
Owned	60	–	–	2 samples
Rented	100	–	–	3 samples
Subtotal			1,087	136 WD
6) Productivities				
Land (kg/ha)			1,212	
Labor (kg/workday)			9	

[a] Data have been disregarded because samples were small. [b] Only farmers at Block I were interviewed.

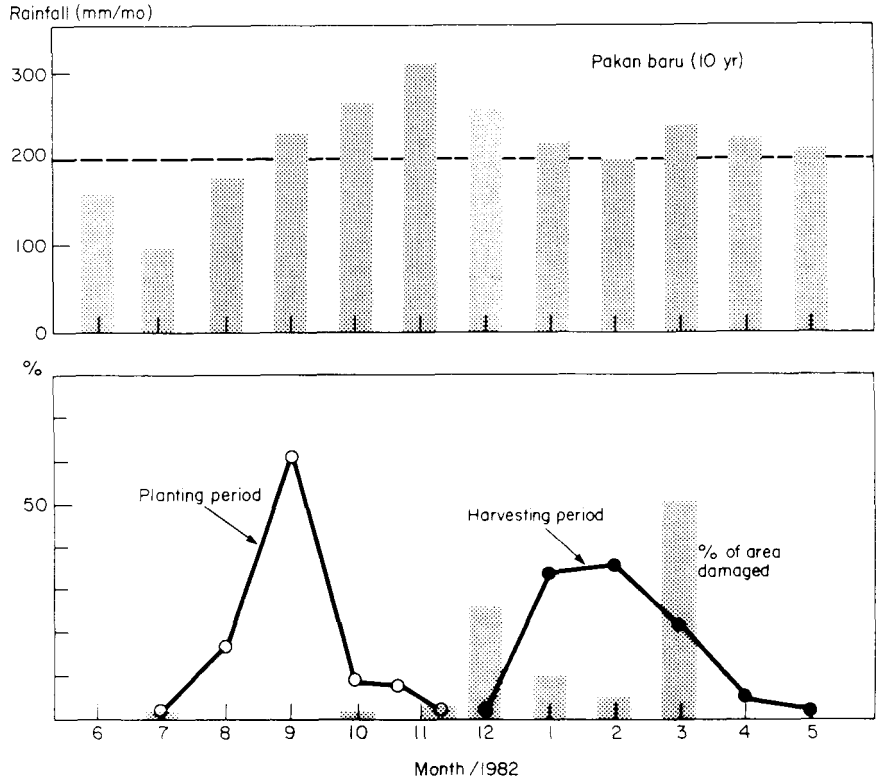
March. In Riau, farmers can plant upland rice in a relatively long period because rainfall is abundant and evenly distributed. Rice damaged was greatest in March and December.

Since farmers settled in the area, upland rice has remained the first priority to grow in the wet season. During this season, upland rice occupied more than 50% of the total crop area. However, between 1981 and 1984, farmers changed their crop priorities as follows:

Wet season: 1980-81, upland rice, cassava, peanut, maize, and soybean; 1983-84, upland rice, cassava, maize, peanut, stringbean, and sweet potato.

Dry season: 1980, maize and peanut; 1983, peanut, maize, and mungbean.

In upland rice based farming, a system of rotations or combinations of crops is important because it helps: 1) maintain soil fertility, 2) distribute risk, and 3) efficiently use land and distribute the seasonal labor utilization. However, because farm size is relatively large in transmigration areas, farmers prefer to specify a certain crop rather than mix and/or intercrop. The survey showed that more than 60% of the crop was monocrop, the rest was intercropped.



4. Upland rice planting and harvesting periods, and monthly rainfall pattern, Pasir Pangarayan I, Riau, 1982. Sources: (5; rain observations, Meteorological and Geophysical Institute, 1970).

ECONOMIC PERFORMANCE OF UPLAND RICE

Fertilization and yield

Under the most favorable climatic and soil conditions in the Philippines, about 4 t/ha is the upper limit for most traditional upland varieties, while IRRI varieties may yield nearly 7 t/ha with high rates of N (6). In Lampung Province in southern Sumatra, even if farmers applied 100 kg urea (equivalent to 45 kg N/ha) and 100 kg triple superphosphate (TSP: equivalent to 46 kg P_2O_5/ha), they obtained yields of only about 2.1 t/ha (10).

In 1983 in Riau, 100 kg urea and 150 kg TSP was recommended to farmers who use traditional upland rice varieties. Farmers in Pasir Pangarayan I through their own trials have been experimenting on how to apply fertilizer. However, the survey showed that most sample farmers (75% of the total) used only TSP without urea during the 1982 cropping season because phosphoric acid is generally deficient in such newly opened areas. The acid-soil characteristic of these areas fix P so it is not available to plants. However, the soil is comparatively fertile in N.

Assuming that soil fertility is similar over the whole sample area, a response function of TSP to yield can be derived. Based on the function, maximum yield can be estimated as 1,250 t/ha with 113 kg TSP/ha. The function also suggests that farmers who did not use TSP could produce an average of 1100 kg of unhulled rice, a yield difference of 150 kg/ha. Accordingly, the fertilizer efficiency (yield/P) is calculated at about 1.32. In 1982, the purchase price of TSP in this site was Rp 90/kg (US$1 =Rp 1,000) whereas the farm-gate price of unhulled rice was Rp 120/kg. Therefore, it is estimated that farmers gained Rp 18,000 from each Rp 10,000 of TSP input.

The effectiveness of fertilizer depends on the varieties used; the amount, timing, and number of applications; and the soil conditions. In addition, TSP usually has a slow but relatively long-term effect on the rice plant. However, the Riau study suggests the economic incentive that TSP application has at the farm level.

Cost and return analysis

In the long run, land receives the residual earnings after other factors have been paid for at their market rate. However, the cost of land is the most difficult input to value because it is closely related to productivity under different tenure statuses. Because Pasir Pangarayan I has only recently been opened, data for evaluating the land value are unavailable and have been excluded in the following cost and return analysis.

In addition, capital such as machinery and farm equipment is also difficult to evaluate because most farmers still use traditional methods to cultivate upland rice. The economic value of these traditional methods is low compared to that of irrigated farming. By contrast, labor is highly valued, particularly in newly opened transmigration areas. According to the survey on labor utilization for 80 sample farmers in Block I, 1,087 h/ha (136 workday/ha) were used for the farming. Of the total, family labor input was estimated at 101 workdays whereas that of hired labor was about 34 workdays (Table 1). Most farmers grew upland rice using their family as the labor force. Animal power use is still limited.

At the prevailing price of Rp 120/kg of unhulled rice, farmers in the area received gross returns of Rp 145,440/ha from rice production (Table 2). Results indicate their gross margin was around Rp 98,400/ha per year. The imputed value of family labor was estimated at Rp 72,500. Hence, the remaining Rp 25,900 was accounted for return to family labor/management. Financially, farmers were thus at a loss once land and capital costs were incorporated into the analysis. But most of the costs were attributed to labor, which constitutes 82% of the total cost including imputed family labor. The enterprise may break even if the productivity reached more than 1.5 t/ha under the same level of inputs.

The value added from the upland rice production system, calculated by subtracting current intermediate inputs (seed, chemicals, and fertilizers) from the output value, was 85% of total output value. This percentage is reasonably high for a conventional production system. However, because

Table 2. Cost and return analysis of upland rice production on average farm at Pasir Pangarayan I, Riau, 1982-83.

Item	AV
Production (kg)	1,212
Gross return (GR) (Rp. 120/kg) [a]	145,440
Variable cost (Rp)	
Seed (Rp 120/kg)	3,840
Chemicals (Rp 1,000 kg)	2,000
Fertilizers	
Urea (Rp 90/kg)	–
TSP (Rp 90/kg)	16,200
Manure (–)	–
Subtotal	22,040
Value added (VA)	123,400
Hired labor	
Land preparation (Rp 1,000/WD)	16,000
Others (Rp 500/WD)	9,000
Subtotal	25,000
Gross margin (Rp)	
Land	–
Capital cost	–
Farm income (Rp)	98,400
Imputed family labor [b]	72,500
Return to family labor/management (Rp)	25,900
Days of family labor (WD)	101
Family labor return (Rp/WD)	256
Shares(%)	
Farm income of GR	68
Return to management of GR	18
VA of GR	85
Land	–
Labor	79
Residual (capital)	21

[a] US$1 equals Rp 1,000. [b] Inputed value of family labor is estimated at Rp 72,500, including Rp 44,000 for land preparation and Rp 28,500 for other practices.

family and hired labors were used intensively, the return to family labor and capital made up 18% of total returns and 21% of the total value added. The family labor return was calculated at only Rp 256/d for 101 workdays.

Upland rice involves another aspect, in that farmers do not always sell their rice, because most of it is for home consumption in Pasir Pangarayan I. Supplemental data show that 23% of sample farmers could meet their annual home consumption needs.

CONCLUSION

The gap between upland and lowland rice in terms of productivity has widened since the mid-1960s. Upland rice occupies only 13% of Indonesia's

rice area and accounts for 6% of production. However, upland rice is important for home consumption as well as for income generation at remote sites.

The Riau study shows that the majority of farmers rely primarily on upland rice farming. Because the farmers have only little experience after settling in the area, several problems in growing upland rice as a cash crop have to be solved. Socioeconomic research focused on upland rice is limited in Indonesia. Because of this, it is difficult to specify in detail socioeconomic constraints, which constitute one of the most difficult problems associated with upland rice farming. In-depth and detailed socioeconomic studies are therefore urgently needed.

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STRATEGIES FOR ECOLOGICAL PRESERVATION IN UPLAND RICE FARMING SYSTEMS

R. LAL

Traditional farming systems comprising shifting cultivation and bush fallow rotation are diverse, flexible, ecologically stable, and unproductive. They involve simple land use practices that cause few long-range ecological perturbations because of the short length of cropping in relation to the fallow period and to maintenance of a partial vegetation cover even during the cultivation phase. The soil is also alive with intense activity of microfauna, e.g., earthworms, termites, centipedes, and millipedes. The nutrient capital is maintained and even built up, depending on the relative proportion of leguminous plants in the community. Upland rice, as a first crop in the cultivation phase, is grown without mechanical seedbed preparation and with minimal inputs. Although the yields are low, the net production is generally high per unit input.

SHIFTING CULTIVATION AND ECOLOGICAL STABILITY

The small amount of quantitative data available in relation to soil properties and microclimate under shifting cultivation indicate that the magnitude of alterations with reference to the forested control depends on the length of the cultivation phase in relation to the fallow phase. For example, in Senegal, Siband (14) observed that a long cultivation exceeding 16 yr caused a marked deterioration of the surface soil resulting from decline in organic matter content, decrease in clay content, and reduction in water-holding capacity (Table 1). As a result of the decrease in soil quality with duration of cultivation, the grain yield of rice declined. Charreau (1) observed a decrease in clay and silt content, organic matter content, and percent available water-holding capacity with increased duration of cultivation. However, drastic alterations in soils were minor if the cultivation phase was about 3 years or less (Fig. 1). The depletion of exchangeable cations, e.g. Ca^{++}, was severe even within the first 3 yr of cultivation. Immediately after deforestation by traditional methods in comparison with the mechanized land

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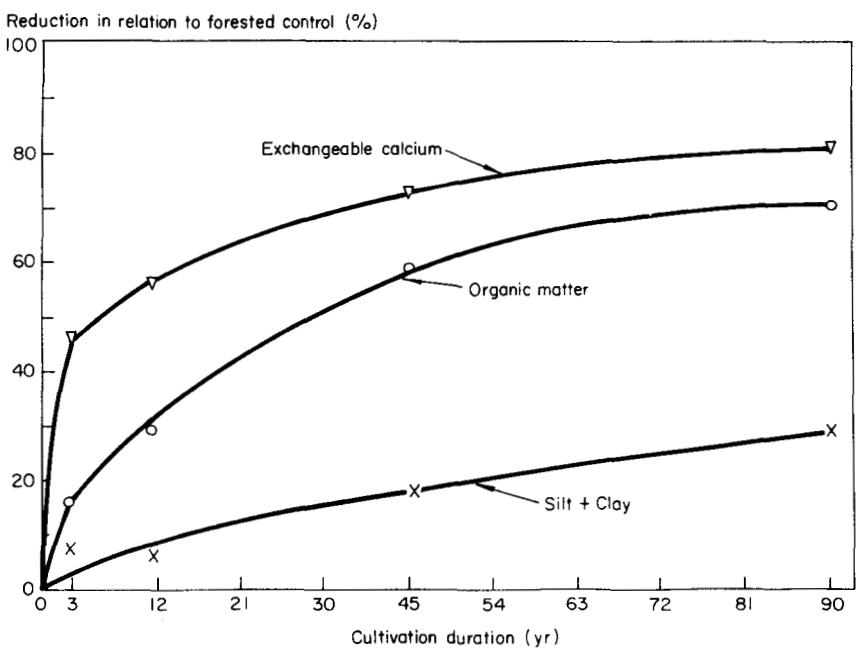
Table 1. Effect of duration of cultivation on properties of 0-10 cm layer and rice yield in Senegal (after 14).

Soil properties and rice yield	Cultivation durations (yr)		
	5	16	50
Clay (%)	9.1	9.2	6.0
Silt (%)	5.5	4.3	2.9
Sand (%)	85.4	86.5	91.1
Available water capacity (%)	5.7	4.5	4.4
Organic matter content (%)	2.4	1.5	1.3
CEC (meq/100 g)	4.7	3.5	2.6
Base saturation (%)	86	80	69
Rice production			
(1) grain yield (kg/ha)	2078	1250	0
(2) stover yield (kg/ha)	2555	2698	655
(3) root density in 0-30 cm layer (mg/4500 cm^3)	2286	1907	1067



1. Effect of duration of cultivation on percent decrease in organic matter, silt + clay, and exchangeable calcium in a soil from Senegal. (Redrawn from 1).

clearing, Kang and Lal (4) observed little difference in the chemical properties of an Alfisol, although the soil physical properties were more adversely affected by the mechanical clearing methods.

Data from a watershed management experiment at IITA compare the effects of land management systems on soil physical properties. With

incomplete clearing followed by a 2-yr manual cultivation period, the effects on soil physical properties, e.g. infiltration rate, bulk density, soil temperature, and moisture regimes, were not as drastic as in plots cleared by motorized farm operations. Data in Table 2 show favorable levels of some soil physical properties in traditionally cleared treatments. Similar observations have been reported from Thailand by Takahashi et al (15).

As a consequence of favorable soil physical properties, soil erosion and water runoff are often less from land under shifting cultivation. Runoff and soil erosion, however, increase with increase in duration of cultivation. In the Philippines, Kellman (6) studied water runoff and soil erosion during cultivation and fallow phases. Data in Table 3 show that water runoff increased from 1.08% in the first year after clearing to 11.64% in the 12th consecutive year of cultivation. Similarly, the soil erosion losses increased from 1.45 g/day in the first year to 119.31 g/day in the 12th year. Lal (8) observed negligible runoff and soil erosion from a traditionally cultivated plot, in comparison with manually cleared but intensively cultivated plots (Table 4). Similar observations were made by Takahashi et al (15) from Thailand.

True shifting cultivation (with land use factor of >10) maintains an ecological balance similar to that under the climax vegetation of the region.

Table 2. Effects of land clearing methods and postclearing management on physical properties of an Alfisol (unpubl. data, Lal 1981).

Treatment	Bulk density (g/cm^3)				Penetrometer resistance (kg/cm^2)				Equilibrium infiltration rate (cm/h)			
	1978	1979	1980	1981	1978	1979	1980	1981	1978	1979	1980	1981
Traditional farming	0.64	1.06	1.07	1.27	0.21	0.96	0.52	1.32	175	51	35	86
Manual clearing	0.68	1.17	1.17	1.39	0.20	1.40	0.75	1.19	383	20	10	7
Shear blade	0.70	1.19	1.37	1.38	0.26	1.00	1.84	2.19	102	11	14	5
Tree pusher/ root rake	0.60	1.24	1.32	1.42	0.20	1.30	0.73	1.23	162	17	11	3

Table 3. Erosion and runoff from soil under shifting cultivation in the Philippines (6).

Treatment	Runoff (%)		Sediment loss (g/day)	
	Cropping period	Post-harvest	Cropping period	Post-harvest
Logged-over forest	-	-	-	-
New maize swidden	1.52	0.86	3.03	0.65
New rice swidden	1.08	0.42	1.45	0.37
2-year-old maize swidden	1.78	0.69 (4.08)	12.05	9.81
12-year-old rice swidden	1 1.64	6.73 (14.15)	119.31	6.32

Numbers in parentheses refer to post-cropping period.

Table 4. Soil erosion and water runoff from 1979 to 1981 in shifting cultivation and intensive land use treatments (8).

Treatment	Runoff (mm)		Erosion (t/ha)	
	1979	1979-81	1979	1979-81
Forest control	–	–	–	–
Manual clearing, shifting cultivation	3.0	6.6	0.01	0.02
Manual clearing, no-till	16.0	16.1	0.4	0.4
Manual clearing, conventional till	54.0	79.7	5.0	9.8

Deterioration in soil properties and micro- or mesoclimate occurs with an increase in the cultivation duration. The duration of cultivation phase is being prolonged because of the shortage of suitable arable lands in relation to increased demographic pressure.

ENERGY REQUIREMENTS

Traditional tropical agricultural systems are the most energy efficient. Rappaport (13) studied the flow of energy in the traditional agricultural society of New Guinea and estimated energy output:input ratio for root crop based traditional cropping systems to be more than a 16:1 return on the human energy investment. Le Pape and Mercier (9) reported the output: input ratio for rice production in the Philippines to be 7.7 in comparison with only 1.35 for the United States. Although more quantitative data are needed for output:input ratios for upland rice production in different ecologies, the scanty information available suggests that the out:in ratio is much more favorable for traditional than for high-input modern agricultural systems. This is because the traditional agricultural practices are based on human and animal labor, and limited inputs of agricultural chemicals and farm machinery. However, these practices are not conducive to increased food production, as is evidenced by severe food deficit, widespread malnutrition, and recurring famines. The strategy, therefore, has to be drastically changed.

CONSTRAINTS IN INTRODUCING IMPROVED UPLAND RICE SYSTEMS

Intensive and continuous land use for production of rice and other grain crops leads to rapid decline in soil organic matter content, compaction of the surface and the subsoil, decreased available water and nutrient retention capacity, accelerated soil erosion, and erosion-induced soil degradation.

From the time of clearing and burning, the exposed soil attains supraoptimal soil temperatures, is readily desiccated, and is susceptible to accelerated erosion by raindrop impact. Under these changed soil micro-

climate conditions, the activity of microfauna is adversely affected. The loose friable and crumb structure under forest vegetation and the bush fallow rotation gives way to crusted and compacted surface soil devoid of any biotic activity. The degree and rapidity of these structural alterations depend on soil type, prevalent microclimatic conditions, and soil and crop management. Soils containing predominantly low activity clays are more susceptible to degradation than those containing high activity clays and high organic matter content.

However, fears of environmental and soil degradation with introduction of intensive and motorized agriculture are easily exaggerated because of lack of basic data on cause-effect relationships. Soil degradation needs to be defined quantitatively in terms of rate of change in soil quality in relation to rice productivity.

For example, what are the lower limits of soil organic matter content, porosity, water and nutrient status, and tolerable levels of toxic elements for major soils of the tropics below which rice yield is drastically reduced?

Over what time periods do soils reach these production limits under different levels of land use intensity and soil and crop management systems?

What are the critical limits beyond which a soil is liable to undergo irreversible degradation?

It is important to define these limits so that mining of soil's productivity can be stopped before it reaches the point of no return.

The critical soil bulk density values for development of rice are different than those for other crops. Data in Table 5 show that critical bulk density for rice growth varies between upland and lowland rice cultures, and among soils of different mechanical compositions. The critical soil bulk density values for upland culture are attained more rapidly with motorized tillage than with manual systems of soil management. Similar information is needed to define the effects of erosion on rice production for different levels of inputs.

Drought stress is the direct result of decrease in available water-holding capacity caused by soil compaction, water runoff, and supraoptimal soil temperatures. The critical limits of soil moisture potential are different for different rice varieties (10). The effects of low soil moisture content are highly aggravated by high soil temperatures, and compacted subsoil horizons.

The major concern to agricultural scientists and planners is the appropriate strategies to be adopted for land development and soil management that will alleviate these ecological constraints and enable intensive land use with high and sustained rice production.

ECOLOGICAL APPROACH TO UPLAND RICE PRODUCTION

Because uplands in the tropics are easily degraded by adoption of high input motorized agriculture, it is important to adopt an ecological approach to sustainable, low-input and efficient agricultural systems for rice production.

Table 5. Critical soil bulk density for upland and lowland rice cultures.

Water regime	Soil	Bulk density (g/cm^3)	Country	Reference
Upland	Vertisol	1.6	Nigeria	(12)
Upland	Ultisol	1.5	Nigeria	(12)
Upland	Alfisol	1.38	Senegal	(11)
Lowland	Sandy clay loam	1.63	India	(3)
Lowland	Sandy loam	1.80	India	(2)
Lowland	Sandy loam	1.60	India	(5)

A self-sustaining system implies that inputs are minimized and supplemented but not prohibited. For example, with appropriate soil management systems and crop rotation the N requirement for rice production may be reduced from 100 kg/ha to, say, 50 kg/ha. The rotation system and methods of land preparation are designed to minimize losses of nutrient capital through leaching, runoff and erosion, and volatilization. The frequent use of desirable legumes in rotation is an important aspect of a sustainable rice production system, and the no-till and mulch farming techniques are proven soil-conserving measures.

An ecologically stable production system must also be diversified. Multiple cropping, eg, mixed cropping, relay cropping, and sequential cropping are important components of a stable diversified system. Growing rice in association with woody perennials is another useful way to create the desired diversity and decrease dependence on agrochemicals.

The lesson to be learned from past mistakes involving expansion of agricultural practices in the tropics is that the issues concerned with upland management must look beyond the question of production economics and specifically address the questions of environmental and ecological preservation. Rather than increase yield at whatever cost, the emphasis should be to increase the net yield with a minimum of soil or environmental degradation. The preservation of natural resources should be given high priority in making a farm an economically viable enterprise.

RESOURCE AND ECOLOGICAL PRESERVATION STRATEGIES

Killey-Worthington (7) identified seven requirements of "Ecological Agriculture." Among them, three important components are sustainability, diversity, and resource preservation.

For a system to be ecologically stable it must:

1) maintain or improve soil structure.

   This can be done through built-in mechanisms, e.g., conserving soil organic matter content, providing a continuous ground cover, preventing raindrop impact, and enhancing soil fauna activity. The biotic activity is an important factor in improving the structure of tropical soils and it must be preserved.

2) prevent accelerated soil erosion.

Erosion-induced degradation of soil properties is a major cause of productivity decline and environmental deterioration. An important principle to prevent erosion is not to disturb the surface soil. The practice of seeding through crop residue mulch without plowing, e.g., no-till farming, is a proven conservation-effective measure. Soil compaction, a direct consequence of motorized farm operations, must be avoided by minimizing tillage operations and using crops with deep tap root systems in rotation with rice.

3) reduce drought stress.

Drought stress is a severe constraint in upland rice. Soil management systems must minimize water losses by decreasing both water runoff and evaporation. The soil temperature range must also be regulated to within-the-optimum range. Soil management techniques that encourage deep root penetration are desirable. There are also differences among cultivars in relation to their drought susceptibility. Cultivars with deep root systems and those that can maintain high leaf water potential can withstand drought better than those with fibrous and shallow root systems.

4) provide a nutrient recycling mechanism.

The practice of multiple cropping of different but compatible species is an important concept to be considered. Frequent use of legume or grass covers in the rotation is another system to minimize nutrient losses. The use of fire as a management tool may be feasible under specific circumstances. The uncontrolled fire is a severe liability.

The application of these principles in developing sustainable farming systems for management of tropical uplands is shown in Figure 2. The strategy so described has three major components:

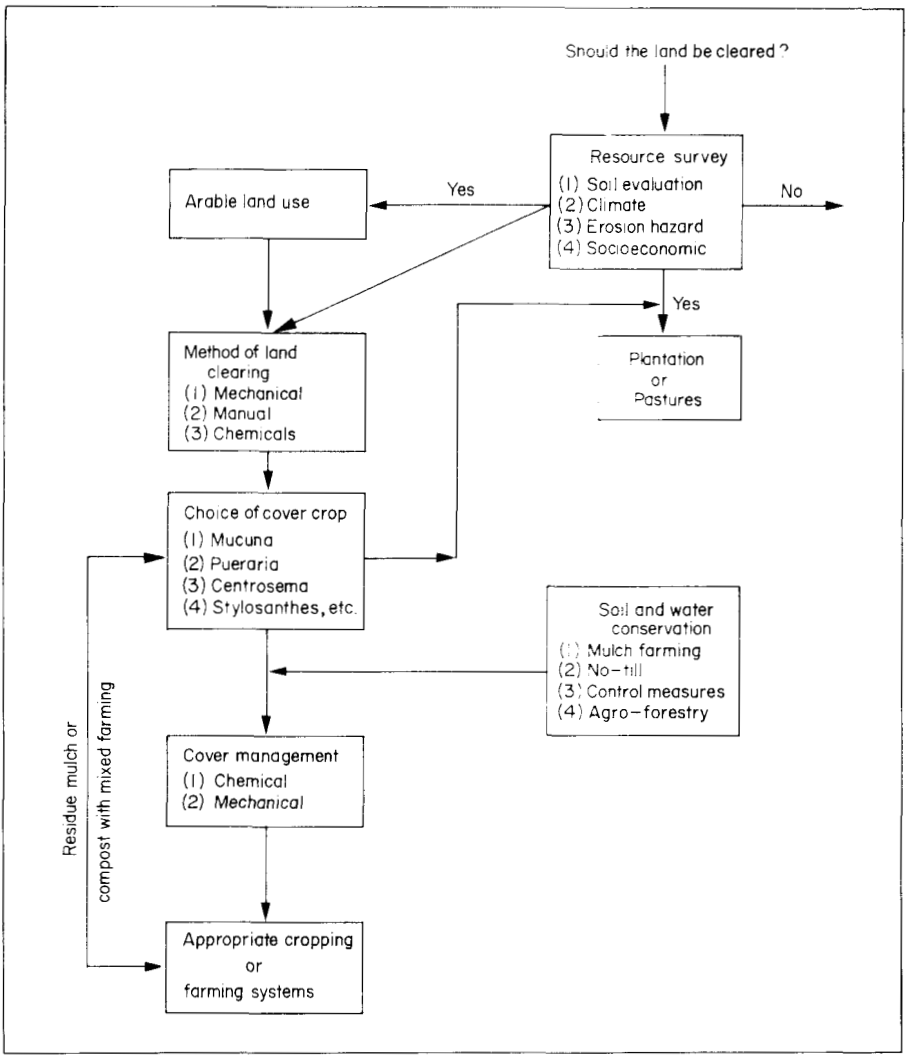
1) Land Clearing and Development.

The choice of land to be cleared must be based on a detailed resource survey with regard to soil, terrain, micro and mesoclimate and socioeconomic factors. The prime land for rice production should be free from severe hazards of soil erosion. The soil should be deep with a favorable moisture regime. If not, the land should either not be cleared or should be cleared for perennial crops or pastures.

Method of land clearing also depends on the intended land use, the type of cropping or farming system, and the degree of mechanization. In general, manual clearing methods are to be preferred over mechanical land clearing techniques. Deep plowing is often not necessary for grain crop production provided that the regrowth is minimized.

2) Mulch Farming.

Newly cleared land must be immediately covered by establishing a quick-growing legume, e.g., *Mucuna, Pueraria, Centrosema, Stylosanthes,* or others. Once ground cover is effectively restored, rice can be seeded through the killed or suppressed sod without mechanical



2. Strategies for ecological preservation in tropical uplands.

seedbed preparation. Experiments at IITA on 3 to 4 ha watersheds (Lal, unpublished data) show that the watershed growing rice by the no-till system was adequately protected even from a high-intensity rainstorm. For the no-till system to be effective, however, there must be an adequate quantity of crop residue mulch, and weeds must be controlled in a timely manner.

3) Farming Systems.

Rice must fit into the scheme of the upland farming or cropping system appropriate to the ecological conditions. Rice can be grown in rotation with legumes or in association with woody perennials by alley

cropping. The use of livestock and controlled grazing may be an important aspect if upland rice is to be grown on marginal lands. Close integration of plants and animals can provide the needed diversity to render the system more stable.

CONCLUSIONS

Expanding upland rice production must be considered on the basis of ecologically stable farming systems. Ecologically stable systems are self-sustaining with low-level input, diversification, and productiveness. The important concept is to decrease environmental degradation and preserve the natural resource. For a system to be stable it must maintain or improve soil structure, prevent accelerated soil erosion, preserve or improve soil organic matter content, and have a built-in nutrient recycling mechanism.

The components or subsystems of an ecologically stable system include manual land clearing, mulch farming, no-till, and multiple cropping with possibilities of integrating crops and livestock.

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SUBSISTENCE UPLAND RICE CULTIVATION SYSTEMS: AN ECONOMIC CONSIDERATION

R. R. GONZAGA, N. M. ROXAS, and E. C. PRICE, JR.

Upland, pluvial, or dryland rice constitutes 13% of about 19 million ha of the world's rice areas. Its relative importance varies: in Latin America 76% of ricelands are upland rice (3), in West Africa 65% (14), and in South and Southeast Asia 13% (Table 1) (8). Despite the sizable area which upland rice occupies, it accounts for only 5% of the world's total rice production (10). This minimal contribution to the total rice crop cannot be ignored. Its importance lies in the large number of highland subsistence farmers who depend on it — in many cases, completely.

In the Philippines, upland rice occupies 157,100 ha or 4% of the country's rice-growing area (1983 data). The important upland rice areas are Mindanao (52% of the country's upland area) and southern Luzon (20%) (Table 2). Upland rice production accounted for 3% of the country's total rice production in 1983.

During the last decade, upland rice areas in the Philippines have declined and so has production (Fig. 1, 2). The decline was brought about by development of irrigation facilities, a shift to maize, and, more recently, to crops such as cotton and soybeans (12).

Upland rice yields lower than irrigated and rainfed lowland rice. At the national level, rice grown under irrigated conditions yields thrice as much as rice grown in upland areas regardless of variety. On a regional basis, Central Luzon has the highest observed mean yield for all varieties across rice culture types while southern Luzon has the lowest (Table 3). The yield trend of local upland rice varieties stabilized in the 1970s to early 1980s and later declined again. Modern variety (MV) yield under upland conditions has increased (Fig. 2). The promotion of modern rice varieties, notably in Mindanao through the Philippine-Australian Development Project (PADAP) in Zamboanga peninsula and the Ministry of Agriculture and Food, contributed partly to the increased mean yield in that region (12).

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Table 1. Rice area by culture type in South and Southeast Asian countries, 1979 (8).

Country	Area allocated (thousand ha)					
	Upland	Deepwater	Irrigated		Rainfed	
			Wet	Dry	Shallow (0-30 cm)	Intermediate (30-100 cm)
Southeast Asia						
Burma	793	173	780	115	2,291	1,165
Indonesia	1,134	258	3,274	1,920	1,084	534
Kampuchea	499	435	214	–	713	170
Laos	342	–	67	9	277	–
Malaysia	91	–	266	220	147	11
Philippines	415	–	892	622	1,207	379
Thailand	961	400	866	320	5,128	1,002
Vietnam	407	420	1,326	894	1,549	977
Total	4,642	1,686	7,685	4,100	12,396	4,238
South Asia						
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	13,569	3,513	17,979	7,349

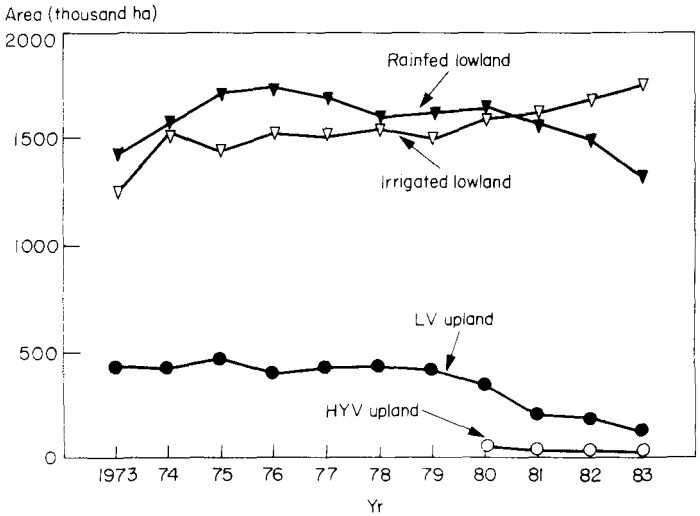
Table 2. Total rice area and upland rice, by variety, Philippines, 1983 (1).

Region	Rice area (thousand ha)			
	Total	MV	LV	Total
Northern Luzon	733.9	13.2	6.0	19.2
Central Luzon	494.9	1.7	0.1	1.8
Southern Luzon	649.6	5.9	26.0	31.9
Visayas	738.8	3.7	19.1	23.2
Mindanao	622.3	3.7	77.3	8.1
Philippines	3,239.5	28.6	128.5	157.1

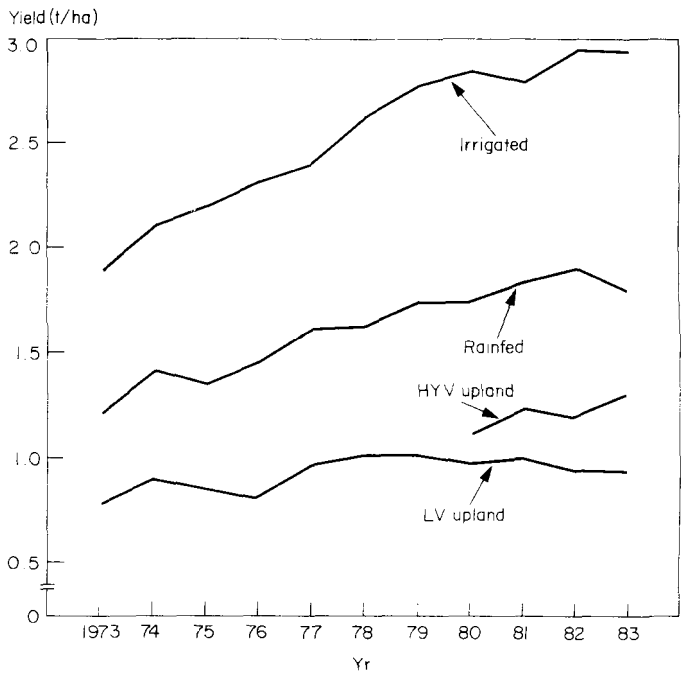
Table 3. Mean rice yield, by variety and culture type, Philippines, 1980-83 (1).

Region	Yield[a] (t/ha)					
	Irrigated		Rainfed lowland		Upland	
	MV	LV	MV	LV	MV	LV
Northern Luzon	2.76	2.00	1.90	1.48	1.03	0.89
Central Luzon	3.39	2.72	2.51	2.12	1.68	1.13
Southern Luzon	2.59	1.90	1.72	1.23	1.08	0.88
Visayas	2.72	1.77	1.76	1.67	1.06	0.78
Mindanao	3.26	2.78	2.12	1.52	1.36	1.09
Philippines	2.96	2.21	1.94	1.38	1.22	0.97

[a]MV = modern variety, LV = local variety.



1. Rice area by culture type and variety, Philippines, 1973-83.



2. Mean rice yield by culture type, Philippines, 1973-83.

Upland rice production in the Philippines includes both sedentary and shifting cultivation (*kaingin*). In the Philippine context, kaingin refers to any portion of the forest land subjected to shifting or permanent slash-and-burn

cultivation. Data are scant as to extent of upland rice production in a shifiing cultivation environment. Kaingin was practiced on an estimated 100 000 ha or 25% of the country's upland rice area in 1960 and declined in 1974 to 11% (4). Occupants of forests in the Philippines totals 177 616 families on an estimated 634 210 ha (2).

Shifting cultivation is practiced in most Asian countries. Philippine shifting cultivation is responsible for 20% of the deforestation (Table 4). Historically, Philippine highlands ethnic groups have always been associated with kaingin or were believed to have started it. Shifting cultivation is seen as rampant and nefarious, as the kaingin peril and a national arson, and may be spoken of as makeshift or overnight farming without an appreciation of all that is entailed in swidden (another name for it) as a subsistence activity (5). This stereotyped image was widely held in the Philippines. Presidential Decree No. 705, known as the Revised Forestry Code of the Philippines, created the Social Forestry Program. This program calls for proper classification, management, and utilization of forest lands of the public domain to maximize their productivity to meet the demand of an increasing population. Protection, rehabilitation, and development will be emphasized.

Under the program, interested parties are given 7 ha of forest land on a 25-yr stewardship. The land can then be converted into agroforestry projects, such as agricultural crops and tree/forest crops combined. Forest reserves not open to cultivation under the Social Forestry Program include national parks, watershed areas, game refuge, and logging concessions (2).

Many studies describe the different kinds of shifting cultivation practiced by different ethnic groups in the Philippines. Most are from an anthropological point of view. Among them is a study about tribal mobility. The mobility of Pinatubo Negritos, a function of swidden farming, is also motivated by a sheer love of travel, adherence to abandonment of dwellings after a family member's death, and the desire to keep away from government control. The Tagbanua tribe, on the other hand, puts particular emphasis on their religion (rituals) as a major factor for their relative sedentarization in large villages (6). In contrast, Frake (7) suggests that swidden technology does "little to stimulate,' the growth of complex sociopolitical structures that might restrict the spatial mobility of the highly independent family swiddening unit among the Subanun tribe.

Table 4. Extent of forest destruction by cause, Philippines, 1982 (2).

Cause	Area	
	ha	%
Kaingin	3,286	20
Forest fire	8,063	48
Logging operation	4,954	30
Pests and diseases	351	2
Total	16,654	100

Studies on changing swidden systems suggest that the landless and the rural unemployed or the lowland migrant kaingineros with poor knowledge of swidden techniques are the major factor in soil erosion in contrast to the deep forest dwellers whose traditional methods allow natural reforestation (9).

As the forest ecosystem becomes unbalanced with the advent of grasses, a choice must be made between moving to a new forest or sedentarizing and taking up the plow in cash cropping. Socioeconomic changes then involve the need for capital investment, the need for formerly independent but kin-related households to pool their labor, a developing market-cash orientation, and dietary changes related to greater dependence on the market (14). This is what happened to many Tirurays, who were forced to take up plow farming and became peasant-tenant members of the market-oriented lowland Filipino society (11).

Only limited studies on the economics of upland rice under shifting cultivation system are available. This paper describes the socioeconomic conditions of an unfavorable upland research site where shifting cultivation is being practiced and focuses on lowland migrants who wish to establish a sedentary type of highland farming as exemplified in the village of Magsaysay. Specifically, this paper characterizes the resources, technology, and benefits realized by settlers under kaingin cultivation system where upland rice is grown.

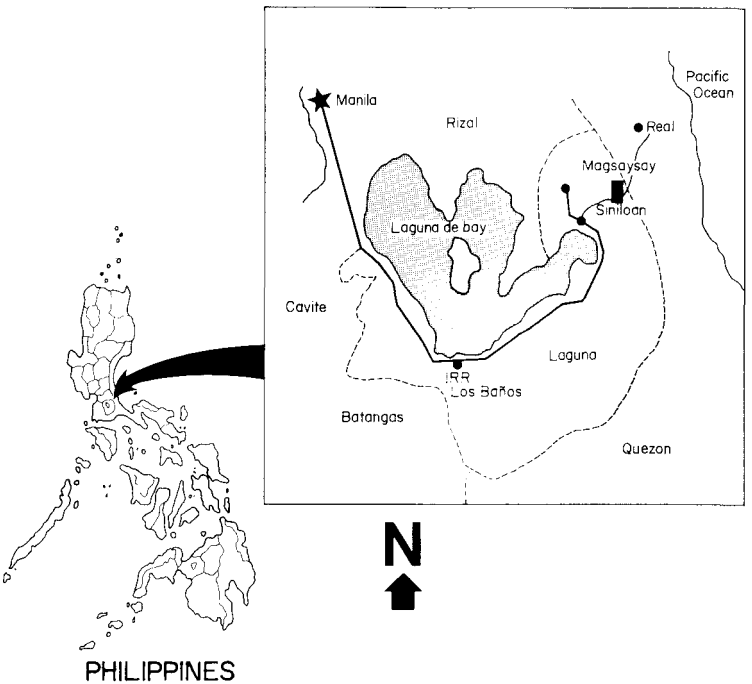
Physical environment

Magsaysay is a village in the watershed area of the Sierra Madre mountains draining the tributaries that flow into the Laguna de Bay. It is bounded on the east by the Pacific Ocean, neighboring towns of Laguna Province on the south and west, and by Rizal Province on the north. It is about 70 km northeast of IRRI, Los Baños, Laguna (Fig. 3).

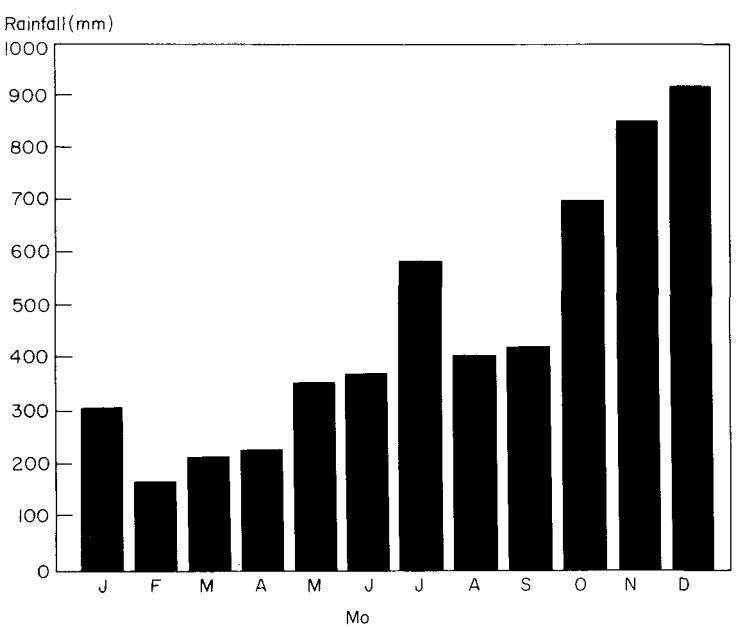
Total annual rainfall is 5430 mm, a high in December with 919 mm, a low in July with 584 mm and lowest in February with 171 mm (Fig. 4). Rainfall distribution precludes establishment of year-round upland crops. Variability of the onset of rainfall, therefore, may not be a major concern relative to crop production.

The research site is 220 m above sea level. Its terrain is characterized by moderate to steeply sloping with secondary growth forest, except where kaingin farming has been established. The topographic characteristics are one limiting factor for continued cultivation of upland crops alone in the long-run. Soil characteristics, on the other hand, limit the production of some upland crops. The high acidity of the soil, e.g. pH 4.1, although not necessarily critical for upland rice, poses a major problem if farmers want to plant leguminous crops.

Initial soil analysis showed low soil pH is interrelated with high Al ion saturation of the CEC. This would mean a base saturation and low P availability in the soil. It is highly probable that Mo and Mn are deficient (H. U. Neue, International Rice Research Institute, 1985, pers. comm.).



3. Map of the research site, Magsaysay, Siniloan, Laguna, Philippines.



4. Thirteen-year mean monthly rainfall distribution, Magsaysay, Siniloan, Laguna, Philippines, 1969-81. Source: National Botanic Garden, Magsaysay, Siniloan, Laguna, Philippines.

Socioeconomic environment

Most settlers in the area are of migrant families who arrived after logging operations. The original settlers previously worked for the defunct logging company. Settlers from neighboring towns of Laguna who were also shifting cultivators, arrived next. Later, Bicolanos, Visayans, and even Ifugaos arrived (Table 5). A steady stream of migrants continues from other parts of the country. Most of them are from the lowlands and were landless farmers or individuals with few opportunities for gainful occupation in the lowlands.

The old and new migrants brought little capital or technical knowledge useful for highland farming. Over the years they tried almost any crop; continued experimentation by the settlers has not generated a productive and stabie cropping system. Rice could be grown only once and followed by root crops for 2 or 3 yr - only providing a marginal food supply.

Subsistence-level production typifies most highland communities in the country. Migrants in Magsaysay support themselves with marginal crops and receding forest resources. Their cash income barely meets purchases of basic commodities - rice in particular. Planting of annual and perennial crops neither helped improve their living standard nor the technology in crop production. The current high demand for charcoal in urban areas has greatly contributed to improving the cash position of the settlers. However, the long-run prospects of charcoal are dim because of deforestation.

Shifting cultivation to primitive sedentary cultivation

Under a strictly shifting cultivation system, forests are cleared and cultivated for a short period before they are left fallow to regenerate into forest or turn into grasslands. Fallow periods range from 5 to 10 yr. However, in a system where the forest itself becomes the limiting factor (declining land-man ratio), highland cultivation is transformed into a sedentary type, rather than a shifting type. This type of highland agriculture is now becoming typical in the village of Magsaysay.

The location and area swiddened by the household depend largely on when they migrated and on size of the household. Farmers who migrated

Table 5. Demographic characteristics of Magsaysay, Siniloan, Laguna, Philippines, 1983. (Source: Barangay secretary, Magsaysay, Siniloan, Laguna, Philippines).

Characteristic	
Household (no.)	200
Size of household (no.)	6
Years in school (no.)	4.5
Origin of settlers (%)	
Bicol region	50
Tagalog provinces	35
Visayas	10
Other places	5
Total	100

earlier have large households, tend to occupy larger fields, and are situated near the road. On the other hand, new migrants generally locate their fields in the interior of the forest and usually acquire smaller plots. Similarly, if some households desire to expand their landholdings, they have no choice on its location. Similarly, additional fields of old migrants are situated farther from their house or other plots.

Farmers who arrived earlier could virtually claim (for free) as much land as they could cultivate. Currently, however, the cost of just the legal right to cultivate can reach about $57/ha. A farmer who cannot afford the cost could clear and cultivate a particular area, and if after some time nobody lays claim to the land, he may consider it his own. For some, becoming a tenant of absentee landlords is a safe strategy in gaining access to land.

During the first year of the swidden, the household clears the portion of the forest near the house. Over the years, the clearing proceeds on a circular manner relative to their dwelling. On the average each household can clear 0.50 ha of land per year out of their 5.5 ha of land (Table 6).

Land use in the area follows a diverse intercropping of annual and perennial crops. Strict adherence to this system is dictated not by dietary requirements (rice is the staple food) but by physical environment and the exigencies of their technologies. The preference for a sedentary type of agriculture contributes to the existing land-use patterns. In most cases the shift to a sedentary type is achieved through cultivation of perennial crops.

Upland rice is the first crop planted after the land is cleared of secondary growth. Immediately after rice, a variety of root crops are established until the second or, in some instances, even until the third year of kaingin. During these initial years, farmers see to it that perennial crops are planted along with the root crops. The most common perennial crops are coconut, coffee, citrus, banana, and fruit trees. Upland rice is never planted in the same area 2 yr consecutively. Farmers described the soil as "sour" (acidic) and therefore rice should be planted only once at a particular plot. To have rice, the household must continually open up new forest. The farmers are aware, however, that this cannot go on forever.

Upland farming in Magsaysay at present involves a more intensive land-use pattern than that normally evoked by a stereotype shifting cultivation or swiddening. Fallowing in a strict sense is not practiced.

Table 6. Present status of kaingin of 11 farmer cooperators, Barangay Magsaysay, Siniloan, Laguna, Philippines, 1983.

Status	Area	
	Ha	%
Forested	2.5	45
Under cultivation [a]	2.5	45
Newly opened	0.5	10
Total	5.5	100

[a] Includes perennial and annual crops.

Existing upland rice technology

Farmers do not presently grow any modern upland rice varieties. At least nine local rice varieties in the area are those that migrants brought with them. Rice seeds can be traded, bought from other farmers, or purchased commercially. Most farmers plant several local varieties on their clearings hoping to find a suitable upland rice variety. The continued experimentation of the farmers suggests the unavailability of upland rice technology in the area. Yields are well below the national average (Table 7).

Upland rice is usually planted in June when rainfall is about 368 mm. Upland rice is dibbled at 30 kg/ha using zero tillage. About 30 d after emergence, hand weeding is done mostly by women and children of the household. This operation lasts for a week or more, depending on weed population, field size, and available weeders in the household. The second weeding is about 60 d after emergence. In some instances, hand weeding is unnecessary if burning had been thorough. No other crop care is provided to the rice crop after the weeding operation. Chemical inputs such as fertilizers and pesticides are rarely applied.

After 4-5 mo, the crop is harvested, mainly by women and children of the household. The yield is apportioned between household consumption and seed stock for the next clearing. The average yield of upland rice is around 390 kg/ha.

Farmers claim that rice production is not a profitable enterprise. Partial budget analysis supports the farmers' claim. When all inputs are valued, the farmer stands to lose $113 (Table 8). This loss does not dissuade them from planting while forest remains open. Some farmers who do not foresee future clearings never attempt to plant upland rice again. The farmers' apprehension about an upland rice crop, particularly a second rice crop, is justified. Soil fertility is inadequate even for the first rice crop. Some elements (Al, for example) are near toxic levels. Insect pests are a major limiting factor. Entomologists have identified common rice insect pests that

Table 7. Mean yield of traditional upland rice varieties, Barangay Magsaysay, Siniloan, Laguna, Philippines, 1983.

Variety	No. of observations	Yield (t/ha)
Kinawayan	8	0.37
Pinilik	9	0.89
Benernal	5	0.50
Minita	3	0.22
Binikol	2	0.40
Milagrosa	3	0.28
Eningkanto[a]		
Buluhan[a]		
Initlog daga[a]		
Av		0.39
National average		0.97

[a]No available yield observation.

are of economic significance: seedling maggots, leaffolder, rice bug, rice root aphids, thrips, and leaf aphids (A. Barrion, International Rice Research Institute, 1985, pers. comm.).

Cash flow

Despite continuous cultivation of upland crops, Magsaysay migrants rely heavily on the receding forest resources as a source of cash income (Table 9). In fact, more than 70% of the cash income is derived from forest products. Charcoal-making is the single activity that provides 58% of the household's total cash revenue. The rising high demand for charcoal results as it becomes a cheap source of fuel for the urban population. Charcoal production is not as profitable as farmers claim (Table 10). It appears profitable because the only cash cost they incur is transport from the charcoal pit to the roadside. The rest of the inputs involve noncash transactions. Labor in particular can

Table 8. Cost and returns of upland rice in a newly opened kaingin system, Barangay Magsaysay, Siniloan, Laguna, Philippines, 1984.

Item	Quantity/ha	Cost/ha ($)
Yield	390 kg	
Labor		
Clearing and burning[a]	28 d	52
Dibbling of seeds	13 d	24
Hand weeding	32 d	59
Harvesting	39 d	71
Materials		
Seeds	30 kg	8
Total variable cost		214
Gross returns		101
Returns above variable cost		−113
Returns to cash		93

[a] After cutting logs for charcoal and firewood. US$1 = ₱17.50 (unofficial 1984 average).

Table 9. Average annual cash income of 11 farmers, Magsaysay, Siniloan, Laguna, Philippines, 1984.

Source of income	Cash income	
	Av household ($)	%
Charcoal-making	357	58
Salaries and wages	131	21
Informal credit	20	3
Crop sales	40	6
Sale of fern leaves	29	5
Sale of firewood	28	4
Contribution from children	7	1
Others	16	3
Total	628	100

US$1 = ₱17.50 (unofficial 1984 average).

Table 10. Cost and returns of charcoal production for an average-sized charcoal pit (15 m^3), Magsaysay, Siniloan, Laguna, Philippines, 1984.

Item	Quantity	Cost ($)
Labor		
Digging pit	1 d	2
Cutting logs	5 d	9
Hauling logs	16 d	30
Gathering grasses	1 d	2
Covering pit	2 d	4
Other care	1 d	2
Harvesting charcoal	7 d	12
Hauling pit to roadside		10
Materials		
Sacks	75 pc	5
Gasoline and oil		4
Total variable cost		80
Total production	75 sacks/pit	
Gross returns		62
Returns above variable cost		-18
Returns to cash		51

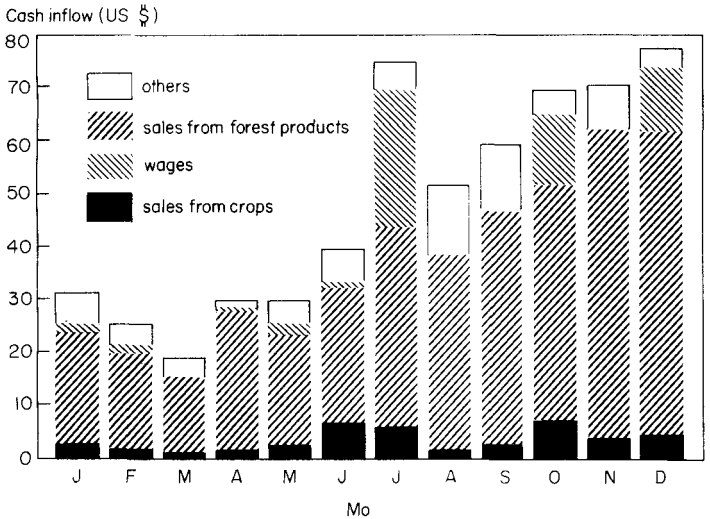
US$1 = ₱17.50 (unofficial 1984 average).

be acquired through a reciprocal basis. As the farmer goes deeper inside the forest to make charcoal, the cost of hauling increases.

Crop sales, once the major source of cash income, have become a supplemental source of cash. Crop production as a source of cash income accounts for 6% of the household's total cash earnings. Upland rice produced in the kaingin is rarely sold, mainly being for home consumption. Other current cash-generating activities just as important as crop production are gathering of firewood and of ferns for floral shops in Manila. The figures, however, do not understate the importance of crops in the household economy. In fact, about 20% of the total food consumption comes from their own farm. Figure 5 illustrates the typical cash inflow of a household in Magsaysay. The increasing cash earnings of the household toward the end of the year largely resulted from increased sales volume and prices of charcoal.

The single most important expenditure of the farm household is for rice, which accounts for 75% of the total food purchases (Table 11). The amount of rice the kaingin produces contributes less than 10% of the household rice requirements. Crop production investment is negligible. If ever there is any investment aside from labor, it is mainly for purchases of planting stocks of perennial crops, such as budded citrus.

The increase in cash income provided farmers enough cash to meet their household needs. Notably, rice purchases increased proportionately (Fig. 6).



5. Monthly average cash inflow by source, 11 farm record keeping farmers, Magsaysay, Siniloan, Laguna, Philippines, 1984.

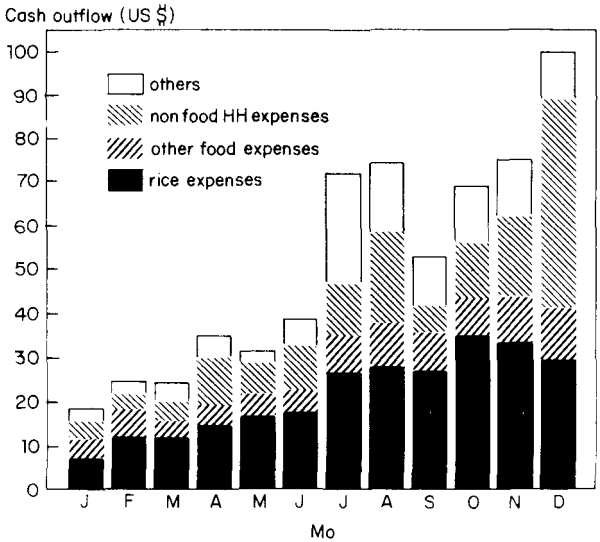
Table 11. Average annual cash expenditure of 11 Farm Record Keeping farmers, Barangay Magsaysay, Siniloan, Laguna, Philippines, 1984.

Item of expenditure	Cash expenditure	
	Av household ($)	%
Rice	258	42
Fish/meat	71	12
Other food items	14	2
Nonfood household items	80	13
Medical care	63	10
Education	13	2
Livestock	10	2
Marketing/transportation	18	3
Repayment of loan	28	5
Farm hired labor	3	–
Other farm/household expenses	54	9
Total	612	100

US$1 = ₱17.50 (unofficial 1984 average).

Labor use and wage rate

Kaingineros meet most labor requirements for swiddening by drawing manpower from their households. One major problem is low labor availability relative to farm size. Allocation of labor within the household is largely determined by the kind of operation. Able-bodied males of the household are responsible for initial clearing of the forest while women and children are responsible for the cultivation and weeding of the annual crops. This labor structure may not be followed strictly particularly if land is not available for clearing. At this stage, crop cultivation is a collective activity of the farm household.



6. Monthly average cash outflow by item of expenditure, 11 farm record keeping farmers, Magsaysay, Siniloan, Laguna, Philippines, 1984.

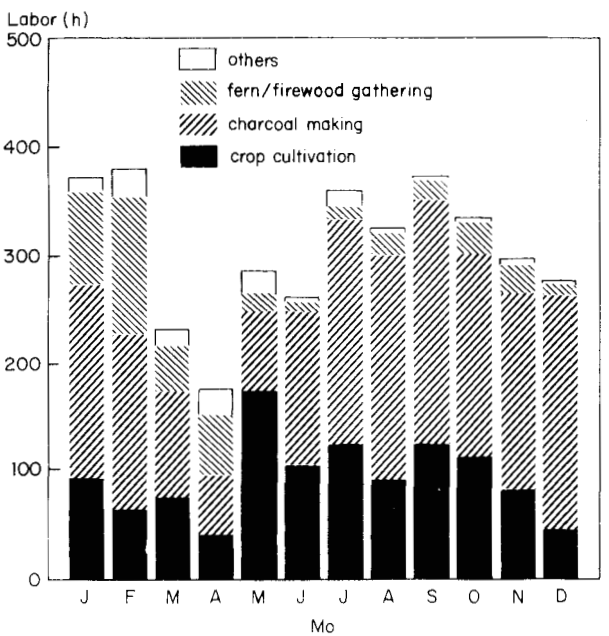
Lately, allocation of male labor became competitive between crop cultivation and noncrop related activities. Charcoal making, an easy source of income, is drawing most of the available male labor in the area. Its importance to the household economy is that it draws labor away from other traditional cash-generating activities such as crop production, cutting and hauling of logs, and gathering of rattan and firewood. Crop cultivation was reverted to women and children of the household while the men are deep inside the forest making charcoal. Charcoal production demands 47% of the household's weekly available labor force (Table 12 and Fig. 7). This single activity has placed an upward pressure on the local wage rate. When charcoal-making was only a source of supplemental cash income, the nominal wage rate was $1.54/d. This year it is $1.83/d, the same wage paid to labor hired for clearing operations. It should be noted, however, that the labor market is largely dominated by exchange labor rather than cash wage transaction.

Potential of upland rice-based technology

Kaingin is exemplified by a high degree of subsistence farming (Fig. 8). The household interacts with three subsystems: (1) the forest-based, (2) the crop-based, and (3) the market subsystems. The household allocates labor and power to the forest-based subsystem and labor alone to the crop-based subsystem. The forest-based subsystem directly provides the household some of its basic needs, e.g., food, shelter, and fuel. Through the product market, it provides the bulk of the household cash requirements from the sale of charcoal and other forest products. On the other hand, most of the labor requirement of the forest-based subsystem is satisfied through the exchange labor.

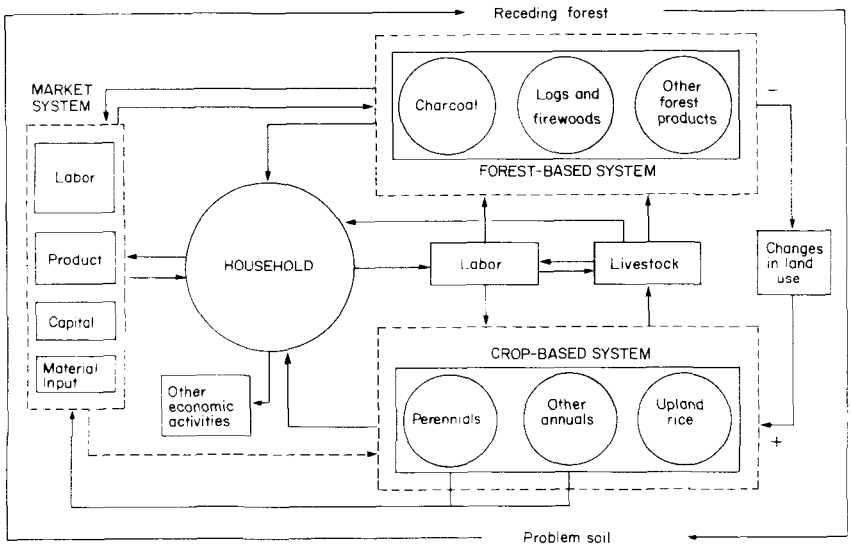
Table 12. Weekly labor distribution in crop production and other economic activities of 11 farm record keeping farmers, Barangay Magsaysay, Siniloan, Laguna, Philippines, 1984.

Activity	Weekly labor distribution	
	h/household	%
Crop production:		
Cultivation/planting	5	7
Harvesting	2	3
Weeding	15	19
Firewood gathering	4	5
Charcoal making	37	47
Fern gathering	4	6
Off-farm labor	1	2
Nonfarm labor	5	7
Total	73	100



7. Monthly distribution of household labor by type of activity, 11 farm record keeping farmers, Magsaysay, Siniloan, Laguna, Philippines, 1984.

The household is largely dependent on the product market for its food requirements, rice in particular. This is supplemented by the crop-based subsystem. Almost all of the rice produced by the kaingin is consumed by the household. On the other hand, a substantial portion of the nonrice crops produced by the kaingin goes to the market while a small portion goes to the household.



8. Schematic diagram of a farming system under upland environment, Magsaysay Village, Siniloan, Laguna, Philippines.

The whole kaingin system is constrained by two major factors. The crop-based subsystem is faced with problem soil, while the forest resources are rapidly receding. As the forest is cleared and transformed into cultivable land, the forest gradually loses its character as a dependable cash resource base.

The immediate concern of the shifting cultivators is receding forest resources. At the rate the forest resources are depleted, cultivated crops such as root crops and perennials will directly or indirectly provide the basic needs of the farm household. Similarly, since upland rice can only be cultivated once on the same freshly cut plot, the receding forest means that the expenditure on rice alone will continue to be a substantial share of the household budget. Conflicting opinions arise regarding the potential of upland rice under this unfavorable environment. The question most often raised is: Why should one invest in upland rice when one can raise other nonrice crops that could be more profitable and buy the rice for the household?

The empirical estimate of the proportion of cash income derived from forest resources like charcoal-making and fern gathering for floral decorations constitutes a much larger proportion (67%) of the total cash earnings of the household compared to rice. This, however, is not an absolute indication that the potential of upland rice is low under this unfavorable upland environment. The observation should be interpreted as an urgent need to develop the economic viability of upland rice technology so as to reverse the present situation.

Shifting cultivators in the area support the idea that increased upland rice productivity is the most valuable improvement that can be incorporated within their system.

Initial observations indicate that technically there is a potential for upland rice in the Magsaysay area. While the rainfall pattern precludes establishment of upland crops year-round, preliminary experiments on upland rice in 1984 indicate that MVs may offer higher yields under farmers' existing technology than traditional varieties. A variety trial comparing some improved cultivars with the local varieties suggests that UP215 yields five to six times more than the local variety both under zero and with some fertilizer inputs. Experiments on insect control may significantly increase upland rice yields. Seedling maggots, a severe problem at the site, can be controlled by application of chemicals.

CONCLUSION

The socioeconomic conditions of an unfavorable upland rice environment typified by Magsaysay Village highlights the need to develop upland rice technology. In view of increasing forest resource exploitation, brought about primarily by increased migration of lowland landless workers to upland areas, new research and policy directions should be provided regarding upland rice development. These directions should encompass both increased productivity as well as attaining ecological objectives.

The economic evidence is fairly obvious that the long-term mainstay of the farm household is the crop-based production system. It could be used as benchmark informational inputs in creating a scenario for the design of appropriate technology for upland rice production. In the specific case of subsistence farmers of Magsaysay, the demand for improving upland rice production can be accentuated along with other nonrice crop technologies that could improve both labor and land productivity. This must also include the emphasis on other crops that could economically be grown in the area.

Overall, on the basis ofthe findings ofthe study, upland rice development in unfavorable upland rice cultivation system should emphasize attainment of stable and sustainable yield.

ACKNOWLEDGMENT

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FARMING SYSTEMS RESEARCH TO CONSERVE THE ENVIRONMENT OF UPPER WATERSHEDS

D. MULJADI, INU GANDANA ISMAIL, and J. L. MCINTOSH

In many upper watershed areas of Java the basic problem is the concentration of too many people on too small a land base. As population pressure increases, cultivation has been pushed farther up the hillsides, thus bringing steep slopes and vulnerable land areas under intensive cultivation. Consequently in many instances, there are severe erosion problems.

This problem is of such dimension that unless the preventive and corrective measures now undertaken by the Government receive substantial reinforcement, the agricultural productivity in Java, both upland and lowland, is likely to be seriously impaired within the next few years. At stake, in a larger sense, is not only the nation's natural resources heritage and environment stability, but the livelihood of several million hill farmers, which represent more than two-thirds of the total farm population.

Based on the report of the Joint GOI-USAID Watershed Evaluation Team in 1983, several research and institutional constraints limit the implementation and rehabilitation of upper watershed regions:

- Technology is not fully developed and implemented.
- Number of trained development staff is limited.
- Mandates and directions of institutions need sharper focus.

Technology relevant to upper river watersheds throughout Indonesia is available but with many limitations. Improved practices for soil and water conservation have been identified for some areas and implemented through the Regreening Program of the Ministry of Forestry. This work has been effective but the technical options for different soil, climatic, biologic, and physiographic conditions prevailing throughout the country are still limited. Furthermore, the technologies available for the agricultural use of the areas stabilized through soil and water conservation practices are only first approximations.

Consequently, farming systems research is needed to improve and expand both conservation and agricultural technology and to tailor them to the

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special requirements of specific watersheds. This technology must be implemented. The staff and institutional development must parallel research so that implementation may flow smoothly. However, this paper will deal primarily with the research phases.

Overall objectives of the research are:

- The design of soil conservation practices appropriate for the varying conditions in different target areas.
- The improvement of the productive capacity of existing cropping patterns and development of new ones.
- Stabilization of agricultural production in terms of levels and time.
- Stabilization or improvement of farmer incomes through alternative farming systems that are more diversified.

To develop appropriate technology, research must be tested in the development stages and refined through on-site experience in the field.

RESEARCH APPROACH

Basic strategy

Stabilization of upland agriculture in any watershed may be enhanced by applying results of farming systems research and development activities. A farming systems approach would develop a package of technology from integration of at least these five components of the farm systems: soil and water conservation, cropping systems, livestock, perennial crops (including silvipasture), and economic evaluation.

In any given area the appropriate farming system will depend on local site conditions and aspirations of individual farmers. It is considered that, in general, sufficient knowledge exists on the major components to assemble them into effective farming systems applicable to conditions in Java.

Approach

The research approach may be patterned after the methodologies of ongoing farming systems research and development strategies used under Indonesian conditions for several years. Research experiences gained from other watershed projects (Citanduy and Yogyakarta projects) may be especially useful in project planning.

The strategy includes five distinct research phases: site selection and description; economic and biological potential studies; designing and testing of farming systems; expansion or preproduction testing; and implementation. Concurrent with this on-site research, more in-depth and interdisciplinary research should provide opportunities for longer term studies, experimentation with extreme treatments, and development of colleagueal relationships among scientists from different disciplines.

Erosion and agricultural problems identified in upper river watersheds are interrelated. Consequently, an integrated farming systems research approach must include three major components of the farming systems (soil and water conservation management, crop and livestock systems, and tree

crops and silvipasture) plus comprehensive socioeconomic studies. The goal would be to produce improved technology for the farm systems in the target areas as well as for direct application to areas with similar agroecological characteristics.

RESEARCH IMPLEMENTATION

The strategies described above have been used for developing a farming systems research project for two major watersheds in Java. These watersheds are the Brantas in East Java and the Jratunseluna (acronym for five rivers that make up one watershed) in Central Java.

A field laboratory (primary experimental site) will be established within one of the target basins, on a location representative of a major ecological zone. The laboratory will be situated on a site where infrastructure and preferably some research and extension facilities exist. The proposed location is Sidomulyo, Ungaran, Central Java.

This field laboratory will include longer term and in-depth studies that are impractical on farmers' land. On-site research (OSR) located on farmers' land will be in four locations in each project watershed (secondary site). As much as possible these eight locations (total) will be synchronized with the target locations of the expansion program.

A research headquarters in each watershed is for communication and logistic support to the field staff. These headquarters will be at Salatiga, Central Java, for the Jratunseluna Basin, and at Malang, East Java, for the Brantas Basin.

Characterization of target areas

The Jratunseluna and Brantas watersheds are representative of other densely populated and humid watersheds of Java. Further partitioning of target areas will focus the research on typical conditions of the watersheds. Appropriate technologies can be developed for the different ecological areas within the Jratunseluna and Brantas upper watersheds to provide bases for technology transfer and application to other areas with comparable agro-ecological conditions.

The following factors will be considered in delineating categories for soil and erosion within the target areas:

- Erodibility
  - — highly erodible
  - — less erodible
- Soil depth
  - — deep (>90 cm)
  - — medium (40-90 cm)
  - — shallow (<40 cm)
- Slope
  - — 15-30%
  - — 30-45%
  - — >45%

Detailed surveys to characterize these factors and to provide basic data for development of land suitability maps will be useful for long-term objectives of this project. However, for short-term and, more specifically, for planning purposes, aerial photographs plus on-site reconnaisance should be sufficient to provide this information.

The socioeconomic and biophysical surveys at early stages of the project development will help get a better understanding of the target areas. More detailed characterization of the physical, biological, and socioeconomic aspects will receive high priority as the project develops. The available resource base will be more adequately quantified and production constraints identified. From past experiences and observations, the land tenure system seems to be a major factor affecting the development of upland agriculture. Farmers who do not own, but only manage the land, may have different perceptions about the suitability of farming systems from those of farmers who manage their own land. This aspect must be carefully considered when designing the farming systems trials.

Integrated farming systems and conservation research

As erosion and agricultural production problems identified in upper watershed areas are interrelated, an integrated farming systems research approach will be followed. This research is to develop technologies to promote soil and water conservation and provide stable and sustainable agricultural production in the upland rainfed areas in ways that are socially and economically acceptable.

The land categories delineated by using the criteria mentioned (erodibility, soil depth, and slope) include 18 types of land. But, all types of land may not appear in a target area. Terracing has been a popular means of soil conservation in the upland farming areas of Java. However, in many places erosion rates remain unacceptable. This indicates that improvement is badly needed, either for soil conservation (for example, in terracing techniques) or for farming systems management or both.

Erodibility, soil depth, and slope should be carefully considered in designing and testing soil conservation practices. Soils that are highly erodible, shallow, and with slopes of more than 15% are absolutely unsuitable for bench terraces. On the other hand, even if the slope is more than 15% and the soil is deep and less erodible, it may be possible to use bench terraces. Other alternative practices are contour ridging and individual terraces, especially for slopes of less than 30%.

Crop management in the upland farming areas also affects the degree of erosion. Most farmers in the target areas grow annual food crops as the main agricultural commodity, even on land with slopes greater than 45%. This creates a dilemma, because farmers have reasons for this practice. The basic reason is that they have to produce food for family consumption and since they own such a small amount of land, almost all must be used for food crops just to meet their needs. To solve this problem an appropriate combination of soil conservation practices and farming systems must be identified and developed *to meet the needs of people* as well as the different land categories.

Three major components will be included in the design of appropriate integrated farming systems. These are annual crops, perennial crops, and forage and livestock.

Annual crops. In many instances, farmers wish to grow food crops in their fields although the slope may be more than 15%. The main food crops are corn, cassava and upland rice, legumes (such as peanut, mungbean, and soybean), and vegetable crops at the higher elevations. However, the basic strategy for developing stable agriculture on the sloping lands will be to keep food crops to a minimum — just enough to support subsistence needs. The remaining land should be in tree crops, pasture, a combination of both, or some other permanent vegetative cover. Furthermore, areas where annual food crops may be grown in the system must be carefully selected. Alternative food crops, such as plantain or cooking banana and yams, can be grown under shade; they are nutritious and high-calorie producers, and are compatible with objectives of this project.

Perennial crops. Most upper river watershed areas are too steep for annual food crops and should be protected by a permanent vegetative cover. Ideally, this cover should simulate the natural forest condition. Crops may be arranged in multistory systems, ranging in height from tall fruit or industrial tree crops to intermediate height crops and down to shrubs, bushes, and shade-tolerant spice and root crops. The feasible perennial crops should be identified early in the project through economic analysis and researcher experience, especially for the on-site research. Present farmer systems can be used as a basic source of information. Because crops require several years before yield results can be used for evaluation, information gained from discussions with farmer cooperators, along with researchers' knowledge and experiences from other places, must be considered before perennial tree crops are actually planted.

Forage and livestock. Forage grass production would provide animal feed and help stabilize the soil under various kinds of management. Forage grasses such as *Setaria* or *Brachiaria* can be grown on terrace risers and other erosion-control structures. Legume tree crops such as lamtoro (Leucaena) can be used to stabilize soil, produce firewood, and provide animal feed in year-round forage production systems. Therefore, livestock can be an important component of these systems. Because they grow and yield fast, small ruminants such as goats or sheep are most appropriate for small-farm systems.

Tree components, forage grasses and legumes, and conventional soil conservation practices will be combined in designing alternative systems for testing for different land categories in the target areas. The alternative systems will be tested on the farmers' land with the farmers as cooperators. The testing area, preferably a contiguous land area representing a small catchment or miniwatershed, will probably involve several farmer cooperators. The existing farmer systems will be monitored from surrounding farms for baseline comparisons. Data collected will include agronomic performances and measurements of soil erosion. Land productivity and soil fertility will be evaluated periodically.

Support for integrated farming systems research

Farming systems research is a systems approach that integrates the components (commodities and disciplines) into production systems. Therefore, all component research, as part of the farming systems, should be systems oriented to facilitate integration of the technological components into the appropriate farming systems. Four major farming systems components plus socioeconomic studies will be investigated:

- food crop systems,
- livestock systems,
- soil and water conservation,
- perennial crops and silvipasture systems, and
- socioeconomic evaluation.

LINKAGE WITH EXTENSION

Linkages between research and extension in the field testing of technologies, on demonstration farms and in the expansion areas, are essential. Key farmers and field personnel should be involved in a continual learning process through more effective use of demonstration farms and experimental areas as field laboratories for training purposes. This practice would also increase field contact among field staff, specialists, and researchers. This approach would broaden the research and extension workers' knowledge of improved practices and sharpen observational, practical, and analytical skills.

SUMMARY

These studies in upper watershed areas of Indonesia must be comprehensive and carried out from a farming systems research approach. The ultimate objective is to stabilize the soil and provide the technology by which farmers, who cannot be displaced, may improve their physical, economic, and social well-being.

Existing research has identified the problems that farmers must cope with in these land areas. Future research must more effectively address these specific problems:

- Strengthening technologies for management of steep and otherwise unstable slopes. The technologies must include strategies for soil conservation, mixed agroforestry, tree and fruit crops, and silvipasture; and a relevant livestock industry must be developed.
- Development of better management practices for collection, analysis, and storage of data on rainfall, erosion, soil conservation practices, crop and livestock performances, and economic returns.
- Development of a system of *ex ante* analysis to model and systematically eliminate economically weak farm systems and conversely identify those that are strong.
- Improvement of availability of suitable seed and planting materials.

UPLAND RICE IN HIGHLAND AREAS OF THAILAND

B. SOMRITH and B. PROMMANI

The highland areas of northern Thailand comprise approximately 61% of the upper northern land areas. Upland rice, the only staple food for the hill tribe households, occupies more than 90% of the wet season cultivated land.

Rice is the crop of greatest nutritional, cultural and economic importance to the hill tribe people. However, production each year fails to meet the demand. The limitation of cultivated land and low yield per unit area have been the major production constraints.

Several organizations are involved in highland rice improvement. Highland production constraints have been investigated and attempts made to solve the problems. Results from the Rice Research Institute trials show some progress in the breeding program. To accelerate highland rice development, research strategies should be based on collaboration among concerned organizations.

Upper northern Thailand consists of nine provinces, Chiang Mai, Chiangrai, Phrae, Nan, Phayao, Lampang, Tak, Lamphun, and Mae Hong Son. The region is bounded by Burma and Laos. Highland areas are generally populated by six major hill tribes — Karen, H'mong, Yao, Lahu, Akha, and Lisu. Approximately 500 000 tribesmen are scattered over the northern region. Population has rapidly increased, probably because of lack of knowledge of birth control and migration from the neighboring countries.

Upland rice is the most important food crop grown by hill tribe households (2, 5).

Land holdings, which total approximately 10.51 million ha, can be classified as

- lowland areas, about 0.86 million ha, devoted to all types of crop cultivation;

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- upland areas with less than 20-degree slope and below 700 m altitude consisting of 3.14 million ha (usable for agriculture, if soil erosion can be prevented); and
- highland areas with more than 20-degree slope and above 700-m altitude, totalling about 6.51 million ha, mostly natural forests and major watersheds that are the sources of streams and rivers.

Highland cultivated areas are scattered around the watershed among the green forests. The upland rice area under highland conditions has not been accurately estimated because of shifting agricultural systems. It is believed that after the opium poppy, upland rice occupies the second largest area.

The forest area of northern Thailand is decreasing from year to year. For example, from an original total of 17.0 million ha it was reduced to 14.9 million ha by 1971, and further to 9.7 million ha by 1977, the average reduction being 0.4 million ha each year. This forest area decrease results from an increase in cultivated areas under highland conditions, with both slash-and-burn agriculture or permanent settlement.

UPLAND RICE CULTIVATION

Upland rice is normally grown under two main systems of shifting cultivation in the northern highlands. The first system uses the field only 1 yr and then fallows it for 3-10 yr, depending on slope, land availability, and soil fertility. This system is traditionally practiced by the nonopium-growing tribes (Karen and Lawa). The second is widely used by the opium-growing tribes (H'mong, Lisu, Lahu, Akha, and Yao). Upland rice is usually rotated with maize and poppy (5), and the field is used until the soil nutrients are exhausted or fertility is almost depleted.

The date of planting highland rice usually coincides with annual rainfall, but the work starts earlier than for upland rice at low elevation. For new swiddens, it generally begins in March. The hill tribe farmers clear the land by slashing weeds and small trees, which dry for 1-2 mo before burning. Forest fires are clearly observed as scattered spots on the hillsides during March and April. The land is prepared by clearing, burning, and hoeing.

Rice is planted usually in May, by dibbling with a pointed stick, dropping 6-10 rice seeds into each hole, and covering the hole with soil by using the foot. The space between holes depends on soil fertility but is usually about 25-50 cm. One hand weeding is usual in June. Herbicides are not widely applied.

Most local upland rice varieties are tall with long and broad, droopy leaves that compete well with weeds. The highland rice germplasm collection of the Tribal Research Institute and Rice Experiment Station in Chiang Mai indicates that several hundred upland rice varieties are grown by the northern highlanders. Most varieties are nonglutinous and are named specifically after the tribes. Generally, the hill tribe people grow their favorite varieties every year. Most of the varieties are early maturing and flower in August and September, and are harvested in late September. The

rice is cut about 6 inches above the ground with a small sickle, then the stalks are laid on the stubble to dry in the sun for 4-5 d. After drying, stalks are tied into small bundles with bamboo string and the bundles are piled into a large stack where threshing is done.

Threshing methods vary with the tribes. The most common method is by holding the bundle with a bamboo handrail and then hitting it against other bundles on the threshing floor or against the side of a basket. The dry rough rice is stored in a small bin near the house or even inside the house (1, 7).

ECONOMIC IMPORTANCE OF UPLAND RICE

Rice, regarded by the hill tribe people as the crop of greatest nutritional, cultural, and economic importance, receives the highest priority in allocation of land, labor, and capital resources. Sudthi (7) and Hoare (2) summarized the importance of highland rice as follows:

- Rice provides most of the protein consumed and therefore it is the main food source.
- Surplus rice is highly important in relation to market purchases for other basic needs.
- Rice bran is used directly in feeding poultry and pigs.
- Glutinous rice is ordinarily used to manufacture a local alcoholic drink for tribal festivals and it can also be prepared with many sweets.
- Rice and popped-rice always are part of the rituals and culture of hill tribe people.

Accordingly, hill tribe households attempt to produce sufficient rice to meet all demands every year, but production is insufficient and unstable.

From census studies Hoare (2) concluded that limitation of cultivated land and low yield per unit area were the major production constraints. The instability of highland rice production in one Lahu village (Pahlo) at 1200-m elevation on steep slopes with soil fertility (deficient in N, P, and S) is illustrated in Table 1. Hoare (2) has also suggested that to increase highland rice production, the irrigated rice area should be reformed by terrace development.

Hoey (3, Table 1) summarized reported yields of traditional upland rice from previous surveys of northern Thai and hill tribe farms in selected provinces, as follows:

Ethnic group	Province	Yield (kg/ha)
Northern Thai	Nan	814
Akha	Chiangrai	840
Shaw Karen	Mae Hong Son	959
Lau’	Mae Hong Son	1032
Lahu Nyi	Chiang Mai	1293
Pwo Karen	Mae Hong Son	1464
Yao	Chiangrai	1849
Av		1178

Table 1. Rice production at Pahlo village from 1979 to 1981[a] (adopted from Hoare [2]).

Year	Seed planted (kg)	Rice harvested (kg)	Rice needed[a] for self-sufficiency	Village surplus or deficit (%)	Yield ratio[b]
1979	968	33 770	27 720	+ 22	35
1980	479	14 641	32 010	– 54	31
1981	72	572	32 010	– 98	8

[a]Based on average annual consumption of 600 litres unhusked rice per capita. [b]Ratio of rice harvest to rice planted.

RESEARCH AND UPLAND RICE DEVELOPMENT

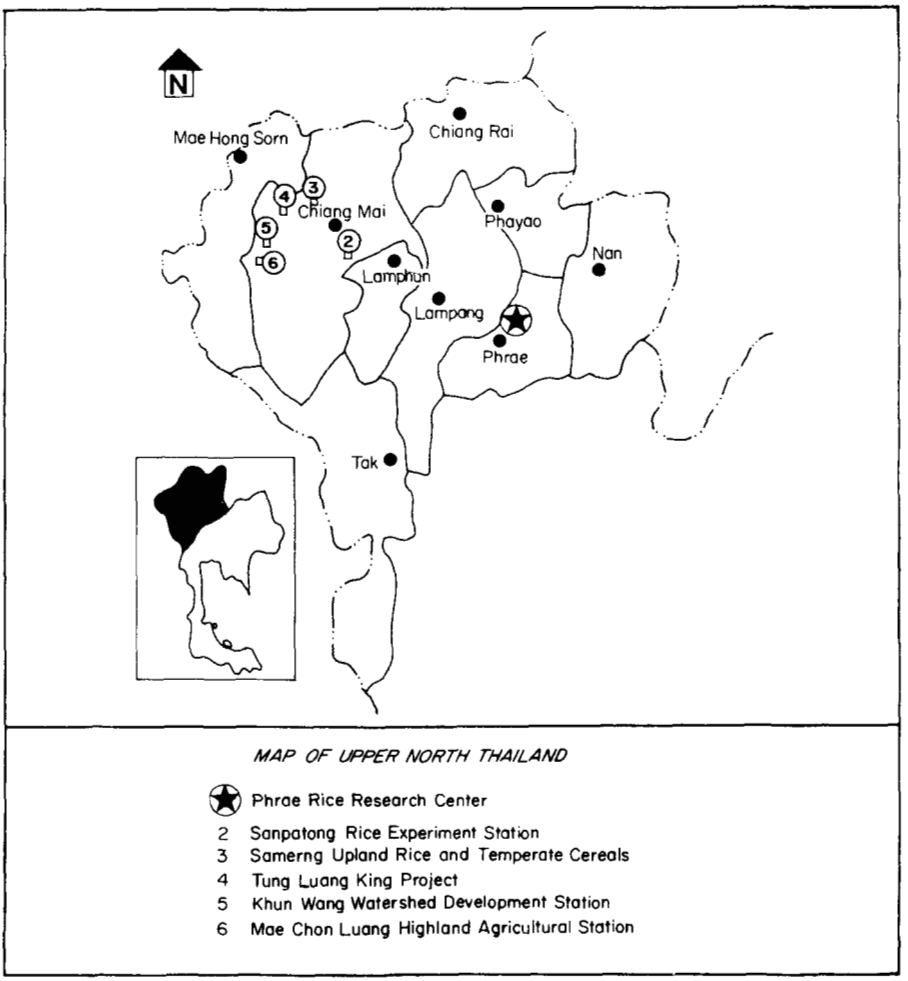
To solve the rice shortage problem of the hill tribes, His Majesty King Bhumipol initiated improvement of highland rice production in 1978 by founding the Samerng Upland Rice and Temperate Cereals Experiment Station. His Majesty provided his personal funds to support the station during the first few years.

The station, operated by the Department of Agriculture, is at 800-m altitude about 55 km northwest of the city of Chiang Mai. Its functions are to conduct and develop research programs to improve upland rice and temperate cereals. By the end of 1979, the Department of Agriculture had released three upland rice varieties for upland farmers. One of them, Sew Mae Jan, is well adapted to areas below 1000-m altitude and now is widely grown in northern Thailand. However, rice varieties adapted to higher areas have been requested by organizations concerned with hill tribe development projects.

Upland rice breeding is now directed to the rice areas situated over 1000 m above sea level. Sanpatong Rice Experiment Station is developing research programs that started in 1981. A highland rice germplasm collection has been launched, with coordination from the Tribal Research Center in Chiang Mai University and Sanpatong Rice Experiment Station. At present, work on germplasm collection is expanding with supporting funds from International Rice Research Institute (IRRI) and International Board for Plant Germplasm Resources (IBPGR). Crossing work uses existing upland rice varieties. Breeding lines or varieties have been put in an observational nursery and planted at Khun Wang Royal Highland Research Station. In 1982, both observation and preliminary yield trials were in the upland fields of many highland research stations in Chiang Mai and Mae Hong Son (Fig. 1). These stations are located at different altitudes and have different microclimates (Table 2).

Only a few varieties can adapt to 1300-1400 m altitudes, but many performed better under lower conditions. During 1981 and 1982, major environmental and technical problems were observed:

- Low air temperature, low light intensity, and high humidity during the reproductive stage occur in most highland rice fields. These can adversely affect plant growth, flowering, fertilization, seed set, and grain formation.



1. Map of upper north Thailand showing location of rice research center/stations and some related highland agricultural research sites.

- Decline in yield or poor adaptability of some varieties might be caused by soil problems, such as low P and high Al content.
- Blast, leaf scald, sheath rot, and panicle discoloration were recorded as severe diseases.
- High rainfall is always associated with heavy weed infestation.
- Damage from birds, rats, rabbits, horses, and cattle caused failure of many tests.

In 1983, interstation yield trials evaluated upland rice varieties in highland agricultural research stations at altitudes ranging from 800 to 1400 m. From 14 selected varieties of nonglutinous rice at Khun Wang Royal Highland Agricultural Research Station, only two, Motoza and Nam

Table 2. Geographic and climatic conditions of research stations for highland rice interstation yield trials, 1983 [a] (6).

Station or project	Abbr	Altitude (m. a. s. l.)	Soil pH	Organic matter (%)	Rainfall days (no.)	Accumulated rainfall (mm)	Av temp	
							Max	Min
Khun Wang Royal Highland Agriculture Research Station, Chiang Mai	KWG	1 400	4.7	5.91	128 [b]	2 889.5 [b]	27.6	18.3
Inthanon Royal Highland Agriculture Station, Chiang Mai	ITN	1 300	4.8	2.67	84 [c]	465.8 [c]	24.6	18.6
Khun Wang Watershed Development Station, Chiang Mai	KWF-F	1 200	5.1	4.17	138 [d]	3 015.8 [d]	29.3	16.7
Tung Luang King Project (at Ban Nawng Tao), Chiang Mai	TLG	1 100	5.0	5.51	95 [e]	907.5 [e]	23.2	15.6
Pang Tong Royal Highland Development Center, Mae Hong Son	PTG	960	5.2	5.33	–	–	–	–
Samerng Upland Rice and Temperate Cereals Experiment Station, Chiang Mai	SMG	800	5.4	2.09	–	–	–	–

[a] – means records not available. [b] Av from 1976 to 1980. [c] May-October 1983. [d] June-November 1983. [e] May-October 1983.

Roo, gave satisfactory yields (6). Table 3 compares yields of 14 upland rice varieties grown under two different altitudes. Differences may indicate adaptability of varieties under test.

At about the same period, 1980-83, Julsrigival and Tiyawalee (4) of Chiang Mai University also actively worked in improving upland rice yield. To develop upland rice varieties for highland areas the program was partly supported by the King's Project and the U.S. Department of Agriculture (USDA). Many selections such as Khao Nong Hoi, KU-15, R-179, 6863, and 6843, which could adapt to highland conditions, were promising.

In 1984 the multilocation highland rice yield trials were continuing under the National Upland Rice Project of the Rice Research Institute, mostly at the previous testing sites. Yield data from two locations, Tung Luang King's Project and Khun Wang Watershed Development Station, are compared for 1983 and 1984 in Table 4. In 1984 the experimental fields at both stations were heavily infested with weeds. Although the 1984 yields were much lower than the 1983 yields at Tung Luang Station, the consistent performance of some highly adaptable varieties, such as Ve Chai, SMGC80017, Motoza, and Khao' Jao' 4, is encouraging. It has been suggested that the National Upland Rice Project evaluate these varieties on hill tribe fields. Because of an urgent need for the highland rice variety, a seed multiplication program should also begin along with the current breeding program.

Table 3. Comparison of yield performance of 14 nonglutinous highland rice varieties in interstation yield trials at 2 altitudes in Chiang Mai (1983).

Designation	Yield[a] (kg/ha)		Difference (%)
	SMG (800 m)	KWG-A (1400 m)	
Nam Roo	1556	1438	- 7.58
Motoza	1231	1925	+ 56.37
Ve Ra	2225	_[b]	−100
Ve Chai	2794	569	- 79.63
SMGC80011	2256	_[b]	−100
SMGC80013	2306	1162	- 49.60
SMGC80017	2044	638	- 68.78
SMGC80019	2356	994	- 57.80
Pokharali Masino	1938	600	- 69.04
Jao' Khao	2425	1144	- 52.82
Silewah	1525	1088	- 28.65
Khao' Jao' 4	2562	588	- 77.04
Jao' Haw (ck)	1369	_[b]	−100
Khi Chang (ck)	1731	700	- 59.56

[a]SMG = Samerng Upland Rice and Temperate Cereals Experiment Station (800 m altitude), KWG-A = Khun Wang Royal Highland Agricultural Research Station (1200 m altitude). Difference based on performance at SMG as representative for medium highland area.
[b]Field to flowering or incomplete heading and not harvested.

Table 4. Comparison of yield performance of 10 nonglutinous highland rice varieties in the intestation yield trials of 1983 and 1984.

Designation	1983 yield[a] (kg/ha)			Rank	1984 yield (kg/ha)			Rank
	TLG	KWG-F	Av		TLG	KWG-F	Av	
Motoza	1694	1188	1441	5	1027	1972	1500	2
Ve Ra	1143	1619	1381	6	827	1507	1167	8
Ve Chai	1444	1569	1506	3	1362	1672	1517	1
SMGC80011	394	1406	900	10	703	1343	1023	10
SMGC80013	1200	1312	1256	9	1047	1372	1210	7
SMGC80017	1612	1931	1772	2	1180	1565	1372	5
SMGC80019	988	1581	1284	8	940	1953	1446	4
Khao' Jao' 4	1400	1488	1444	4	1234	1699	1466	3
Nam Roo (ck)	1688	912	1300	7	662	1808	1235	6
Jao' Khao	1938	1981	1910	1	588	1597	1092	9
Mean	1340	1499			957	1649		

[a] TLG = Tung Lung King's Project at Ban Nawng Tao (1100 m altitude), KWG-F = Khun Wang Royal Forestry Department Watershed Development Station (1200 m altitude).

NORTHERN HIGHLAND RICE DEVELOPMENT PROJECT

From these surveys and studies, the major highland rice production constraints have been summarized as:

- Lack of improved varieties with high and stable yielding ability under environmental stresses with low inputs.
- Low temperature, low light intensity, and sometimes high humidity due to late rainfalls, which affect plant growth during flowering, grain filling, and ripening stages.
- High incidence of diseases, insects, and animal pests, which cause yield reduction.
- Heavy weed infestation, a recurrent problem.
- Poor soil fertility management.

A Northern Highland Rice Development Project was proposed at the Thai/IRRI Collaborative Research and Training Planning Meeting in April 1984 at Bangkok. The project's main objective is to strengthen the existing Rice Research Institute's upland rice research project, especially in northern highlands. Besides training, the proposals also emphasized

- varietal improvement,
- cultural practices and cropping systems improvement,
- weed control, and
- fertilizer efficiency trials.

The collaborative research work has been conducted since shortly after the Agreement on Collaboration between IRRI and the Thailand Ministry of Agriculture and Cooperatives was signed on 12 April 1984.

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B. Component technologies

RELEVANT UPLAND RICE BREEDING OBJECTIVES

M. ARRAUDEAU and Z. HARAHAP

Upland rice grows on about 20 million hectares in the world. Mean yield, estimated at 1 t/ha, indicates upland rice production is only 6% of total rice production; area is 13%.

Low mean yield is the consequence of two main factors:

- About 65% of the total upland rice area is under infertile environments: poor soils with deficiencies and toxicities, medium to high injury caused by diseases, pests, and drought.
- Management of upland rice fields is frequently lacking: no fertilizers, low control of weeds.

In the most difficult conditions, mean yield is below 0.5 t/ha. Under best conditions, mean yield exceeds 4 t/ha. Large areas in western Africa or in Asia are representative of difficult conditions: no inputs, no weeding, high risks from drought, insects and pests, and poor soils. High inputs, limited risks, and good soils characterize the best conditions. These prevail in some areas in Latin America.

Except in Brazil and in some Latin American countries where upland rice is frequently grown in a mechanized system, upland rice is largely a subsistence crop. The soils and rainfall patterns vary widely and, as a result, varieties and associated cultural practices are location specific. The potential for increasing rice production in upland areas is often limited because of erratic rainfall and inherent low soil fertility in many areas. An increase of production would be of great importance to farmers dependent on this type of production. Moreover, the potential in terms of area available in the tropics for upland crops, including rice, is important in many countries such as Indonesia, Brazil, and some in Africa, and can be estimated in millions of hectares. In Asia, prospects for improving productivity by modifying the cropping systems in upland areas are good. Productivity in terms of cropping intensity can move from 1.5 t/ha in many cases to more than 2 t/ha. In long rainy season ecosystems, potentia1 increases are from 1.0 t/ha to a projected 2.5 t/ha.

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THE MAJOR CONSTRAINTS IN UPLAND RICE BREEDING

Upland rice breeding constraints vary considerably according to environments. In terms of yield potential, major constraints increase from long to short rainy seasons and from fertile to infertile soils.

As a general approach, the constraints are classified in three groups: socioeconomical, biological, and environmental.

Socioeconomical constraints

Except in mainly Latin American favorable ecosystems where the crop is grown with high cash input technologies, upland rice farmers are generally poor and accordingly use less than adequate management techniques, such as little or no fertilizers, no insecticides, and no fungicides. Production is self-sufficient and frequently farmers lack access to high technologies. Slash-and-burn systems, shifting cultivation, and mixed cropping patterns are most frequent in upland rice production and mean yield is low. New cropping systems using high cash inputs and modern technologies cannot be suggested under these conditions. Low or moderate technologies would be preferable.

Biological constraints

Disease and insect pests, weeds, birds, rats, and nematodes are included in biological restraints. A recent survey from 23 upland rice producing countries representing more than 80% of the crop worldwide is used to classify biological constraints (Table 1). The two prominent biological constraints are weeds and blast, followed by birds, stem borers, brown spot, rice bugs, and rats. Some diseases or insects vary widely in importance according to country. Blast is important everywhere except in Bangladesh. Viruses and planthoppers are not severe constraints. Sheath rot, *Sogatodes*, and seedling flies are severe constraints in restricted areas.

The breeder is unable to breed for resistance to three major constraints: weeds, birds, and rats. Rapid early vigor is useful against weeds and awnings seem efficient protection against birds. There is no breeding solution against rats.

Environmental constraints

Climatic and soil constraints reported by 23 countries indicate the three major ones are drought, soil acidity, and P deficiency (Table 1). Although drought is not reported as the most severe stress in some areas, it appears clearly as one of the most severe constraints, along with weeds and blast, for yield increases. Soil deficiencies and toxicities are apparently less important than some diseases and insects, according to the survey. That could be due to an underestimation of their effects on disease severity such as brown spot, which is more important in poor and acid soils. It may also be from a lack of information concerning soils where upland rice is grown. Aluminum toxicity and zinc deficiency are given as major constraints in some countries. Extreme temperatures — high or low — are not frequently reported as important stresses.

Table 1. Biological and environmental constraints (23 countries in survey).

Biological constraints	Countries reported (no.)	Ranking (1-10)	Relative importance[a] (%)	Environmental constraints	Countries reported (no.)	Ranking (1-10)	Relative importance[a] (%)
			Major				
Weeds	23	0.4	100	Drought	23	1.4	100
Blast	23	1.8	86	Soil acidity	19	4.2	72
Birds	20	4.0	65	P deficiency	20	4.2	72
Stem borers	18	4.8	56	Al toxicity	14	7.0	45
Brown spot	20	5.0	54	Low temperature	14	7.0	45
Rice bugs	16	5.6	48	Zn deficiency	11	7.4	40
Rats	19	5.7	47	Fe deficiency	13	8.2	32
Bacterial leaf blight	9	6.2	42	High temperature	13	8.2	32
Glume discoloration	15	6.5	38	Fe toxicity	12	9.6	18
Sheath blight	15	7.4	30				
Leaf scald	16	7.8	25				
Viruses	10	9.0	14				
Brown planthopper	9	9.5	9				
Green leafhopper	7	10.0	4				
Gall midge	6	10.0	4				
			Minor				
Leaf rollers	2			Other soil deficiencies	3		
Sheath rot	2			Sulfur deficiency	1		
Other insects	2			Low solar radiation	1		
Narrow brown leaf spot	1			Typhoons	1		
Bakanae	1			Late rains	1		
Ants	1						
Bacterial leaf streak	1						
Mealy bug	1						
Sogatodes	1						
Root nematodes	1						
Seedling flies	1						
Tettigoniidae	1						
Wild pigs	1						

[a] Relative importance in %, as compared to the most important constraint rated as 100.

MAJOR UPLAND RICE BREEDING OBJECTIVES

The first objective given in all upland rice breeding programs is yield increase. Yield of a given variety on a given site is the combination of three factors: the variety potential; the environment, as the result of physical and biological pressures; and land management by the farmer. Increasing yield will, of course, depend on variety yield potential, but also and perhaps more so, on a good level of tolerance or resistance to the most important constraints, and on the level of inputs such as clean weeding and fertilizers.

Yield potential

The yield potential of a given variety may vary considerably, according to the environment. Even if it has a good yield potential, that potential cannot be expressed if constraints occur. So, under upland conditions, the yield potential is frequently repressed by environmentally difficult conditions. On the other hand, a given constraint rarely occurs alone, and frequently there is a synergy between the constraints: drought increases the effect of a disease, low nutrient availability increases drought effect. Increasing yield means essentially increasing the level of tolerance to the main constraints rather than increasing the productivity without constraints. Even under the best upland conditions the harvest will always depend on the level of a constraint which may suddenly occur. Upland rice is a risky crop. The best variety buffers the risks with an internal capability to resist risks, which can occur during growth.

Tolerance of or resistance to the major constraints

Intensity of constraints varies with location. Objectives are defined according to problems occurring in a given ecosystem. However, some common tendencies appear in many research programs. The most frequently reported breeding objectives are for disease resistance to blast, brown spot, glume discoloration, sheath blight, and sheath rot; for insect resistance to stem borers and rice bugs; and for soil P deficiency tolerance.

Blast is one of the most important constraints in the world, except, curiously, in some areas as Bangladesh and parts of West Bengal, Bihar, and Orissa in India. But blast is a potential problem and breeding programs should have a blast resistance component.

Soil problems seem generally underestimated; deficiencies and toxicities probably have a greater influence on yield than reported in many countries.

High response to inputs

Except in favorable environments, the level of inputs cannot be high in upland rice cultivation for many reasons: risks, inputs costs, poverty of the farmers. Response of new materials from low cash inputs must be as high as possible and they must be as input-efficient as possible.

To reduce the level of cash inputs, good management is important: crop rotation with pulses, straw incorporated into the soil, and returning hulls to the fields. These help increase organic matter, frequently low in upland fields.

Yield stability

The main objective is not the highest yield, but the best yield stability. In general, a low stability index is not associated with a high yield potential, and the cultivars showing the highest stability indexes are the most productive under the best conditions. But their yields are severely affected in the most deficient environments. The solution will probably be intermediate: a fairly good yield potential associated with a fairly low stability index.

Specific characters

Some more specific characters, according to environments or farmer's needs, are of course required. They are numerous, and different from location to location, but the most frequently reported are:

- *Early or medium maturity.* In some areas, early maturity — aus cultivation in Bangladesh — is absolutely required. In others, a second crop becomes possible or easier with early varieties.
- *Plant characters.* For drought resistance, deep and thick roots associated with a good recovery after water stress are preferable. Long and well-exserted panicles associated with moderately long leaves and moderately tall plants with medium tillering ability are classical objectives, except in favorable areas where semidwarf plant types with higher tillering ability can be used.
- *Grain characters.* If grain size and shape requirements vary considerably, the grain quality, often associated with aroma, is a major objective.
- *Temperature tolerance.* Two extremes of breeding for temperature tolerance are reported: resistance to high temperature at seedling stage (such as in Bangladesh) and resistance to low temperature at flowering stage (such as in the mountains of Thailand) or even resistance to high temperature at the same stage (such as in some areas in India).

Summary of breeding objectives

The strategies for any breeding objective should be specific for any given ecosystem, because of the important variability of the constraints requirements. A unique ideotype for upland rice is not realistic. Different plant types are required for different agro-socio-economic environments. For the major constraints, a collaborative breeding effort is suggested. Better collaboration between research station seems the most productive way to accomplish rapid progress.

AVAILABLE BREEDING MATERIAL

Already available material can be divided into two categories, traditional varieties and improved varieties, each of which can provide useful material for breeding purposes and objectives.

Traditional varieties

Farmers' fields. In most upland rice growing countries, thousands of cultivars or populations have been collected and were or are the basic

compoment of many germplasms. It is necessary to seek new plant materials first in the areas that have not been explored and second, in the areas that are the most important in upland rice cultivation. For the former, remote areas in Burma and Malaysia are examples. For the latter, Cambodia, Laos, and India would apply.

Germplasm banks. Traditional cultivars are frequently low yielding, low tillering, and, in summary, not very interesting material. That position must be carefully reviewed because while many may not show interesting characteristics, some are promising.

First, impressive variations for many characters exist in some upland rice cultivars in the IRRI germplasm bank (Table 2).

Second, some traditional cultivars seem particularly interesting for their "durable disease/insect tolerance," in areas where given diseases or insects are prevalent.

Third, they are generally highly adapted to environments where they are grown, and, as a consequence, some have related tolerance characters, such as Al toxicity tolerance or a deep rooting system.

Finally, they may possess good grain quality and aroma.

Tillering ability (Table 3) depends on origin and could sometimes be high with good cultivation practices. For yield potential, many traditional cultivars provide good yields in many trials, also with good cultivation practices.

In conclusion, traditional cultivars should probably be investigated more and used in upland breeding programs.

Improved varieties. Hundreds of upland improved varieties are available in the world, and many plant breeding programs are doing an excellent job to improve new plant types fitting in with farmer's needs.

There are three broad groups:

1. Slightly modified traditional types. These varieties are selected directly from upland traditional populations, generally by mass of pedigree methods. N22 in India, from Rajbhog, is a good example.

Table 2. Variability of some traditional cultivars.

Maturity (days)			*Grain length (mm)*		
25852	Dumai	91	15173	Miro Miro	6.4
25856	Gorebai	95	17078	Tahobin	6.5
05824	Wagwag	181	19603	Ba Ke Gonh	11.6
19502	Ikogan	186	23741	Khamu	12.3
1000 grain weight (g)			*Plant height (cm)*		
25867	Jhum Begunbichi	1.3	19415	Inambog	67
28766	Padi Puteh	1.4	00579	Nagpunit	80
44468	Incantado	4.4	44266	Baning	172
24110	Khao Khae	5.4	44306	Agat	180
Panicle length (cm)			*Culm number*		
11788	Khao Hay	17	23713	Daw Hen	6
14778	Hatahonami	18	14382	Padi Tamsayungan	8
33090	Haoru	33	25848	Chiknal	30
12937	Khao Meui	34	00798	Bolibod	30

Table 3. Tillering potential of 100 cultivars from six countries.

Tiller no.	*Indonesia*	*Ivory Coast*	*Thailand*	*Malaysia*	*Philippines*	*Bangladesh*
5-8	6	13	26	5		1
9-12	57	44	44	50	30	12
13-16	32	36	22	38	45	29
17-20	5	7	8	6	20	18
21-24				1		18
25-28					2	12
29-32					3	9
33-36						1

2. Moderately modified traditional types. These include IRAT varieties, UPLRI-5 from the Philippines, or IAC 164 from Brazil.
3. High yielding variety type. Examples are IR43 or Sentani from Indonesia, or many Indian recent accessions. This third group is mainly obtained from semidwarf lowland/upland type crosses.

NEED FOR BASIC RESEARCH

Understanding the mechanisms that control the characters desirable for upland rice varieties is of great importance. To mount a successful breeding program for upland rice, we need more basic information on 1) the physiology ofwater-soil-plant relationships, 2) tolerance and resistance, and 3) adaptability and yield potential.

Water-soil-plant relationships

More information is needed on absorption and water loss by the plant, deep rooting, transpiration ratio, and stomatal and cuticular transpiration.

More study is needed on the mechanisms of:

- plant dessication,
- tolerance of toxic elements,
- assimilate storing during periods of adequate moisture, and
- translocation of assimilates during drought at grain filling.

The mineral nutrition of upland rice is not well understood, particularly in relation to P and low P inputs.

Tolerance for and resistance to major disease and insect pests

Some traditional cultivars show durable resistance to blast in upland conditions when they are grown with low inputs in farmers' fields. These mechanisms need further investigation. There is a real need for research in sheath blight and glume discoloration, which are major diseases in many wetland areas. Nematode damage is probably underestimated in many upland rice fields. Rice bugs cause extensive damage, but research on that insect is insignificant.

Adaptability and yield potential

Mechanisms involved in adaptability are unknown and those conditioning

yield in upland sites need further investigation. This could be achieved partly by better characterization of the environment on upland trial sites.

In conclusion, there is a paucity of detailed studies about upland rice. This is probably due to lack of adequately equipped and staffed upland rice centers in the world, except in some countries such as Brazil and India.

THE NEED FOR COLLABORATIVE RESEARCH

Collaborative research already exists in upland rice. Agreements have been signed between some centers, and more or less close relations for breeding material and information exchange exist between some countries.

The first need is for attaching more importance to the circulation of information. Many reports and results are available in many research stations, data on varieties exist in many countries. Collecting, grouping, summarizing, and disseminating available information would help many isolated breeders who do not have time or funds to proceed with such studies. The creation of an *International Upland Rice Information Service* to act for knowledge transmission between the countries is suggested.

The second need is for a more intensive exchange of materials not only of varieties, but of early generations. IRRI, IITA, and CIAT play an important role in materials exchange, but that role could be increased in the future.

The third need is for more deeply studied collaborative trials. The International Rice Testing Program network provides useful information for many countries. But efficiency would be greater if more details on more specified characters were to be studied in some key sites. More well chosen traditional varieties could be included in the trials as local checks, to provide better comparisons with varieties widely cultivated by the farmers.

CONCLUSIONS

The area planted to upland rice has increased from 14 million hectares 10 yr ago to 20 million hectares now. Moreover, in tropical countries there is a tremendous land potential for extending upland rice cultivation. Given that growth and potential, upland rice breeding programs must receive more emphasis, especially varieties for infertile areas, which represent 60% of upland rice lands. Substantial progress has been attained and many promising lines are being evaluated. But the mean upland rice yield remains about 1 t/ha, although new varieties have been adopted by the farmers. Socioeconomical and technical constraints must be overcome, and the global approach for yield increase must be integrated. Weed control, problem soil tolerance, and stable disease resistance are components of that approach as well as varieties. If a real need for further investigation in basic research exists, a more collaborative network among breeders is one key to success. The lack of equipment and scientists for full-time research and the too frequently limited interest for upland rice because of its lesser importance

regarding the world's total rice production are probably as important constraints as diseases, drought, or poor soils. If research funds increase, the payback will be greater not only for upland rice but for other rice growing environments because the same diseases and insects, and most of the problem soils exist in rainfed lowland as well as in upland environments.

GERMPLASM RESOURCES AND BREEDING FOR DROUGHT RESISTANCE

T. T. CHANG and G. C. LORESTO

Upland rice represents 15% (about 19 million ha) of the total rice hectarage of the world. Upland rice yields are generally low and are further destabilized by frequent drought. Drought is a common limiting factor for crop production in rainfed fields of three cultural types - upland, lowland, and deepwater - and in irrigated areas when water supplies are short (35).

When drought occurs at different stages the frequency and severity of the injury it causes on plant growth and crop yield vary (6, 14, 35). Water deficit reduces plant height, number of productive tillers, leaf area index, root-to-shoot ratio, total dry matter production, grain development, and, finally, grain yield (6,7,44). Crop failures or lowered yields have primarily resulted from prolonged water deficit caused by lack of rain for 3-4 wk (7, 12, 20, 23). Severe drought at any growth stage affects grain production because plant growth is a continuous process. Water deficits during the reproductive stage inflict the most serious damage to grain yield (7, 11, 32, 33, 35).

Next to drought, and frequently associated with it, blast disease is another chronic constraint to stable yields. In most upland areas, the highly acidic soils are often deficient in N and P, and excessive in Al and Mn. These adverse soil factors place additional constraints on upland rice yield.

A combination of variable rainfall patterns, chronic blast incidence, adverse soil conditions and a lack of adapted varieties with improved yield potential further set back the prospects for improving the yield of upland rice. IRRI's Genetic Evaluation and Utilization (GEU) program aims to exploit the full use of gene pools in diverse germplasm to cope with one or more production constraints in unfavored production areas where drought is a major factor (5). This paper discusses the identification of drought-resistant germplasm and efforts to use the genetic resources for upland rice improvement by IRRI staff and cooperators.

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GERMPLASM RESOURCES

The cultivated rices consist of two crop species: *Oryza sativa* L. and *O. glaberrima* Steud. *O. sativa* is a cosmopolitan cultigen while *O. glaberrima* is grown only in West Africa. Rainfed-upland culture in its various forms includes both species. *O. sativa* contains greater genetic diversity than *O. glaberrima* (3).

The genetic resources of upland rice of Asia may be found mainly in the land races of Bangladesh, Burma, India, Indonesia, Laos, Malaysia, Philippines, and Thailand. A small number of improved types have been developed by breeders of India, Indonesia, Japan, and the Philippines. The mentioned group comprises the major segment of the upland rices in the International Rice Germplasm Center (IRGC) at IRRI. The IRGC has more than 4,000 accessions that belong to the upland group in a broad sense. Upland rices, however, are less diverse than the lowland group.

Among the upland cultivars, the Asian group is the most diverse ecogeographic group and it overlaps with the rainfed-lowland cultivars in the short-growth-duration group. The upland rices of Southeast Asia form a distinct morphoecologic group frequently called the hill rices, while most of the "upland rices" of India are more of the rainfed-lowland type and have some intermediate features. In many cases these rices of the Indian subcontinent are a dual-purpose type that began under dryland culture and terminated under lowland conditions. Along the eastern side of Bangladesh and India, such rices are known as the Aus varieties (10).

African germplasm includes both *O. glaberrima* and *O. sativa;* the latter was introduced into Africa from Asian countries during a span of several centuries. The *O. glaberrima* segment consists exclusively of land races. *O. glaberrima* strains have shown high levels of resistance to biotic and environmental stresses, especially on soils of poor fertility. The *glaberrima* rices also have excellent vegetative vigor expressed as recovery ability (8). On the other hand, many Asian upland cultivars have deeper and thicker roots than *O. glaberrima* strains.

A limited number of upland cultivars originating from Asia were hybridized in Africa, and several improved varieties such as OS4, OS6, and E425 were developed and grown in some parts of West Africa. These varieties, together with other unimproved but undoubtedly locally selected Asian cultivars such as Moroberekan and Agbede, were found to have high levels of resistance to stresses, especially drought. Our experiments have shown that these varieties generally have deep and thick root systems, high cuticular resistance, larger xylem vessels, and low and stable yields. Recently the Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) in Ivory Coast and the International Institute of Tropical Agriculture (IITA) in Nigeria have produced a number of improved *sativa* lines.

The Latin American germplasm consists of foreign introductions and the IAC series bred in Brazil. A small number of U.S.-bred varieties were grown

in upland culture over scattered areas. The principal U. S. variety Bluebonnet has a Philippine upland variety (Rexoro) in its parentage. The IAC varieties are outstanding in drought resistance mainly with the avoidance or escape mechanism type (19, 25, 26). Like most traditional upland varieties of Asia, IAC varieties have smooth leaves (2). Some IAC varieties have tolerance for aluminum toxicity (21).

PHYSIOLOGIC MECHANISMS IN UPLAND RICE GERMPLASM

In evaluating rice germplasm for drought resistance and elucidating varietal differences, the four underlying physiological mechanisms - escape, avoidance, tolerance, and recovery - are referred to (7, 27, 30, 43). Meanwhile, drought resistance is recognized as a complex trait that results from the plant's histological and physiological characteristics with environmental factors. A high degree of drought resistance allows the plant to maintain its growth and development under water stress. Varietal responses are both growth stage and location specific (5).

Most upland rices have either the escape mechanism of early maturity or the avoidance mechanism involving deep and thick root systems and the adaptive mechanisms of the shoot such as plasticity in leaf rolling and unrolling, early stomatal closure, and cuticular resistance. However, the tolerance mechanism at the tissue level and the recovery ability are generally poorer in traditional upland rices than in the rainfed lowland group (4).

Each type of mechanism must be taken as an integral part of drought resistance as a whole in relation to its ecological perspective (35).

The ability of the plants to recover and produce new tillers after soil moisture is replenished after a prolonged drought is another feature related to drought resistance. Drought resistance and recovery ability are two independent traits. In chronic areas with erratic rainfall distribution, recovery ability determines the crop's final yield (7).

Most upland varieties of drought-prone areas are characterized by low and rigid tillering ability, tall plant stature, poor resistance to lodging, and low yielding potential. On the other hand, upland rices have good yield stability under unfavorable conditions and popular grain quality preferred by growers. Most upland rice growers are subsistence farmers, except in Brazil (5).

Rice germplasm has such remarkably rich diversity that a continuous spectrum of genotypes differing in the various physiological mechanisms can be found and is available for genetic manipulation (3).

EVALUATION FOR DROUGHT RESISTANCE

In screening large numbers of germplasm bank accessions and early-generation breeding lines, the mass field screening technique devised in 1972 (7) has been primarily relied on. The technique includes the test for recovery ability. A decimal scoring system has been developed (29) on the

basis of visual scoring of the plant's plasticity in leaf rolling and unrolling, extent of tissue damage, and panicle development during moisture stress under simulated field conditions in the dry season. The visual scores have shown high correlation with the leafwater status (17, 18, 37, 39) and the root system (6, 7, 28, 31, 41). Although the visual scores are not as precise as some other sophisticated physiologic determinations in the field (40), it has been most useful in dry-season evaluation, in which several thousand entries are screened each year. Dry-season data also showed high correlation with wet-season reactions when prolonged moisture stress occurred during the wet season (5, 15, 36).

IRRI data on screening 44 379 varieties and lines from 1973 to 1984 during the dry seasons are summarized in Table 1. While a large number of cultivars and breeding lines are resistant at the vegetative stage (5, 13), only a few are highly resistant at the reproductive stage (5, 9, 18).

Other evaluation techniques have been recently reviewed (4). Measurement of leaf canopy temperature by infrared thermometer may be most promising for field plots when each plot has several rows of plants.

The drought responses shown in the mass-screening test largely reflect a variety's avoidance mechanism and, to some extent, its escape mechanism. Most drought-resistant entries have deep and thick roots, although the root number may not be high (6, 7, 15, 28). Moreover, early and gentle leaf-rolling during the hottest hours of the day also helps to conserve water in the plant (38). The contribution of deep and thick roots to the avoidance mechanism has been verified by a series of studies at IRRI (5, 7, 15, 20, 21, 25, 34, 45).

In recent years the aeroponic technique has been used to compare the root system of different varieties and lines (1, 31). Data obtained in aeroponic culture correlated well with root data obtained in the field, root boxes, or soil tubes, and are highly reproducible (23, 31). The contributions of root length and root thickness to drought resistance at two growth stages are shown in Table 2.

Tolerance of plant tissues for water stress is the least understood mechanism in the syndrome of moisture stress. It appears that the lowland varieties may have higher levels of tolerance than the traditional upland varieties (4).

Selection for vigorous and deep roots has recently been expanded by selecting seedlings at the time of transplanting. Seedlings 21 days old show marked varietal differences that permit the acceleration of the selection process during the dry season. The effectiveness of this approach has been confirmed in our wet season plantings when water stress occurred during the 1983 and 1984 wet seasons (4, 26).

PROGRESS IN BREEDING FOR DROUGHT RESISTANCE

While drought resistance is the primary topic in this paper, our breeding objectives involve other economically important traits: a range of maturities

Table 1. Summary of field scores on drought resistance of 44 379 varieties and lines, Upland Rice Breeding Team and International Rice Germplasm Center, IRRI, 1973-84 dry seasons.

Groups	Entries (no.)	Entries (no.) with given vegetative score								
		1	2	3	4	5	6	7	8	9
Germplasm bank accessions[a]	25 333	96	807	2334	5103	8825	6458	1632	68	10
Dryland breeding lines	10 009	394	543	1397	2457	3416	1527	261	14	0
Wetland breeding lines	5 260	0	14	138	471	1635	1963	882	145	12
Breeding lines from other countries	2 155	93	250	336	451	542	379	87	11	6
Entries in international nurseries	479	1	1	11	40	141	166	80	4	35
Oryza glaberrima strains	1 143	16	291	109	124	322	195	68	7	11
		Entries (no.) with given reproductive score								
		1	2	3	4	5	6	7	8	9
Germplasm bank accessions	7 567	12	24	249	191	738	341	2008	763	3241
Dryland breeding lines	2 879	0	1	24	16	152	151	1114	633	788
Wetland breeding lines	2 073	0	0	1	2	49	52	676	348	945
Breeding lines from other countries	596	0	0	24	21	54	53	137	26	281
Entries in international nurseries	151	0	1	2	3	8	7	60	10	60
Oryza glaberrima strains	635	0	2	132	51	49	26	100	6	269

[a] 21 000 accessions have field drought scores and recovery data in the GB file. About 4 000 accessions were either duplicates or were retested 2 to 3 times.

Table 2. Correlation coefficients between root characters obtained under aeroponic culture and field resistance to drought at vegetative and reproductive stages of growth.

	Correlation coefficient			
	Root length	Root diameter	Root number	Root-Shoot ratio
Vegetative field reaction score [a]	-0.16^{ns}	-0.46*	0.27^{ns}	-0.36^{ns}
Reproductive field reaction score [a]	0.54**	-0.78**	0.53**	-0.77**

[a] 1 = resistant, 9 = susceptible.

to suit precipitation patterns, intermediate plant stature for improved nitrogen response and lodging resistance, resistance to the major diseases and insects, tolerance for adverse soil factors, relatively long and well-exserted panicles, and intermediate amylose content of the grain. To meet the multiple breeding objectives, the diverse genetic resources have been drawn upon to recombine some of the characters that originate from contrasting variety groups. The semidwarfs have been extensively used to improve yield potential and pest resistance. Traditional upland and dual-purpose varieties and some of the rainfed-wetland cultivars are used as sources of tolerance for various adverse environmental factors.

Table 3 shows some promising sources of the desired traits in improving upland rice. Progeny testing indicates that drought-resistant progenies are obtainable only when one parent is drought resistant (5, 16, 19, 20, 21, 30, 42).

Since the early 1970s some 5,700 crosses have been made for local testing and selection (5). Collaborative activities on a global scale have been initiated. A total of 1,159 crosses were furnished to 25 upland rice breeders in 3 regional and international centers and 18 national centers.

The primary constraints in the breeding process were briefly reviewed during the 1982 International Upland Rice Workshop at Bouaké. The constraints are updated and discussed further as follows:

1. A lack of donor parents with drought resistance at the reproductive stage and good recombining ability.
2. Genetic barriers to obtaining desirable progenies in upland/semidwarf crosses, and geographically isolated upland/upland crosses.
3. Negative correlation between drought escape and avoidance mechanisms on one hand and recovery ability on the other.
4. The test sites in the Philippines are not representative of drought-prone production areas with low soil fertility.
5. A lack of adequately equipped and well-staffed experiment stations in cooperating countries.

Continued upgrading of breeding lines and their use as principal parents in the crosses partly overcome some handicaps. However, whenever a

Table 3. Promising sources of desired traits.

Trait	Sources
Moderately high drought resistance and early maturity	Some aus varieties, Black Gora, Brown Gora, Kalakeri, Bala, Lal Nakanda, N22, IAC 25, Dular.
High drought resistance and good root systems	Moroberekan, OS4, OS6, E425, 20A, LAC 23, 63-83.
	Seratus Malam, Arias Halus.
	Khao Lo, Khao Youth, Padi Tatakin, KU86, KU 70-1, Kinandang Patong, Salumpikit, Azucena.
Improved drought resistance (moderate levels) and good recovery ability	Semidwarfs: IET 1444, IR43, IR9575 selection.
	Intermediate talls: C22, UPLRi-5, IR6023-10-1-1.
High tillering ability and yield potential	Many high yielding semidwarfs of lowland parentage: IR6115-1-1-1.
Resistance to blast	Most traditional upland varieties from West Africa, South and Southeast Asia, and Latin America.
	Blast-resistant IR lines: IR5931-110-1, IR9669 sel., IR10068-18-2.
Resistance to white-backed planthopper	N22, ARC 10239, Sathra 267, ADR 52, Podiwi-A8, IR lines derived from the above.
Tolerance to adverse soil factors (Mn and Al toxicities; Fe deficiency)	Agbede, E425, OS4, OS6, LAC 23, Binerhen, Tres Meses, M1-48, Dourado Agulha, IAC 1131, IR6023-10-1-1, IR1754-F_5B-22.
Intermediate amylose content	Most traditional upland varieties; lowland varieties of the Philippines; many IRRI upland lines.

traditional upland or semidwarf parent is included in the crossing program, frequently in three-way or double crosses, the progenies tend to swing one way or the other toward the new parent involved. This tendency indicates that genetic barriers to obtaining full segregation and recombination in the wide crosses still exist.

The following progress has been achieved during recent years:

1) Moderately high levels ofdrought resistance have been combined with a moderate level of recovery ability from divergent sources. Lines such as IR6023-10-1-1, IR6115-1-1-1, and IR12979-24-1 have been shown to have the desired recornbination at multiple test sites (22, 24, 25).
2) In years of favorable rainfall and favorable areas, an experimental yield of 4 t/ha, or slightly higher, can be readily obtained under moderate levels of fertilization. During seasons of water deficit, genotypes with deep and thick roots have performed better than existing improved varieties by greater extraction of water and nitrogen from the soil (5, 17, 19, 20, 21, 23, 25).

3) Some lines showing drought resistance under upland conditions also demonstrate high levels of drought resistance under rainfed-wetland conditions. This correlation has broadened usefulness of the search for drought-resistance materials. Through multidisciplinary research and multisite testing, insight is being gained into the genotype/environmental interactions in terms of grain yield (5). Some promising lines identified through multisite testing are enumerated in Table 4.
4) More efforts are being devoted to production of crosses for workers in national and regional centers to overcome the restricted range of environments available in the Philippines. Such cooperation would lead to a fuller use of the donor parents and their useful genes by both IRRI scientists and national scientists.

   Collaboration among upland rice workers and especially the breeders would benefit from periodic international meetings such as this conference. Our participation in the Upland Rice Testing Course at IRRI (1983 and 1984) has strengthened not only the technical manpower of national centers but also the collaborative network.
5) A crossing and selection program aimed at incorporating blast and drought resistance in collaboration with IRRI plant pathologists was initiated in 1983 to cope with different environmental and biotic constraints. An upland composite for population improvement using a genetic male-sterile (*ms*) line of IR36 background was generated. Simultaneously, backcrosses were made with both adapted improved and traditional materials such as C22, IR5178-1-1-4, IR3839-1 or Sew Maew Jan as recurrent parents.

In the last quarter of 1984, preliminary evaluation trials for unfavorable upland conditions were established at two locations in the Philippines that have contrasting pH values of 4.0 and 7.0 but low soil fertility. Our breeding lines with upland parentage grew more vigorously than lowland materials.

These recent thrusts in IRRI's breeding program will greatly augment the progress in improving upland rice for drought- and blast-prone areas as well as for areas with adverse soil conditions.

CONCLUSION

The complex interaction of genotype and environments is a challenge to both crop physiologists and rice breeders in the improvement of upland rice. Vagaries of weather and ecoedaphic variability interact with rice genotypes, agronomic practices, biotic factors, and the specific growth stages of the rice plant when water deficit occurs and is removed. These account for the location - and growth stage-specific manifestations of drought response.

The Genetic Evaluation and Utilization (GEU) Program of IRRI emphasizes the need for understanding the complexities of drought resistance toward the improvement of upland rice. The rich diversity of the germplasm in the International Rice Germplasm Center (IRGC) — now in excess of 75 000 accessions — provides a broad genetic base for upland rice

Table 4. Promising IR breeding lines that have shown good performance in various screening nurseries.

(parents) and Breeding lines	Site of testing	Type of experiment	Reputed superior features[a]
IR1750-F_5B-5	East India,	IURON '77	High yield potential
(E425/IR22)	Ecuador, Peru	VIRAL-S '77	High yield potential; early
IR1746 lines (OS4/IR8)	Thailand (Chiangmai), India (Faizabad, U. P.)	IURON '77	Drought-R, high phenotypic acceptability
IR1752-F_5B-22 (E425/IR8)	Philippines	Screening nursery for adverse soils	Tolerant to Mn/AI toxicity; drought-R
IR3839-1	Rajshahi, Bangladesh,	IURYN '77, '79	High yield potential
(Pelita I-2/IR1529-680-3// IR442-2-58/RN21)	Philippines	Phil. Seed Board 1980 and 1981	High yield potential
	Latin America (favorable upland areas)	VIRAL-S 1980 WS	High yield potential
IR3880-13	Ranchi, Bihar;	IURYN '79 WS	High yield potential
(IR841-67/C22//Pelita I-2/ IR1541-76)	Philippines	Philippine Seed Board 1976 WS & 1977 WS	High yield potential
IR5178-1-1-4	Philippines;	Phil. Seed Board '78	Blast-R
(IR1746-194-1/IR1487-372)	Nangina, India,	IURYN '79	Drought-R
	Joydebpur, Bangladesh	IURYN '79	High yield
IR5931-110-1-1	Nigeria;	IURYN '80, '81 WS	High yield, blast-R
(MRC172-9/IR1544-340// IR4520-76-90)	Chiangmai, Thailand; IRTP test sites	IURYN '80, '81 WS IURYN 1981	High yield, blast-R; early; good recovery ability

Continued on next page.

Table 4. Continued.

(parents) and Breeding lines	Site of testing	Type of experiment	Reputed superior features[a]
IR6023-10-1-1 (BPI-76*9/Dawn//LAC 23)	IRTP test sites	Screening for adverse soils '82 WS	Good on acid upland soils
		IURON '81 WS	Good performance
	Caliraya, Philippines	Observational trial '84 WS	Good on low fertility soils
IR6115-1-1 (IR1529-680-3/Moroberekan)	Philippines,	Phil. Seed Board 1978 trials	Blast-R
	Philippines (IRRI)	Screening for adverse soils	Good on low pH upland soils
	IRTP test sites,	IURYN 1981	High yield
	Philippines (IRRI)	Screening for insect resistance	R to BPH-1
IR6115-1-1 (IR1529-680-3/Moroberekan)	Thailand & Southeast Asia;	IURYN '80 & '81	High yield
	Huimanguillo, Mexico	VIRAL–S'80	High yield
IR7844-12-2-2 (IR1721-11-8/63-83//MRC172-9)	Vinh, Vietnam	IURON '81	High phenotypic acceptability; and good recovery ability
IR10110-23-1 (IR1754-F_5B-23/IR3179-25// BPI-76*/Dawn)	Khon Kaen,	IURON '81	Drought-R; high phenotypic acceptability
	IRTP test sites	IURON '81	
IR12979-24-1 (IR3179-25/K. Patong// IR36///1R879-314-2)	Philippines, Khon Kaen; Ranchi, Nawagam, Hawalbagh (India)	IURON '81	Drought-R; high phenotypic acceptability
IR10004-3-1 (IR1746-F_5B-24/1R2992-27// BPI–76*9/Dawn)	IRTP test sites	IURON '81	Phenotypic acceptability, good performance
	Caliraya, Philippines	Observational yield trial	Good on low pH and low fertility soils

[a]R = resistant.

improvement. Meanwhile, drought, blast, and adverse soils will persist as the major constraints in upland rice areas.

Among the different physiologic mechanisms of drought, the escape phase, largely represented by early maturity, is the simplest form for breeders to deal with. On the other hand, the avoidance mechanism, typified by a deep and thick root system and plasticity in leaf rolling and unrolling, showed much promise in coping with water stress in upland soils. Deep and thick roots, coupled with the thrifty growth of traditional upland varieties, enable rice plants to complete their life cycle under stress by drawing on residual moisture in the lower soil horizons. However, rice genotypes possessing deep and thick roots are frequently deficient in tissue tolerance or recovery ability. Tolerance of plant tissues compensates for the lack of a deep and extensive root system. Its nature remains unclear, however.

Recovery ability is a principal determinant factor in the final grain yield (7, 16, 18). The semidwarfs are generally superior in recovery ability while the traditional upland varieties are generally poor. As the avoidance mechanism and recovery ability are frequently uncorrelated, a compromise has to be made in recombining both mechanisms.

A rapid and efficient screening technique is essential to any breeding program. Several screening techniques for field resistance to drought have been developed at IRRI. Research on such methods has also provided a better understanding of the complexities of the mechanisms of drought. However, no single screening technique can be applied in every situation encountered under farmer's field conditions. Moreover, screening during the wet season is highly subjected to the vagaries of weather, while testing in the dry season does not reveal the agronomic potential in the wet season. Only in areas where drought frequently occurs, such as the plains of Brazil and northcentral India, can breeders depend on multiseason and multilocation testing to identify truly drought-resistant genotypes.

Thus, international and interinstitutional collaboration is needed to further improve the screening techniques and selection criteria for broadening their usefulness in dealing with location-specific situations.

In our attempts to recombine the drought resistance components from wide crosses, repeated field drought tests have shown that a relatively high percentage of resistant progenies can be obtained from those cross combinations that involved at least one drought-resistant parent (5). The heritable nature of drought resistance is essential to progress in breeding.

The choice of breeding methods and screening technique or selection criteria depends on the desired character traits and environmental conditions of the breeding targets. A thorough knowledge of the environmental factors and the rice genotypes desired will greatly aid the breeders and the crop physiologists in selecting the appropriate screening techniques in combining field resistance to drought and recovery ability.

We have made considerable progress in generating materials adapted to different ecoedaphic conditions with improved yield potential and yield stability. However, genetic barriers in recombining many desired traits have

slowed down the breeding progress and still pose as a constraint.

The use of "shuttle breeding" (between IRRI and a cooperating station) for location-specific adaptability promises to speed up breeding for drought resistance. However, the rice breeders of IRRI and the collaborating institutions or countries must maintain open and continuous communication as well as free exchange of genetic materials to attain the broad objectives.

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THE USE OF *O. SATIVA* AND *O. GLABERRIMA* IN WEST AFRICAN FARMING SYSTEMS

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In West Africa upland rice is grown in a wide range of environmental conditions, and various land conditions are exploited. The term upland refers to any land not subjected to flooding and where, throughout cultivation, the soil is not covered by water, except in extraordinary circumstances and for short periods. This describes more realistically the conditions in which upland rice is cultivated in West Africa.

MAJOR ENVIRONMENTAL FACTORS

Rainfall

Rainfall patterns in West Africa are monomodal and bimodal (Fig. 1).

Solar radiation

Solar energy seems less critical than moisture supply for upland rice in West Africa. High solar energy may be undesirable if moisture supply is inadequate for rice plants during the various growth stages.

Temperature

Frequent high temperatures during the day and in soil for most upland rice-growing areas in West Africa constitute a performance constraint (6).

Day length

Seasonal variation in day length is small for all of West Africa, but it is sufficient in some places, notably in the north of West Africa, to affect sensitive varieties. However, most upland rice varieties traditionally grown in forest zones of West Africa are of the japonica type and nonphotoperiodic in general (5).

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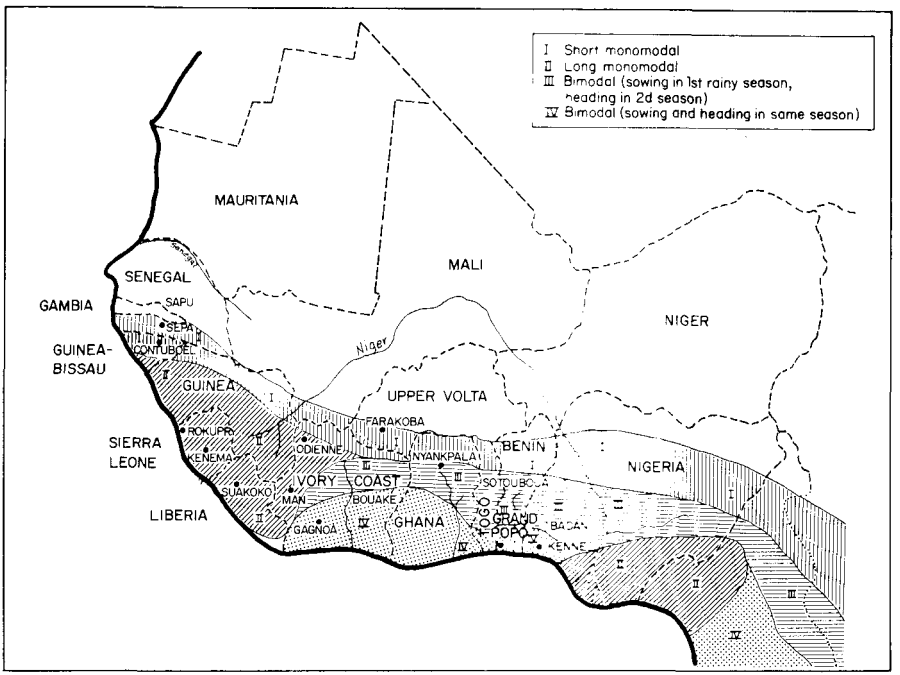

1. Rainfall patterns in West Africa (Source: 3).

Soils

Upland rice-growing soils of Africa are divided into two main groups: freely drained soils and hydromorphic soils. In freely drained soils, rice depends entirely on rainfall. These soils, classified by the FAO system, include Nitosols, Acrisols, Luvisols, Ferralsols, and Combisols (4). In the hydromorphic soil rice production is not limited to rainfall distribution patterns. The main types of soils are Entisols, Ultisols, and Vertisols. Riquier (7) suggested that fine-textured soils are preferable for rainfed rice because of hydromorphy. Riquier (7) describes the suitability of soils in selected West African countries as follows:

- In Senegal, upland rice can be grown on ferric and gleyic Luvisols in the region south of the Casamance River, where rainfall is satisfactory.
- In Guinea Bissau, upland rice is grown on low-fertility Ferralsols and on some mangrove soils.
- In Guinea, upland rice is grown on humic Ferralsols on hills.
- Many poorly drained areas in Sierra Leone are suitable for upland rice.
- In Liberia, upland rice is grown mostly on Oxisols, which degrade rapidly.
- In the region north of Upper Volta, the soils are dry and fine textured, similar to sodic soils, which are difficult to cultivate.
- The valleys of northern Niger are too sandy.
- Nigeria has large areas highly suitable for upland rice.
- Good areas for upland rice are found in Ivory Coast.

Table 1. Methods of upland cultivation in some West African countries.

Country	Land preparation in addition to minimum tillage	Planting	Fertilizer	Crop protection	Harvesting
Gambia	Clearing by burning	Broadcast	None	Hand weeding	Manual
Senegal	Slash and burn	Broadcast	None	Hand weeding	Manual
Guinea Bissau	Slash and burn	Broadcast	None	Hand weeding	Manual
Guinea C.	Slash and burn	Broadcast	None	Hand weeding	Manual
Sierra Leone	Slash and burn	Broadcast	None	Hand weeding	Manual
Liberia	Slash and burn minimum tillage	Broadcast	None	Hand weeding	Manual
Ivory Coast	Slash and burn	Broadcast, dibbling	None	Hand weeding	Manual
Ghana		Broadcast	None	Hand weeding	Manual
Nigeria	Slash and burn	Broadcast	None	Hand weeding	Manual

UPLAND RICE CULTIVATION

Three levels of cultural practices for upland rice are used in West Africa:

- traditional,
- intermediate, and
- improved.

These practices apply to land preparation, planting, plant protection, harvest, and storage activities. However, traditional methods are the most widely used (Table 1).

TRADITIONAL RICE CULTIVARS

In traditional upland rice farms in Africa, patches of different varieties grow in the same field. They are usually *Oryza sativa* species, although *O. glaberrima* plots can still be seen in Ivory Coast and Guinea under upland conditions (2, 5). However, in many West African countries, isolated *O. glaberrima* plants can be seen in mixtures with *O. sativa* on upland rice farms. These mixtures are usually accidental. In fact, in most West African countries *O. glaberrima* is rapidly disappearing as a monocrop under upland conditions. However, various germplasm-collecting missions, undertaken by the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) and Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) in West and East Africa gathered more than 2,000 samples of traditional rice cultivars including about 500 *O. glaberrima.* Morphologically, traditional rice cultivars are characterized under upland conditions by their quick early growth, taller plants, longer panicles, and good grains for *O. sativa* and by earliness, natural shattering, high tiller number, and few secondary branches for *O. glaberrima.*

Various analyses of the genetic structure of the traditional African rice cultivars (5, 8) indicate that *O. sativa* in Africa can be subdivided into indica and japonica and *O. glaberrima* can be subdivided into a floating type (long duration) and an erect type, the latter being more suitable to upland conditions (5, 8).

O. sativa appears to be genetically more variable than *O. glaberrima,* which constitutes a more homogenous group both morphologically and enzymatically.

The phenol reaction subdivides *O. sativa* into an indica group and a japonica group. Hybrid fertility tests, isozymic patterns, and morphological traits indicate a continuation of types between extreme indica and japonica so that roughly five major types can be designated:

- extreme japonica,
- hybrid japonica,
- javanica,
- hybrid indica, and
- extreme indica.

An additional variability is due to natural introgression between cultivated and wild species as detected by electrophoresis, and between the cultivated species.

Most African *O. sativa* studied are of hybrid types (about 80%), the javanica type representing about 50% of all the hybrids. Also worth noting is that nearly all traditional upland varieties collected from West Africa are of the "hybrid japonica" type. In the Sahelian zones, where rice is essentially grown in aquatic conditions, only the indica types are found (5).

CREATING UPLAND RICE VARIETIES

Surveys of farmers' fields show that despite the introduction or release of improved plant materials, traditional cultivars still remain the most popular upland rice varieties in West Africa. These varieties, which have never been subjected to improvement, are little known essentially because the "improved" varieties either are not known to the farmer, or, when known, are not adapted to the West African farmer's physical and socioeconomic realities.

The question arises: What types of upland rice plant would be most suitable to the farmers' environment and at the same time increase rice production in West Africa? Experience indicates that upland rice varieties should be released within an appropriate technological context and not as an isolated element within any farming system. In West Africa, the technological level of the farmers has evolved slowly, from the low intensive or traditional toward a highly intensive upland rice culture.

In planning upland rice technology in West Africa, one should be concerned with low, intermediate, and high levels, all at the same time but in different proportions. Breeders should aim at developing varieties adapted to low, intermediate, and high technologies, especially the first two. Breeders involved in upland rice research in West Africa should consider short-term and long-term objectives. Short-term programs would provide optimum exploitation of the low and intermediate technological levels. As technological levels of farmers in West Africa improve, priorities can be switched to developing varieties for more intensive upland rice culture.

Currently the most urgent need is for varieties to maximize upland rice production under present technological levels used by most farmers in West Africa rather than for varieties adapted to a more intensive upland rice culture. Some varieties adapted to high technology are already available. For breeding upland rice in West Africa, *O. sativa* and *O. glaberrima* should be used when and where appropriate.

Materials

Three major sources of genetic materials will be

1. African germplasm collections,
2. some national programs in South America and Asia, and
3. other international centers such as International Rice Research Institute, International Institute of Tropical Agriculture, and Centro Internacional de Agricultura Tropical.

Methods

Methods will be objective oriented. Under the short term, varieties that fit into the most common cultivation systems in West Africa will be developed using low soil fertility, medium-tall plants (120-150 an), quick initial growth, short to medium duration, minimum average yield of 1.5 t/ha, long and slender grain, disease resistance, well-exserted panicles, and shattering resistance as criteria. The present variability in the local cultivars of the *sativa* species would be intensively exploited, and introduced materials from other international centers and some national programs would be used intensively.

The long-term plan, corresponding to intensive agriculture, would use the same criteria except that its aims would be higher yielding ability (2.0 to 3.0 t/ha), fertility responsiveness, and shorter plants considering that farmers could have access to some improved cultural practices, such as good land preparation, better planting methods, and fertilizers.

Varieties could be developed through introduction of fixed and segregating materials from various institutions whenever possible and appropriate, and hybridization within the *sativa* species, with the breeder keeping in mind the genetic structure adapted to each ecology. For forest zones, for example, the aim would be toward the japonica types.

Under the long-term plan, possibilities of *sativa/glaberrima* crosses could be considered. Preliminary data obtained by the Institut des Savannes, Ivory Coast (IDESSA) seem encouraging. Persistent efforts will be required for a longer time before commercial varieties from *glaberrima/sativa* crosses can be developed.

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EVALUATION OF INTERNATIONAL UPLAND RICE NURSERIES

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

The international nurseries are broadly grouped into: target environment nurseries and stress screening nurseries. Target environments include irrigated and rainfed. The rainfed category includes 1) upland, 2) lowland (shallow water), 3) deepwater, 4) floating rice, and 5) tidal wetlands.

The rainfed upland nurseries are designed to provide a mechanism for exchanging, evaluating, and identifying superior breeding lines and varieties suitable for upland (dryland) rice culture. Upland rice is cultivated on nearly 13% of the world's rice area. Rice in Africa and Latin America is cultivated predominantly under upland conditions. Duration of growing seasons, as dictated by the amount and distribution of rainfall and the physical and chemical properties of the soils, vary from region to region. The major varietal requirements for upland culture include early to medium growth duration, semidwarf to intermediate plant height, tolerance for drought, for soil problems such as aluminum toxicity and phosphorus deficiency, and for diseases, particularly blast.

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TEST SITES AND GENETIC MATERIAL

The International Upland Rice Yield Nursery (IURYN) began in 1974, and the observational nursery (IURON) in 1975. Commencing in 1984, the yield nursery was subdivided into two maturity groups, early and medium. The test sites 1973-1983 trials are indicated in Table 1.

The test material consisted of photoperiod-insensitive lines of early to medium growth duration and included three categories of plant height, semidwarf, intermediate, and tall stature. Many improved lines and some traditional varieties were included. Entries originated from several national programs in Asia, Africa, and Latin America and from the international centers, IRRI, IITA, and CIAT.

The entries in observational nurseries are grown in unreplicated two-row plots and the yield nurseries are laid out in a randomized complete block design with three replications. The plot size, row spacing, fertilizer rates, insecticide applications, and other cultural practices appropriate to individual test sites are followed. Planting of the nurseries coincides with the upland rice cropping season in each area where they are evaluated.

The traits evaluated in the observational nurseries include plant height; days to flowering; phenotypic acceptability; tolerance for stresses such as drought, blast disease, and aluminum toxicity. In the absence of yield evaluation, the phenotypic acceptability ratings provide the most important information as a first approximation on varietal adaptability to different situations. The data obtained for yield nurseries are the same, except that replicated grain yield measurements are taken instead of phenotypic ratings. Information on rainfall during the crop season is provided for both yield and observational nurseries.

NURSERY PERFORMANCE

Table 2 summarizes the number of entries in the trial, the number of participating countries, and the number of trials that returned data by year.

Observational nurseries

Entries that received the best phenotypic acceptability ratings from the upland observational nurseries evaluated during 1975-83 are summarized, by year, in Table 3. Entries rated good more frequently over locations and years are:

Tall, early maturity	: Aus 61, DJ29, ARC10372, Kinandang Patong
Intermediate early maturity	: IR1746-226-1-1-4, KN361-1-8-6
Tall, medium maturity	: Azucena
Intermediate, mediummaturity	: IR9575 sel., BPI76 (NS), C22, KN96, IRAT13, IR3880-13, IRAT 104, IRAT 106, IRAT 140, UPL Ri-7, B2997c-Tb-60-3-3
Short, medium maturity	: BG35-2

Table 1. Test sites that evaluated the International Upland Rice Yield Observational Nurseries (IURYN and IURON), 1975-83.

Country	Test sites
China	Nanjing
Korea	Suweon
Burma	Heho, Kyaukse, Yezin
Indonesia	Banguntapan, Bone-Bone, Bontobili, Jeneponto, Kendari, Muara, Padang, Pleihari, Sitiung, Subang, Tamanbogo, Tilang, Wajo
Malaysia	Bertam, Bumbong Lima, Tuaran
Philippines	Antique, Bacolod, Cuenca, Dasmarinas, Davao City, Ilagan, Kibawe, La Carlota, Los Baños, Musuan, Pagadian, Pambujan, Puerto Princesa, Quezon, Silang, Sto. Tomas, Tacloban, Tupi
Thailand	Chiang Mai, Chiang Rai, Chumpae, Hinsawn, Khon Kaen, Khun Wang, Kuan Gut, Mai Hong Son, Makasarakham, Nakornrajsima, Pang Mapha, Phrae, Samerng. Ubon Rachathani
Vietnam	Buon Me Thuat, Hung Loc, Nghe Tinh, Nghi Kim, Nghi Loc, O Mon
Bangladesh	Comilla, Joydebpur, Mymensingh, Rajshahi, Sonagazi
India	Aduthurai, Almora, Bankura, Bhubaneswar, Coimbatore, Cuttack, Derol, Faizabad, Hathwara, Hawalbagh, Hazaribagh, Hyderabad, Jeypore, Karjat, Majhera, Mandya, Mugad, Nagina, Palampur, Pantnagar, Paramakudi, Pattambi, Raipur, Ranchi, Rewa, Rudrur, Samba, Sambalpur, Shillong, Tirurkuppam
Nepal	Biratnagar, Nepalganj, Parwanipur, Rampur, Tarhara
Pakistan	D. I. Khan, Dokri, Kala Shah Kaku
Sri Lanka	Gannoruwa, Maha Illupallarna, Paranthan
Afghanistan	Jalalabad
Iraq	Bakrajo
Saudi Arabia	Riyadh, Unayzah
Sudan	Wad-Medani
Cameroon	Mbo Plain, Ndop, Santchou
Ethiopia	Debrezeit, Woretta
Ivory Coast	Bouaké
Liberia	Suakoko
Malawi	Salima
Mozambique	Maputo
Nigeria	Amakama, Ibadan, lkenne
Senegal	Dj ibelor
Sierra Leone	Kenema, Njala, Rokupr
Tanzania	Dar Es Salaam, Katrin, Zanzibar
Upper Volta	Bobo-Dioulasso
Zambia	Mansa
Brazil	Campinas, Goiania, Piaui
Colombia	Chigorodo, Palmira, Sta. Rosa, Villavicencio
Costa Rica	Cañas
Cuba	Habana
Mexico	Chetumal, Cuxtepeques, Edzna, H. Cardenas, Huixtla, Juchitan, Mazatlan, Medias Aguas, Ros. Izapa, Villaflores
Panama	Bayano, Rio Hato, Tocumen
Peru	Rioja, San Ramon
Surinam	Paramaribo

Table 2. Size of international upland rice nurseries and level of cooperative participation in performance testing, 1975-83.

Year	IURYN[a]			IURON[b]		
	Entries (no.)	Countries (no.)	Trials (no.) returning data	Entries (no.)	Countries (no.)	Trials (no.) returning data
1975	25	8	24	146	10	23
1976	25	8	24	185	14	33
1977	25	14	27	153	17	37
1978	28	10	23	190	19	45
1979	25	10	25	141	11	27
1980	28	10	19	217	15	35
1981	26	9	15	104	8	27
1982	–[c]	–	–	185	14	37
1983	21	7	19	204	13	26

[a] International Upland Rice Yield Nursery. [b] International Upland Rice Observational Nursery. [c] An IURYN was not composed in 1982.

Table 3. Entries in the International Upland Rice Observational Nursery (IURON, 1975-83) that received good overall phenotypic ratings.

Year	Growth duration	Entries with broad phenotypic acceptability
1975	Early	Aus 61, C46-15/IR22[2] sel., IR1746-226-1-1-2, IR1746-226-1-14, IR2061-522-6-9
	Medium	IR1693-P36-197-875
1976	Early	IRI746-194-1-1-1, IR1746-226-1-1-4, Binaritos, Kinandang Patong, ARC10372, DV110, DJ-29
	Medium	IR3304-23, IR9575 sel., BPI 76 (NS), C22, Dinalaga, M1-48
1977	Early	Aus 61, DJ29, ARC10372, KN361-1-8-6
	Medium	IR9575 sel., IRAT13, C22, IR3880-17, IR3880-13, KN96
1978	Early	Kinandang Patong, KN361-1-8-6, Bala, Rikuto Norin 21
	Medium	Azucena, B733c-67-3-2, BPI-76 (NS), IR4503-12-1-3-1, KN96, IR9576-4-5-5, IR3880-13, IRAT13, IR3646-9-3-1 B995-BCI-TB-13, IR9575 sel., BG35-2, IRAT104, IRAT105, IRAT106
1979	Early	TOX95-5-1-1-1,IR3880-29
	Medium	BG35-2, Gama 318, IR5929-12-3, C424-2, C732-14, C894-21, IR9575 sel., BPI 76 (NS), C22, KN96, MRC-172-9, Salumpikit
1980	Early	IR3880-29, KMP34, ARC10372, TOX340-1-5-1, IAC47
	Medium	BG35-2, CR156-5021-207, C924-9, IRAT140, Azucena, IRAT104, IRAT106, IRAT111
1981	Early	IR9761-19-1, IR19793-25-2-2, Jhum Sonalichikon
	Medium	IAC1246, IR10004-3-1, IR10110-23-1, IR12979-24-1, IR5440-1-1-3, IR3794-9-2-3, IR6023-10-1-1, UPL Ri-3, ITA175, ITA235
1982	Early	IRAT109, IRAT112, IRAT144
	Medium	B2997c-Tb-60-3-3, B3016b-Tb-260-3-2, B2992b-Tb-73-4-2, M18, UPL Ri-7, IRAT140, IRAT101, ITA139, ITA235, TOX502-2-SLR2-LS3-Bl, BG35-2
1983	Early	B3619c-Tb-8-14
	Medium	UPL Ri-7, C1019-1, IRAT140, IRAT13, B2997c-Tb-60-3-3

In Latin American and African countries, several TOX lines from IITA and IRAT lines were rated good (e.g. TOX503-7-4-2, TOX95-5-1-1-1, TOX728-1, TOX502-l-SLRl-LS3-B, IRAT13, IRAT104, IRAT106, and IRAT140). Other entries rated good in these regions include MI-48, Sein Ta Lay, IR9575 sel., IR8103-4-1, IR8098-41-3, IR10781-143-2-3, BG35-2, and KMP34.

At Goiania, Brazil, where conditions are less favorable, these entries were rated good in different years:

ASD7	IR9575 sel.	B981k-Tb-14
DJ29	IR2307-217-2-3	IRAT104
Azucena	IR4503-12-1-3	IRAT106
MI-48	IR4515-409-2-6	IRAT111
IRAT13	IR4535-14-4-3	Sein Ta Lay
IR52	Kinandang Patong	Seratus Malam
IAC25	IAC47	IAC1246

Most of the mentioned entries are early maturing and intermediate to tall in stature.

The nurseries at the various sites are exposed to different stresses, predominantly drought, which may occur at the vegetative or the productive stage or both. Some entries were rated good in specific trials under serious stress conditions.

Severe drought occurred in parts of eastern India in 1976. In West Bengal, Purulia and Bankura Districts were declared drought-affected areas by the government. Only 30% of the normal rainfall was received during the crop season. The two districts were represented by two IURON sites, Hathwara and Bankura. Drought occurred at various growth stages in the trials at both sites. Entries rated good were IR3304-23, IRAT10, and Aus 61 at Bankura; and SE322b-19, IR3880-29, IR5179-2, KN144, IET1444, and IET3226 at Hathwara. Most entries were rated good for ability to recover from drought, whereas SE322b-19 was rated good for both tolerance and recovery.

The 1978 IURON site at Joydebpur, Bangladesh, was exposed to severe drought for 1 mo during the early vegetative stage. Only one entry (C12) was given the best phenotypic score of 3.0.

At Khonkaen, Thailand, the 1979 IURON experienced prolonged drought stress from maximum tillering to ripening stages. Rains were lacking after maximum tillering. Total rainfall for the season was 684 mm during 53 rainy days. Entries that received the best phenotypic scores (2.0-3.0) include IR8098-231-2, KMP12, TOX504-14-11-1, TOX504-14-6-1, and TOX494-5-1-2.

Drought stress occurred for a 90-d period between early tillering and flowering stages in the 1981 IURON trial at Nagina, India. Twenty rainy days brought 569 mm rainfall during the crop season. Entries given good phenotypic ratings under those conditions included IR9761-19-1, Mijingem, DZ41, IR19793-25-2-2, Jhum Sonalichikon, ITA117, ITA118,

ITA162, ITA235, ITA141, and ITA164, all of which have relatively early growth durations, except ITA164, which has medium growth duration.

At Sukarami, Indonesia, situated at an elevation of 928 m, most entries in the 1981 IURON received poor ratings. The soil pH of the test site was 4.2. Blast was severe. IR12979-24-1, ITA142, and the local check were rated good (score of 3.0).

The test site at Almora, India, is at an elevation of 1300 m. During the 1981 trial season, the minimum temperatures (monthly means) varied from 7 to 19° C and the maximum, 27 to 32° C. The 1981 IURON experienced, in addition to low temperature, severe moisture stress for 4 wk around flowering stage. Total season rainfall was 625 mm. Several entries failed to flower. Nearly all entries were given a phenotypic rating of 9.0. The best score was 3.0 and entries that received it were Katakchikon, Mijingem, DZ41, IR19793-25-2-2, Jhum Sonalichikon, and VL502 (local check). These entries took 80-90 d to flower.

At Worretta, Ethiopia, the mean monthly minimum temperatures varied from 7 to 13 °C during the 1983 trial season. The trial also experienced drought stress at flowering stage. A total of 916 mm of rainfall was received during the season. Only two entries from 1983 IURON, B2992b-Tb-73-4-2 and B3016c-Tb-227-2-2, received the best score (3.0) for phenotypic acceptability. The remaining entries were rated 7.0-9.0.

The 1983 IURON at Mansa, Zambia, was planted on an acid soil of pH 4.3. Entries rated good were Sein Ta Lay, TOX502-1-SLRl-LS3-B, IRAT132, IR12979-24-1, M55, Rata 244, IRAT13, IRATl33, and IRAT146.

The appropriateness of plant height, growth duration, and the other relevant traits of the test entries to individual situations determines the frequency at which entries were rated good at a given location. The frequency distribution of the phenotypic acceptability scores in selected tests of the IURON is summarized in Table 4. The frequency of good ratings (scores of 1 to 3) was relatively high at sites in Indonesia, Philippines, and Mexico. The frequency of poor ratings (scores 7 to 9) was highest at Faizabad and Ranchi, India, where early maturity, preferably with intermediate height, is important; at Worretta, Ethiopia, where tolerance for low temperature is needed; and at Goiania, Brazil, where tolerance for drought, A1 toxicity, and blast disease are critical.

When the IURON entries were grouped into four maturity × height classes, the relative performance of these groups varied across sites (Table 5). For example, at Ranchi, India, where a short growing season and acidic soils are a constraint, the early-maturity groups consistently received better phenotypic acceptability scores than the medium-maturity groups. In Joydebpur, Bangladesh, most entries in all four groups scored poorly over the 3-yr period. In Yezin, Burma, and Bogor, Indonesia, average scores among the groups also did not vary greatly, although phenotypic acceptability among the entries, in general, was considerably more promising than at Joydebpur.

Table 4. Frequency distribution of phenotypic acceptability scores of entries in selected International Upland Rice Observational Nurseries (IURON).

Region, location	Year	Entries with phenotypic acceptability scores of 1-3		4-8		7-9	
		No,	Total (%)	No.	Total (%)	No.	Total (%)
Southeast Asia							
Yezin, Pyinmana, Burma	1983	36	18.0	119	59.5	45	22.5
Heho, Burma	1979	0	0.0	42	50.0	42	50.0
Muara, Bogor, Indonesia	1982	51	30.7	100	60.2	15	9.0
Sukamandi, Subang, Indonesia	1981	39	37.5	65	62.5	0	0.0
Ilagan, Isabela, Philippines	1983	39	19.3	64	31.7	99	49.0
Los Baños, Laguna, Philippines	1982	81	44.3	68	37.2	34	18.6
Chiang Mai, Thailand	1982	70	39.3	67	37.6	41	23.0
Khonkaen, Thailand	1983	21	10.3	53	26.1	129	63.5
Ubon Rachathani, Thailand	1980	6	6.4	19	20.2	69	73.4
Vinh, Vietnam	1981	29	28.2	45	43.7	29	28.2
South Asia							
Joydebpur, Bangladesh	1982	1	0.6	49	29.9	114	69.5
Ranchi, Bihar, India	1982	37	20.6	0	0.0	143	79.4
Faizabad, Uttar P., India	1983	4	2.0	15	7.4	184	90.6
Bankura, West Bengal, India	1983	15	7.7	100	51.5	79	40.7
Hazaribagh, Bihar, India	1983	53	26.0	69	33.8	82	40.2
West Asia & North Africa							
Worretta, Bagemdir, Ethiopia	1983	2	1.3	1	0.7	148	98.0
Wad-Medani, Sudan	1980	3	3.2	80	85.7	11	11.7
Sub-Sahara Africa							
Bouake, Ivory Coast	1977	14	9.6	34	23.3	98	67.1
Ikenne, Oyo, Nigeria	1983	5	4.2	72	61.0	41	34.7
Santchou, Cameroon	1983	16	8.0	87	43.5	97	48.5
Latin America							
Goiania, Goias, Brazil	1982	0	0.0	8	5.0	151	95.0
Villavicencio, Colombia	1983	54	26.5	107	52.5	43	21.1
Edzna, Campeche, Mexico	1982	26	15.2	50	29.2	95	55.6
H. Cardenas, Tabasco, Mexico	1977	121	79.1	27	17.6	5	3.3
Medias Aguas, V. Cruz, Mexico	1982	35	19.6	44	24.6	100	55.9
Paramaribo, Surinam	1977	13	8.6	35	23.0	104	68.4
Cañas, Costa Rica	1982	39	21.4	20	11.0	123	67.6

Yield nurseries

Most test sites were in Asia, with a relatively large number in India and Philippines. The highest yielding entries in IURYN, on the basis of averages over locations, are listed by year (1975-83) in Table 6. Entries that showed higher consistency of performance over different locations and years include IR43, IET1444, IR36, IR5931-110-1, and UPL Ri-5. Except for UPL Ri-5, which is of intermediate height, the remaining four are semidwarfs. IET1444 and IR36 are early maturing.

The yield performance of different entries in specific trials was as follows.

Table 5. Average scores for phenotypic acceptability among entries of the IURON classified into 4 maturity/height groups. Early maturity is less than 115 d. Short stature is less than 100 cm.

Site	Year	Av score of entries with			
		Medium maturity		Early maturity	
		Intermediate/ tall	Short	Intermediate/ tall	Short
Ranchi, India	1980	6	5	2	3
	1981	5	5	4	4
	1982	7	7	5	5
Joydebpur, Bangladesh	1980	6	7	8	8
	1981	7	6	8	7
	1982	6	7	6	7
Yezin, Burma	1980	3	4	4	4
	1981	3	4	5	5
	1982	4	6	4	6
Bogor, Indonesia	1980	5	6	5	5
	1981	4	5	5	6
	1982	4	5	4	4

The upland conditions at Goiania, Brazil are less favorable, being located in the "cerrado" region characterized by deep soils with high permeability, low organic matter content, low fertility (particularly P), and toxic levels of Al. Dry spells known as *veranico* for 2 to 4 wk usually occur in the region. Soil pH at the Goiania test site was around 5.0. The 1975 IURYN had a mean yield of 0.8 t/ha with the local check IAC1246 producing 1.8 t/ha. There was a severe incidence of blast and *Helminthosporium.* The only entry that produced statistically significant higher yield than the check was IET1444, an entry of similar maturity. In the 1976 trial (777 mm rainfall, 70 rainy days), all entries including the local check produced low yields (0.2-0.7 t/ha). In the 1977 trial (1088 mm rainfall, 67 rainy days), the mean yield was 1.8 t/ha, with 16 of the 25 entries producing yields less than 2.0 t/ha (6 of which yielded less than 0.8 t/ha). The local check IAC1246 yielded 4.0 t/ha and only IRAT13 and IET1444 produced higher yields than the check. IRAT13, however, was later maturing than the check by 11 d, whereas IET1444 had similar growth duration.

Minimum temperatures during the crop season at Heho, Burma, are relatively low. During the 1978 testing season, the mean monthly minimum temperatures ranged from 16 to 19 °C and the maximum from 27 to 30 °C. The mean yield of that trial was 0.8 t/ha and the local check Khao Pa Pyu produced the highest yield, 1.8 t/ha, with none of the test entries being statistically on par with it. Under those conditions, the local check had a height of 105 cm, whereas the remaining entries varied in height from 38 to 73 cm.

Another location where minimum temperatures during the crop season are relatively low is Santchou in Cameroon, which is at an elevation of 712 m.

Table 6. Highest yielding entries in the International Upland Rice Yield Nursery trials during 1975-83.

Year	Trials (no.)		Highest yielding entries			
	Total	By country	Designation	Yield (t/ha)	Days to flower	Plant ht (cm)
1975	16	7 Philippines, 5 India, 1 Sierra Leone, 1 Liberia, 2 Brazil	IR43	2.9	96	
			IR9575 sel .	2.8	91	
			IR45	2.7	98	
			MRC172-9	2.6	95	
			IR1529-680-3-2	2.6	100	
1976	17	9 Philippines, 6 India, 1 Bangladesh, 1 Mexico	IET1444	3.3	77	
			IR36	3.1	83	
			IR43	3.1	93	
			IR2061-522-6-9	3.1	82	
			B541b-Kn-19-3-4	3.0	89	
1977	20	1 Burma, 2 Indonesia, 4 Philippines, 2 Bangladesh 4 India, 1 Pakistan (irrig.) 1 Ivory Coast, 1 Brazil, 2 Panama, 1 C. Rica	IET1444	3.0	85	
			IR36	3.0	89	
			C22	3.0	99	
			C46-15/IR24[2]	3.0	99	
			IR43	2.9	104	
			IR3839-1	2.9	93	
1978	14	6 Philippines, 1 Thailand, 2 Nepal, 1 Cameroon, 1 Colombia, 3 Mexico	IR43	3.8	102	
			IR9669 sel .	3.7	108	
			IET1444	3.6	86	
			IR36	3.6	94	
1979	10	1 Indonesia, 5 Philippines, 3 India, 1 Cameroon	UPL Ri-5	2.8	101	
			IR9669 sel.	2.8	106	
			BG35-2	2.7	91	
			IR2061-522-6-9	2.7	88	
			IR45	2.7	103	
1980	14	1 China, 2 Indonesia, 5 Philippines, 1 Thailand, 1 Vietnam, 1 Bangladesh, 1 India, 2 Nigeria	IR5931-110-1	3.9	91	97
			BG35-2	3.6	89	87
			B733c-167-3-2	3.5	94	101
			CR156-5021-207	3.5	94	81
			IR52	3.5	97	89
1981	10	1 Philippines, 1 Thailand, 1 Vietnam, 1 Bangladesh, 3 India, 1 Nepal, 1 Pakistan, 1 Nigeria	IR5931-110-1	2.5	96	87
			IR6115-1-1-1	2.4	93	70
			UPL Ri-5	2.4	100	98
			IR43	2.4	100	76
			BPI Ri-6	2.3	101	92
1983[a]	12	1 Malaysia, 5 Philippines, 5 India, 1 Colombia	UPL Ri-7	3.0	84	98
			BR319-1	2.9	87	98
			IR5931-110-1	2.9	90	92
			UPL Ri-5	2.9	94	102

[a]Yield trials not conducted in 1982.

The soil pH at the test site was 5.0. In the 1978 trial, which produced a mean yield of 3.8 t/ha, three entries from Indonesia, B541b-Kn-19-3-4, B9c-Md-3-3, and KN361-1-8-6, gave the highest yields. In the 1979 trial at that location a severe blast incidence caused low yields (mean, 1.2 t/ha). IR2061-522-6-9, IR45, and UPL Ri-5 had a moderate incidence of blast and yielded the highest (3.2, 2.6, and 2.3 t/ha, respectively).

Highest yielding entries under drought stress in the 1976 yield trial at Hathwara, India, were B9c-Md-3-3, KN361-1-8-6, SE322G-19, and IET1444, although their yields were not statistically superior to the yield of the local check. There was a significant negative correlation between days to flowering and grain yield.

In the 1979 IURYN at Vinh, Vietnam, severe drought occurred from booting to dough stages. The mean yield was 0.5 t/ha. Of the 25 entries, 22 yielded less than 0.8 t/ha. C22, UPL Ri-5, and IR3880-13-7 yielded more than 1.0 t/ha. Yield performance did not show any relation to flowering duration.

In the 1981 trial at Chiang Mai, Thailand, drought occurred during the booting and heading stages. For the crop season, a total of 618 mm of rainfall was received from 56 rainy days. Only three entries, UPL Ri-5, IR5931-110-1, and UPL Ri-3, produced significantly higher yields than the local check Jao' Haw.

The top three yielders in the 1981 IURYN at Faizabad were Seratus Malam, N22 (local check), and IR43, in that order. Significantly, N22 was 3 wk earlier than IR43 and 5 d earlier than Seratus Malam. In an earlier trial in 1976 at this location, IET1444 was the only entry superior to N22, but it matured 9 d later.

None of the entries were superior to the local check CH45 at Parwanipur (Nepal) in the 1981 IURYN trial. CH45 was also distinctly earlier than most entries.

Continuous drought during the vegetative stage in the 1983 IURYN trial at Ilagan, Philippines, resulted in a mean yield of 1.1 t/ha. During the crop season a total of 784 mm rainfall was received from 79 rainy days. IR43, UPL Ri-5, and IR3179-25-3-4 were the top yielders (2.7, 1.8, and 1.7 t/ha, respectively). The local check Kinandang Patong, one of the earliest to mature, was the lowest yielder (0.2 t/ha). The top yielders, which are of medium growth duration, obviously recovered from the moisture stress during vegetative stage and used the improved moisture status at flowering stage.

UPL Ri-7, IR52, and IR9782-111-2-1-2 yielded the highest in the 1983 IURYN trial at Rewa, India, which experienced a prolonged moisture stress during the flowering stage.

Plant height and grain yield were significantly positively correlated in the 1983 IURYN trial at Bankura, India. Three UPL lines of intermediate plant stature, UPL Ri-3, UPL Ri-5, and UPL Ri-7, yielded the highest.

Flowering duration and grain yield were significantly negatively correlated in the late-planted 1983 IURYN trial at Jeypore, India, situated at an elevation of 607 m. CR156-5021-207, IR6115-1-1-1, and the local check (Umuria Chudi) were the top yielders and were relatively early to flower.

Acid upland soils screening

An observational nursery was started in 1982 to identify rices adapted to the severely acid soils in numerous upland rice growing areas. Characters

particularly significant in adaptation to this environment are tolerance for Al toxicity and P deficiency.

1982 screening set. At Villavicencio, Colombia, with a soil pH of 3.8, Azucena and ITA 116 were given the best phenotypic rating of 5.0 under a treatment with no added P_2O_5. At Goiania, Brazil, with a soil pH of 4.8, the entries rated good under a treatment with no added P_2O_5 included Azucena, BG35-2, BPI Ri-6, IR3646-8-1-2, IR5931-110-1, IR6023-10-1-1, ITA 116, Salumpikit, and Sein Ta Lay. The entries rated good for tolerance for Al toxicity at both Huimanguillo, Mexico (soil pH 4.6), and Malinao, Philippines (soil pH 3.8), included Azucena, B733c-167-3-2, IR26, and Seratus Malam.

1983 screening set. At Sitiung, Indonesia, where the soil pH was 3.9, the entries phenotypically rated good included Azucena, IR3839-1, Cica 8, IR5931-110-1, IR9814-11-3, IRAT104, ITA116, ITA142, and ITA235.

Drought tolerance and recovery

Entries in the IURON are scored at certain test sites for drought tolerance and ability to recover from drought. On the basis of average scores over different tests, the following entries were rated good by year for tolerance and recovery:

1976 IURON:	ARC7046, ARC7060, ARC7102, ARC10372, Dular, Aus 61, DV110
1977 IURON:	DM59, DV110, BR51-46-5, P901-22-11-2, Dular, FH109, IR2035-349-2, Salumpikit, DJ29, IRAT13, PN679, PN680
1978 IURON:	IRAT104, IRAT108, IRAT109, IRAT110
1979 IURON:	Salumpikit, IAC25, ARC1175, IR8103-34-1
1981 IURON:	IR13240-10-1, IR3794-9-2-3, ITA235, ITA164, ITA173, ITA175, ITA183, ITA186
1982 IURON:	IR10025-16-2, IRAT101, M55
1983 IURON:	B3016c-Tb-263-3-5,B3619c-Tb-8-1-4

Reactions to blast disease

Blast *(Pyricularia oryzae)* is an important fungal disease that threatens rice production under upland conditions. Entries in the upland nurseries are therefore scored for degree of resistance to blast at sites where the level of incidence is such that the varietal differences in resistance are discernible. The following entries were rated good for leaf blast tolerance at most locations in different years:

1977 IURON:	DM59, IR38
1979 IURON:	IR3262-3-338-5, IR3273-339-2-5, IR5929-12-3, C424-2, C894-21, IRAT105, IR3271-760-1482, IR5533-15-1-1, IR7790-19-2-3, IR8072-31-2, IR9101-124-1, IR9828-36-3, IR9828-74-3, KMP12, Pattambi 1727, Pattambi 1751, C168-134, MRC172-

		9, Salumpikit, Sein Ta Lay, TOX504-14-11-1, TOX504-14-6-1, TOX503-7-16-1, TOX340-1-5-1, TOX503-7-21, TOX340-B-11, TOX378-1-6-1, TOX502-8-12-1, TOX503-7-4-2, OS6, TOX95-5-1-1-1, TOX356-1-1-1, TOX494-1-1-1, TOX494-5-1-2
1980	IURON:	IR9782-111-2-1-2, IR13240-10-1, UPL Ri-5, C894-21, Sein Ta Lay, Intan, IR6023-20-1-1, IR10781-4-3, Kaika
1981	IURON:	IR10025-16-2, IR12979-24-1, IR5853-198-1-2, IR3260-PP91-100, IR5931-110-1, ITA118, ITAl42, ITA164, ITAl75
1982	IURON:	ITA235, IRAT112, IRAT146
1983	IURON:	B2997c-Tb-4-2-1, B2997c-Tb-60-3-3, C1008-1, E425, IAC1246, IRAT106, IR10068-11-1, ITA141, ITA173, ITA183, IR6115-1-1-1

Entries rated good against neck blast were the following:

1980	IURON:	IR9669 sel., IR3265-193-6-3, Intan, IR4427-207-2-2-2, IR5931-81-1-1
1981	IURON:	IAC1246, IR10025-16-2, IR10004-3-1, IR10110-23-1, IR12979-24-1, IR3262-3-9-4-5, ITAl16, ITA142, ITAl73
1982	IURON:	IRAT104, M18, M55, ITAl18
1983	IURON:	IR2053-436-1-2, IR8997-4-4-2, ITA184, INIAP415, IRAT119, IRATl25, ITA142, BW170, IRAT132, ITA130, KN96, Mikotchu, Minti, M18, IRAT133, IRAT147

Many IURYN entries have been tested in the International Rice Blast Nursery (IRBN). Thirteen of the 47 IURYN entries tested in the IRBN showed a high or moderate level of blast resistance (Table 7). These included two lines from West Africa (IRAT13 and IRAT104), one from Bangladesh (BR319), and several from IRRI.

INCREASING UPLAND RICE YIELD POTENTIAL

Numerous physical and biological stresses strongly limit upland rice yields on aerobic soils. Recognition of the many serious constraints to higher upland rice productivity has led to the question: is progress possible in increasing upland rice yields?

This question may be evaluated in two parts:

1. Is significant progress being made to evaluate upland rice yield potential at the research level?
2. If so, is the genetic potential for higher yields being transferred to production at the farm level?

Table 7. Reactions to leaf blast of the IURYN entries tested in the International Rice Blast Nursery.

Designation	Year tested in IRBN	Score (% of sites)		
		0-2	3-4	5-9
IRAT13	1978	82	13	5
	1981	64	28	8
	1983	79	15	6
IR1544-238-2-3	1977	70	28	2
	1978	74	20	6
	1979	60	31	9
	1980	64	24	12
	1981	57	32	11
IR45	1978	73	23	5
	1979	56	34	9
	1980	55	30	15
IR52	1978	75	19	6
	1979	59	31	9
	1980	52	24	24
	1983[a]	67	22	11
IR5929-12-3	1979	50	34	16
IR5931-110-1	1979	58	30	12
IR7760-4-8-2	1978	66	31	3
	1979	47	41	13
IR7790-18-1-2	1979	61	30	9
IR9560-2-6-3-1	1978	54	36	10
MRC172-9	1978	58	35	8
BR319	1983[a]	66	29	6
IRAT104	1983	80	14	6
		70	19	11
UPL Ri-7	1983	44	47	8

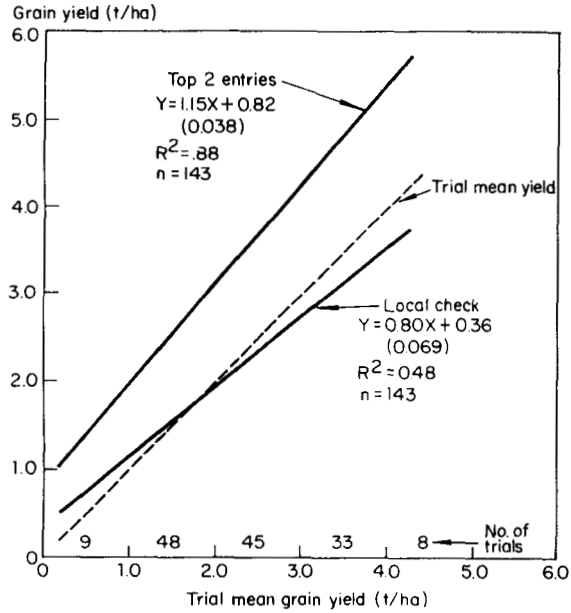
[a]In 1983 the score groups were changed to 0-3, 4-6, 7-9.

Results from the past decade of international upland rice testing tend to provide insight to the first issue, that of raising yield potential. A data set was constructed for 143 trials of the IURYN during the 1975-83 period. Included were the data from all trials reported, except six trials, which were irrigated.

Trial mean yields varied from 0.2 to 4.3 t/ha over the 143 trials. Mean yields were most commonly between 1.0 and 3.0 t/ha. Less than 12% of the trial mean yields were lower than 1.0 t/ha or higher than 4.0 t/ha.

The mean yield of the two highest yielding entries in each trial, and the yield of the local check variety, were regressed on the mean yield of the trial (Fig. 1). The linear model accounted for about 70% of the variation in both regressions.

The mean yield of the top two entries was taken as an expression of the yield potential because of genetic improvement. The local check varieties included by the cooperating scientists were either a popular variety now in production or an improved variety or breeding line from that national program.



1. Regression of the two highest yielding entries and the yield of the local check variety on the mean yields of the International Upland Rice Yield Nursery, 1975-83. Values in parentheses are the standard errors of the slopes.

Predicted yields for the top two entries exceeded the predicted local check yields over the entire range of yield levels. The gap between the best entries and the local check increased from the low-productivity trial environments to the relatively favorable-trial environments. When trial mean yields were less than 1.0 t/ha, the best entries yielded 0.5-0.8 t/ha higher than the local check. When mean yields exceeded 3.0 t/ha, the best entries yielded 1.5–1.8 t/ha higher than the local check. The differences in yields between the two entries and the local check were statistically significant in 102 of the 143 trials, or 71% of the trials. Percentage-wise, the yield gap of the best entries was about 100% in the low-yield situations and about 50% in the most favorable conditions.

These results must be interpreted with caution. They indicate nothing about the yield stability of the high-yielding cultivars over time, considering prevalent diseases, insects, and physicochemical stresses. But they do suggest the existence of improved germplasm that may elevate the yield potential of the cultivars used locally in many programs. Whether or not this yield gap would remain substantial under actual farm conditions is an issue about which little is known.

FUTURE DIRECTIONS

Research on upland rice improvement has been significantly strengthened in the past few years. The definitive characteristics of the major distinct upland rice environments are now better understood. Mechanisms are needed that make the exchange and evaluation of elite germplasm as efficient as possible with respect to the major target ecosystems.

The international upland rice nurseries have been evolving in response to these needs. In 1983 the materials in the International Upland Rice Observational Nursery (IURON) were grouped into four classes of maturity and height. In 1985 the maturity groups have been developed in a modular form. Scientists from environments with a growing season length constraint, who are interested in only the early-maturing entries, will now be receiving only that particular module. Scientists interested in evaluating all entries in both modules may continue to receive the complete nursery set.

Beginning in 1984 the International Upland Rice Yield Nursery (IURYN) was separated into two yield nurseries. Previously, the IURYN was composed predominantly of medium-maturing entries (120-140 d). However, about half of the world upland rice area, particularly in parts of South Asia and Africa, experiences a short growing season, requiring cultivars that mature in 90-110 d. The IURYN-E was created to exchange and evaluate elite materials for these situations.

A large proportion of upland rice grown on all three tropical continents is constrained by highly acidic soils with low available P and high exchangeable Al levels. The Acid Upland Soils Screening Set was specifically developed to facilitate the selection and exchange of materials that are adapted to these conditions. The set is now replicated and managed under two P levels to better distinguish the relative response to P on these soils.

A more determined international effort to develop improved blast resistance in our upland rices will be crucial to our effort to increase and stabilize yields in the next decade. We are now considering a proposal to split the International Rice Blast Nursery (IRBN) into two nurseries. One set contains materials adapted specifically for upland. The other set would be for lowland conditions, for which a major portion of the materials are for the cooler temperature irrigated situations.

Creating a blast set specifically for upland rice may direct increased international attention to evaluation of upland materials for resistance to the disease. Our past experience indicates that relatively few upland rices have been included in the IRBN. To substantially increase the proportion of upland rices would necessitate making the nursery even larger than the present 450 entries.

Mass screening at specific sites for the major stresses encountered in upland culture will help provide more relevant material to the nurseries for evaluation under different upland environments.

ACKNOWLEDGMENTS

Excellent contributions made by all the rice scientists who participated in the international upland nurseries during 1975 to 1983 are gratefully acknowledged. Names of those scientists are listed in the IURYN and IURON reports published annually by the IRTP.

UPLAND RICE IMPROVEMENT IN HUMID AND SUBHUMID TROPICS OF WEST AFRICA

M. S. ALAM, K. ALLURI, T. M. MASAJO, KAUNG ZAN, and V. T. JOHN

The area (3.4%) and production (1.9%) of rice in Africa are small compared with world figures. Fifty percent of the total African rice area is in West Africa, which produces 35% of the continent's supply. In some countries such as Sierra Leone and Liberia, the annual per capita consumption of rice is 100 kg; in others it ranges from 15 to 22 kg. Populous countries such as Nigeria import large amounts of rice to bridge the gap between supply and demand. Rice is a strategically important crop in the food security system in West African Countries.

IMPORTANCE OF UPLAND RICE

In Sub-Sahara Africa, upland rice is the most predominant growing system. An estimated 2 million ha (50%) of the total rice area in Africa is grown as upland rice (18). Upland rice is defined in this paper as "rice grown in rainfed, naturally well-drained soils, without surface water accumulation, normally without phreatic water supply, and normally not bunded" (14).

The West Africa Rice Development Association (1 9) classifies upland rice cultivation into four groups: hill rice, flatland rice, upland rice cultivated with use of ground water in addition to rain, and upland rice grown with use of ground water only. Among these groups, flatland rice is the predominant growing ecology and, along with hill rice, is situated in the moist forest zone and the humid fringes of the savanna. In both ecologies, rice is cultivated under slash-and-burn bush-fallow system and is often intercropped. Fields are not bunded and direct seeding is practiced.

MAJOR CONSTRAINTS

Upland rice generally yields about 1 t/ha, depending on rainfall and management. Major constraints are soil and climate, varieties, diseases and insects, cultural practices, and socioeconomic conditions. This paper deals with the first three.

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Soil

Upland rice soils in humid and subhumid tropics of Africa are fragile, erosion prone, and low in water-holding capacity, organic matter content, CEC, and nutrient status (especially N). In high-rainfall regions, acidity is high and nutrient imbalances are frequently severe.

Climate

The quantity, distribution pattern, and reliability of rain are important determinants of success of upland rice cultivation. In the humid zone where rainfall is high, yields are limited by fungal diseases. Disease severity is increased by low light intensity caused by overcast skies.

Varieties

The tall and low-yielding traditional upland rice varieties are generally panicle-weight type. They lodge when planted under high density and good management with adequate soil moisture. However, most African upland rice possess high levels of tolerance for drought, blast, and grain discoloration.

Modern, semidwarf varieties perform unpredictably in upland conditions. Research at the International Institute of Tropical Agriculture (IITA) shows that performance of semidwarf varieties in upland conditions is variety specific and not a general plant characteristic (3, 10). Some semidwarf varieties under favorable soil and moisture conditions and in the absence of severe disease pressures have outperformed the traditional varieties (10).

Diseases

Major diseases of upland rice are blast, leaf scald, grain discoloration, and sheath blight. Drought aggravates but is not a prerequisite for blast (6). Most improved introductions such as IR43, IR5931-110-1, and UPL Ri-5 with proven resistance to blast in Asia, have shown susceptibility under upland conditions in West Africa. Leaf scald caused by *Rhyncosporium oryzae* is widespread, particularly in humid areas, and it usually occurs late, around flowering stage. Sheath blight caused by *Thanatephorus cucumeris,* Frank Donk (*Rhizoctonia solani*) is particularly severe under high rainfall, close planting, and high fertilization. Varieties with good levels of resistance to this disease have yet to be identified.

The most common panicle disease in upland rice is grain discoloration or dirty panicle. It is often caused by a group of fungal pathogens, among which *Sarocladium oryzae* (*Acrocylindrium oryzae*) is the most dominant species (16). Soil acidity, highly leached conditions and low CEC, and deficiency of Ca, Mg, Zn, and Si have been reported to be implicated in the severity of this syndrome (5).

Insect pests

More than 80 species of insects attack rice in West Africa but only about 13

are considered pests of major importance. Breniere (7) estimated that about 25% of rice yield losses are caused by insects in general. Stem borers, particularly the pink borers (*Sesamia calamistis* and *S. botanephaga*), are the most important pests of upland rice in the humid tropics of West Africa. The African specific white borer *Maliarpha separatella* is the most predominant species, but because it does not cause deadhearts or white heads it causes considerably less damage than the pink borer. Next in importance to the pink borers are the grain-sucking bugs *Aspavia armigera* Fab. and *Stenocoris southwoodi*.

BREEDING OBJECTIVES AND STRATEGIES

Upland rice improvement for the humid and subhumid zones of Africa aims to develop improved varieties with high yield potential, good seedling and vegetative vigor, intermediate plant stature, medium tillering ability, maturity ranges of 95-140 d, acceptable grain quality, and sufficient levels of tolerance for or resistance to various stresses.

The breeding approaches involve systematic evaluation of available germplasm, introductions, generation of breeding materials and selection, and an organized scheme of testing early as well as advanced breeding materials to identify superior genotypes. Multilocational testing is a combined effort between national programs, International Institute of Tropical Agriculture (IITA), Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT), International Rice Research Institute (IRRI), and West Africa Rice Development Association (WARDA). The major problem in Africa with high yield-potential introductions is their susceptibility to drought, blast, and grain discoloration.

The strategy for upland rice improvement has been to combine specific adaptational attributes of local upland varieties with the yield potential of unadapted introductions through appropriate hybridization programs (crossing and intercrossing).

Drought resistance

Using a toposequence transect with life-saving sprinkler irrigation and standard varieties at fixed intervals to study the drought line, several entries were evaluated for drought resistance. Another field screening approach used controlled sprinkler irrigation during the dry season to select superior genotypes for drought tolerance and recovery. These approaches have identified several superior lines (10, 11).

Deep-growing and thick roots are associated with drought resistance in rice (4, 17). Root length is positively correlated with root thickness (8). Selection for deep root systems at IITA is done by evaluating lines for root thickness.

Among African varieties, LAC 23 has thick and deep roots and as such has been a standard check variety for root system screening. LAC 23 was used as the check for evaluating 500 upland rice accessions from IITA's Genetic

Resources Unit (GRU) Tropical *Oryza sativa* (TOs) collections from the humid regions of West Africa. Sixteen were distinctly superior to LAC 23 in thick and deep root system (Table 1). Interestingly, 15 of these originated from Liberia, from where the check LAC 23 was selected.

Multilocation testing

Entries in the advanced yield trial tested at four different sites in Nigeria representing different ecological zones are shown in Table 2. The two high yielding varieties ITA 305 and ITA 307 were derived from the cross TOx 936 (IR43/Iguape Cateto). IR43 is an upland selection from IRRI while Iguape Cateto is a drought-resistant upland variety with desirable root and panicle characters.

ITA 305, selected specifically for high drought resistance, has shown stability at higher yield level than OS6 (Fig. 1).

Eight elite lines were tested at two locations in Nigeria, in Onne, situated in humid forest ecology, and in Ilorin, representing a transitional zone near savanna (Table 3). In 1983, the conditions in Ilorin were favorable, while at Onne, the disease pressure was high.

Screening for acid upland

Upland soils in some high rainfall areas such as eastern Nigeria have high Al, high acidity, and low P. Under severe nutritional imbalance in such areas, several IITA lines have shown high tolerance. Results of this test are reported elsewhere in this volume (2).

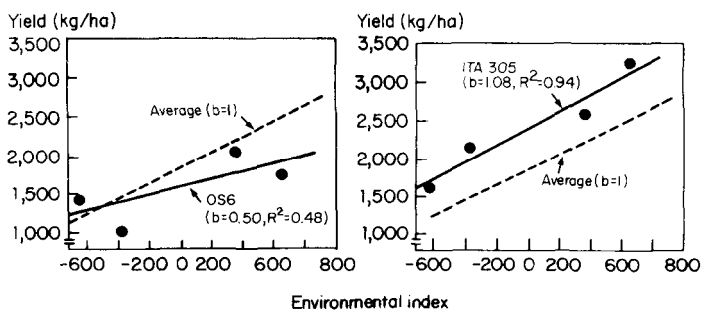
Table 1. Performance of selected lines with deeper and thicker root system, IITA, 1983.

		Visual score (0-9)					
Entry[a]	Score	Vigor	Leaf blast	Neck blast	Grain discoloration	Sheath blight	Panicle exsertion
TOs 5227	Liberia	1	0	1	3	2	3
TOs 5234	Liberia	1	0	1	3	1	3
TOs 5243	Liberia	1	0	2	3	3	1
TOs 5731	Liberia	1	0	1	3	4	3
TOs 5793	Liberia	1	0	1	3	4	3
TOs 5797	Liberia	1	0	1	3	4	3
TOs 5801	Liberia	1	0	2	3	3	5
TOs 5844	Liberia	1	0	1	3	3	1
TOs 5852	Liberia	1	1	1	3	6	3
TOs 5855	Liberia	3	0	2	5	3	3
TOs 5866	Liberia	3	0	1	1	4	5
TOs 5880	Liberia	1	0	1	1	4	1
TOs 9418	Liberia	1	1	1	3	5	7
TOs 9579	Liberia	1	0	3	–	3	–
TOs 9591	Liberia	1	0	3	–	3	–
TOs 5268	Ivory Coast	1	0	1	5	3	1
LAC 23 (check)	Liberia	1	0	1	3	3	1

[a] These entries scored 2 for deep and thick root system compared to score of 3 for LAC 23. Based on *Standard evaluation system for rice* (13).

Table 2. Promising entries in the Advanced Yield Trial at 4 locations in Nigeria, 1983.

Entry	Plant ht (cm)	Days to maturity	Yield (kg/ha)				
			Onne	Ikenne	Ibadan	Ilorin	Mean
ITA 305	92	125	2470	2180	3230	1650	2407
ITA 307	87	125	2700	1610	3320	1500	2282
ITA 128	131	125	2370	1550	3180	1620	2180
IRAT 170	116	120	2370	1880	2040	1280	1892
DJ 12-539-2	83	120	1904	1280	2718	2069	1992
OS 6 (check)	144	125	2069	1081	1749	1485	1596
Mean			2330	1363	2706	1408	2094
LSD (5%)			440	684	826	782	
C. V. %			12	27	21	38	



1. Regression of yield on environmental index for two upland rice varieties, IITA, 1983.

Resistance to blast

The African rice breeding program focuses on developing superior upland varieties with high levels of blast resistance. The following upland varieties show durable resistance to blast and are being extensively used as donors (15).

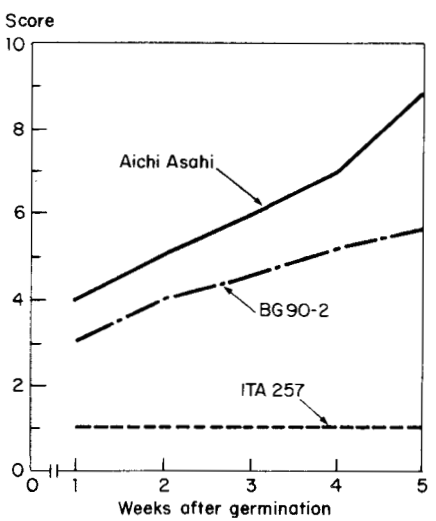
IRAT 13	OS 6
IRAT 79	Moroberekan
IRAT 109	LAC 23
IRAT 133	ITA 257
IAC 25	ITA 116
Dourado Precose	Iguape Cateto
63-83	

One or more of the named varieties, were used in developing a large number of improved lines with high levels of blast resistance.

Among the good yielding varieties, DJ 4-135, D J 11-307-3-1-5, DJ 11-541-1, and ITA 117 were highly resistant to leaf blast. Other resistant varieties were DJ 11-509, IRAT 147, IRAT 168, IRAT 169, ITA 135, ITA 138, ITA 174, and ITA 225.

Table 3. Elite upland lines for humid and subhumid tropics. International Institute of Tropical Agriculture, 1983.

Entry	Plant ht (cm)	Days to maturity	Yield (kg/ha)		
			Onne	Ilorin	Mean
ITA 117	110	120	2478	2340	2409
ITA 235	120	121	2500	1840	21 70
ITA 118	109	129	2420	1560	1990
ITA 135	120	125	2330	1620	1975
ITA 150	109	110	1980	1940	1960
IR 5931-110-1	102	125	1670	2240	1955
ITA 257	90	108	2140	1750	1945
IRAT 112	98	110	2010	1840	1925
OS 6 (check)	137	125	2030	1232	1631
Mean			2173	1818	
LSD (5%)			350	800	
C. V. %			11	32	



2. Blast disease progress in some selected varieties, IITA, 1984.

IRAT 104, IRAT 132, TOx 718-1-23, ITA 141, ITA 158, TOx 494-SLR, TOx 502-13-SLR, ITA 116, TOx 906-67-3-1, TOx 936-267-1-1, and TOx 936-354-2-1 were highly resistant to neck blast. For instance, ITA 257 had high tolerance for blast under severe stress (Fig. 2).

Grain discoloration

Many traditional varieties, while being good sources of blast resistance, also possess high tolerance for grain discoloration. The following lines, which have shown good tolerance for grain discoloration under high rainfall conditions at Onne, were derived from crosses involving such traditional varieties:

Table 4. Physicochemical aspects of elite upland lines. (9).

Entry	Length[a] (1-7)	Shape[a] (1-9)	Chalkiness[a] (0-9)	Gel temp[a]	Amylose (%)	Gel consistency (mm)
ITA 117	3	5	1	L	25.9	86
ITA 141	1	1	1	HI/L	20.1	73
ITA 150	3	5	1	I/L	23.7	43
ITA 257	1	5	1	HI/L	20.0	84
IRAT 112	1	5	5	L	24.0	53
IR 5931-110-1	5	5	5	L	28.5	24
OS 6	3	5	5	L	21.5	56

[a]Ratings are based on *Standard evaluation system for rice* (13). L= Low, I = Intermediate, and H = High.

Fixed lines	Selections from TOx crosses
ITA 117	TOx 936
ITA 118	TOx 955
ITA 135	TOx 1753
ITA 141	TOx 1757
ITA 182	TOx 1768
ITA 235	TOx 1857
ITA 257	
IRAT 104	
IRAT 170	

Resistance to insect pests

The strategy for insect control at IITA has been mainly through resistance breeding. Resistance breeding success depends on suitable and reliable screening techniques. At IITA, techniques for varietal screening have been developed (12). A total of 1,296 lines for pink borer and 2,000 lines for white borer have been evaluated. As a result, six entries (W1263, Taichung 16, SML 81 B, Sikasso, DNJ146, and DNJ171) for pink borer and five entries (TKM 6, ITA 6-4-2, ITA 7-7-2, IR 1168-76, and IR 1561-38-6-5) for white borer have been identified as sources of resistance (1).

Superior grain quality

One objective of IITA's upland rice improvement program has been to develop rice varieties with superior grain characteristics. This objective has been realized in several elite upland lines (Table 4).

PROMISING SELECTIONS IN AFRICA

In tests with materials originating from diverse sources, several improved lines have been found to be promising for African uplands (Table 5).

Table 5. Characteristics of some improved upland rice lines for Africa.

Cultivar	Ht (cm)	Maturity (d)	Early vigor score	Reaction to					Acid soils[a]	Grain quality	
				Leaf blast[a]	Neck blast[a]	Grain discoloration[a]	Sheath blight[a]	Drought		Chalkiness[a]	Amylose (%)
IRAT 104	115	125	4	2	1	1	3	5	4	9	–
IRAT 109	100	110	5	3	2	2	–	3	3	3	–
IRAT 112	100	110	4	3	2	1	–	3	5	3	24.0
IRAT 144	100	105	3	0	1	1	1	2	3	5	
IRAT 170	110	130	2	2	2	1	2	4	4	1	
ITA 116	130	120	2	0	2	2	–	3	2	1	
ITA 117	100	115	4	2	1	3	4	4	3	2	25.9
ITA 135	125	120	3	2	2	2	1	3	4	1	15.2
ITA 141	125	125	2	2	1	2	2	4	3	1	20.1
ITA 150	115	105	3	1	2	1	1	2	5	1	23.7
ITA 235	120	120	2	4	2	3	3	2	4	1	14.0
ITA 257	95	100	3	1	1	1	1	2	5	1	20.0
ITA 305	90	120	3	3	1	3	3		2	–	
DJ 12-539-2	85	115	5	3	2	3	1	4	6	9	–
IR 5931-110-1	105	125	5	4	3	3	1	3	6	5	28.5
UPLR-i-5	110	135	3	4	2	1		–	3	5	21.5
FARO 11 (OS 6)	140	120	2	3	1	1	3	3	4	5	

[a] Based on *Standard evaluation system for rice* (13).

FUTURE EMPHASIS

Hybridization programs should be expanded to generate more and diverse materials for the different upland rice-growing environments of Africa. Such an expanded breeding program will have for its base improved and adapted germplasm developed and selected from within Africa and will use introduced varieties as possible donors of plant type, earliness, yield potential, and better grain quality.

Mass-screening methods for drought resistance to allow for systematic evaluation of all breeding lines are needed to ensure that only those with acceptable tolerance levels are kept. Selection for genotypes with a deep and thick root system in the early segregating generations should be continued.

To hasten identification of breeding lines with durable resistance, screening for blast must be done at key sites within the major rice-growing regions. Such a multilocational testing scheme would also yield information on differences in virulence of the blast pathogen in the key production areas. Studies of grain discoloration, sheath blight, and leaf scald diseases should be conducted and be the basis of practical screening methodologies to support the breeding program. Efforts to obtain quantitative figures on crop losses due to stem borers and grain-sucking bugs must be emphasized. Studies on how to develop suitable screening techniques for grain-sucking bugs (*Aspavia armigera* and *Stenocoris sourhwoodi*) must be started and stem borer screening given more emphasis.

Collaboration among national, regional, and international programs to promote better interaction among rice scientists and assist in the exchange of rice germplasm and information is essential to more rapid growth of rice varietal improvement work in Africa.

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SCREENING UPLAND RICE FOR DROUGHT TOLERANCE

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Drought is an important constraint of productivity and production in major rice-growing areas. Assured irrigation is a solution to the problem. However, despite all governmental and voluntary organizational efforts, 65-75 million ha of rice area remain rainfed. In numerous traditional rainfed upland rice areas several indigenous rice varieties that possess drought resistance but have low yield are cultivated.

For rapid improvement for drought conditions two approaches are suggested: separate breeding programs, or breeding lines from the irrigated sector. Despite differences of opinion on screening approaches (empirical and analytical) for identifying drought-resistant parents, efforts should be made to use easily identifiable plant type traits contributing to yield and also drought resistance.

The line source sprinkler technique should be used for screening during dry season to assess various traits at varying water regimes at a single location.

While genetic variability for drought resistance at the reproductive stage is meager, concerted efforts are needed to screen germplasm for reproductive-stage drought resistance as it is directly related to productivity under drought. Systematic screening for different drought traits is desirable as no single resistance-contributing trait directly influences yield and final drought resistance capacity. Therefore, accumulation of more than one drought trait in a suitable plant-type background is desirable.

Agriculturists have always struggled to overcome problems of water deficit. An improved agriculture started ensuring a water supply through artificial means (irrigation). The world's total 141-million-ha rice area includes 65-75 million ha rainfed (44) and a 19-million-ha upland area (26) that depends

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exclusively on natural precipitation for its water needs. Dry periods occur often enough during rainy seasons to make drought resistance in rice an important attribute to stabilize grain yields in farmers' fields (Table 1).

The biggest problem in drought research has been the proper characterization of drought. At the simplest level, drought is shortage of water in the system concerned and is a product of the soil-plant-atmosphere continuum. Drought in India refers to a situation when the normal rainfall is 5 mm or less for the week. Agricultural drought is a period of 4 such weeks from mid-May to mid-October or 6 such consecutive weeks during the remainder of the year.

The loss of kharif food grain alone in India during 1979 was estimated at more than 10 million t. The nature of adverse effects of drought depends upon its time of occurrence (Table 2).

Early cessation of rain may mean drought at flowering, a real disaster similar to the one that occurred in 1979 in South Asia, eastern India, Bangladesh, Burma, and Thailand (26).

BREEDING PHILOSOPHY

If high-yielding varieties evolved for irrigated situations are screened rigorously under upland conditions it would ensure adaptability of selected materials to local conditions as well as a high yield potential (18, 37, 38, 39). Drought resistance is a difficult concept and selection criteria in the field are also difficult to define (23, 57).

However, many practical agronomists and breeders have realized that the best yielding varieties of irrigated rice are not necessarily the best in rainfed, drought-prone conditions (6, 23, 57).

Rapid yield improvement under rainfed, dry conditions demands a separate breeding program. However, suitable materials generated from irrigated culture should also be utilized. Use of such a program would bring various benefits: broad spectrum of genetic variability (7, 13, 18, 45, 57) as yield and drought resistance are not negatively correlated (1, 6, 18); genes for yield, adaptability, and resistance to stress are separate, at least at some of the loci, and stress resistance can be further improved without sacrificing yield or adaptability (59).

Table 1. Occurrence (in percent) of various classes of drought over a 60-yr period.

Class	Index value	Bihar plateau	East Uttar Pradesh	Gujarat	East Madhya Pradesh
Mild	-1.00 to -1.99	18	16	17	15
Moderate	-2.00 to -2.99	13	9	12	7
Severe	-3.00 to -3.99	4	5	9	4
Extreme	-4.00	1	6	1	4
		36	36	39	30

Table 2. Effect of drought on national production of rice in India.

Year	Total area (thousand ha)	Total production (million t)	Av yield (t/ha)	Remarks
1970-71	37 432	42 448	1.134	
1971-72	37 758	43 068	1.141	
1972-73	36 688	39 245	1.070	Partial drought
1973-74	38 285	44 051	1.151	
1974-75	37 588	39 579	1.045	Partial drought
1975-76	39 475	48 740	1.235	
1976-77	38 606	42 787	1.108	Partial drought in some states
1977-78	40 282	52 670	1.308	
1978-79	40 146	53 829	1.339	
1979-80	39 414	42 330	1.074	Acute drought
1980-81	39 773	53 231	1.338	
1981-82	40 708	53 248	1.300	
1982-83	37 793	46 480	1.200	Partial drought

SCREENING APPROACHES

Blum (6) and O'Toole and Chang (47) concluded that before further progress can be made in utilizing morphologically and physiologically based adaptations to drought, suitable screening methods must be developed. Lack of proper screening methods is a constraint and often delays attainment of breeding objectives. No single technique covers all aspects of drought resistance (18). Available methods must meet a criterion so when several hundred lines are being screened, measurement is easily reproducible, rapid, and simple.

Controversy surrounds the priority and reliability use of direct and indirect screening approaches. The empirical (direct) approach relies on grain yield loss as the screening criteria because it integrates all components that determine yield in a water-limited environment and is the economic product (13, 22, 57). Others feel that absolute yield under stress is most important although breeders' target is a poor estimate of drought resistance because yield under stress is affected by the genotypes' yield potential and by any given nonstress environmental factor masking genotype-stress interaction (6, 24, 41); and genetic component of variation relative to the environmental component of variation in yield is usually low under stress (16, 25, 37).

A major setback in drought resistance breeding is the missing link between physiological drought-resistance traits and plant productivity (6).

Both screening approaches are likely to contribute significantly to yield improvements under drought. Both should be seen as complementary rather than mutually exclusive. For evaluation of number of germplasm and breeding lines, field screening should have priority. The selected lines can be subjected to individual tests so that the diverse components and underlying mechanisms contributing to stress resistance can be identified and better understood.

Screening for absolute yield under stress

Screening for yield can be made both under natural drought situations during the wet season as well as under artificially created drought during the dry season. The problem of testing under natural drought conditions is uncertainty in the rainfall distribution patterns. Suggestions are to screen under dry season conditions with restricted and controlled irrigation supply to create specific desired conditions at any stage of plant growth. The major objection is that dry season environment is quite different from a wet season environment and the screening may not be reliable.

Screening under drought in wet season

Eastern Uttar Pradesh in India is subject to frequent droughts during the wet season. For 7 yr (1977-84) droughts occurred during 1977, 1979, 1982, and 1984 at various stages of crop growth. During 1977 in the international upland rice observational nursery, only 11 out of 147 entries (Table 3) produced grain. The result further showed that the earliest flowering varieties (lines), including standard check N 22, produced no grain because their flowering period coincided with a drought spell whereas longer duration varieties recovered during later rains to produce some grain. Variation in growth duration is a real problem in assessment of varieties for reproductive-phase drought resistance (12). During the same year in another trial at Faizabad, no yield was obtained from any variety and at Balchandpur (Bahraich) only a few varieties produced some grains (Table 4).

Table 3. Grain yield under wet season drought. Faizabad (IURON 1977).

Strain	Days to 50% flowering [a, b]	Grain yield (g/plot)
UPR83 D-8-1	102	85
Tai chung Sengn	112	70
IR 1750-F 585	103	65
IR2307-217-2-3	101	55
UPR190-D-8-1	103	55
UPR103 DD-6-1	110	50
Aus 8	111	45
DV 110	103	45
B981 K 123	116	45
MRC172.9	115	45
IR3880-29	100	15
SE302 G	66	0
BR51-46-1-C 1	69	0
SE322 B-19	69	0
D2-41	73	0
N22	62	0

[a] Date of sowing 7/7/77, plot size 2 rows of 2.5 m. [b] First drought occurred 27 days after seeding (DAS) and continued for 13 d. Second drought occurred 72 DAS and continued for 13 d.

Table 4. Initial evaluation trial (rainfed upland). 1977.

Variety	Faizabad	Balchandpur Yield (t/ha)
FH446	0	1.844
IET2924	0	1.064
IET3975	0	1.064
IET4471	0	1.064
J X S 36-5	0	1.01 2
IET2959	0	0.912
IET4320	0	0.708
IET3226	0	0.608
FH575	0	0.304
FH442	0	0
IET2707	0	0
IET2728	0	0
J X S 36-5	0	0
J X S 35	0	0
IR1544-238-2-3	0	0
IR2031-729-3	0	0
IR2033-227-7	0	0
FH109	0	0
N22	0	0

Table 5. Screening for fertility percentage in 96 traditional indigenous lines under actual drought conditions during wet season. (1979).

Frequency distribution (%)	Varieties (no.)	Varieties
100-80	7	Anjani, Kachni, B, Kachni, C, Mutmuri B, Rengi, Sarya B, Thelai
76-60	26	Bagri white, Bagri Red Sawani Bagri, Kanyadali Kudia, Kachni A, Kachni, Lalmati A, Lalmati B, Nandhi, Padhni, Raimuniya Rengi B, Rani Kazal A, Rani Kazal B, Sathi B, Sokan, Sarya A, Sarya D, Sarya E, Tipakhia 'A', Tipakhia 'B', Vinega, Vishnuparag, Lalnakanda, Browngora.
59-40	35	Dehula, Gajgaur, Ketki, Kwari, Kalakeri, Bagri (Black), Beni, Bendi, Badam Farm, Dehula, White, Hansraj Kwari, Kwarahwa Kalakeri, Karhani, B Lurkan, Mutmuria, Maliva, Mutri 'A', Mutri 'B' Nagina, Paras, Raimuriya A, Raimuriya C, Rengi A, Rani-kajal C, Rani-kajal D, Sonkharcha, Sonkhal, Varanasi local, Suraj mukta.
39-20	7	Bagri, Hansraj A, Karhani A, Mutmuri A, Satha A, Sarya F, Salumpipit.
20	7	Kalamdan, Satha B, Satha C, Satha D, Sathi A, Mirkirak Pakyan.
No flowering	14	Bali, Bashawa A, Basahawa B, Dudhi B, Hansraj B, Jilhaur, Kalaband, Lalmati C, Muskan, Raskadam, Kinandang Patong, Sugapankhi GNOBA.

In a 1979 test, during severe drought, 96 traditional tall varieties from upland areas showed varying degrees of fertility, ranging from 100% to less than 20% to complete failure of flowering (Table 5).

Mass screening during dry season

An IRRI-developed mass screening technique removes general effects of flowering dates so entries can be compared directly. The data obtained on three aspects — absolute grain yield under stress, relative grain yield, percentage spikelet fertility (visual) — with respect to top and lowest yields are enumerated in Tables 6, 7, and 8. Based on the three parameters, the lines IR9669 sel, IRAT140, and M18 were most outstanding. Estimated fertility percentage was positively correlated with yield and actual fertility percentage. The data support the usefulness of these parameters for drought screening on a mass scale.

Line source sprinkler technique

Originally proposed by Hanks (27) and improved by Puckridge and O'Toole (52), the line source sprinkler (LSS) system efficiently creates a continuously variable water regime during the dry season. By sampling at several places across the water supply gradient, growth and yield of varieties in terms of *stability* can be assessed with minimum variation in soil and climate.

The degree of panicle exsertion of plants subjected to water stress during flowering serves as a useful criterion for visual selection for reproductive-phase drought resistance (11, 43). The use of LSS in the dry season enables breeders to accurately simulate desired levels of water stress and deal selectively with growth stage.

Table 6. Absolute grain yield under stress (top and lowest yield out of 172 entries).

Entry	Grain yield (g/m^2)
Top	
IR9669 sel	112
IRAT140	102
RAU4020-10	97
IRAT144	89
IR10147-113-5-1	77
B3007b-Tb-22-2-3-3-1, B 201-193-1	71
IR5873-9-1, IR11383-20	67
IR3880-10	66
ITA139	64
IR10029-26-3, M 18	61
Lowest	
Rata 74-5, IR 25863-8-2-3, IR 25898-57-2-3	3
B3016b-Tb-64-3-3-4-2-3, RP 1931-14-2-1-1 C894-21, IR 17494-32-1-1-3-2, IR3839-1	2
IR19670-263-3-2-2-1, IR 19058-107-1, IR25882-32-1-3, RP 1442-4-3-1-1.	1
IT28, IR2987-13-1	0

Table 7. Percent spikelet fertility stress treatment (top and lowest entries out of 115).

Genotypes	Mean spikelet fertility (%)
Top	
IRAT 140	71.2
M55	61.0
IRAT 110	45.0
IR113	39.2
M18	37.2
Sokoni	36.5
IR10025-16-2	34.8
83007 b-Tb-22-2-3-3-1	34.0
Lowest	
IR25588-7-3-1, IR7950-31-4-1, IR17494-32-1-1-3-2.	1.2
IR10133-30-1-2, IR22082-41-2	1.0
RP14424-3-1-1	0.8
BPI RI-6 (MRC 438), IR2987-13-1	0.7
IR258638-2-3, IR25882-32-1-3	0.5
IR25621-94-3-2	0.3

Table 8. Relative grain yield (top and lowest yielding lines out of 172 entries).

Genotypes	Relative grain yield (%)
Top	
IRAT140	66
ITA139	60
IR52	54
B201 -193-1	53
IR3880-10, IRAU 4020-10	49
I R 1138-3-20	47
Rate 35	45
IR9669 sel	43
IR5873-9-1	35
Lowest	
IRAT109, IR25898-87-2-3, IR25863-8-2-3, IR25774-3-1 (A)	2
RP1931-14-2-1-1, V894-21, (B3016 b-Tb-64-3-4-2-3) IR17494,32-1-1-3-2, IR3839-1, RP1442-4-3-1-1.	1
IR28, IR2987-13-1	0

Toposequence technique

The toposequence wet season technique consists of a long row of plants grown along a sloped field to evaluate the ability of different genotypes to extract soil moisture at varying distances from the water table (32). Only a limited number of varieties can be evaluated because the technique requires a field of uniform grade and fertility.

Analytical (indirect) approach

The analytical approach to breeding for drought resistance stems from two basic philosophies, one (19) refers to effects of competition, the second holds that yield is the ultimate expression of individual processes interacting with and modulated by the prevailing climate and crop environment. Selection for those traits or processes may be more efficient than selection for yield. Physiologists and breeders have to identify possible indirect criteria for improved yield or drought resistance (30, 64).

Screening for growth

Undoubtedly the drought-escape mechanism, as provided by growth adjustment, is a first line of defense and a most successful form of resistance. It is a highly heritable character and easily identifiable (early maturity) either in germplasm or in segregating complex populations. At Faizabad, first priority is placed on early maturity because of its simplicity and high heritability. This trait is being used as the base trait for developing drought-resistant varieties; however, other traits are also identified.

Screening for seedling vigor

Seedling vigor is generally considered essential in upland rice for good stand establishment and ability to compete with weed growth (10, 14, 17, 18, 38). Significant variation for this trait was noted among 100 genotypes. Three semidwarf varieties, generally grown in rainfed uplands, had lowest scores, while other varieties had good seedling vigor (Table 9).

Screening for height

Appropriate height for varieties suited to rainfed upland conditions is in question (10, 53). A medium height (80-100 cm) has been suggested. With this in view traditional varieties were screened for mature height. In eastern UP., India, the Satha group of indigenous upland varieties are shorter than some typical dwarfs and Rasi varieties (Table 10). This may further elucidate that under upland conditions, dwarf height may not be undesirable or unfavorable.

Screening for root characteristics

Root characteristics, such as size, morphology, depth, length density, and function, are important in maintaining relatively high leaf water potential against evapotranspirational demand. A deep root system is an important component of drought resistance because it enables the plant to exploit water in the deep soil layers. Of all the root attributes, root length density is probably the major operative factor that largely determines the extent to which roots can extract water from adjacent soil (44). Root systems were studied by a variety of techniques including root boxes, mylar tubes, extraction from the soil either whole or in cores, aeroponics using radioactive ^{32}P and others.

Root box technique. In the root box technique the root-shoot ratio (R:S)

Table 9. Screening for seedling vigor in 100 rice genotypes, (highest and lowest scoring genotypes).

Class interval	Frequency	Variety
		Highest vigor
60-65	7	Karangagora, Kolhapur scented, Nagpur-14, Padhini, Pawas, Sarya-E, Thelai.
65-70	2	Mirkirak, Panke.
		Lowest vigor
25-30	1	*Cauvery*
30-35	6	Narendra-1, Rasi, Sathi, Satha-B, Satha-E, Vaigai.
35-40	5	Bhadailakala, Dudhi-B, Dudhi-C, N-22, Sawani bagri.

Table 10. Screening for height of 100 indigenous rice genotypes (dwarf and tall stature scoring genotypes).

Class interval (cm)	Frequency	Variety
		Dwarf
55-75	4	Sathi, Satha B, Satha-E, Satha-F.
75-95	20	Bagri red, Bhadailakala, Champa, *Cauvery,* Kwari, Karhani-A Kudia, *Narendra-1,* Raimunia-B, Rani kajal-C, Rani kajal-D, *Rasi,* Sawani bagri, Sonkharcha, Sarya-B Safedwa, Sapna, Tinpakhia-A, Tinpakhia-C, Vaigai.
95-135	75	
		Tall stature
135-155	1	Mirkirak.

and the vertical distribution of roots of different varieties are compared. Traditional upland varieties have high R:S, while drought-susceptible varieties have lower R:S. Higher R:S were correlated with field resistance to drought (31, 35, 67).

Soil core sampling technique. Core samples estimate root density as well as vertical and lateral root distribution. Varieties differ in distribution patterns and density ratio below 30-cm depth. The core sampling method, however, is laborious and time-consuming (34).

Aeroponic culture technique. A rapid and systematic method of screening root characters is the aeroponic culture technique which was patterned after the initial model of Carter (9). This approach gives a comprehensive assay of the root characters and their relationship to the shoot characters. Rice transplants were grown in 1-m-deep circular drums for 45 d with most plants developing roots that extend to the bottom of the drum. Plants are

removed from the drum and shoots and roots that remain intact are counted and measured (2). This method also permits study of the inheritance of root characters in different crosses (3). The technique has advantages over root boxes or field sampling in screening fairly large numbers of rice cultivars and breeding lines.

Hydroponic culture technique. Hydroponic culture solution in a phytotron glasshouse has been used by Ekanayake (20) for inheritance studies of root characters. Selection for better root type based on individual plant performance can be successful in early segregating generation if selected for root thickness, dry weight, and length density (Table 11, 12). Relatively high heritability estimates for several root characters have been observed.

Root-pulling force. O'Toole and Soemartono (50) developed a simple method of evaluating root systems to measure the pulling force required to uproot rice seedlings 3-4 wk after emergence (33). Among six varieties studied, the differences in the required pulling force were related to root length, root weight, root number, and root branching. Resistant varieties were harder to pull than susceptible ones.

Root characterization in situ using ^{32}P. Use of ^{32}P to study rooting behavior under field conditions to integrate all factors of root growth in crop

Table 11. Root length (cm) in 100 rice genotypes (highest and lowest values).

Class interval	Frequency	Varieties
Top		
15-20	1	Sawani Bagri
20-25	6	Anjani, Badam farm, Kwari Safedawa, Tetco, Junagarh 68.
Lowest		
40-45	2	Rani Kajal D, Chipti,
50-55	1	Kolha-pur scented

Table 12. Root weight (g) in 100 rice genotypes (highest and lowest).

Class interval	Frequency	Varieties
Highest		
0-5	37	Satha B (2-72)
5-10	53	Dular, Jhona 349, kalakeri, Lalnakandra, N 22, Browngora ARC 11775.
Lowest		
10-15	9	Bagri, Bagri white, Sakun Nagpur A, Poongar, Kolhapur scented, Dehula B, Ambemohar, Chitraikar
15-20	1	Anjani

improvement was suggested by Reyniers (56). The principle is to place ^{32}P solution in the soil at different depths and distances from the plant. Measurement is by recording radioactivity absorbed by the aerial parts of the plant (55, 63). Sowing is adjusted so that all varieties reach the reproductive stage at the same time and are screened under the same conditions (heading stage). Table 13 indicates that varietal differences exist, irrespective of growth duration.

Screening for leaf rolling

A field screening method has been devised to evaluate reactions of large numbers of cultivars to drought at vegetative and reproductive phases as well as their ability to recover (40). Irrigation water is withheld 40 DS for about 20 d until the plants show distinct signs of internal water deficit (Table 14). The stress treatment and continuous scoring by a decimal system usually extends over 15–20 d until the soil moisture content reaches 13% and is no longer differentiated by soil tensiometers. Data recording is stopped when soil moisture tension at 20-cm depth reaches 8–10 bars (18).

After drought scores have been recorded, the field is rewatered and the plants are screened for recovery ability.

Crop canopy temperature technique

Water deficits induce stomatal closure; consequently, leaf temperatures usually rise. Leaf or canopy temperature measurement by infrared thermometry may be used as an indicator of plant water stress (Table 15). The ability of a cultivar to satisfy evapotranspiration demand and maintain low

Table 13. Varietal differences in ^{32}P absorbed by roots at 60 cm depth.

Variety		Counts per labeled place
Short duration		
NOIKU MOCHI		1757
R23 K	Top	1688
SE 3490		1453
MACK0		193
CHAO HAY	Bottom	178
Pratatao Precoce		158
Medium duration		
IRAT/MOROBEREKAN 2603/10		3276
IRAT116	Top	3169
IRAT13/Moroberekan 2303/4/9		3137
RE19 A		189
C1345	Bottom	163
IRAT103		149
Long duration		
IRAT/Moroberekan 2532/8	Top	1705
IRAT13/Moroberekan 2525/7	Bottom	420

Table 14. Genetic variation in 100 rice genotypes for leaf rolling index.

Class interval	Frequency	Varieties
1	3	Lurkan, Ambemohar, Chitraikar
2	12	Kalakeri, Brown gora
3	43	Jhona 349, Lalnakanda, Mirkirak
4	33	N22, Panke, Chipti, Kolhapur-scented *Cauvery, Rasi, Narendra-1*
5	9	Bagri white, Dular, Thelai

Table 15. Genetic variation in 100 rice varieties for leaf water potential (bar).

Class interval	Frequency	Varieties
-8-10	50	Tetko, Panke, Chipti, N22, Narendra-1, Laknakanda
-10-12	28	Dular, Kalakeri, *Rasi*
-12-14	14	Browngora, Mirkirak, Jhona 344, *Cauvery,* Thelai
-14-16	5	Dudhi-C, Lalmati, Padhni, Sakun, Tinpaptia-C
-16-18	2	Gajaser, Sonkharcha
-18-20	1	Ketki

canopy temperature and high plant water status can be attributed to its rooting behavior. In comparisons, cultivar IR52 had 2 °C cooler canopy temperatures and higher leafwater potential than IR36 in the upper 30 cm of soil where about 93% of the total water extraction occurred (36).

Canopy temperature at 50% flowering was linearly related to relative spikelet sterility (r = 0.79). There was a 0.20 increase in relative sterility for every degree increase in canopy temperature (12).

Screening for leaf water potential

Leaf water potential as an integrator of soil and atmosphere conditions is related to drought in rice. Variations in leaf water potential among cultivars or strains under moisture stress up to 10-13 bars between extreme rice genotypes have been found (48, 49). Significant differences were detected among the genotypes for maintenance of relatively high leafwater potential.

Screening for osmotic adjustment

Osmotic adjustment, generally considered as the net increase in intracellular solutes, usually occurs in response to various environmental stresses (61). Lowering by osmotic adjustment enables the plant to maintain turgor at lower water potentials (35). A comprehensive analysis ofosmotic adjustment in dryland rice cultivars in response to drought hardening (conditioning) has been made (15, 60) for developing drought-resistant dryland rice cultivars.

Screening for translocation of photosynthates

Screening for relative ability among genotypes for translocation efficiency as a measure of water stress tolerance has been suggested. Translocation of photosynthates within the plant is more tolerant of water stress relative to growth and photosynthesis (8). It is therefore reasonable to take advantage of translocation as a yield-supporting process under stress. Growth of cereal grain is supported by both transient photosynthesis in the flag leaf and the inflorescence and by translocation of assimilates stored mainly in the stems (21). When stress develops, the relative importance of translocation in supplying carbohydrates to the grain increases (4, 21, 29, 54). Varieties differ in the amount of stored stem carbohydrates and in the rate of their translocation into the grain under stress. Up to 31% of rice grain yield under stress was accounted for by translocation of stem reserves. A variety that yielded well under stress had an advantage in this respect (54). Both apparent translocation and ^{14}C radioactive isotope techniques can be used for study of translocation (56).

Screening for amino acid accumulation

Certain amino acids increase dramatically under stress and screening for them has been suggested as a means of evaluating drought resistance. Observations suggest that proline could provide metabolic advantages within limits of water stress. Depending upon the plant's growth stage and the chance of recovery from the water stress, the advantage may or may not be reflected in source or yield components. The degree of variation for proline accumulation as an adaptive mechanism in rice is still unknown.

Screening for stomatal behavior

Actions of stomata provide important mechanisms to reduce water loss during stress. Crop plants show variation in sensitivity of stomata to water deficits. Higher leaf water potential can be maintained by stomatal closure. There are genotypic variations in the relationship between stomatal conductance and leaf water potential (48). Dehydration avoidance through stomatal closure implies a negative effect on plant production through CO_2 exchange.

Screening for cuticle characteristic

An important nonstomatal water vapor pathway is the leaf cuticle. Cuticular permeability, or transpiration, is affected by thickness of cuticular layer and subsequently is influenced by the amount, composition, and physical configuration of epicuticular wax deposits (5, 28, 42, 58). Yoshida and de los Reyes (66) reported a twofold range in cuticular resistance among rice cultivars and suggested that this resistance accounted for part of the ability of the cultivar to resist drought and perform well under dryland conditions.

Screening for xylem vessel structure

Dryland varieties generally have larger xylem vessels in seminal roots than

semidwarf IR20 (36). Larger vessels decrease root axial resistance to upward water transport (51) so, axial resistance may be improved by breeding for larger xylem vessels in the main seminal roots.

Richards and Passioura in their breeding program aimed at increasing the hydraulic resistance of the upper part of the seminal root system by selecting for smaller xylem vessels (57).

Screening for desiccation tolerance ability

The development of simple screening techniques based on exposure of leaf portions or seedlings to heat shows wide variation in dehydration tolerance among species and cultivars (46, 62, 65). Screening for dehydration tolerance shows that stability from generation to generation is related to field performance under drought, and is more strongly developed in species and cultivars that have no dehydration avoidance mechanisms (46, 65).

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SCREENING RICE VARIETIES IN ACID UPLAND SOILS

K. ALLURI

Vast regions of the world's tropical rainforests for expanding agriculture are dominated by acid, infertile soils classified as Oxisols and Ultisols (6). These regions have much favorable topography for agriculture, adequate temperature for plant growth throughout the year, and sufficient moisture throughout the year in 70% of the region and for 6-9 mo in the remainder (8).

In West Africa, upland rice is the predominant rice ecology in the moist forest zone of Sierra Leone, Liberia, Guinea, Ivory Coast, Ghana, and Nigeria (9). Upland rice areas in south and southeast Asia are also mainly in the moist zones (3).

One major thrust of upland rice research at the International Institute of Tropical Agriculture (IITA) has been to increase yields and improve food quality in the humid tropics. To meet this objective, IITA has established a station at Onne, a high-rainfall area at Rivers State, in southeast Nigeria. Research on rice is directed toward developing a high yielding variety technology.

High humidity and tropical temperatures favor fungal pathogens causing blast, grain discoloration, sheath blight, and leaf scald, and insects, particularly pink stem borers and grain-sucking bugs. The following environmental data for Onne indicate the soil constraints.

Soil

Classification	:	Ultisols (Typic Paleudult)
pH (H_2O)	:	4.0
Texture	:	Sandy loam (81% sand, 5% silt, 14% clay)
CEC	:	3.0 meq/100 g soil
Exchangeable Ca	:	0.3 meq/100 g
Exchangeable Mg	:	0.05 ml/100 g
Exchangeable K	:	0.03 ml/100 g
Exchangeable Al and H	:	1.18 meq/100 g
Total N	:	0.06%
Organic C	:	0.98%
Extractable P (Bray 1)	:	20 ppm
Annual rainfall	:	2,400 mm (monomodal)
Sunshine period (March-November 1983)	:	0.83 to 4.56 h

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Soil acidity, Al toxicity, and low exchangeable bases are common to Onne and other humid tropics of West Africa; the eastern plains of Colombia (7); and Cerrado, central Brazil, the predominant upland rice-producing region in the country (2).

Selection criteria

Studies at Onne suggest that grain-filling is a serious problem because of high sterility and low 1,000-grain weight. The number of spikelets per panicle is reduced while panicle number is less affected (Table 1). The percentage of sterile spikelets was more than 50 in most nutrient treatments with Onne soil (4 and Yamaguchi, unpublished). These results suggest that panicle weight could be considerably increased by applying a combination of all nutrients (N, P, K, Ca, and Mg) to Onne soil. The results (Table 2) of a pot study conducted by adding different nutrients confirmed that applying Ca, Mg, and P improves various yield components and yield.

Although improved introductions occasionally give satisfactory yields, most do not show good adaptation at Onne. Their vegetative vigor is usually normal. Their major limitations — susceptibility to neck blast, and poorly filled and dirty grains — occur after flowering. Some others succumb, even at the vegetative stage, to leaf blast. However, in the absence of severe

Table 1. Grain yield and yield components of rice cultivars under different plant densities in Ibadan and Onne, Nigeria.

Cultivar	Location	Grain yield (kg/ha)	Panicles (no./m^2)	Spikelets (no./ panicle)	Sterility (%)	1,000-grain wt (g)
ITA117	Ibadan	3070	241	110	9	31
	Onne	2378	226	86	15	26
ITA235	Ibadan	4430	181	136	8	33
	Onne	1550	231	99	21	25

Data compiled from IITA, 1982 and Alluri, unpublished.

Table 2. Effect of added Ca, Mg, and P on grain yield and yield components of ITA 303 grown in Onne soils.

Nutrient	Grain yield (g/plant)	Panicles (no./ (plant)	Spikelets (no./ panicle)	Filled spikelets (%)	1,000-grain Wt (g)
Control (N+K)	6	5	95	61	27
+P	6	5	111	66	26
+ Ca	7	5	110	74	26
+ Mg	5	7	93	58	26
+ P, Mg	8	7	107	68	27
+ P, Ca	10	7	120	68	28
+ Ca, Mg	9	6	110	70	27
+ P, Ca, Mg	10	6	108	77	29

disease problems and under good management, semidwarf lowland variety ITA 212 and an improved upland introduction from the Philippines, UPL Ri-5, gave high grain yields (Table 3). Most adapted tall, traditional varieties are low yielding and are susceptible to lodging and stem borers.

On the basis of observations of varietal characteristics and their performance, efforts of Onne are directed toward selecting plants with good vegetative vigor, short to intermediate height (90-120 cm), intermediate to high tillering (200-350 panicles/m^2), moderately long panicles (>100 spikelets/panicle), and clean and well-filled grains. The breeding lines and introductions are screened specifically for soil acidity, blast, and pink stem borer. In all the nurseries, selection is routinely practiced against grain discoloration, sheath blight, and leaf scald. In this paper, results from acid screening are discussed. Results on diseases and insects are presented elsewhere in this volume (1).

Selection for root characters

Soil acidity with Al toxicity impedes root development. Owen (7) observed low yields in the eastern plains of Colombia with acid soils even at high lime levels. He attributed the low yields to short drought periods and lack of effective root depth; because the subsoils were not limed, the roots could not grow in the acid subsoil. The traditional upland varieties such as LAC 23, Ngovie, and Azucena have deep roots and produce clean and well-filled grains.

Vigorous and deep root systems in selections for acid soils explore a larger soil volume for water and particularly for nutrients that are limiting in acid soils. A total of 600 *Oryza sativa* accessions from the Genetic Resources Unit at IITA collected from humid forest regions of West Africa were critically evaluated using as check a variety from Liberia, LAC 23, which has a deep and thick root system. Sixteen cultivars, 15 from Liberia and 1 from Ivory Coast, were superior to LAC 23 in root thickness (1). In addition they produced clean and well-filled grains.

SCREENING RICE IN ACID STRIPS (ONNE)

Common features of acid soils are Al and Mn toxicity and Ca, Mg, and P deficiency. Varietal screening should be directed to identifying upland rice genotypes tolerant of acid, infertile soils in general, rather than specifically tolerant of Al toxicity. As such, we screen the cultivars in the acid soil fields.

To uniformly acidify the fields for varietal screening, a 1-ha field (200 m × 50 m) was divided into 4-m strips, each 200 m long. A 2-m-wide alley was demarcated between each 4-m strip of which there are 5 pairs. A pair consisted of one control strip (limed) and another acid or unlimed strip. The plots were developed initially for soybean screening in 1980, but in the last 3 yr these acid and control strips have been used for screening upland rice lines. The analytical data on soil from acid and control strips are in Table 4.

Table 3. Performance of upland rice in bush fallow, fertilized plot, Onne, 1984.

Cultivar	Grain yield t/ha)	Ht (cm)	Days to flowering	Panicles (no./cm²)	Spikelets (no./panicle)	Filled spikelets (%)	100-grain wt (g)	Harvest index (%)	Lodging (%)
ITA212	4.3	121	97	356	157	55	2.0	49	0
ITA303	4.2	124	102	267	134	64	2.7	45	0
ITA117	4.1	126	82	200	124	65	4.3	48	30
UPL Ri-5	3.5	106	99	333	93	47	3.7	51	0
TOx936-937-9-1-2	3.4	118	81	222	167	66	3.0	56	10
IRAT170	3.3	131	85	244	111	63	3.8	43	0
ITA307	3.2	104	89	311	129	49	3.7	51	0
ITA235	1.6	144	80	267	115	12	2.7	13	90

Table 4. Chemical properties of soils in limed and unlimed plots, Onne.

Treatment	Soil depth (cm)	pH	NH_4 OAC Extractable cations (meq/100 g)					Total acidity Kcl (meq/ 100 g)	
			Ca	Mg	K	Na	Mn	Al	H
Limed	0-1 5	4.6	1.11	0.36	0.25	0.04	0.01	1.49	0
	15-30	4.3	0.63	0.25	0.14	0.02	0.01	2.21	0.04
Unlimed	0-1 5	3.9	0.25	0.10	0.26	0.03	0.02	2.34	0.37
	15-30	3.8	0.20	0.06	0.19	0.02	0.01	2.98	0.61

Table 5. Rice varieties tested in acid upland soils, Onne, 1983.

Trial	Entries (no.)	Promising selections
1983 acid upland (IRTP)	44	3
1983/IURON (IRTP)	204	13
1982 IRLRYN (IRTP)	29	2
1983 WARDA, CVT, Short	15	3
1983 WARDA, CVT, Medium	15	3
1982 WARDA, IET	99	2
IITA breeding lines	290	25
IITA advanced lines	77	10
Total	773	61

The control strips received 0.5 t/ha dolomitic lime and 45 kg P/ha. Before planting both control and acid strips received N and K each at 45 kg/ha, and 20 kg N/ha was topdressed at 20 days after sowing (DS) and again at 40 DS. Each variety was planted across the 4-m acid and control strips. A total of 773 cultivars were screened in 1983 in acid strips (Table 5). The materials included were from the trials coordinated by the International Rice Testing Program (IRTP), the Coordinated Variety Trials from the West African Rice Development Association (WARDA), fixed lines from IITA's breeding program, and advanced lines selected from the 1982 screening at Onne.

Data on growth, yield performance, and reaction to disease and insects were collected. The performance of the test entries were compared with various check cultivars. ITA117, ITA235, and LAC23 were the resistant checks while FARO 27, IR52, and ITA212 were used as susceptible checks. Final selection was based on moderate to high yield potential in the control strips and their ability to retain their yield in the acid strips. Cultivars highly responsive to added lime were also retained.

In 1984, all the 61 selections from 1983 trials, additional advanced breeding lines from IITA, and all the entries in 1984 Acid Upland Soils Screening Set from IRTP were evaluated.

Results showed that in the limed strips, most varieties had improved vegetative vigor, better tolerance for blast, sheath blight, and grain discoloration (Table 6). However, occasionally some entries, e.g. IR5260-1 and IR10198-66-7 (Table 6), suffered from more disease even in limed plots. This may or may not be reflected in the grain yield. All entries in the acid

Table 6. Performance of 1983 acid upland rice screening set (IRTP), Onne (based on *Standard Evaluation System for Rice* [5]).

Variety	Treatment	Vigor	Grain discolorations	Neck blast	Leaf scald	Sheath blight	Grain yield (kg/ha)
Azucena	Acid	5	5	1	1	1	1619
	Control	3	5	1	1	1	2143
IAC25	Acid	7	7	1	1	5	589
	Control	5	7	1	1	3	1190
IR10198-66-2	Acid	9	7	5	3	5	254
	Control	5	5	5	3	5	1073
IR10206-29-2	Acid	7	7	5	3	5	48
	Control	5	7	1	1	1	195
IR2029-11-6-5-1	Acid	7	3	5	1	3	190
	Control	5	3	1	1	1	1045
IR3262-3-9-4-5	Acid	7	5	3	1	5	425
	Control	7	5	1	1	5	1942
IR5260-1	Acid	7	5	1	1	5	175
	Control	3	7	3	3	1	690
IR10198-66-2	Acid	7	5	1	1	1	248
	Control	3	7	3	3	3	648

upland screening set (1983 IRTP) yielded higher in limed (control) plots. The entries in 1983 IURON suffered more. They had poor growth both in unlimed (acid) and limed strips, and responded to lime also poorly.

Fageria and Barbosa Filho (2) evaluated 142 varieties to identify rice cultivars tolerant of Al toxicity in central Brazil. Either no lime was applied, or lime was applied to plots at 3 t/ha. Grain yields were used to rate for Al toxicity and susceptibility. They scored tolerance for Al toxicity (Al_1) as

$$Al_1 = \frac{\text{Yield in limed plots - yield in unlimed plots}}{\text{difference in Al saturation without and with lime at flowering.}}$$

Based on the varietal response, the cultivars were divided into four groups:

1. those that yielded well under high Al level and responded well to added lime;
2. cultivars that yielded well under high Al level but did not respond to added lime;
3. cultivars that produced less under higher Al level but responded to added lime; and
4. those that yielded less under high Al level and did not respond to added lime.

Yield trials on selected varieties

Twenty-four varieties selected from previous tests at Onne were evaluated in a yield trial. The varietal response to added lime and P was different among the cultivars. Based on the varietal response, the varieties could be broadly divided into three groups:

1. *Tolerant, respond marginally to liming.* Varieties that yielded about 2 t/ha or more with marginal depression or increase due to applied lime and phosphorus. Four improved African varieties may be grouped as tolerant of soil acidity with moderately high yield potential: TOx936-81-1-4, ITA307, IRAT170 and IRAT104.
2. *Tolerant, respond poorly to liming.* Traditional African varieties that yielded about 1 t/ha with negligible effect from applied lime and P, e.g. LAC23 and OS 6.
3. *Susceptible, respond well to liming.* Varieties that performed poorly in the absence of lime and P but gained 0.5 t/ha when these nutrients were applied: IR5931-110-1 and UPLRi-5. These are high yield potential, improved introductions but unadapted to African upland stresses. However, these cultivars also recorded high yields in the absence of severe disease pressure. For example, in 1983 tests, UPLRi-5 yielded 2.7 t/ha in acid plots and 3.1 t/ha in control plots.

Susceptible varieties which respond poorly to liming, such as IR5260-1 and IR10198-66-7, are eliminated from the test. The cultivars from the other three above categories are utilized in the breeding program based on their merit.

From the crosses at IITA, F_3 seeds from F_2 plants selected at Onne were sent to IRRI for Rapid Generation Advance (RGA). These progenies along with F_3 seed from IRRI crosses involving African parents were evaluated at Onne in 1983 and 1984. The F_3 material from IRRI had excellent phenotypic characters. However, most succumbed to blast or grain discoloration. The better selections came from crosses IR38575 (TOx571-201-8/IR6256-8-2), IR40531 (TOx378-1-2-1/IR13429-287-3), IR40534 (TOx378-1-2-1/IR19807-21-2-2-2), and IR40415 (IRAT73/IR5931-110-1). The study indicates the need for increased collaboration with various rice research workers worldwide.

ACID UPLAND SOILS SCREENING SET (IRTP)

The objective of the screening set is to exchange and evaluate varieties and breeding lines that may have adaptation to upland areas with low pH and associated problems.

In the 1981 acid upland soils screening set evaluated at Man, Ivory Coast, B2443B-KN-10-1-1-1 and two *glaberrima* selections were rated good for phenotypic acceptability without P treatment. The varieties ITA116, ITA117, ITA118, ITA162, ITA225, and ITA235 also performed well but only when P was applied. These ITA lines were also reported superior in acid soil (pH 4.5) with high Al in David, Chiriqui Province, in Panama (Trip report, Dr. J. C. O'Toole, IRRI, 1981).

The 1982 acid upland soils screening set was composed of 35 entries. Characters of particular significance in adaptation to acid soils are tolerance for Al toxicity and P deficiency. The best performing entries were BG35-2, IR9410-80, ITAl 16, and Salumpikit. Both at Huimanguillo, Mexico, and at Albay, Philippines, the entries B733C-167-3-2, IR24, IR36, Azucena, IR9101-124-1, ITA116, and Seratus Malam showed better tolerance for Al toxicity. These varieties also performed well without applied phosphate fertilizer.

Data from the 1983 acid upland soils screening set are in Table 7.

Table 7. Acid upland soil screening set, Onne, 1983. Based on *Standard Evaluation System for Rice* **(5).**

Entry	Grain yield (t/ha)		Plant ht (cm)	Days to 50% flowering	Visual score (0-9)				
	Control	Acid			Vigor	Leaf blast	Neck blast	Grain disco-loration	Sheath blight
Azucena	2.0	1.2	97	87	3	3	2	1	2
ClCA 8	2.7	0.9	87	75	3	0	1	5	1
Local check (ITA235)	2.2	1.4	95	91	1	1	1	1	2
ITA162	2.3	0.8	85	94	1	1	1	3	1

Number of cultivars tested: 45.

The results indicate considerable merit in screening varieties for tolerance for acid upland soil stresses in situ, as evidenced by the superior performance of ITA lines in the international trials. Combined with superior varieties, the adoption of appropriate nutritional management practices should make possible the use of the vast regions of tropical forests for increasing rice production.

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SCREENING UPLAND RICE FOR ALUMINUM TOLERANCE AND BLAST RESISTANCE

SURAPONG SARKARUNG

Rice in Latin America is cultivated under many different ecosystems. The major division among ecosystems is primarily based on rainfall (amount and distribution), cultural practices, soil types, and pathosystems. The main production systems in the Americas have been classified tentatively into irrigated, rainfed lowland, highly favored upland, moderately favored upland, unfavored upland, and traditional manual upland (2). Continuing characterization will undoubtedly identify additional ecosystems.

The total area planted to rice in 1982-83 was approximately 8.2 million ha, of which 24% were irrigated and 76% upland. Although little rice is produced in the rainfed lowland ecology, the rice area will expand in coming years. More than 50% of the total rice production came from the irrigated ecologies (3).

Vast areas of infertile acid soils in tropical Latin America are under-utilized. Some irrigated rice, but essentially no upland rice, is cultivated on these soils. Strongly acid soils found in savanna and rain forest ecologies account for approximately 1,400 million ha. They consist primarily of Oxisols and Ultisols; a smaller area is represented by acid Inceptisols, Entisols, and Alfisols (4).

Chemically, these acid soils suffer Al toxicity (higher than 60%), and N, P, K, Ca, Mg, S, and Zn deficiencies. Physically, they are easily worked, have low water-holding capacity, and are easily eroded.

The interest of CIAT (Centro Internacional de Agricultura Tropical) in research on infertile, acid soils is to develop a mechanized, low-input , upland rice production system in the savanna ecology where rainfall is heavy (over 1,800 mm) and well distributed during the growing season. Upland rice could be considered as a monoculture or, more likely, as a frontier crop to open land for pastures after one or two rice harvests. The potential area for upland rice is approximately 300 million ha, mainly in the Llanos of Colombia and Venezuela, northern Brazil, southern Mexico, Guyana, Bolivia, and Peru.

Centro Internacional de Agricultura Tropical.

PRODUCTION CONSTRAINTS

The major production constraints for upland rice in acid savannas are

- lack of adapted varieties,
- biological and physical factors, and
- agronomic practices.

Lack of adapted varieties

Adapted upland varieties that combine excellent quality, moderate yield potential, resistance to diseases and insects, and tolerance for mineral stresses are not available. Our modem dwarf irrigated varieties (CICA 8, Oryzica 1) and varieties bred in Surinam are successful in favored upland ecologies, but totally unadapted to infertile acid soils. Some improved upland materials developed in West Africa by IITA and IRAT are outstanding in high-aluminum soils, but they have shortcomings such as susceptibility to insects and to the hoja blanca virus, and poor grain quality.

Biological and physical factors

Inherent soil infertility, mineral toxicities and deficiencies, and low water-holding capacity directly affect yield and predispose rice to disease and insect attack. In addition to physical limitations, the important biological factors are diseases (blast, hoja blanca, grain discoloration, leaf scald, and brown spot), insects (*Sogatodes* and *Diatraea*), and weeds.

Agronomic practices

Since upland rice is not grown in the high-rainfall, strongly acid savannas, agronomic practices must be defined. Research must focus on fertilization, weed control, and planting methods. NPK rates and timing, and minor element (Ca, Mg, Zn, and S) requirements must be defined. Chemical control of the unique savanna weed communities is required. Initial studies with drilled rice have given better results than broadcast seeding. More work is required with appropriate machinery and plant densities.

BREEDING OBJECTIVES FOR UPLAND SAVANNA RICE

Adaptation to the savanna ecology requires resistance to diseases and insects, and tolerance for mineral toxicities and deficiencies. The target yield for upland savanna cultivars is 3-3.5 t/ha. Specific traits include

- tolerance for Al toxicity and minor element defficencies;
- resistance to blast disease;
- resistance to other foliage/panicle diseases such as leaf scald and brown spot;
- resistance to grain discoloration;
- tolerance for insects *Sogatodes* and *Diatraea;*
- short to intermediate stature (not semidwarf) and moderate tillering;
- early to medium maturity (100-130 d);

- resistance to lodging;
- deep, thick roots;
- good grain quality (no white belly, intermediate amylose content); and
- mild drought resistance.

CIAT's approach to upland rice research for acid soils is directed toward development of varieties that grow successfully with minimum inputs. Varietal development requires germplasm adapted to the adverse conditions of the hostile upland environment and efficient utilization of limited available soil nutrients.

In acid environments, high soil Al and the extremely variable blast pathogen are considered principal factors limiting production. This paper, therefore, focuses on screening methods for Al tolerance and stable resistance to blast.

Our initial breeding activity was to identify rice cultivars tolerant of Al toxicity. Rice germplasm consisting of improved breeding materials, traditional, and native varieties was obtained from the International Institute of Tropical Agriculture (IITA), Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (IRAT), International Rice Research Institute (IRRI), and national programs. More than 1,360 cultivars, representing diversified genetic backgrounds, were evaluated for Al tolerance.

The cultivars were screened at the La Libertad Experiment Station located at the Colombian llanos on an Oxisol typical of Latin American savannas. The soil fertility is as follows.

O.M.	pH	P (Bray II) (ppm)	meq./100 g soil				Al saturation (%)
			Al	Ca	Mg	K	
3.7	4.1	4.6	3.1	0.37	0.07	0.17	83.6

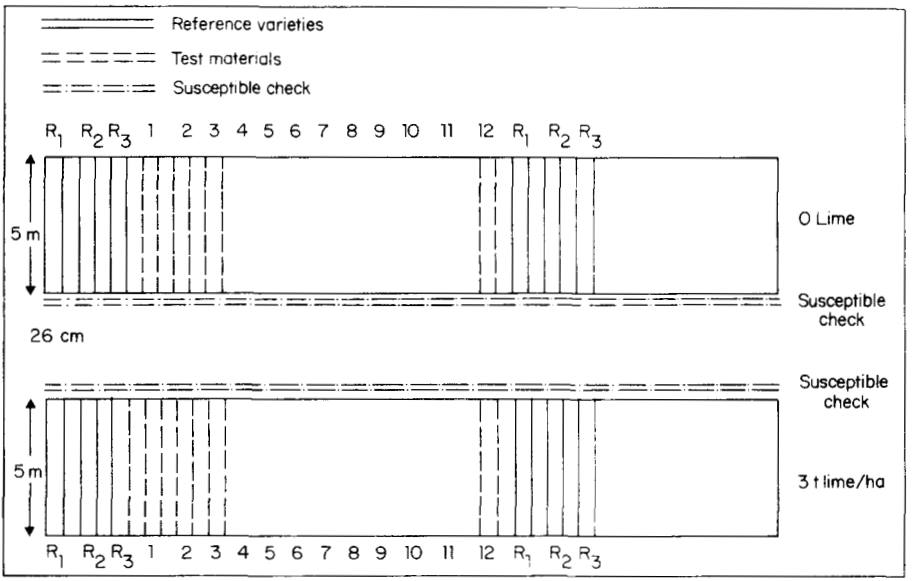
Microelements (ppm)				
B	Zn	Mn	Cu	Fe
0.32	0.50	9.3	0.73	40.8

A screening design was developed to compare cultivars under two different conditions of high and low acidity. "Acid strips" (Fig. 1) consisting of alternating high- and low-acid blocks, each 5 meters wide, were developed. The high-acid strips received no lime, while alternate strips were treated with 3 t dolomitic lime/ha, 15 d before sowing.

Fertilizer rate was 50-26-33 (NPK)/ha.

Each cultivar was sown directly in double rows in a high- and a low-acid strip. Three reference varieties (susceptible Metica 1 and tolerant IAC 165 and IRAT 122) were planted after every 24 rows of test materials. The plots were protected from disease and insect damage with fungicides and insecticides.

Toxicity symptoms were noted on both strips 40 d after sowing, or as soon



1. Field design for screening cultivars for aluminum toxicity tolerance.

as symptoms appeared on the susceptible check. A second reading was made at preflowering. A scale of 1 to 5 (1 = strong tolerance, 5 = total susceptibility) was used (Table 1). Root system development was noted. A few plants from each treatment were carefully uprooted and their root system development scored on a 1-5 scale (Table 2).

Table 3 compares the soil analyses of the unlimed and limed strips. Lime markedly reduced AI saturation, and increased pH, Ca, and Mg. Potassium was unchanged. For unknown reasons P was abnormally high in some unlimed strips.

Aluminum symptoms were expressed directly as typical chlorosis (severe yellowing of entire plant) or indirectly as interactive deficiency of other elements. Resistant cultivars (scale rating 1 and 2) had little or no yellowing and no height reduction or abnormal root development.

Only 17% of 1,360 varieties evaluated were tolerant of Al-toxic soils. Semidwarf varieties bred under irrigated conditions failed in both limed and unlimed conditions. They are obviously unadapted.

Excellent Al tolerance is available in rice. Superior cultivars were found in different genetic backgrounds, originating from the rain forests of West Africa, Asian highlands, and the Campo Cerrado of Brazil. These cultivars also are adapted to infertile soils.

Tolerant varieties were grouped, according to morphological improvement, into improved breeding lines and traditional land races or native varieties. Many improved breeding materials recently developed by IITA and IRAT appear to possess higher Al tolerance than the original parents, suggesting that genes for tolerance were accumulated in the newly bred cultivars.

Table 1. Evaluation scale for aluminum toxicity.

Scale	Description
1	No difference in growth between high- and low-acid strips.
2	Slight yellowing of a few plants in high-acid strip. No difference in growth.
3	Some yellowing of plants. Slight height reduction in acid strips.
4	Uniform yellowing, marked height reduction. No leaf death.
5	Severe yellowing, strong height reduction, lower leaf death.

Table 2. Scale for root system morphology in acid soils, 75 d after planting.

Scale	Description	Variety examples
1	Few, thick, and long	Monolaya, IAC 165
2	Many, thick, and long	Breeding lines: IITA, IRAT
3	Many, slender, and long	IRAT 122, Surinam varieties
4	Few long, mostly fibrous	Traditional rainfed lowland
5	All fibrous, superficial	IR8, ClCA 8

Table 3. Soil analysis of some limed and unlimed strips, 75 d after planting.

	OM (%)	P Bray II (ppm)	pH	CEC (meq/100 g soil)				Al saturation (%)
				Al	Ca	Mg	K	
Not limed	3.04	16.0	4.6	2.6	0.29	0.09	0.11	84
Limed	3.48	19.2	5.4	0.8	1.70	0.93	0.10	23
Not limed	3.53	24.5	4.7	2.7	0.27	0.06	0.10	86
Limed	3.36	10.7	5.5	0.6	1.69	1.00	0.08	17
Not limed	3.68	9.6	4.5	2.7	0.22	0.06	0.12	87
Limed	3.80	11.9	5.6	0.5	1.88	1.09	0.08	14
Not limed	3.58	27.1	4.6	2.7	0.31	0.07	0.10	85
Limed	3.80	8.8	5.8	0.2	2.48	1.34	0.08	5
Not limed	3.58	17.1	4.7	2.7	0.31	0.08	0.12	84
Limed	3.68	9.0	5.9	0.2	2.63	1.45	0.09	5

Plant height, reaction to Al, and root growth of selected improved cultivars, taken from the unlimed plots, are shown in Table 4. Several deep-rooted, short-stature lines having vigorous vegetative growth were outstanding in strongly acid soil, indicating that no relationship exists between plant height and level of Al tolerance or root morphology. Table 5 lists some tolerant traditional land races and native varieties. Several varieties — Ngovie, 63-83, Lac23, and OS6 — have been used extensively as parental sources in several breeding programs, notably those of IITA and IRAT.

Table 4. Plant height, aluminum reaction, and root morphology of selected improved cultivars in unlimed strips.

Cultivar	Ht (cm)	Al reaction[a]	Root growth[b]
Tox 1010-22-7-18	47	1	3
Tox 891-212-2-102	55	1	3
Tox 936-81-3-5-201	55	2	3
Tox 1871-38-1	64	1	3
Tox 1010-49-1	67	1	2
Tox 1010-45-1	67	2	1
Tox 1177-17-16B	65	1	2
Tox 1785-19-18	78	2	2
Tox 718-AL-11-CM-JM	90	2	2
Tox 1010-24-6-1-1B	61	2	2
Tox 1815-34-201-201-1	75	1	3
IRAT 146	55	2	1
IRAT 147	60	2	1
IRAT 112	77	2	2
IRAT 194-1-2-1B	66	2	3
IAC 47	91	2	1
IAC 164	80	2	3
IAC 5032	96	2	1
M 18	68	2	2
M 55	73	2	2
(Col 1/M312A)	67	1	2
(IAC 25/PJ-110-99-1-4-1)	63	1	3
IAC 165 (check)	96	2	1
IRAT 122 (check)	73	1	3
Metica 1 (check)	55	4	Very few roots

[a] Al reactions according to Al toxicity scores given in Table 1. [b] Root growth according to growth scale given in Table 2.

Table 5. Plant height, aluminum reaction, and root growth of some traditional and native varieties in unlimed strips.

Cultivar	Ht (cm)	Al reaction[a]	Root growth[b]
Ngovie	93	2	2
Lac 23	96	2	2
63-83	87	2	3
Meht-Noi	105	2	3
Ku 28	97	2	2
Khao Konedan	95	2	2
Padi Bokokut	116	2	2
Monolaya	95	2	2
OS 6	95	2	2
E 425	90	2	1
Tos 5806	85	2	3
Tos 58 11	90	2	1
Zebu	91	2	2
Kinandang Patong	112	2	1

[a] Al reactions according to Al toxicity scores given in Table 1. [b] Root growth according to growth scale given in Table 2.

The tolerant cultivars not only are adapted to acid soils, and tolerant of various mineral stresses, but are resistant to blast, dirty grain, and brown spot. Their defects include susceptibility to the hoja blanca virus, *Sogatodes,* and *Diatraea;* and poor grain quality. A hybridization program to incorporate traits into acid-tolerant backgrounds was begun.

The relative yields were 92% for the Al-tolerant entries, 70% for the moderately tolerant, and 48% for the susceptible.

SCREENING FOR BLAST RESISTANCE

Rice blast, caused by *Pyricularia oryzae,* continues to be the most important disease-limiting rice production in tropical Latin America. Highly variable pathogenic populations of *P. oryzae* make breeding for durable resistance difficult (1).

Cultural practices greatly influence blast epidemics. In most Latin American countries, rice is directly sown after dryland preparation, using heavy seeding and fertilizer rates. Dense plant population, combined with heavy nitrogen applications, enhances disease development, particularly in upland rice.

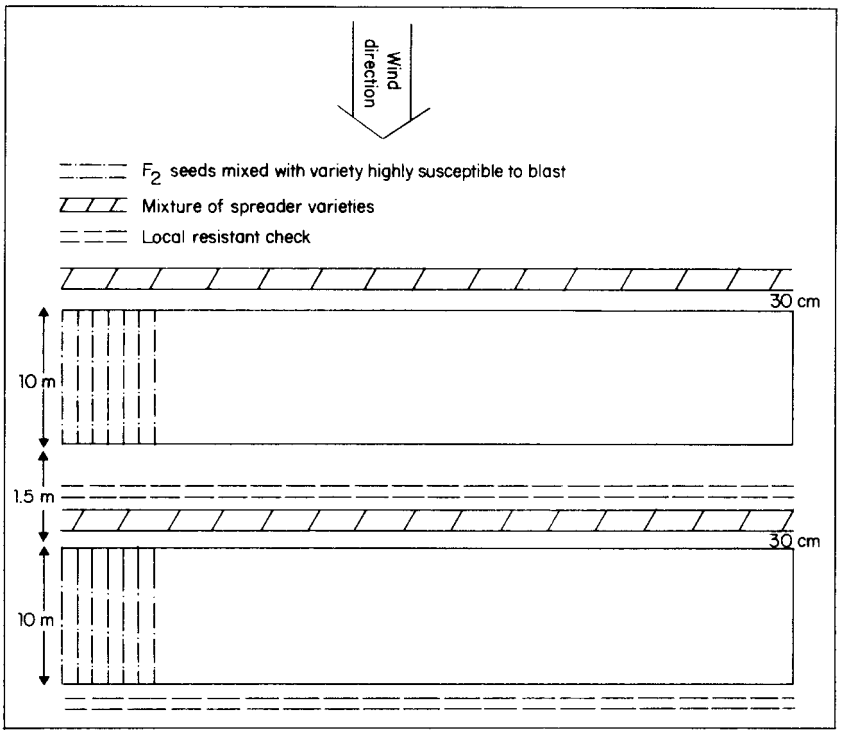
A fundamental question rice breeders face is whether durable blast resistance can be obtained in stressed ecologies such as savanna upland. Inoculum of a particular race increases after many years of continuous cultivation, provoking population shifts in virulence or aggressiveness of that race. One way to minimize rapid breakdown of resistance is to design appropriate screening methods involving three key components of screening location, field designs, and early generation evaluation.

Screening location

A critical factor in crop improvement is the choice of location(s) for screening representing the target ecosystem and ensuring heavy pressures of major constraints. Our segregating materials are exposed to high-stress conditions, biologically and physically, at La Libertad, an ideal site for screening and evaluation. Infertile, acid soils provoke epidemics of leaf and neck blast, leaf scald, dirty grain, and brown spot.

Field designs

CIAT has assessed different field designs to create adequate blast infection in F_2 populations and pedigree families. In general, uniform blast infection is difficult to obtain in F_2 populations because of extreme genotype differences. Blast pressure is always best near spreader rows. Seed of one or two highly susceptible varieties carrying genetic markers are now mixed with F_2 seeds before sowing. The mixture initiates the first cycle of infection and later spreads the inoculum to F_2 plants. The mixture usually dies 40-50 dafter sowing, by which time the F_2 is uniformly challenged (Fig. 2).



2. Field design for blast disease in F_2 populations.

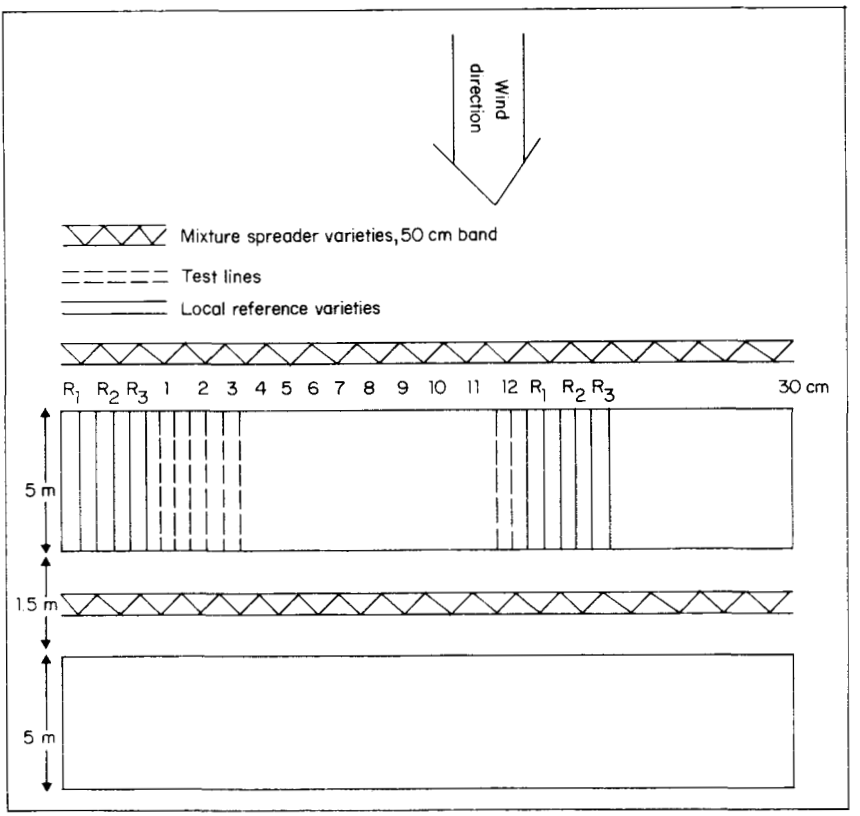
The field design used for F_3 pedigree families and breeding lines is illustrated in Figure 3. Spreaders, consisting of a mixture of susceptible and tolerant cultivars, are sown perpendicularly to the test plots and to the prevailing wind direction 15 d before the breeding lines are planted.

Early generation evaluation. Although predisposing factors (soil, spreaders, upland conditions) facilitate selection, they must not be overemphasized. Continued selection at one location may lead to site-specific resistance. This may be especially pertinent in upland blast breeding because of the heterogeneity of upland soils. For the savanna ecology, we propose to evaluate F_3-F_6 lines in other savanna locations (Fig. 4).

STRATEGIES IN BREEDING DURABLE BLAST RESISTANCE FOR ACID SOILS

Introduction of stable resistance

Several Japanese upland japonicas have high blast tolerance at IITA, and in acid, infertile soils of the Colombian plains. These varieties also have other desirable characteristics such as shortness, earliness, and vigorous early growth. Their genes for resistance appear different from those of other donors; they could have come from the accumulation of major genes that had broken down earlier (1). These japonica sources combine well with other acid soil-tolerant varieties.



3. Field design for pedigree families and elite cultivars.

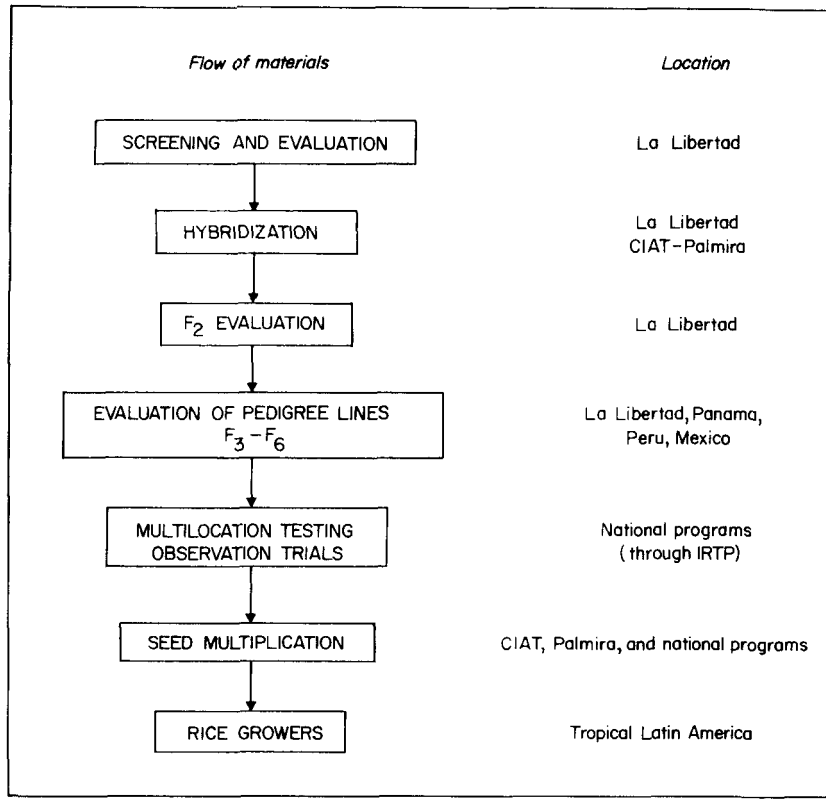
Recurrent selection (RS)

Recurrent selection is a powerful breeding method for accumulating desirable resistance genes. Our main objective in RS is to seek population improvement in relation to blast resistance (2). Continued mass pollination through use of genetic male sterility may facilitate recombination of resistance genes.

Since cross incompatibility characterizes the two ecotypes (irrigated and upland), male sterility in an irrigated background (IR36) would not be appropriate for upland breeding. Thus, another source is being sought in adapted upland cultivars through irradiation.

Steps in forming the base population are

1. Select sterile plants from a mixture of F_2s.
2. Discard susceptible rows and discard sterile plants by the progeny-row method. (The first cycle of recombination is complete.)
3. Mix seed of selected sterile plants.
4. Select fertile plants and discard susceptible rows by the progeny-row method. (This is the second cycle of recombination.)
5. Evaluate and select resistant homozygous fertile plants.
6. Conduct multilocational testing.



4. Flow chart of materials and test locations for upland rice breeding in acid soils.

Blends of phenotypically uniform lines

Another approach to durable resistance is to maintain genetic resistance heterozygosity within a variety otherwise phenotypically uniform in plant height, maturity, and grain quality.

The procedures for each population are

F_1: Identify upland lines tolerant of acid soil and resistant to hoja blanca. Cross each with known upland sources of blast resistance. Backcross once to tolerant lines.

F_2 bulk: Select plants with the least blast.

F_3: Evaluate and select for quality. Bulk resistant, high-quality plants into maturity groups.

F_4: Select within maturity groups for uniformity in maturity, grain quality, and blast resistance.

F_5: Test populations in several blast-prone production areas.

F_6: Conduct yield trials in blast-prone areas.

The purpose of this approach is to have a broad base of genotypic variability for blast in a population uniform in plant height, flowering, and grain quality.

Accumulation of major and minor genes

We attempt to accumulate major and minor genes, assuming there is a difference, in single genotypes in our conventional breeding program by using many distinct donors adapted to the savanna ecology. Breeding plots are challenged with inoculum, which consists of different genes, from a mixture of susceptible (local) varieties.

Selection is judged on a line basis, keeping the plants cleanest for blast and other fungal diseases. Selected lines having similar height and maturity periods are intercrossed.

CONCLUSION

According to our preliminary results, it may be possible to cultivate rice economically in the acid, infertile, savanna soil under low-input management. Many superior rice genotypes are outstanding in this hostile ecology. More work is needed to incorporate other desirable traits such as hoja blanca resistance, good grain quality, and resistance to *Sogatodes* and *Diatraea* into acid-tolerant backgrounds. Since these defects are largely specific to Latin America, improved upland lines now available should be evaluated in the strongly acid, blast-prone areas of Asia.

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Biological stresses with special emphasis on blast

A. Blast resistance methodologies and new strategies

RECENT PROGRESS IN INTERNATIONAL RESEARCH ON BLAST RESISTANCE

V. T. JOHN and J. M. BONMAN

Blast disease of rice, caused by *Pyricularia oryzae* Cav., and resistance to this disease have been subjects of intense research and discussion for the past several years. A major factor that showed resistance breeding is the nature and magnitude of pathogenicity of the causal fungus. This paper advocates identifying and using varieties with durable resistance in crosses as a practical approach to breeding for blast control. Several examples of durably resistant lowland varieties, most of which possess high levels of incomplete resistance, have been cited. By large-scale cultivation of durably blast-resistant lowland varieties in several parts of Asia, the disease severity has been reduced. Some upland varieties with incomplete and complete resistance offer further scope for stabilizing the yields in the vast upland areas of Africa and other countries.

It is emphasized that a careful selection of material with complete and incomplete resistance to blast followed by exchange of information and appropriate testing in blast-prone areas will identify useful lines for the vast rice growing tracts of several countries.

The International Rice Research Institute organized a 1963 symposium in the Philippines to update knowledge of rice blast disease and devise strategies for its control. Another symposium on the same subject was held in Montpellier, France, in 1981. Considerable progress has been made in understanding the disease, the causal agent, the environment, and, more important, methods of controlling disease. Nevertheless, blast continues to be a major disease of rice, particularly in droughty uplands of some countries. National and international agencies continue efforts to breed rice varieties with blast resistance.

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One area of development is the study of the nature of disease resistance. In earlier years interest in blast resistance was largely confined to irrigated rice because the greatest gains in productivity were anticipated in such environment. However, since greater areas in Africa and Latin America are under the drought-prone conditions of upland rice culture, attention has focused on the upland environment. The importance of blast was endorsed at an upland rice workshop in 1982. Among other areas for future research, blast resistance was given top priority at that workshop, and a task force was set up to study the disease in Africa. This paper discusses efforts of rice scientists to evolve strategies for resistance to blast with emphasis on the causal pathogen and approaches to resistance breeding programs.

THE PATHOGEN

The blast fungus *Pyricularia oryzae* Cav. has been studied in great detail, especially in Japan (14). Since Sasaki reported variation in its pathogenicity in 1922, several workers have reported on its physiological races. Most of the work on *P. oryzae* races was done in the mid-1960s (Table 1).

It is doubtful that since the races were first identified, their number and virulence patterns have remained unchanged. Nevertheless controversy over the degree of pathogenic variation in *P. oryzae* continues. One view is that the fungus constantly changes and, if enough differential varieties were available, each conidium from a single lesion or culture could be shown to be a distinct race (13, 15). Other workers maintain that the fungus has stable pathogenicity, and generally all monoconidial isolates from a lesion or a monospore culture have the same virulence pattern (7, 12). This disagreement has to be fully resolved.

The fungus changes in response to the selection pressures it undergoes — the most important being the rice varieties that are widely grown. Varieties have changed, and, thus, so have races of *P. oryzae.* Probably the best way to detect such changes is to use widely grown varieties to assay the fungus population, rather than the traditional differentials (3). Similarly, it would perhaps be more logical to measure virulence in terms of frequencies of

Table 1. Races of *Pyricularia oryzae* in various countries.[a]

Country	Year	Races (no.)
USA	1960	15
Korea	1962	5
India	1965	11
Western hemisphere	1965	16
Japan	1965	18
Philippines	1966	262
Taiwan	1967	27
Colombia	1968	14
Nigeria	1970	11

[a]Compiled from (8).

specific virulences within the pathogen population, rather than in terms of physiological races (20, 21).

Another important aspect of this fungus is that the teleomorph is unknown, although it has been obtained in culture (5, 11). How much genetic variation there could be in homothallic or heterothallic anastomoses is unknown. The role of lipids or multinucleate conditions and chromosomal proliferation have also been implicated in aspects affecting the virulence of the pathogen.

RESISTANCE

Disease resistance in plants can be classified using three criteria:

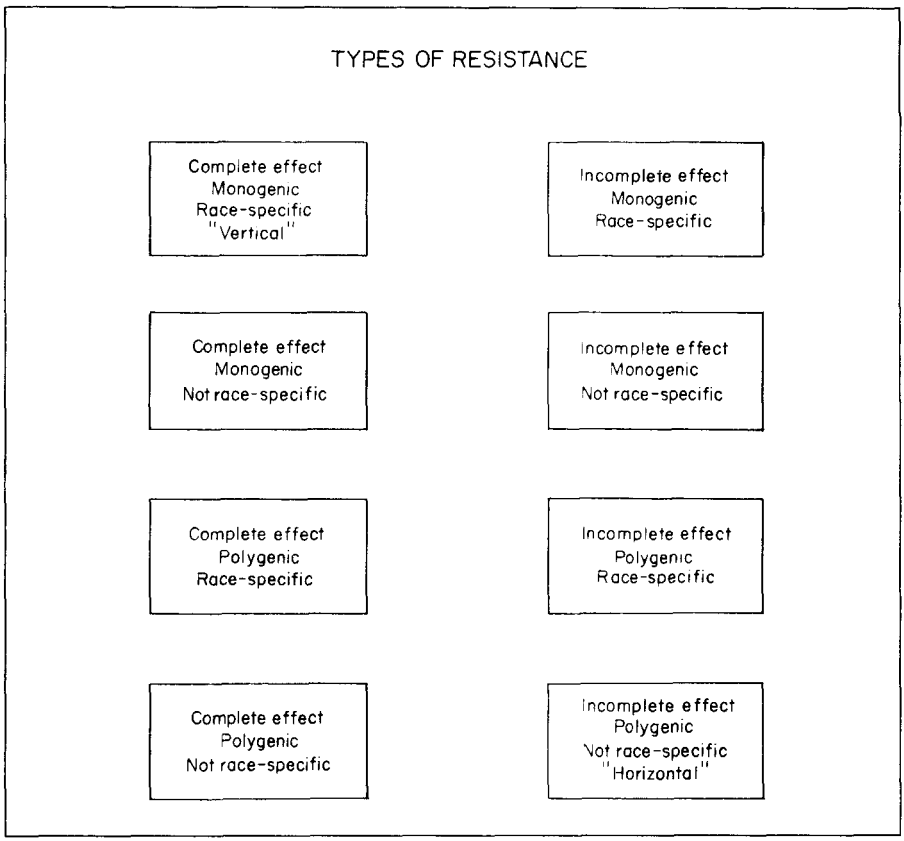
1. how the resistance is inherited (monogenically or polygenically),
2. the magnitude of its effect (complete or incomplete), and
3. the differential nature of the resistance (race specific or not race specific) (4, 17).

Polygenic, incomplete, race-nonspecific resistance has been widely referred to as horizontal resistance. Monogenic, complete, race-specific resistance was described as vertical resistance. However, with these three criteria, eight kinds of resistance in plants are possible (Fig. 1).

Durable resistance (10) is ". . . resistance that has remained effective while a cultivar possessing it has been widely cultivated in an environment favoring the disease." The recognition of resistance as durable says nothing of its mode of inheritance, race specificity, or magnitude of effect (9). The durable-resistance concept and the classification of resistance types may be of value to rice blast disease workers, both in framing current knowledge in a more understandable way and in highlighting areas requiring further intensive research.

Resistance types

The blast resistance of a number of rice cultivars can best be classified using the three criteria. In Japan, the cultivars Chugoku 31 and St. 1 showed few lesions when inoculated with compatible *P. oryzae* isolates and exhibited slow disease development in field tests (18). The effect of the resistance in these two cultivars was incomplete because the pathogen was able to reproduce on the host plant. Also, the resistance was monogenic and was later found to be race-specific because eventually isolates that could cause rapid disease progress in the field were found. The cultivar Metica 1 from Colombia provides a similar example of race-specific incomplete resistance. Before and directly after its release, Metica 1 exhibited only small blast lesions, and disease progress in the field was slow. However, when it was commercially grown, fungus races appeared and caused large lesions (S. W. Ahn, pers. comm.). The number of genes governing incomplete resistance in Metica 1 is unknown. ITA 235, an upland variety derived from the cross OS 6/OS 6 dwarf mutant, previously showed few discrete lesions and hence



1. Eight possible plant resistance types based on magnitude of effect, number of genes controlling inheritance, and race specificity (adapted from [4]).

had incomplete resistance. Recently it began showing greater susceptibility (John and Dobson, unpublished data).

The components of slow blasting (i.e. incomplete) resistance, including disease efficiency, sporulation capacity, and lesion size, were studied in the cultivars Tetep, Gogowierie, Dourado Precose, IRAT 13, and 1021 (19). There were some indications of race-specific interactions between the resistance components and fungus isolates. Such race specificity had been found with incomplete resistance in diseases of other crops, especially when the resistance was monogenic (16).

Durable blast resistance (lowland). From examples cited, it is evident that incomplete or slow blasting resistance to *P. oryzae* can be nondurable, as in Metica 1, Chugoku 31, and St. 1. There might be rice cultivars with durable resistance to blast, but numerous environmental factors greatly influence blast disease intensity. Resistance durable in one agroecosystem may not be as durable in other, more blast-prone environments. The widely cultivated variety IR36 is an example of this phenomenon. In lowland irrigated or

Table 2. Components of incomplete resistance to *Pyricularia oryzae* in 2 lowland rice varieties.[a,b]

Component	IR50[c]	IR36[c]
Disease efficiency (lesions/100 cm^2), fully extended fifth leaf	31.4 a	2.6 b
Disease efficiency (lesions/100 cm^2), partially extended sixth leaf	344.8 a	133.6 b
Lesion size (mm^2)	4.0 a	1.6 b
Sporulation (conidia/mm^2 lesion)	1982 a	1010 a

[a]Unpublished data from Yeh and Bonman. [b]Four *P. oryzae* isolates tested, no isolate by variety interaction detected. [c]In a row, means followed by a common letter are not significantly different (P=0.05).

Table 3. Past and present blast situation in two blast endemic locations in India (data up to 1982).

Location	Previously grown susceptible varieties	Replaced by blast-resistant high yielding varieties
Nellore	HR 12, HR 19, BCP 1	IR8 and other dwarfs
Ponnampet	S 2222, KB 356	Intan and several other dwarfs

favorable rainfed environments IR36 is seldom blasted, whereas other more susceptible varieties, such as IR50, may suffer considerable blast damage. However, when grown in a more blast-favorable environment, as in upland conditions or in lowland drought-prone areas, IR36 can be damaged by the disease. Thus, IR36 has durable blast resistance only in certain environments. The durable resistance in IR36, compared with that in IR50, is associated with a higher level of incomplete resistance (Table 2).

Other examples come from lowland rice-growing areas of India. Before the introduction of semidwarf varieties, blast was a serious problem in many traditional varieties in these areas. Nellore in Andhra Pradesh, and Ponnampet and Mercara in Karnataka state, were hot spots for blast when susceptible varieties were grown. However from 1966, with the introduction of blast-resistant entries, the locations ceased to be hot spots (Table 3).

In the blast-prone areas where varieties such as IR8 and Intan and several other dwarfs have been grown, blast no longer is the problem it was 20 yr ago. Because these varieties have not been seriously damaged by blast for so many years, they are considered durably resistant in those environments.

Durable blast resistance (upland). Under more blast-prone upland culture there also may be some cultivars with durable blast resistance. However, identifying durable resistance is more difficult in upland cultivars than in lowland cultivars, mainly because few upland cultivars have been widely grown.

Denorado, a traditional cultivar grown in the southern Philippines, appears durably resistant to blast in the upland rice-growing regions of

Zamboanga del Sur Province. In the early 1980s, C22 and other higher yielding intermediate-height cultivars were introduced into the area, but soon they became susceptible. Denorado continually showed little blast, even when grown with the same fertilizer rates and plant density as the introduced cultivars. Evidence to date indicates Denorado has durable blast resistance in this particular upland rice-growing region. As with IR36 versus IR50, Denorado has a higher level of incomplete resistance than C22. Varieties such as Denorado, which have been grown widely under upland conditions and have not succumbed to blast, could be valuable parents in breeding programs where blast resistance is a priority.

This general approach has been used at the International Institute of Tropical Agriculture (IITA) where efforts to breed upland rice have been successful. Through use of durably blast-resistant upland donors, such as Moroberekan, Dourado Precose, IAC 25, and LAC 23, a large number of lines with high yielding ability and blast resistance have been evolved (Table 4) in conventional breeding programs.

More than 50% of all rice grown in Africa is in drought-prone uplands where blast is the major constraint. It is well known that the drought-prone uplands aggravate blast disease. However, several African traditional upland varieties like OS 6, LAC 23, and Moroberekan have been grown in large tracts of upland areas by farmers over a number of years. Among these varieties OS 6 possesses incomplete resistance whereas LAC 23 and Moroberekan often show complete resistance at Ibadan, Nigeria. Indeed OS 6 is the popularly grown upland variety in Nigeria. There are no reports of breakdown in resistance of these varieties. These upland varieties, therefore, fall into the durably resistant category, in the disease-prone upland areas of Africa.

As with diseases of cereal crops (10), not all incomplete resistance to rice blast is durable. However, blast resistance that has apparently been durable in certain areas is incomplete resistance.

Several workers have attempted to screen varieties for blast resistance and use them for breeding durably resistant varieties. Some of these varieties have been widely grown and can therefore be classified as having durable resistance (Table 5). The others may eventually prove to be durable, but because they have not yet been grown over sufficiently large areas, their durability has not been established (Table 5). The resistance in such varieties has been consistent despite the wide variation in the population of *P. oryzae* in West Africa (2). Among several varieties tested in Cameroon, Dourado Precose, IRAT 10, IRAT 13, LAC 25, and 63-83 showed resistance during their entire growth period (1).

DISEASE ASSESSMENT

Leaf spot lesions can be caused by pathogens other than *P. oyzae* and in the early stages of lesion formation as when the lesion scores 1, 2, and 3, it is difficult to determine the causal pathogen (Fig. 2). Therefore, sometimes a

Table 4. Percentage of entries in different score groups of lines developed for upland situation at IITA, 1983.

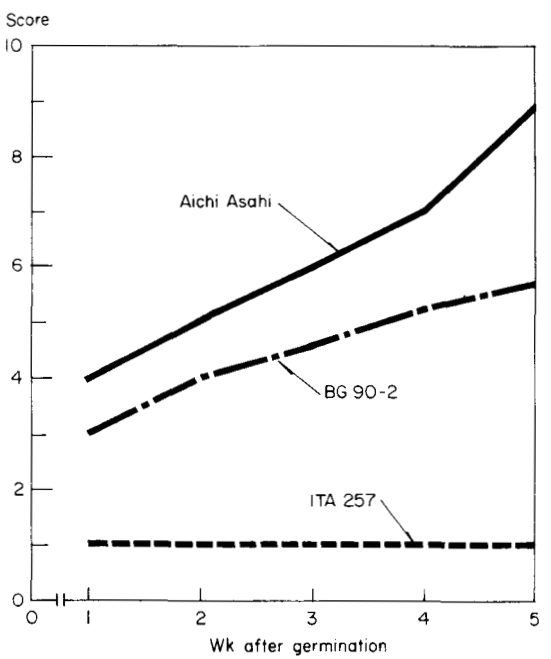
Score group[a]	Percentage
0-2	87.5
4-5	8.5
6-9	3.9

[a]Score based on IRRI *Standard Evaluation System for Rice.*

Table 5. Upland varieties with resistance to blast.

Variety	Where tested and grown
IRAT 13	Ivory Coast, Nigeria, Mali, Colombia, Cameroon
IRAT 79	Ivory Coast, Nigeria
IRAT 109	Ivory Coast, Nigeria
IRAT 133	Ivory Coast
IAC 25[a]	Ivory Coast, Cameroon, Nigeria, Colombia
Dourado Precose	Ivory Coast, Cameroon, Nigeria, Mali
63-83	Senegal, Nigeria, Colombia, Cameroon
OS 6[a]	Nigeria, Colombia
Moroberekan[a]	Nigeria, Colombia
ITA 257	Nigeria
ITA 116	Nigeria
Iguape Cateto	Nigeria, Colombia

[a]Widely grown for many years, thus can be classified as durable.



2. Blast disease progress in some selected varieties, IITA, 1984.

score of 3 and definitely a score of 4 indicates a clear infection of *P. oryzae.* An added problem is the influence of environment on the severity of the disease. Thus varieties with a high disease score in some months suffer less in other months when the environment is less conducive to the disease (6). Most discussions on resistance overlook these aspects in the assessment of resistance. Thus it is possible that a case of resistance can later be seen as a case of susceptibility.

CONCLUSION

Using parents with durable resistance is a practical approach for blast resistance breeding. From the examples of durably resistant varieties, mostly from lowland and some upland areas, it is clear that blast resistance can be achieved. Materials with higher levels of incomplete/complete resistance coming out of blast resistance breeding programs should be tested in various agroecological areas where blast is a severe constraint for rice production.

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GENE ANALYSIS FOR MAJOR RESISTANCE GENES TO RICE BLAST IN SOME BRAZILIAN UPLAND VARIETIES

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Brazil is the largest upland rice producer in the world. A total of 4.2 million ha produced more than 4.5 million t of rice in 1983. Two cultivars, IAC 47 (released in 1971) and IAC 25 (1974), which are mainly cultivated in upland areas, were released by the Instituto Agronômico de Campinas (IAC), São Paulo. With expansion of upland rice cultivation, rice blast disease became a more serious problem. Therefore, it became important to conduct research for resistance breeding to control blast disease and obtain higher and more stable yield. In the past, true (vertical, major R gene, gene specific) resistance breeding was common. The resistance gene was introduced from different sources of true resistance. True resistance to blast, however, has been shifty and unpredictable, with varieties previously considered as resistant becoming susceptible. The phenomenon "breakdown" of a resistant variety is caused by breeding of a strain of blast pathogen that did not exist during the development of the variety.

Recently, mechanisms for blast resistance as a function of individual genes have been studied. However, knowledge of resistant genes in tropical varieties is not available. Required is more knowledge of pathology, genetics, and breeding, and general information on rice cultivation. In Brazil, according to Amaral and Ribeiro (1, 2) and Ribeiro (4, 5), race differentiation was done with a set of international differentials. Results showed that there were different races in the state of São Paulo and Rio Grande do Sul. Based on reaction type to the international differentials, Yunoki and Igarashi (9) identified 10 races from 45 isolates collected from various locations in the state of Parana. However, based on the Japanese differentials 12 races could be identified. It was concluded that further studies on the choice of differential varieties and the identifying race are needed.

The breakdown of varietal resistance caused breeders and pathologists to reconsider and reevaluate field (horizontal, slow blasting, non-gene specific) and true (vertical, major R gene, gene specific) resistance breeding.

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Horizontal resistance has been called either field resistance or generalized resistance. In this report the term *field resistance* is used instead of horizontal resistance because resistance showing horizontal reaction, in the strict sense, as defined by van der Plank (8), has not been observed in any rice varieties by Japanese investigators.

Rice breeders in Japan classified blast resistance into *true* resistance and *field* resistance. True resistance is specific and qualitative resistance characterized by hypersensitivity to a pathogen. On the other hand, field resistance is resistance other than true resistance. To classify the essential nature of field resistance, investigations in Japan have been made on the basis of information on true resistance through a process of elimination (7).

Field resistance and true resistance are important in obtaining more stable yields. However, to evaluate the degree of field resistance, it is necessary to exclude the effect of true resistance. On the other hand, to evaluate true resistance it is necessary to know the relationships between blast races and resistance gene constitutions of varieties. So far, 13 major R genes in seven gene loci and their allelic relationships were identified in Japanese varieties through a set of seven fungus isolates and their mutants (3).

Estimating number of effective major R genes and characterizing the function of individual genes require gene analysis. They provide much needed information for resistance breeding.

Brazilian blast fungus isolates have been used in series of experiments to identify major R genes in Brazilian local varieties and breeding materials.

EVALUATION METHODS

Suitable materials, methods, and criteria for determining the pathogenicity of blast fungus isolates must be established to determine the major R genes under different climatic conditions.

Differential varieties

Seven major R genes and six allelic genes were identified by Kiyosawa (3) and others.

Selections of differential varieties were based on tests with 85 candidate varieties with well-known major R gene constitution and field resistance in Japan. Sixteen differentials with known genes and a low level of field resistance were selected for tests at CNPAF/EZMBRAPA, Goiânia (Table 1).

Differential races

Seven differential races were established in accordance with the reaction patterns to the above 16 differentials.

They were selected from approximately 850 blast fungus isolates obtained from different varieties in various locations in Brazil. These isolates showed relatively clear reactions to the differentials and were stable in pathogenicity through continuous subculture.

Table 1. Reaction patterns to 7 pathogenic races of the Kiyosawa and Japanese differential varieties.

N♀	Variety	Resistance gene	Code no.	Reaction to pathogenic race						
				11	39	162	240	303	305	431
1	Shin 2	K^s	1	S	S	S	S	S	S	S
2	Aichi Asahi	a	2	S	S	S	S	S	S	S
3	Fujisaka 5	i	4	S	S	S	S	S	S	S
4	Kanto 51	K	10	S	R	S	S	R	R	R
5	Tsuyuake	K^m	20	R^h	R^h	R^h	S	R^h	R^h	R^h
6	Fukunishiki	z	40	M	MR	R^h	R^h	R^h	R^h	S
7	K 1	ta	100	S	S	S	R	S	R^h	S
8	Pi No. 4	ta^2	200	R^h	R^h	R^h	R^h	M	R^h	R^h
9	Toride 1	z^t	400	R^h	R^h	R^h	R^h	Rh	R^h	R^h
10	K 60	K^p	0.1	S	S	S	R^h	S	S	S
11	BL 1	b	0.2	R^h	R^h	R^h	R^h	R^h	S	R^h
12	K 59	t	0.4	S	S	S	S	R^h	R^h	R
13	K 3	K^h	1.000	R	R	R	R	R^h	R^h	R
14	Kusabue	K	10	R	R	S	S	R^h	R^h	S
15	Zenith	z, a	42	S	S	R^h	R^h	R^h	R	R^h
16	K 2	K^s, a	3	S	S	S	S	R^h	R^h	S
	Code no.			157.5	147.5	117.5	1037.4	307.1	7.3	147.1
	Origin variety			IAC 25	IAC 25	IAC 47	SR-2041-50-1	IRGA-408	BR-IRGA-409	COL. 163
	Location			CNPAF GOIAS	CNPAF GOIAS	JATAI GOIAS	CNPAF GOIAS	URUSSANGA ST^a CAT.	URUSSANGA ST^a CAT.	CHAPECO ST^a CAT.

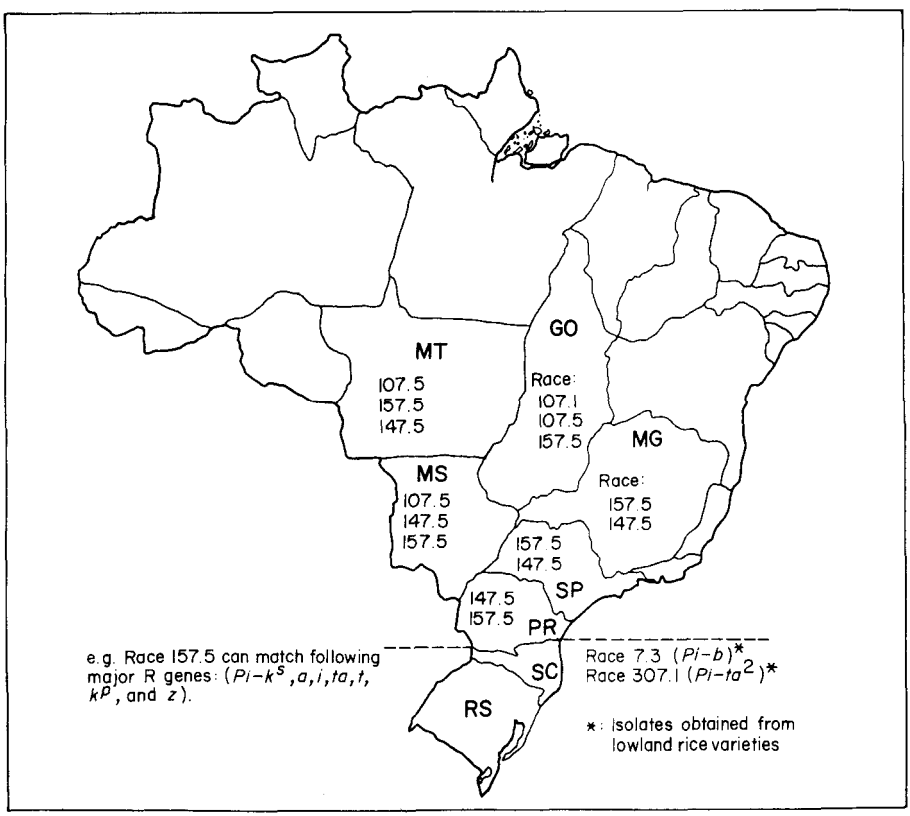
It is possible to estimate the following 9 out of 13 known major R genes, *Pi-k, z, t, ta, ta*^{2}, *b*, k^p, k^m, and k^h using the seven Brazilian races.

Gene markers

Aichi Asahi (*pi-a,* susceptible) and Toride 1 (*pi-z*^{t}, resistant) are used as gene markers in F_2 progeny tests of Brazilian varieties and introduced materials to estimate the number of major R genes. They show typical susceptible or resistant reaction to all Brazilian blast fungus isolates. To estimate the major R genes in Brazilian varieties, a set of differentials (7 gene loci) were used for a diallel cross.

RACE FREQUENCY AND DISTRIBUTION IN BRAZIL

Knowledge of race frequency and distribution of blast fungus is essential to forecast epidemics, predict breakdown of varietal resistance, and develop breeding strategies. Figure 1 shows race frequency and distribution of predominant races in upland and lowland areas in Brazil (1981-82).



1. The distribution of main races of blast in each state of Brazil (1981-82).

Observations over 3 yr (1981-84) showed no change in race composition both within upland and lowland areas reflecting the host cultivars grown in each location. There was a critical difference in race frequency between upland and lowland cultivated areas.

In upland areas, the predominant races were 107.5 and 157.5, which are mainly specific to the following major R genes: *Pi-a, i, k, ta,* k^p, and *z.* On the other hand, in irrigated areas, predominant races were 7.3 and 307.1, which are specific to *Pi-b* and $Pi\text{-}ta^2$ major R genes, respectively.

The race frequency and distribution in upland rice suggested that the constitution of resistance genes in upland cultivars are mainly controlled by *Pi-a, i, k,* k^p, k^s, *t, z,* and possibly others yet to be identified. On the other hand, resistance in many lowland cultivars in the southern part of Brazil are mainly controlled by $Pi\text{-}ta^2$, *b,* k^h, and unidentified genes. These results should be confirmed by gene analysis.

GENE ANALYSIS OF MAJOR R GENES

Some widely grown cultivars and their parents (IAC 47, IAC 25, Matão Perola, Pratão, and others) were crossed with a total of 12 Japanese and Kiyosawa differentials with resistance genes at seven loci (*Pi-a, i, k, ta, b, z, t*). The results of F_2 progeny tests of cultivars IAC 47 and IAC 25 using three different pathogenic races are shown in Tables 2 and 3. The analysis of the segregating F_2 populations indicated that they have major R genes to blast.

The segregating ratio varied from monogenic (3:1) to trigenic (63:1) in accordance with the races. The F_2 population size was not adequate to estimate trigenic segregation; however, the results showed that IAC 47 and

Table 2. Segregation ratios of resistant and susceptible plants in F_2 population of crosses between IAC 47 and gene markers.

Combination	Major R gene	Race (code no.)		
		39 (147.5)	240 (37.4)	303 (307.1)
IAC 47/Aichi Asahi	*Pi-a*	3:1	3:1	3:1
Fujisaka 5	*Pi-i*	3:1	3:1	3:1
Kusabue	*Pi-k*	15:1 (?)	15:1	15:1 (?)
Kanto 51	*Pi-k*	15:1	?	15:1
K1	*Pi-ta*	N.S.[a] (MR-S)	3:1	15:1
BI 1	*Pi-b*	15:1	15:1 or 63:1	15:1 or 63:1
Fukunishiki	*Pi-z*	15:1[b]	15:1 or 63:1	15:1[b]
Zenith	*Pi-z. a*	N.S.[a] (M-S)	3:1	15:1[b]
Toride 1	$Pi\text{-}z^t$	63:1	15:1[b]	15:1 or 63:1
Pi No. 4	$Pi\text{-}ta^2$	15:1[b]	15:1[b]	15:1
K 3	$Pi\text{-}k^h$	15:1	15:1	15:1
K 59	*Pi- t*	15:1	15:1	15:1
IAC 25		15:1	15:1	15:1 or 63:1
IRAT 13		3:1	15:1[b]	15:1

[a]No segregation and all F_2 populations showed either resistant or susceptible reaction, [b]Both parents are resistant.

Table 3. Segregation ratios of resistant and susceptible plants in F_2 population of crosses between IAC 25 and gene markers.

Combination	Major R gene	Race [a] (code no.)		
		39 (147.5)	240 (37.4)	303 (307.1)
IAC 47/Aichi Asahi	*Pi-a*	3:1	3:1 (?)	3:1
Fujisaka 5	*Pi-i*	NS	1:3 (?)	3:1
Kusabue	*Pi-k*	15:1	15:1	63:1
Kanto 51	*Pi-k*	NS (S)	NS (M-S)	15:1 or 63:1
K 1	*Pi-ta*	3:1	15:1	3:1
BI 1	*Pi-b*	15:1	15:1 or 63:1	15:1 or 63:1
Fukunishiki	*Pi-z*	3:1	15:1 or 63:1	15:1 or 63:1
Zenith	*Pi-z. a*	NS	15:1 [b]	15:1 or 63:1
Toride 1	*Pi-z* [t]	15:1	15:1 or 63:1	15:1 or 63:1
Pi No. 4	*pi-ta* [2]	15:1	15:1 [b]	15:1
K 3	*Pi-k* [h]	3:1	15:1	15:1
K 59	*Pi-t*	NS (S)	(MR-S)	(R^h)

[a] N. S. = no segregation and all F_2 populations showed either resistant or susceptible reaction. [b] Both parents are resistant. [c] One parent is resistant, another is susceptible.

IAC 25 have at least two major R genes. The F_2 progeny test of a cross between IAC 47 and IAC 25 showed digenic (15:1) segregation to all the three races and possibly each one of them possesses a different major R gene. The cultivar IAC 25 showed no significant segregation in F_2 populations when crossed with the differential K 59 (*Pi-t*), indicating thereby that the former is identical or closely linked with the *Pi-t* gene. On the other hand, these two cultivars do not possess *Pi-b*, ta^2, and z^t genes. Some parents of the above cultivars such as Perola, Matão, Pratão, Dourado Precose, Pratao Precose, and Cateto were intercrossed to determine the linkage relationships of these resistance genes. The results of F_2 progeny tests suggested that these varieties have genes which are identical or closely linked with one of the resistance genes of Zenith. The results showed that the Brazilian rice varieties possess certain major R genes not previously identified in Japan.

MAJOR R GENES IN INTRODUCED MATERIALS

Identification of major R genes in indica and javanica varieties has been initiated.

At first, the introduced materials were evaluated for existence of major R genes by the artificial inoculation method using a set of standard races. Results showed that they can be classified into different groups based on their reactions to the differentials (Table 4, 5). After this evaluation, some materials in the same group were crossed with each other and with some selected differentials to estimate the major R genes in further F_2 tests. Estimation of major R genes and their linkage relationships needs further F_3 progeny tests. On the other hand, it requires a set of fungus races, which possess specific pathogenicity to certain major R gene or genes. Identification of useful major R genes and a high level of field resistance in these

Table 4. Classification into categories by reaction patterns in accordance with the major R gene (upland varieties).

	Variety or line
Pi-b (BL 1 type)	CNA 296-B-BM27, BR 51-46-5, GA 3463, GA 3464, IET 2881, BG 90-2, Miliyang 30, T 1, A 105, CGA 62, Diwani, M 302, Filipinas, BR 1, Ram Tulasi, Nanicao, De Marias, De Abril.
Pi-k^m (Tsuyuake type)	CNAx 104,434 R, EEPG 369, SR 2041-50-1
Pi-k^h (K 3 type)	IR34
Pi-ta^2 (Tadukan type)	Tadukan
Pi-z^t (Toride 1 type)	CNAx 2432, CO 25, C 4615, IREM 16B, TKM 1, Moroberekan, Arroz de Guerra, Tres Marias, TOS 2259, Carreon

Table 5. Classification into categories by reaction patterns in accordance with the major R genes (lowland varieties).

	Variety or line
Pi-a (Aichi Asahi type)	Blue Belle, IAC 435
Pi-ta^2 (Tadukan type)	IRGA 408, IR 9202-21-1, P 805-84-4-1T
Pi-k^h (K 3 type)	Dawn, Lebonnet
Pi-z (Zenith type)	Zenith
Pi-b (BL 1 type)	BR-IRGA 409, IRGA 410, EMPASC 101, EMPASC 102, EMPASC 103, IAC 899, IR 22, IR 24, IR 841, IR 6441-JN-6B, RS 16-516-1-16-1T-1, BG 90-2
Pi-z^t (Toride 1 type)	ClCA 8, ClCA 9

varieties provides information for the future breeding program. Many Brazilian varieties are supposed to belong to javanica, the so-called intermediate type according to the phylogenic differentiation (acid phosphate, phenol reaction, grain characteristics and sterility) (6). The problem of sterility was overcome in crosses with Japanese differentials.

Before the breeding materials are introduced to the national breeding programs, the identification of major R genes and estimation of the number of effective major R genes should be evaluated.

DISCUSSION AND CONCLUSIONS

The use of single genes to control blast disease is risky, as it may cause the broadly cultivated resistant variety to break down in a few years. Field resistance of the varieties is estimated by the degree of damage in the field where the virulent fungus races are prevalent. Field resistance itself is influenced by environmental conditions and has less effect than true resistance.

In Japan, the genotype of blast resistance has been determined for about 3,000 varieties, including almost all commercial varieties. Furthermore,

information available on the level of field resistance to certain pathogenic races in all these varieties is effectively used for predicting the breakdown of varietal resistance and in forecasting blast epidemics to minimize damage by blast disease.

The indica and javanica varieties have not been studied for their major R genes. Some varieties did not show the race specificity at certain locations; under different conditions specificity could be demonstrated. Whether these varieties with high levels of field resistance show only their effect because of field resistance or because of the accumulation of major R genes under different conditions is not known. It is important for cooperative research at many locations to identify their effective major R genes.

The level of field resistance can be measured by inoculation of the fungus isolates that can match the major R gene or genes in the host varieties. It will lead to the possibility of utilizing different strategies to control or minimize the yield losses from blast epidemics. The combination of major R genes and field resistance, or gene rotation using different major R genes are practical control methods. Multiline, multivariety, composite variety, and F_1 hybrid breeding can also be developed by using the results of gene analysis.

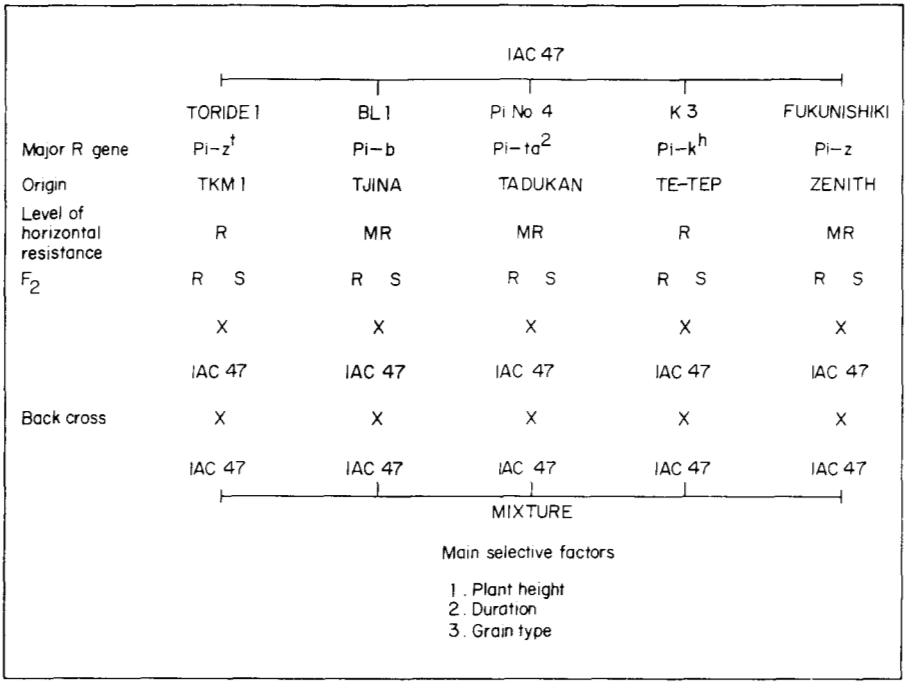
The ambiguous reaction shown by Japanese differentials to some Brazilian blast fungus isolates at different locations suggested that some differential varieties may have other effective major R genes besides the 13 major R genes that were identified in Japan. In other words, many unidentified genes in Brazilian varieties are effective under different conditions. A set of seven differentials that have different major R genes at different gene loci are used for gene markers. By studying F_2 populations, the linkage relationships among these different genes can be estimated.

Whether or not the resistance gene in a variety is effective under a different race constitution remains a major question. These reactions and results at different locations should be compared.

The Brazilian land varieties showed excellent adaptability for upland cultivation and possessed high levels of field resistance to blast. They were screened under natural conditions with severe epidemics for a few decades.

There is no doubt as to the introduction of major R gene sources such as *Pi-b*, z^t, and ta^2 which are supposed to be effective even though temporarily. There are several examples of breakdown of varietal resistance resulting in vertifolia effect.

Introduction of major R gene is normally easy as a breeding technique. However, the replacement of major R gene only results in new corresponding fungus strains. The principle problem cannot be solved by this replacement method. These improved materials will inevitably break down in the future if a suitable method is not applied to breeding for resistance. At first we should know the background of major R genes and the level of field resistance in each variety and introduced materials. Some breeding methods not suitable under upland cultivation in Brazil resulted from the lack of basic research and seed production cost. Existing basic information is useful for



2. Model of near-isogenic lines of IAC 47 using 5 different major R genes.

the multiline approach and incorporation of major R genes into cultivars with a high level of field resistance. Figure 2 shows a model of near isogenic lines of IAC 47 by using five different major R genes.

Further, the F_1 hybrid method may be effective if the basic economic problems for seed distribution are resolved.

The basic information on genetics is also useful for monitoring the frequency of blast races at each location to predict future breakdown of varietal resistance.

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BLAST RESISTANCE METHODOLOGIES IN THE IVORY COAST, 1972-85

J. L. NOTTEGHEM

ABSTRACT

Many recent analyses of blast resistance of upland rice prove that most varieties have one or two genes of vertical resistance and various levels of horizontal resistance. Interactions of the two kinds of resistance make it necessary to use a breeding program that includes: the analysis of the resistance of the parents, an efficient method of screening from F_2 to F_8, and an analysis of the resistance of the most promising lines. Several new techniques are being tried in the Ivory Coast where first results are promising. Their use is necessary in obtaining new improved varieties with a higher level of horizontal resistance.

A multidisciplinary program of breeding for upland rice began in the Ivory Coast in 1972. The main objective was to obtain new varieties with a stable resistance to blast, resistance to drought, and stable yields.

Before 1970, breeders observed that traditional upland varieties have a resistance to blast that remains stable for many years. Bidaux's experiments (2) led him to the conclusion that these varieties have a nonspecific and polygenic resistance similar to horizontal resistance (HR), as defined by van der Plank (18). This resistance was different from the race-specific monogenic resistance (VR, vertical resistance), studied by Kiyosawa (8), which so often broke down.

Recently breeders have used different techniques to classify rice varieties into different groups. Jacquot and Arnaud (7) used a method based on analysis of several morphological characters. Then Glaszmann et al (6) used isozyme analysis. These results have been complemented by the study of F_1 and F_2 progenies obtained by crossing varieties from different groups (4, 5). This classification greatly helps breeders and plant pathologists to construct breeding programs. Studies on the heritability of horizontal resistance in different types of crosses are under way.

Success in breeding for HR requires a clear analysis of the resistance of the parents and a screening technique that permits the breeder to choose the lines with the resistance wanted.

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BREEDING FOR STABLE RESISTANCE TO BLAST

Bidaux (2) analyzed rice blast interactions in the Ivory Coast. He observed that in Africa races of blast exist that are virulent against any of the genes of vertical resistance (VR) identified by Kiyosawa (8). There are, however, traditional African upland varieties that possess a high level of HR. In the field this HR has the main effect. These observations led the breeder to the following strategy:

1. The parents are chosen from upland varieties that show a stable resistance during many years in upland fields at Bouaké (Ivory Coast).
2. It is necessary to discard lines that show a total resistance in the fields and to choose those that exhibit a few small lesions.

At the International Institute of Tropical Agriculture (IITA) Buddenhagen (3) recommended the screening of lines seeded along slopes from upland to lowland conditions, and the use of a susceptible spreader to increase the epidemic. Variations in the amount of spores produced by the spreader and variations due to different conditions of culture result in differences in the amount of disease on the tested lines. This method makes it possible to evaluate the level of resistance of each line under different environmental conditions.

However, in the Ivory Coast and at IITA, the progeny lines were tested with a natural epidemic produced by an unknown blast population. Do interactions between VR and HR effects allow the breeder to screen for a chosen type of resistance?

ANALYSIS OF COMPLETE RESISTANCE OF UPLAND VARIETIES

Kiyosawa (9, 10) made a clear analysis of the VR of the Japanese varieties and of some foreign varieties. He used two techniques. The first one is the inoculation of rice varieties with a collection of differential strains of blast. The second is analysis of the heredity of the resistance by inoculation of F_2 and F_3 obtained by crossing the tested variety with some of the Kiyosawa set of differential varieties. During recent years, several researchers have carried on similar experiments with upland varieties.

Upland varieties inoculated with differential strains

Bidaux (2) observed on traditional upland varieties typical reactions of resistance or susceptibility to different local strains of blast. Vodouhe (19) inoculated 36 varieties (most of them upland) used as parents at Bouaké, with Kiyosawa's differential strains of blast (Table 1). Vales (pers. comm.) did the same with 13 varieties from Brazil. Tanaka (15, 16, 17) in Brazil inoculated many local and foreign varieties with six local differential strains of blast. These experiments indicate that nearly all upland varieties have differential reactions when inoculated with different strains of blast.

Analysis of heredity of complete resistance. Tanaka (15, 16, 17) studied heredity of the complete resistance of 31 varieties, mainly upland, by

Table 1. Results of inoculation of 36 varieties with Kiyosawa's differential and CI41 strain of blast (19).

Rice varieties	Kiyosawa's differential set of blast strains							Strain from Ivory Coast
	Hoku 1	INA 168	INA 72	P2 b	KEN 5333	KEN 5420	KEN 5404	CI 41
902 TONI	R	R	R	R	R	R	R	S
R 67	R	R	R	R		R	R	S
RT 1031 69	R	R	R	R	R	R	R	S
Makouta	R	R	R	R	R	R	R	S
Moroberekan	MR	R	S	S	S	MS	S	S
62 667	R	R	MS	MS	R	R	R	S
63 104	R	R	MR	MS	S	MS	R	S
Pate Blanc Man 1	MS		S	S	S	MR	R	S
Chianan 8	S	S	S	S	S	S	S	S
63 83	R	R	R	R	R	R	R	S
H 105	MS	R	MS	R		MS	R	MR
Carreon	R	R	R	R	R	R	R	MR
Tjempo Welut	S	R	S	S	MS	R	S	S
DK 11	S	R	S	S	S	S	S	S
Todoroki Wase	S	R		R	S	S	R	S
Fossa HV	S	S	S	S	S	S	S	S
Chiu Tswoh Tao Yi	S	S	S	S	MS	S	S	S
Bansi	R		R	R	R	MR	R	R
Cuttack 4	MR	MR	R	S	R	S	MR	S
Tainan Iku S 12	S	S	S	S	S	S	S	S
Sa-moow-thou-goo	S	MS	S	R	MR	MR	MS	S
R 3-1	R		R	R	MR	R	R	R
Teksichut	R		R	R	R	R	R	R
Pursigui	R	S	MS	R	R	R	R	R
Khao Mone Tia	S		R	MS	S	S	MR	MS
Khao Hay	R		R	R	R	MR	R	R
KH Chebrock	R		R	R	R	R	R	S
Khao Chao	S		R	R	MS	MS	S	MS
Ku 86	R		R	R	R	R	R	R
Bete 3	R	R		MR	MR	R	R	R
Hyb. 1716/2/3/3	MS	R	MR	MR	R	S	R	S
IRAT 105	S	S	S	S	S	S	S	S
BG 90-2	S		S	R	R	R	R	S
Lung Sheng 1	S	S	S	S	S	S	S	S
IRAT 13	R	R	R	R	R	R	R	S
Delta (S check)	S	S	S	S	S	S	S	S

inoculating F_2 with five differential strains of blast. The crosses were R/S type, or R/variety/one variety of Kiyosawa differential set. He observed that most of the time complete resistance is due to one gene and, in some cases, to two genes. In a few cases the resistance heredity is more complex.

Vodouhe (19) inoculated the F_2 of 16 crosses with some of Kiyosawa's differential set of blast strains. He observed that the source of complete resistance in nine varieties is one dominant gene, that in one variety two dominant genes, and that in three upland varieties from Laos two complementary genes. Similar results were obtained in the Ivory Coast with the same F_2 inoculated with local strains.

The main conclusion is that the complete resistance of upland rice varieties is similar to that of japonica-type varieties studied by Kiyosawa. It is a VR.

Effect of vertical resistance

Except in a few cases, it is impossible to distinguish between symptoms caused by VR or HR. In some cases an avirulent strain makes small lesions with a gray center. Often under good environmental conditions in the field, HR limits the symptoms to small lesions.

Theoretically symptoms that the breeder observes in his fields may result from several causes:

- All strains of blast are virulent on the two parents of one cross. Only HR is working and the breeder can evaluate its level in each line. For this purpose, this is the best situation.
- All strains are avirulent on one or two of the parents. This case may occur often. In the Ivory Coast in 3 breeder's fields, in 1982 and 1983, the percentages of parents with complete resistance were 17%, 39%, and 47%. In this case it is possible to screen for VR, but not for HR.
- An unknown proportion of the strains is virulent on the parents. In this case the breeder cannot know if a low level of disease is caused by HR or a low percentage of virulent strains. The existence of many different genes of VR and the occurrence of many different races make frequent occurrence of this case hardly probable.

Few observations prove it, but if we compare the resistance of IAC47 and IRATl3 in Brazil, where strains of blast virulent on IAC47 are dominant (16), and in the Ivory Coast, where IAC47 is not grown, we observe different scores. In Brazil, IRAT13 seems more resistant than IAC47. But in the Ivory Coast, in field or greenhouse, with strains virulent to the two varieties, HR of IAC47 is almost as high as that of IRAT13.

It is useful to trap spores by putting sets of differential varieties in the breeder's field. With a natural epidemic we observe great variations in the relative numbers of lesions on the different varieties, probably because of variations in the percentages of virulent strains on each variety. This will also occur on progeny lines.

In a large field where only one variety is grown, only virulent strains can develop. But in the breeder's fields, where a mixture of susceptible

spreaders, and lines and parents with many different genes of VR is grown, we have no idea of the virulence of the blast population and of its evolution. But we have observed spectacular changes in virulence. During some seasons, we observed lines and parents, known to have vertical genes and a low level of HR, in fields where heavy epidemics occurred. They had no lesions at the beginning of tillering but were destroyed at the flowering stage. This was typical on some semidwarf varieties in Goiania (Brazil) in 1983 and in Odienne (Ivory Coast) in 1984.

PROGRESS IN HORIZONTAL RESISTANCE STUDIES

Reports of studies on HR are few.

Heredity of horizontal resistance

Recently in the Ivory Coast, we used local races of blast to inoculate in the greenhouse the F_2 populations of 16 crosses. This gave us results (Fig. 1) that show a clear difference when vertical resistance is or is not efficient, and when the strains of blast are virulent or not on the R parent. The cases of races virulent on the two parents show clearly that the resistance of the F_2 population is intermediate between the two parents (Fig. 2). We have checked this result with crosses including the following upland varieties: IRAT13, IRAT10, Moroberekan, R67, 6383, RT1031-69, Bete 3, 63104, Fossa HV, Pate blanc Mn, IAC47, and Lung Sheng 1 (M. S.)

We know that there is no complete polygenic resistance and we call it horizontal, in contrast to the specific, complete, and monogenic resistance that we call vertical (18).

The heredity of this HR is intermediate. We have much greater chances of getting new resistant progeny lines if we cross parents with a high level of polygenic resistance. The choice of parents is important in breeding for polygenic resistance.

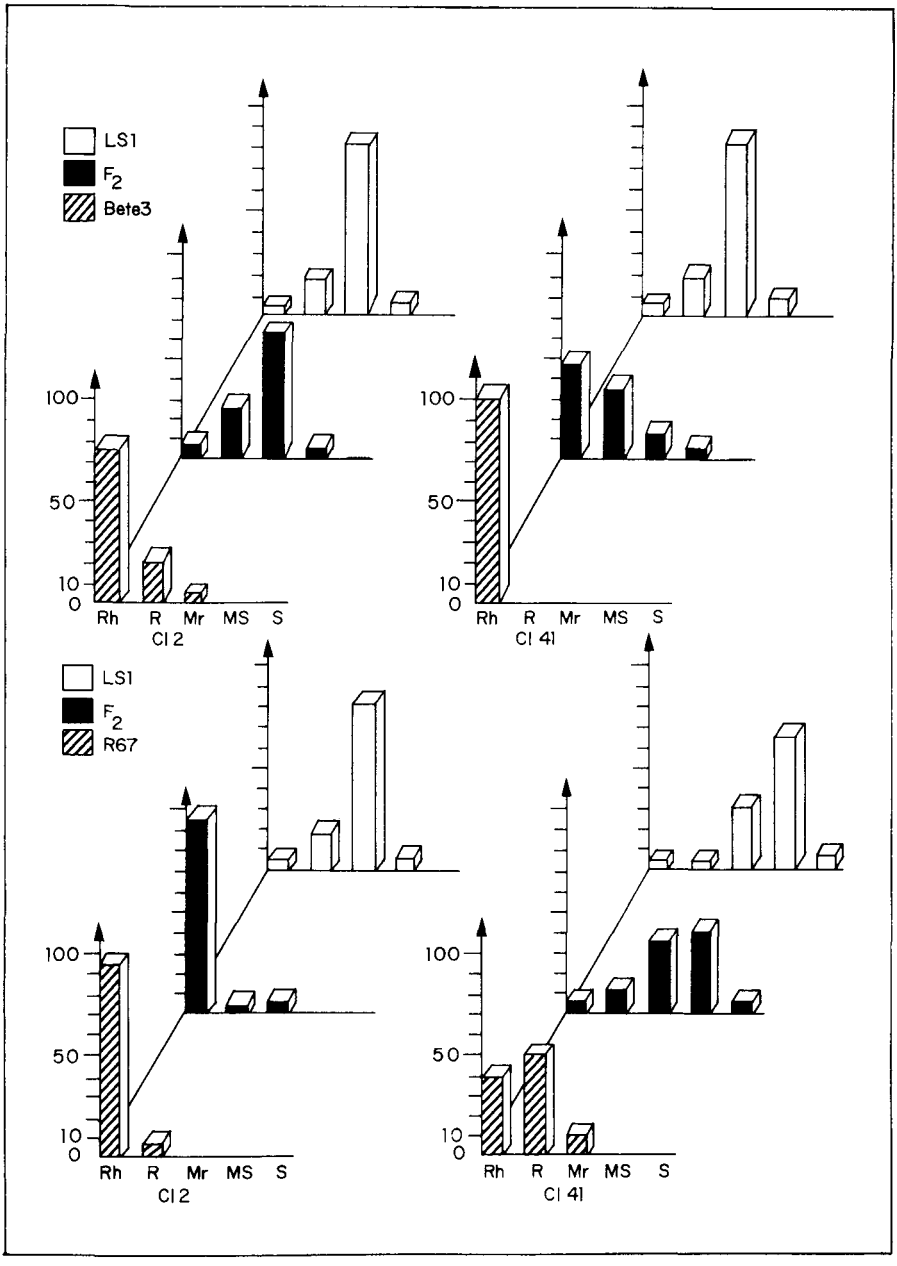
Environment-horizontal resistance interactions

Seguy et al(14) demonstrated the effect of different soils on blast. Prabhu (pers. comm.) said, “there are no resistant varieties,” because he observed in upland areas in Brazil yield losses with all improved released varieties. This means that varieties such as IAC164 and IAC47 may have losses of about 70% in a few fields. In the Ivory Coast also heavy losses on IRAT13 were observed. That means that if the environment is favorable to blast, varieties that seem to have HR may suffer heavy losses.

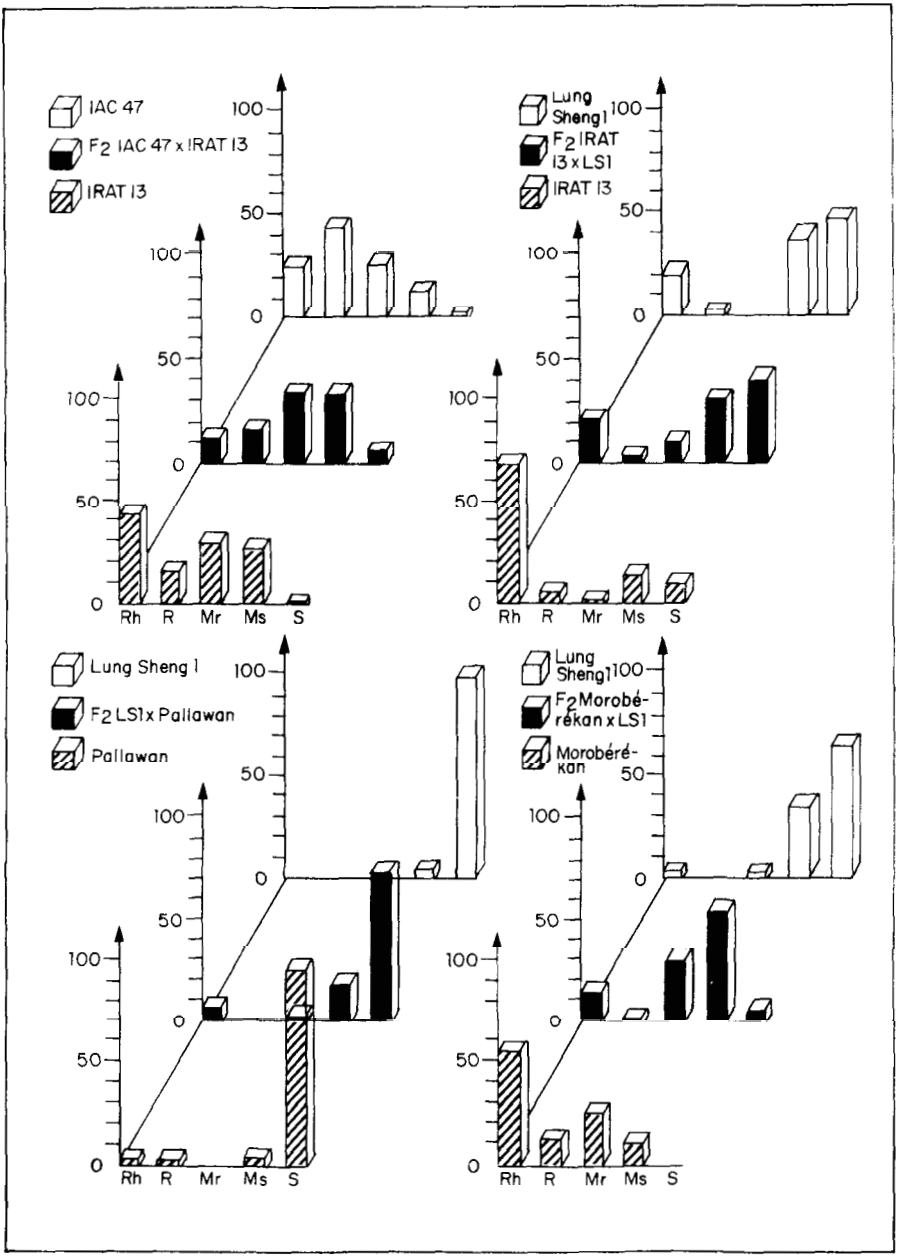
A HORIZONTAL RESISTANCE BREEDING STRATEGY

In 1976, in Madagascar we developed a method of obtaining improved varieties with a high level of HR (12, 13). Since 1981 we have applied these techniques with some improvement in the Ivory Coast.

These techniques are tools to be used by breeders and plant pathologists to learn about the kind of resistance being screened for. These tools are:



1. Repartition in 5 classes (R-S) of percentages of plants, of parents (Bete 3, R67, Lung Sheng l), and F_2 (Bete 3 × Lung Sheng 1, R67 × Lung Sheng l), inoculated with two strains of blast (CI2, CI41) at 1-mo stage in a greenhouse.



2. Comparison of the repartitions in 5 classes (R5) of plants of parents and F_2 of 4 crosses, inoculated with the virulent strain CI58, in a greenhouse, 3 wk after seeding.

Analysis of parents' resistance

Breeders usually choose the parents among thousands of varieties, about 4000 at Bouaké and many more in international research centers. However, a complete analysis of resistance cannot be realized with so many varieties. The first step must be the determination of a restricted list of varieties; perhaps 300-500. This is much easier now because breeders have a better knowledge of the heritability of the main characteristics of their germplasm. Then studies on resistance of the parents can begin.

Inoculating parents with differential strains of blast. A first-step analysis of the VR of the parents is important to identify strains virulent on many varieties. The most virulent strains are useful for DITER experiments (12) or for other screenings.

Crossing a parent with a reference variety. If the reference variety has an identified gene of VR, as one of Kiyosawa's differential, crossing it with a resistant parent identifies genes of VR in the parent. If the reference variety is susceptible, it is possible to analyze the heredity of the quantitative resistance. It is the best method to check if the resistance of the parent is polygenic with the strains of blast used for field tests.

Field tests. Field tests are indispensable for evaluating the level of HR of the parents. The DITER method (11) is efficient. The strain of blast used for the experiment must be virulent on all the tested varieties.

Screening from F_2 to F^n

In the Ivory Coast a spreader made with a mixture of two varieties (Delta S, Lung Sheng 1 MS); and three check varieties (IRAT13 R, Lung Sheng 1 MS, Delta S) are used between tested lines. The spreader ensures a strong epidemic and makes it homogeneous in all the field. The check varieties show how strong and how homogeneous the epidemic is.

Scoring method. For each line we score leaf blast three times. The first scoring is done 15 d after the beginning of the epidemic, then every 10 d using a reference scale based on the percentage of diseased leaf area. We also note the percentage of sterility due to neck blast about 1 wk before maturity. For each line, scoring is made at 0.5 m from the spreader and at the opposite side. There is no fixed level of incidence for discarding lines because of variations of blast according to years and locations, but we compare the scores of progeny lines with those of check varieties and parents, and we keep only lines better than well-known varieties in field performances.

Monitoring the virulence of strains in breeding fields. Differential sets of varieties and parents of crosses are seeded in trays in a greenhouse. Three weeks later, they are placed in breeder fields for 2 d, then in a humid chamber for 1 night. One week after, a measurement is made of virulence of the blast population occurring in the breeder's field. This method is efficient to let the breeder know if the VR is efficient and if he can screen for HR.

Inoculating blast strains in breeders' fields, The artificial inoculation of the spreader in breeders' fields ensures a regular, strong epidemic on time. In the Ivory Coast we began to inoculate a pure strain obtained by mono-

conidial isolation and in vitro culture. We have an improved simple method of storing dry spores. The inoculation is made by syringe injection, 3 wk after seeding, on 3 tillers each 0.5 m on the spreader. The race of blast is chosen among several races tested by inoculating the parents in the greenhouse before the field experiment, so the breeder knows which cross he can screen for HR.

In 1983, in Odienne, the breeder's field was isolated from other rice fields. Using 35 varieties we compared the virulence of the inoculated strain with the virulence of spores collected on necks 4 mo later. The virulences of the two samples were similar except for three varieties. In other cases, breeder's fields were not isolated. In Bouakè in 1984, we observed the development of a natural epidemic in a small part of the breeder's field at the time of inoculation.

We still must experiment more to know the variations of virulence in a breeder's field after inoculation of one race. We also must choose isolated fields, as in the case of hybrid maize seed production.

It now seems possible to control the spread of an epidemic with a selected race and to reduce to a negligible level the HR-VR interactions due to a natural epidemic.

Locations of screening. It is difficult to find one strain virulent on all parents, but it is possible to find strains virulent on many parents (Table 2). In the Ivory Coast screening is done at three locations - Bouaké, Man, and Odienné — where different strains are inoculated. These strains were isolated the previous year in the location where an inoculation is planned. By choice of strains we can ensure one or more locations for all tested crosses where the inoculated strain is virulent on the two parents. The progeny lines are also tested at F_4 with natural epidemics in several other countries: Mali, Burkina Faso, Senegal, Benin, Cameroon, Brazil. This also provides the scores of lines tested with different populations of blast in different environments.

Screening fixed promising lines. The methods of testing that must be applied to these lines are similar to those applied to the parents. Inoculating F_2 obtained by crossing these lines with a susceptible variety is necessary to check that the resistance we have is polygenic (horizontal) with the strains of blast used for field tests.

HOW TO USE VERTICAL RESISTANCE

There is a great risk in releasing varieties which have VR and a low level of HR because of the fast breakdown so often observed. So the first step of a program of breeding for VR is to obtain varieties with a high level of HR. The second step will be to incorporate into these varieties, by backcrossing, chosen genes of vertical resistance.

With this strategy, we can hope that virulent races will not spread fast, because most of the time the HR is adequate to stop the epidemic. If the occurrence of virulent races is greatly reduced, we shall have more chance of

Table 2. Comparison of the virulence of five strains of blast isolated on IRAT13. Strains 49, 55, 58 were inoculated in breeders fields at Odienne, Man, and Bouaké in 1984 in the locations from where they had been isolated in 1983.

Rice varieties	Strain of blast				
	S 58	S 55	S 49	S 48	S 41
Shin 2 Pi-ks	5	5	5	4	2
Aichi Asahi Pi-a	5	5	5	5	5
Fujisaka 5 Pi-i, Piks	5	5	5	5	5
Kusabue Pi-k	5	5	5	5	5
Tsuyuake Pi-km	4	3	5	1	4
Fukunishiki Pi-z	4	3/4	5	5	5
KI Pi-ta	5	1	5	4	1
Pi n° 4 Pi-ta²	1	1	1	1	1
Toride 1 Pi-zt	5	1	5	5	2
K60 Pi-kp	0	1	4	3	1
K3 Pi-kh	0	1	4	1	2
BL1 Pi-b	5	3	1	5	1
K59 Pi-t	5	5	5	6	5
IR 8	1	2	1	1	1
Ceyswoni	1	1	1	1	
Tetep	1	1	1	1	1
Carreon	1	1	1	1	1
Tecksichut	1	1	1	1	1
Columbia 1	4	3	4	4	4
Chianan 8	5	3	5	5	
No Iku 1517	5	5	4	5	
Todoroki wase Pi-i	5	4	5	5	
Tainan Iku 512	5	4	4	5	
31/8/6	4	3	2	4	3
Jaya	3	1	1	1	
IR 5	5	5	5	5	
Bouaké 189	1	1	1	1	
BG 90/2	1	1	1	1	
63-83	5	3/4	5	5	
Makouta	1	2	3	3/4	1
Moro	2	1	1	3	1
63-104	3	4	3/4	4	1
RT 1031-69	2	1	1	2	2
Re 19 A	5	1	5	4	4
R 67	5	1	1	5	1
Khao Mone Tia	1	1	1	1	
Iguape C.	5	4	5	5	1
Dourado P.	5	4	1	3	1
IAC 25	5	1		3	1
IAC 47	2	2	2	2	
IAC 164	2	2	2	2	
IAC1246	5	3	2	5	
IRAT 10	4	3/4	5	4	1
IRAT 13	5	4	5	5	5

Continued on next page.

Table 2. Continued.

Rice varieties	Strain of blast				
	S 58	S 55	S 49	S 48	S 41
IRAT 112	4	4	5	4	1
IRAT 109	4	4	4	4	3
IRAT 144	5	5	4	4	
IRAT 136	5	4	1	4	
IRAT 170	5	4	4	5	5
ISA 6	4	4	5	4	
H 105	1	0	1	2	
Pursigui	3	0	1	1	
LAC 23	1	3	1	2	
Pate Blanc Mn	4	0	1	3	
Tjempo welut	2	2	2	2	
Lung Shen 1	6	6	5	5	

Type of lesions: 1 no lesion; 2 bs; 3 bG; 4 bG; 5 pG; 6 pG; – compatible reaction

having an efficient vertical resistance when necessary, for example, in the case when environmental factors greatly reduce the efficiency of HR.

Bidaux (2) had proved that some identified genes, such as *Pi-Zt*, *Pi-ta*^{2}, are often efficient in West Africa. Varieties such as Tetep and Carreon have a good combination of vertical genes. Upland varieties have also genes for VR different from those of Kiyosawa's differential varieties. We have also observed that upland varieties from Laos have VR efficient in many locations. A recent experiment demonstrated VR in *Oryza glaberrima.* The sources of new genes for VR are many. The strategy of incorporating VR into varieties that have a good HR looks promising.

CONCLUSION

Twelve years of experimentation in West Africa, and important results by researchers of Centro Nacional de Pesquisa de Arroz e Feijão in Brazil, have given a clear understanding of the resistance of upland rice to blast. We know that almost all upland varieties have one or two genes for VR, which is specific, complete, and monogenic. They also have various levels of HR that is not complete and polygenic.

The main difficulty in breeding for horizontal resistance is the interaction between horizontal and vertical resistance. It is impossible to differentiate between symptoms caused by VR and those caused by HR. It is necessary to develop techniques to analyze the resistance of the parents and techniques to monitor the virulence of strains of blast occurring in breeder's fields.

The variations in the level of HR, in relation to variations in the environment, make it necessary to obtain new varieties whose level of HR is higher than that of varieties currently released to farmers.

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SCREENING TECHNIQUES TO IDENTIFY SLOW-BLASTING RICE LINES

M. A. MARCHETTI and LAI XINGHUA

The term *slow-blasting* describes the effect of one or more biological mechanisms on the rate of blast disease development in rice, a phenomenon that Japanese workers recognize as field resistance (4), and which we term *dilatory resistance* (2,9). We distinguish between this disease rate-reducing resistance and so-called major-gene resistance, which tends to be complete against some pathotypes of a pathogen but ineffective against others. *Pyricularia oryzae* Cav., the rice blast pathogen, although pathogenically stable in the USA (7), comprises pathotypes numbering in the hundreds (11). Because of this potential for pathogenic diversity, *P. oryzae* may overcome new sources of major-gene resistance within a few seasons in many rice growing regions. Consequently, considerable effort has been devoted to developing field resistance in national breeding programs to find more durable resistance to blast (1, 3, 4, 12, 13). We began research in slow-blasting in the USA in 1977, after the Rice Blast Workshop at IRRI (5).

BREEDING FOR BLAST RESISTASCE IN THE USA

Over the years relatively little blast has been observed in commercial rice fields in Texas, although occasionally individual fields have been damaged severely by the disease. In most cases, severely blasted fields had been planted to leguminous crops (soybeans, clover) in previous years, or had received excessive amounts of nitrogenous fertilizer. In the rice breeding nursery at Beaumont, Texas, exotic rice lines have been virtually destroyed by blast while adjacent plots of local rice lines suffered little or no damage. These observations indicated the possibilities that climatic conditions, although important, are not the only factors limiting destructiveness of blast in southern USA. Although most southern USA rice cultivars possess one or more major genes (*Pi*) for resistance to many pathotypes of *P. oryzae,* only

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one, LA 110, has major-gene resistance to all known USA pathotypes. It is the only USA cultivar ever released that was not previously known to be susceptible to at least one pathotype of *P. oryzae.* Severe blast in exotic lines not selected locally indicated that our environment did not preclude blast epidemics, and our own cultivars were not totally protected by major-gene resistance. Therefore, we speculated that USA cultivars possess epidemiologically significant levels of field resistance to prevalent pathotypes of *P. oryzae.*

Historically, it has taken 10-12 yr to develop a new rice cultivar in southern USA. This period includes at least 3 yr of multilocation yield trials just before a cultivar's release. The period from crossing to release provides opportunities for observing the performance of potential cultivars under a variety of climatic and cultural conditions that probably include any of those likely to be encountered in commercial production. We believe that this has been advantageous from the standpoint of detecting weaknesses, including disease susceptibilities, that might preclude release of an otherwise promising rice line. Also, USA rice cultivars have been developed from a relatively narrow genetic base, with only an occasional introduction of exotic germplasm whose quantity is diluted ultimately with local germplasm to regain essential agronomic, milling, and cooking qualities. Consequently, most parental lines used in southern USA were themselves selected under USA growing conditions and have demonstrated superior adaptation to our environment, including indigenous pests.

Recent shifts in strategies and emphasis in rice varietal improvement programs for southern USA have brought new importance and urgency to investigating field resistance to blast. Efforts are under way to accelerate the development of improved cultivars by growing extra generations in winter nurseries in Puerto Rico. With increased emphasis on improvements in plant type, cold tolerance, ratooning ability, and resistance to other abiotic sources of stress will come increased reliance on exotic germplasm as parental material to incorporate these traits into USA cultivars. Consequently, the probability of detecting weaknesses will be reduced and the probability of losing some environmental fitness (including field resistance to blast) acquired through decades of hybridization and selection will increase. At least partially in response to these changes, we are evaluating our own germplasm and intend to evaluate potential exotic parental lines for qualities such as slow-blasting, so that, given a choice, we may avoid parental lines with poor resistance.

REQUIREMENTS FOR EVALUATING SLOW-BLASTING

As with any mass screening, slow-blasting evaluation must be time, space, and labor efficient. In addition, it should require only small amounts of seed, since availability frequently is limited in early generations. Conditions must be favorable for blast for extended periods of time to allow polycyclic disease development. We need to determine pathotypes of *P. oryzae* suitable for

challenging the test populations, so that major-gene resistance would not mask the expression of slow-blasting.

Without the mentioned logistical requirements we cannot conduct mass screening successfully. Now let us consider some factors affecting slow-blasting and its differential quantification. *P. oryzae* is an air-borne local lesion-producing pathogen whose rate of spread we wish to measure in adjacent miniplots over a relatively short period. We can divide the disease cycle conveniently into three phases: infection, latent period, and reproduction. One is independent of the other, and variations in anyone of them will affect the rate of disease development. Increased inoculation efficiency, shortened latent period (time from infection to sporulation), and increased sporulation (a function of lesion size and lesion 1ongevity) enhance epidemic potential of the host-pathotype interaction. Conversely, the reverse in any of these phases reduces it. Together the three phases of the disease cycle determine the numbers of spores available for the spread of the pathogen. Greater inoculation efficiency and shorter latent periods result in faster development of more lesions. The larger and longer-lived the lesions, the greater will be the numbers of conidia produced. The greater the numbers of conidia, the greater the potential for intensification and spread to adjacent plants. In screening for slow-blasting, we want to see the effects of several such disease cycles in different rice lines growing in close proximity.

Pertinent to the feasibility of miniplot screening is the relative importance of *allo*infection (infections in one miniplot caused by spores produced outside that miniplot) and *auto*-infection (disease development within a miniplot). In the field, the importance of autoinfection far outweighs alloinfection in blast disease development once the disease is established through alloinfection. Certainly alloinfection plays a greater role in disease development under blast nursery conditions. The question is whether alloinfection would be great enough to mask slow-blasting ability under the conditions required for mass screening.

THE BLAST NURSERY AT BEAUMONT, TEXAS

Our blast nursery appears to fill the physical requirements for a screening facility in that it is compact and equipped with a programmable automatic sprinkling system. Without the sprinklers, we would have little chance for success with any outdoor blast studies in Texas. Our blast nursery consists of 16 beds 15.25 m long by 107 cm wide, separated by 46-cm-wide walkways and surrounded by a 60-cm-wide apron of concrete. Rows of five sprinklers each are in alternate walkways, each row being individually controlled.

Miniplots for slow-blast screening consist of 3 rows 60 cm long and 10 cm apart, planted with about 1 g of seed per row. The test plots are separated by two-row plots of a highly resistant line to minimize alloinfection. A single row of a highly susceptible line is planted the length of the bed on the windward side of the plots. The leeward side is planted to a single row of a resistant line to act as a buffer between beds and to aid in maintaining

uniform conditions in the test plots. The sprinklers are run at 6-min intervals for 6 s from 1600 to 1930 h and from 0900 to 1000 h to ensure leaf wetness and extend the dew period. The beds are fertilized with ammonium sulfate, at 100 kg N/ha as when seedlings are at about the 2-leaf stage.

In our first exploratory experiment, six USA cultivars with similar susceptible greenhouse reactions to race IG-1 (8) of *P. oryzae* were rated in the blast nursery against IG-1, with diseased rice in adjacent beds providing the inoculum. Six weeks after seedling emergence, the percentages of diseased leaf area (% DLA) ranged from 100% in Calrose 76 to less than 10% in Nortai. Subsequent tests with F_3 lines from a narrow cross produced equally encouraging indications that slow-blasting could be evaluated, comparatively at least, in this blast nursery (9). Other experiments demonstrated that many ancestral lines and old US cultivars possessed considerable levels of field resistance to race IG-1. Most currently grown US long-grain cultivars were not included in tests with race IG-1 because of their major-gene resistance to that pathotype. The field resistance of cultivars from Japan, China, Turkey, and Egypt that had no major-gene resistance to IG-1 ranged from greater than that of our resistant check Nortai to less than that of our susceptible check M-101 (10).

Recently we began screening with other pathotypes, with good results. We found that most of the newer US cultivars possess high levels of field resistance to races IC-17 and IB-49. These experiments will be discussed in greater detail later.

RATING SYSTEMS FOR SLOW-BLASTING

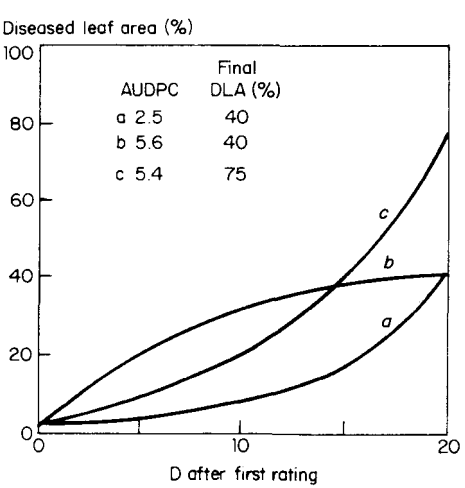
There is no practical way to measure precisely the amount of diseased tissue in a population of plants; therefore, we rely on visual estimates. Pictorial scales for estimating percentages of diseased leaves for several diseases, including blast, have been developed (6). Their use, however, is made cumbersome by the diversity of gross morphology encountered in world collections of rice (height, vigor, sturdiness, growth habit, leaf dimensions), as well as by variations in plant density and by changes in plants with age. We estimate the ratio of diseased to healthy leaf tissue and then record it as % DLA (e.g., 1:4 ratio of diseased to healthy= 20% DLA). We have found that with a little practice and concentration, we can attain good agreement among personnel.

The % DLA is the value we use directly for interline comparisons, or from which we calculate areas under disease progress curves (AUDPC), depending upon objectives of the experiment. For screening great numbers of related breeding lines, a single rating, done when some susceptible standard line is nearly 100% infected, should provide meaningful comparisons among lines. A line with a minimum acceptable level of field resistance, based on commercial performance, may be used as the standard for comparison in screening. Lines showing lower levels of field resistance should be excluded from further development. The test should run long enough for several

cycles of the disease. Most screenings required 30-45 d after seedling emergence.

In early-generation screening, the added confidence in results provided by replication may not justify the extra space, labor, and seed. In practice, lines below an accepted level of performance are dropped from further testing, and those that pass the screening and other criteria set by the breeder will be reevaluated in more advanced generations, when fewer lines will be tested and more seed will be available.

To evaluate cultivars with diverse backgrounds and perhaps breeding lines from wide crosses, as many as five or six sequential ratings, spaced 4-6 d apart, of replicated plots are desirable. From these data, disease progress curves can be plotted and AUDPCs calculated. Usually comparisons among AUDPCs or final % DLA ratings, or both, provide accurate measures of *relative* field resistance. Sometimes, however, neither tells the whole story and the disease development curves themselves are more helpful in deciding among lines. Figure 1 illustrates three hypothetical disease progress curves, along with their respective final % DLAs and AUDPCs. Curves *a* and *b*, with identical final % DLAs, produced widely differing AUDPCs. Curves *b* and *c* differed greatly in final % DLAs but produced similar AUDPCs. In this example, the shape of the curve is probably the best indicator of field resistance. In our judgment, curve *b* represents the best field resistance of the three, because of the declining rate of disease increase. In our experience, except perhaps in response to temporary unfavorable weather, disease progress curves that begin leveling off do not turn upward again. Had the test represented in Figure 1 been continued, curves *a* and *c* probably would have continued to climb more steeply than curve *b*, which would have continued leveling off, perhaps even dropping. In practice, such a situation might signal the researcher to conduct the test for a longer period. Curve *b* could result from increased resistance to infection by *P. oryzae* with plant age, a well-known phenomenon in rice blast. The rate at which this occurs varies among rice lines and is an important component of field resistance.



1. Hypothetical disease progress curves and associated AUDPCs and final % DLAs. In the absence of the curves, the numerical values can be misleading indicators of comparative field resistance.

Other indicators of field resistance are lesion density (e.g., lesions per plant, per leaf, or per unit leaf area), lesion type, and lesion size. Most screening situations would not warrant lesion counts, but lesion types may be noteworthy, especially when lesion density is low. Such information may be valuable in determining potential parental lines with the aim toward combining different sources of field resistance.

AUDPCs are convenient indices for comparing lines in that they take into account host — parasite interaction over a period and tend to even out some of the day-to-day fluctuations in apparent disease severity. When comparing within a test, manipulating ACDPCs has no advantage. But when comparing between tests it may be advantageous to convert the AUDPC to an index based on the maximum possible AUDPC, which happens to be equal to the number of days between the first and last ratings. If the last rating were taken 19 d after the first, then the maximum possible AUDPC would be 19 (100% DLA at the first and last ratings). An AUDPC of 9.5 for a 19-d curve would convert to an index of 50 (100 × 9.5/19). Such a conversion would base all ratings on 100 regardless of the length of the test (Table 1). The Japanese have used an index based on the severity of a susceptible check in a given test (12) (Table 1). For example, if the AUDPC for a test line were 8.4 and that for the susceptible check 16.8, their respective disease indices would be 50 and 100. Each has its advantages. Regardless of the form of presentation, it is most important to remember that the ratings are *comparative,* not absolute.

A blast nursery is an artificial situation in which we attempt to assess disease development in ultrasmall populations in close proximity using environmental conditions that favor disease for extended periods. A

Table 1. A comparison of mean areas under disease progress curves (AUDPC) and certain disease indices for three rice cultivars evaluated for resistance to race IB-49 of *Pyricularia oryzae* on four planting dates in an outdoor blast nursery at Beaumont, Texas. 1984.

Test	Date of emergence	Cultivar	AUDPC[a]	Disease index M[b]	Disease index C[c]
1	12 June	M-101 (check)	13.1	69	100
		Pecos	5.9	31	45
		Lemont	1.8	9	13
2	2 July	M-101 (check)	16.5	87	100
		Pecos	9.7	51	59
		Lemont	3.5	18	21
3	23 July	M-101 (check)	16.6	87	100
		Pecos	13.4	71	82
		Lemont	4.3	23	26
4	14 August	M-101 (check)	17.6	84	100
		Pecos	10.0	48	57
		Lemont	1.5	7	8

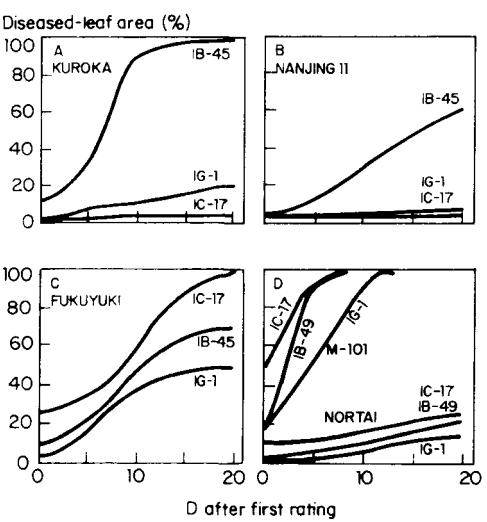
[a]All but test 4 were rated over a 19-d period (maximum AUDPC = 19). Test 4 was rated over a 21-d period. [b]Disease index M = 100 X AUDPC/maximum possible AUDPC (no. of d from first to last rating.) [c]Disease index C = 100 X AUDPC/check AUDPC.

seemingly low level of field resistance may be effective in controlling disease in a large field, i. e., miniplots should *under* evaluate slow-blasting. In this regard, comparisons between field and nursery performance of locally familiar rice cultivars help researchers judge the potential effectiveness of slow-blasting in test lines from nursery tests.

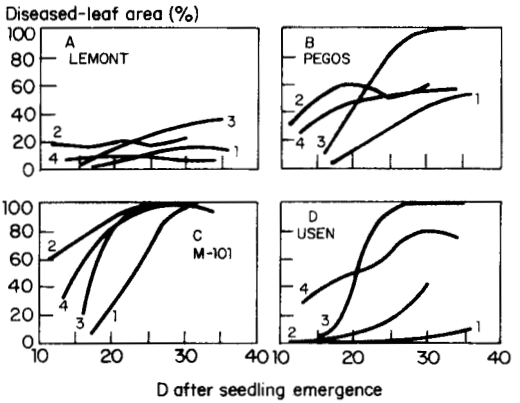
SOME CHARACTERISTICS OF SLOW-BLASTING

Generally, we think of field resistance as being race nonspecific, and consequently more stable against highly variable pathogens than major-gene resistance. Our experiences support the findings of Japanese researchers (12) that field resistance may be race specific in some cases. The disease development curves in Figure 2 illustrate three examples of race-specific field resistance. Kuroka, a highly field-resistant upland cultivar in Japan, and the Chinese cultivar Nanjing 11 both showed high field resistance to races IG-1 and IC-1 7, but low and moderate field resistance, respectively, to race IB-45 (Fig. 2a, b). The Japanese cultivar Fukuyuki, considered poor in field resistance in Japan, showed varying levels of field resistance to the different pathotypes (Fig. 2c), but in each case it was significantly more field resistant than M-101, the susceptible check (Fig. 2d). Other lines showed race-specific field resistance in these tests, but they were the exceptions. The resistant cultivar Nortai and the susceptible check, M-101, were consistent in their reactions to the different pathotypes (Fig. 2d), as were most of the US cultivars.

Weather and changes in pathotype populations also affect rates of disease development. Figure 3 shows the disease progress curves for four cultivars planted in quadruplicate on four dates 3 wk apart, beginning 6 June 1984. Race IB-49 had been established in a spreader bed before the first planting.



2. Mean disease progress curves (2 or 4 replications) for 3 cultivars showing race-specific field resistance to 3 pathotypes of *Pyricularia oryzae* in 3 separate tests, compared with curves for susceptible(M-101) and resistant (Nortal) check cultivars. Race IB-45 occurred naturally in the test in which IB-49 was introduced and became the dominant pathotype in the 3 test cultivars, but not in the checks. Beaumont, Texas.



3. Mean disease progress curves (4 replications) for 4 plantings of 4 cultivars exposed to races IB-49 (introduced) and IB-45 (naturally occurring) of *Pyricularia oryzae* in the blast nursery at Beaumont, Texas. Usen curves reflect the buildup of IB-45. Emergence date of planting No. 1 = 12 Jun, 2 = 2 Jul, 3 = 23 Jul, 4 = 14 Aug 1984.

Disregarding for the moment the curves for Usen (Fig. 3d), note, first, the difference among plantings in the number of days between seedling emergence and the first rating for % DLA, then the differences among first ratings, both within and among cultivars, and finally the magnitude of the differences in disease development between plantings among the cultivars (see also Table 1). Obviously the conditions associated with different planting dates had a greater effect on disease development in Pecos than in Lemont and M-101. In spite of these test-to-test variations, the overall results were similar, i.e., the cultivars were rated similarly relative to each other. Again, it is important to remember the *comparative* nature of screening for slow-blasting. Slow-blasting is environmentally sensitive, and field resistance may be so overwhelmed under blast nursery conditions that it is no longer discernible, especially in the absence of a susceptible check. The highest curve for Pecos (Fig. 3b) (3) would be difficult to recognize as indicative of any field resistance without the comparable M-101 curve (Fig. 3c) (3).

Under our conditions, it appears that the leaf-wetness period most critically limits rice blast, and is the one factor we can modify to favor the disease in the blast nursery. The unintentional shutting off of the sprinklers for 5 d (18-22 July 1984) during disease development in the second planting effectively reduced the dew period from 18.5 h to 13 h. This reduction in potential infection period was reflected by a visible dip in the mean disease development curve for all the cultivars and is illustrated in the "2" curves of Lemont and Pecos (Fig. 3a, b).

Something must be known about the pathotypes present in a screening nursery. We were trying to conduct a polycyclic test in the open with a single pathotype, race IB-49. We purposely included Usen, which has major-gene resistance to IB-49, in the test to monitor for the arrival and possible buildup of other pathotypes. Figure 3d illustrates the gradual buildup of two pathotypes pathogenic to Usen, IB-45, and ID-13. Pecos and M-101 are susceptible to IB-45 and ID-13, and although most isolates from those cultivars were identified as being of IB-49, some were of ID-13 or IB-45.

Having been alerted to the presence of pathotypes other than IB-49, we isolated from all the cultivars being evaluated in other tests being conducted concurrently with the date-of-planting experiment. We found that race IB-45 was prevalent in several cultivars, notably Kuroka, Nanjing 11, and Fukuyuki (Fig. 2), cultivars that are susceptible also to IB-49. We identified at least three other pathotypes among some 150 isolates from the nursery. Although this invasion of naturally occurring pathotypes destroyed the purity of the test in that we could no longer attribute our results solely to the action of a single pathotype, it made the test more meaningful from the screening standpoint. The disease rating of any rice line probably reflected the susceptibility to the pathotype most aggressive to it. Rice lines that showed good field resistance in the presence of many pathotypes were likely to have race-nonspecific resistance. Screening in the presence of many pathotypes probably will be the usual situation in most upland rice areas, where blast is a serious problem year after year.

SLOW-BLASTING IN A NUTSHELL

Slow-blasting describes the ability of rice to reduce the rate of disease development effected by *P. oryzae.* In screening for slow-blasting, we *compare* rates of disease development among rice lines under conditions that favor the pathogen and prevent the full expression of slow-blasting potential in large fields. The environmental sensitivity and race specificity, in some cases, of slow-blasting may explain why slow-blasting lines sometimes break down in places other than where they were developed, and make a strong case for developing slow-blasting lines in areas where they will be grown. Any screening should, therefore, include familiar lines as checks to gauge disease severity and as indicators of various pathotypes.

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BLAST BREEDING METHODOLOGIES IN INDONESIA

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During the past decade, rice production in Indonesia doubled. In 1984 production of milled rice was 25 million t. In year 2000 the expected production is 30 million t, and it can be achieved by intensifying cultivation of irrigated rice and expanding rice areas in dryland and swamp areas.

Efforts to expand dryland rice cultivation outside Java face many constraints. Most land available for cultivation has red-yellow podzolic soils, which are often acid and infertile. Farmers have tried to increase rice production on such land by improving such cultural practices as applying more N fertilizer. Fairly good vegetative growth results from higher rates of fertilization, but severe neck blast attacks that occur after flowering lower grain yields. Dryland yields are not stable; they vary from 0.5 to 4 t/ha, depending upon blast incidence and other constraints such as drought and Al toxicity. Blast infection also occurs in intensively cultivated wetland rice and in high-elevation rice.

VARIETAL RESISTANCE

In general, wetland rice has a lower incidence of blast than dryland rice. Varieties also react differently to the disease at different locations and seasons, and with different cultural practices. In central Java, the varieties Sigadis (released in 1963), Gata and Gati (1976), and IR36 (1980) performed well under both wetland and dryland cultivation, with negligible blast infection. In Lampung, however, when grown in dryland rice they became very susceptible to blast after only two cropping seasons; surprisingly they produced good crops as wetland rice at the same time and place.

IR42 had fairly stable field resistance to blast as wetland or swamp rice. It is popular in areas with problem soils. In 1982 IR42 grown as dryland rice by farmers in Kendari failed because of severe blast infection.

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The variety Semeru was heavily infected by blast in the high-elevation Agam area (about 900 m) during the 1982 wet season. At lower elevations, however, it suffered negligible blast infection during the same season.

IR50 and IR52 were introduced in 1981 to control tungro virus disease in Bali, Sumbawa, and south Sulawesi. IR56 was introduced in 1982 as an emergency measure to control a new brown planthopper biotype in north Sumatra. Unfortunately these varieties are susceptible to blast. Therefore they have been cultivated mostly in the dry season.

Two dryland varieties — Bicol (1973) and C22 (1978) — have been introduced from the Philippines. Bicol (BPI-76) was more susceptible to blast than C22. These varieties are still popular in Lampung because they are early maturing and produce fair yields of 2-3 t/ha. During blast epidemics, however, Bicol may yield less than 1 t/ha.

Four dryland varieties — Sentani, Singkarak, Tondano, and Ranau — were released in 1983-84. Sentani and Singkarak appear more resistant to the major races of blast. However, Tondano and Ranau are better adapted, are moderately resistant to blast, tolerate low pH, and compete better with weeds.

Local dryland rice varieties are still grown widely by farmers. Examples are Arias (north and south Sumatra); Simariti, Klemas, and Sirendah (South Sumatra and Lampung); Sagi (west Java); and Sibuyung (South Kalimantan). These varieties produce fairly stable yields of 1.5-2 t/ha with low inputs. They are resistant to blast, tolerate low pH, but mature late in about 140 d.

Tables 1 and 2 show the reaction of some commercial and local varieties to major races of blast. These reactions are based on laboratory tests. Blast races 24 and 64 seem to be more virulent for wetland varieties. Only the three varieties Bengawan, Asahan, and IR38 are resistant to these races. However, most commercial wetland rice varieties are resistant to races 60, 15, 9, and 39. Asahan is resistant to all races except race 64 (Table 1). The local variety Klemas is resistant to all races; Simariti and Laka to seven races; Rantai Emas, Lagos, and Sirendah to six races (Table 2).

Table 3 shows the reactions of some promising lines to major races of blast. B4057f-Sm-46-1-2, B4262f-Pn-69, GH147M-40Kr-146, B453g-Pn- 1, B4176g-Ng- 14, and B3894-40d-Pn-5- 1 are among lines of wetland rice that have shown resistant reactions. The line B4057f-Sm-46-1-2 was also resistant to all biotypes of brown planthopper. Two lines of dryland rice, B3906f-13-13-St-37 and Napa mutant, have shown good levels of resistance to blast. They are being intensively tested for yield potential and adoption in major dryland rice areas.

BREEDING STRATEGIES

Breeding priorities are developed in accordance with how far farmers have adapted improved technology. In dryland and high-elevation areas where blast disease is the major problem, most farmers still grow local rice

Table 1. Varietal reactions of some wetland rice varieties to major races of blast.

Rice variety	Reaction[a] to isolate no./international race							
	60 ID-13	66 IG-1	64 ID-15	15 ID-14	6 IF-1	24 IG-2	39 IC-15	47 IG-1
Cina	S	R	R	S	R	S	R	R
Bengawan	R	S	R	R	R	R	R	S
Sigadis	R	S	S	R	R	S	S	S
Remaja	R	S	S	R	R	S	R	S
Pelita I-1	R	S	R	R	S	S	S	S
Cisadane	R	S	S	R	R	S	S	S
Ayung	R	S	S	R	R	S	S	S
Asahan	R	R	S	R	R	R	R	R
Semeru	R	R	R	R	M	S	R	R
Kencana	S	S	S	S	S	S	S	S
Adil	R	S	S	R	R	S	R	S
IR5	S	R	M	R	R	S	R	R
IR8	R	S	S	R	R	S	R	S
IR20	R	S	S	R	R	S	R	R
IR26	R	S	S	R	R	S	R	R
IR28	R	S	S	R	R	S	R	S
IR30	R	S	S	R	R	S	R	S
IR32	R	R	S	R	R	S	R	R
IR34	R	R	R	R	R	S	R	R
IR36	R	R	S	R	R	S	R	R
IR38	R	R	R	M	R	R	R	R
IR42	R	R	S	R	R	S	R	R
IR45	R	R	S	R	R	S	R	R

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

Table 2. Varietal reactions of some dryland rice varieties to major races of blast.

Rice variety	Reaction[a] to isolate no./international race							
	60 ID-13	66 IG-1	64 ID-15	15 ID-14	6 IF-1	24 IG-2	39 IC-15	47 IG-1
Sirendan	S	R	S	R	R	R	R	S
Genjah Lampung	S	R	S	R	S	S	R	R
Rantai Emas	R	R	R	R	R	S	R	S
Klemas	R	R	R	R	M	R	R	R
Semariti	M	R	R	R	S	R	R	R
Seratus Malam	S	S	R	S	S	S	R	S
Papah Aren	S	R	S	S	S	S	S	R
Bicol (BPI-76)	S	S	S	S	R	S	R	S
C22	S	S	R	R	S	S	R	S
Lagos	R	R	S	S	R	R	R	R
Gata	R	S	S	R	R	S	R	S
Gati	S	S	S	R	R	S	R	S
Laka	R	R	S	R	R	R	R	R

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

varieties. For these reasons, breeding strategies have been given the following order of priority: 1) gene deployment, 2) gene rotation, 3) gene pyramiding, and 4) horizontal resistance.

Table 3. Reactions of promising rice lines to major races of blast.

Rice variety	Reaction[a] to isolate no./international race							
	6 IF-1	15 ID-I4	24 IG-2	26 IG-1	39 IC-5	60 ID-13	64 ID-I5	66 IG-1
B3064b-Kp-40-3-9-9-1	R	MR	MR	MS	R	R	MR	MR
B2791b-Mr-196-2-3-1-3	R	R	MR	S	R	R	R	MR
B4405g-Mr-9	R	MR	R	S	MR	MR	MR	MR
Bayar Melintang mutant	R	MR	R	MR	R	R	MR	MR
B3632g-Tb-26	R	R	R	S	R	R	R	MR
B3388f-21-Tb-1	R	R	MR	MR	R	MR	R	MR
B4801f-Mr-5	R	R	MR	MR	R	R	MR	MR
B3623g-Tb-41	R	MR	MR	MR	R	MR	R	MR
S268b-58	R	R	MR	S	R	MR	MR	MR
B4179f-Sm-27-1	MR	MR	MR	S	R	MR	MR	MR
B4070d-Pn-199-43	MR	MR	MS	S	R	MR	MR	MR
B4057f-Sm-46-1-2	R	MR	MR	R	R	MR	MR	R
IR13427-45-2-3-3-2-2	MS	MR	R	MS	R	MR	R	MR
B4032b-Mr-1-3-1	MS	MR	R	MR	R	R	R	MR
B4262f-Pn-69	MR	R	R	MR	R	R	R	R
GH147M-40Kr-146	R	R	R	MR	R	R	R	R
B4354g-Pn-1	MR	R	MR	MR	R	R	MR	MR
B4176g-Ng-14	MR	R	MR	MR	R	MR	R	R
B3894-40d-Pn-5-1	MR	R	MR	MR	R	R	MR	MR
B3895-15g-Sm-22-1	R	MR	MR	MR	R	R	MR	MR
B3897-30-Pn-56	MR	R	MR	MS	R	MR	MR	MR
B3622f-Tb-14-2	R	R	MR	MS	R	R	R	MR
B3906f-13-13-St-37	R	R	R	MR	R	R	R	R
Napa mutant	R	R	R	MR	R	R	MR	R

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

Gene deployment

In subsistence agriculture, farmers are usually not concerned with producing maximum yields of high quality. In major dryland rice-growing areas in Indonesia, farmers generally grow the varieties that tolerate drought and soil problems such as low pH, Al toxicity, and nutrient deficiencies. In most cases the farmers' own local rice varieties possess these tolerances along with low yield and poor agronomic traits such as long maturity and tall plant type. Despite low yielding ability, these local varieties have a significant role in maintaining the existence of substantial dryland rice cultivation. Improved varieties are still confined to only a small part of these areas because they lack general adaptability, and are not accepted by farmers. No serious blast disease incidence have been reported on rice at high elevations or on dryland before introduction of the new improved varieties. Because of the wide genetic diversity of varieties planted by farmers, small-scale incidence of the disease in some varieties may have escaped detection. If the adapted local varieties are improved for certain agronomic traits and grain yield, they could become acceptable to farmers. They could be improved by simple breeding procedures in a relatively short time, and planted with methods that farmers know well.

Gene rotation

The basic reason for gene rotation as a pest management strategy is the gene-for-gene concept (3). Many studies reveal the validity of this concept in the relationship between the rice plant and the blast pathogen *Pyricularia oryzae.* Comprehensive reviews on the potential effectiveness of gene rotation in Korea by Crill et al (1) and on the effective and stable control of rice blast with monogenic resistance by Crill and Khush (2) have been published.

Gene rotation would be effective only in areas of intensive agricultural production where plant pathologists maintain adequate and intensive disease surveys in cooperation with plant breeders. Gene rotation has been effective in controlling brown planthopper incidence in Indonesia. The progress in developing rice varieties resistant to blast has been significant; with the more resistant genetic sources now available, further progress can be expected. In Korea, gene rotation could be a good strategy in the management of blast disease if resistant varieties could be developed more rapidly.

Gene pyramiding

The pyramiding of successive genes for resistance into an adapted variety has been the most widely used strategy (7). Its advantage is that when new resistant genes are incorporated into the currently adapted varieties by backcrossing, the new resistant variety differs very little from the adapted ones, and it can be tested simply for yield, quality, and other factors. This is because the new variety should not be greatly different from the recurrent parent. The availability of several improved varieties and resistant genes in national and international collections should make such attempts more feasible soon.

Horizontal resistance

It is easy to understand why gene deployment, gene rotation, and gene pyramiding are in the first lines of defense against blast disease. Their application is straightforward because the breeder works with a limited number of genes. However, in the long run, greater variability and more recombinations should be established.

Advantage should be taken of quantitative traits such as grain yield, adaptability, and minor genes for resistance (horizontal resistance).

Horizontal resistance may be effective longer than vertical resistance. Since it is polygenic, the plant breeder must manipulate many genes. All the research necessary could be done in the field. Because it is assumed that the variety responds similarly to all races, no special inoculum production or inoculation procedures are required (1). The inoculum for blast and brown spot (*Helminthosporium oryzae*) is usually present in a field of dryland rice. The bulk method using various crosses at several sites could be used to increase the frequency of genes conferring resistance to both diseases. Diallel selective mating described by Jensen (6) and male-sterile-facilitated composites (8) could be used.

BREEDING PROGRAMS

Hybridization

Indonesian breeders aim to improve rice genotypes by two approaches. The first is to improve some agronomic traits of adapted local varieties, such as maturity (about 120 d) and plant height (about 100 cm). Some important local varieties are Arias, Sibuyung, Klemas, Sagi, Sirendah, and Simariti.

The second approach is to incorporate some important genes for resistance into improved varieties such as Sentani, Singkarak, Tondano, Ranau, B3906, and B3913. The backcross method is the principal procedure in this approach. Mutation breeding is also occasionally used to reduce plant height and the maturity period.

Various segregants are expected to be derived from different genetic sources such as biparental, double, poly, or diallel crosses. Outcrossing with the use of monogenic recessive male-recessive lines such as in IR36 could be encouraged to establish composites. The composites are grouped according to the nature of the problems of rice cultivation in dryland, high-elevation, swamp, and wetland areas. Breeding models of the male-sterile-facilitated backcrossing (MSBC) of Fujimaki (4) and male-sterile-facilitated recurrent selection of Ikehashi and Fujimaki (5) may be used.

Screening

Both laboratory and field screeening are required for the programs, depending on the nature of the breeding materials being used. Segregating populations are exposed to stress under field conditions using the close-spacing modified bulk method. Some seeds of selected plants are kept at harvest, and the screening is repeated in the following generations at different experiment sites. The major sites for dryland screening are Sitiung, in West Sumatra, Tamanbogo in Lampung, Ciamis in West Java, Pleihari in South Kalimatan, and Kendari in southwest Sulawesi. High-elevation rice is screened for blast at Bukittinggi, West Sumatra.

F_2 seeds are grown at every site in the wet season. Selected seeds from this population are bulked and grown on wetland in the dry season. The procedure is repeated in the following generations. Homozygous lines are gradually extracted from the population for observation and yield testing.

In the selection phase of the recurrent cycle, selfed seeds will be harvested from self-fertile plants to develop S_1 progenies for evaluation. Recurrent selection is terminated when some lines showing promise for practical use are obtained.

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GLOBAL EVALUATION OF RICE VARIETAL REACTIONS TO BLAST DISEASE

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Rice blast caused by the fungus *Pyricularia oryzae* is among the most widespread rice diseases. The disease is common in areas using wetland and bunded rice culture, but it is more serious where dryland or unbunded upland rice is grown. Such areas characterize most rice lands of South America and Africa and in many rice-growing regions of Asia.

Use of resistant varieties is the most economical blast control method, but physiological races of the fungus complicate breeding for resistance. Because of the importance and complexity of the disease, international cooperation is the best way to advance knowledge about the disease and reduce damage caused by it.

The Uniform Blast Nursery (UBN) program was recommended in 1961 at the 9th meeting of the International Rice Commission (IRC) working party on rice production and protection in New Delhi. The UBN, launched in 1962 under the auspices of the IRC, distributed a set of 119 varieties from 17 countries to the various participating countries. Following decisions in the rice blast symposium in 1963, IRRI assumed responsibilities for 1) selecting initial variety groups for testing, 2) multiplying and supplying seeds to cooperators, 3) preparing and distributing testing procedures, and 4) compiling the results obtained from the cooperators.

A set of 258 varieties, including most of those from the FAO-IRC Uniform Blast Nursery, were put together as an International Blast Nursery (IBN) and distributed to 18 countries in 1966 and 1967. An additional set of 321 entries was selected from more than 8,000 varieties from different rice growing countries based on performance in repeated tests in the blast nurseries at the International Rice Research Institute (IRRI), and at other sites in the Philippines. The set was designated as Blast Resistance World Collection Varieties (BRWCV) and distributed to 19 countries in 1967. Selected entries from the BRWCV were included in the IBN in 1969. During the 1971 symposium on rice breeding at IRRI it was decided to include newly developed advanced breeding materials in the blast nursery.

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The International Rice Testing Program (IRTP), funded by the United Nations Development Programme (UNDP) and coordinated by IRRI, was launched in 1975. Since then, the blast nursery with the designation International Rice Blast Nursery (IRBN) became a part of IRTP. The IRBN has been designed to provide a convenient medium for rice scientists around the world concerned with blast disease to exchange and evaluate promising varieties and breeding materials, with a view to identifying appropriate genetic donors for resistance to the disease. The nursery also provides an opportunity to study genetic variation in the pathogen through differential reactions of the test entries.

This paper summarizes results of multilocation evaluation of IRBN from 1975 to 1983. Screening was primarily confined to leaf blast, although on occasions a few cooperators evaluated the entries for neck blast tolerance.

MATERIALS AND METHODS

The test material included several improved semidwarf breeding lines, some traditional tall varieties, some upland-adapted varieties, and a set of differential varieties identified from time to time in different tests. Tetep, Carreon, and IR 1544-238-2-3 were included as resistant checks and B-40 as a susceptible check. A list of the IRBN test sites from 1975 to 1983 is in Table 1. The number of entries evaluated and the number of test sites during the period are in Table 2.

Table 1. International Rice Blast Nursery test sites, 1975-83.

Country	Test sites
China	Canton, Changsha, Fuzhou, Guangzhou, Guangxi, Hangzhou, Pingman
Japan	Konosu
Korea	Icheon, Imsil, Iri, Jinyang, Kaehwado, Milyang, Suweon
Taiwan	Chiayi
Brunei	Kilanas
Burma	Heho, Hmawbi, Yezin
Indonesia	Bogor, G. Medan, Lampegan, Maros, Pacet, Padang, Palembang, Payakumbuh, Puriala, Sukarami, Tamanbogo
Malaysia	Bumbong Lima, Kubang Keranji, Tanjong Karang, Telok Chengai
Philippines	Baybay, Ilagan, Los Baños, Marbel, Narra, San Isidro, Tacloban
Thailand	Bangkhen, Chiang Mai, Khon Kaen, Kuan Gut, Rajburi, Rangsit
Vietnam	Bac Ha, Buon Me Thuat, Dien 'Bien, Long Dinh, Nghi Loc, O Mon, Son La, Van Dien
Bangladesh	Barisal, Comilla, Habiganj, Joydebpur, Rajshahi
India	Aduthurai, Almora, Chinsurah, Coimbatore, Cuttack, Darjeeling, Hawalbagh, Hazaribagh, Hyderabad, Imphal, Jeypore, Kalimpong,

Continued on next page.

Table 1 contd.

Country	Test sites
	Karjat, Khudwani, Larnoo, Lonavale, Majhera, Mandya, Mangalore, Manipur, Nawagam, Nellore, Palampur, Pantnagr, Pattambi, Ponnampet, Raipur, Ranchi, Shalimar, Shillong, Tirurkuppam
Nepal	Kankai, Kathmandu, Makawanpur, Palung, Parwanipur, Rampur
Pakistan	Dokri, Kala Shah Kaku
Sri Lanka	Karadian Aru, Getambe
Egypt	Fars, Sakha
Iran	Amol, Chaparsar, Rasht, Shiraz
Turkey	Edirne
Cameroon	Dschang, Mbo Plain, Ndop
Ivory Coast	Bouake
Kenya	Nairobi
Liberia	Monrovia
Madagascar	Antananarivo
Malawi	Limphasa, Salima
Nigeria	Ibadan
Senegal	Casamance
Sierra Leone	Rokupr
Tanzania	Katrin, Zanzibar
Zambia	Chilanga, Mansa
Brazil	Cachoerinha, Campinas, Goiania, Pelotas
Colombia	Palmira, Villavicencio
Costa Rica	Cañas
Cuba	Nina Bonita
Dominican Republic	Juma
Ecuador	Arenillas, Boliche, Pichlingue
Guyana	Mon Repos
Mexico	Cerro De Ortega, Cotaxtla, Cuauhtemoc, Edzna, H. Cardenas, Huimanguillo, Lorna Bonita, Mazatlan, Nayanit, Villaflores, Yohaltun, Zacatepec
Panama	Tocumen
Peru	Vista Florida
Surinam	Coebiti, Paramaribo
Italy	Mortara

Table 2. Number of entries evaluated in the International Rice Blast Nursery and number of test sites, 1975-83.

Year	Entries (no.)	Test sites (no.)	Countries (no.)
1975	463	25	14
1976	478	22	14
1977	476	29	17
1978	527	46	21
1979	347	33	18
1980	270	35	16
1981	256	39	20
1982	393	41	20
1983	311	40	16

The general procedures for the seedling blast screening follow:

- The nursery bed layout consists of 40-cm-long rows spaced at 10 cm. Each test is planted in 1 row and the resistant and susceptible checks are planted after every 25 test entries. A local susceptible variety is planted along the borders to ensure favorable microclimatic conditions for development of blast in the test rows. Usually 3 to 4 rows are planted lengthwise along the side hit first by the prevailing wind and another 2 or 3 rows along the other side.
- Nitrogen is applied at 100-120 kg/ha (or more if native fertility is low), two-thirds before seeding and the remainder 15 d after seeding. P, K, and minor element fertilizers are applied as needed before seeding.
- The wet season has been recommended as best for conducting the nursery. For good development of blast, the plots are watered 2-3 times each rainless day. Watering in the late afternoon is specifically recommended to raise the humidity during the night. For dry season tests when wind is high, one suggested way to induce a disease epidemic is to cover plots with plastic film just before sunset and remove the plastic at 0900 h the following morning as the dew period is lengthened.
- Natural airborne spores usually present in sufficient quantity to start infection. For locations not commonly experiencing natural epidemics, other specific recommendations such as inoculum placement are suggested.
- Under favorable testing conditions, blast lesions usually appear in about 2-3 wk and a severe blast epidemic develops within 30 d, when entries are scored for reaction to blast. A standard scoring system, based on a 0-9 scale (6, 7), is used:

Scale unit	*Symptom description*
0	No lesions.
1	Small brown specks of pinhead size.
2	Larger brown specks.
3	Small, roundish to slightly elongated, necrotic gray spots, about 1-2 mm in diameter with a brown margin.
4	A typical blast lesion, elliptical, 1-2 cm long, usually confined to the area of the 2 main veins with less than 2% of the leaf area infected with typical blast lesions.
5	Less than 10% of the leaf area infected with typical blast lesions.
6	10-25% leaf area infected with typical blast lesions.
7	26-50% leaf area infected with typical blast lesions.
8	51-75% leaf area infected with typical blast lesions and many leaves dead.
9	All leaves dead.

RESULTS AND DISCUSSION

Seedling blast

Entries frequently rated resistant (0-3 score) across sites in different years

Table 3. International Rice Blast Nursery entries rated resistant to blast at most test sites. 1975-83.

Year[a]	Entries frequently rated resistant
1975	P918-25-15-2, P901-22-7-2, IR1520-52-2-4, IR1905-81-3-1, IR2058-435-3-2, IR1416-128-5-8, Carreon, Ta-poo-cho-z, Tetep
1976	CIAT-ICA5, CIAT-ICA13, IR1905-PP11-29-4, IR1905-PP21-73-4, IR4547-4-1-2, IR4547-14-3-1, IR5533-55-1-11, IR5533-PP850-1, IR5533-PP855-1, IR5533-PP856-1, IR9669-PP836-1, IR1820-52–2-4, IR4227-199-3-2, IR1416-128-5-8, Huan-sen-goo, Ta-poo-cho-z, Tetep,Carreon
1977	CIAT-ICA5, CIAT-ICA12, IR1905-P11-29-4-62, IR3259-5-160-3, IR3259-PP11-186-4, IR5533-PP855-1, IR9559-4-1-1, IR9660-50-3-1, IR966000948-1, IR1820-52-2-4, IR1905-81-3-1, IR1416-1-42-8, IR1416-128-5-8, IR1544-238-2-3, Tadukan, Ta-poo-cho-z, Tetep, IR4547-16-3-4
1978	IR1905-PP11-29-4-61, IR3259-5-1-60-3, IR3259-8-172-5, IR4547-2-1-2, IR4547-4-1-2, IR4547-5-3-6, IR4547-16-1-5, IR5533-PP854-1, IR9660-00948-1, IR9852-18-1
1979	IR5533-13-1-1, IR1905-81-3-1, IR1416-128-5-8, Carreon, Tetep, Tadukan, 5287 (Col.), 5294 (Col.), 5720 (Col.), 5721 (Col.)
1980	IR1416-128-5-8, IR1905-81-3-1, IR4227-18-3-2, IR4547-4-1-2, IR4547-6-2-5, IR5533-PP850-1, IR5533-PP854-1, IR13149-19-1, Tetep, Carreon, Ta-poo-cho-z, C46-15, 5287 (Col.)
1981	CIAT-ICA5, IRAT104, Camponi SML, Huanq-sen-goo, Tetep, IR1905-PP11-29-4-61
1982	CIAT-ICA5, IRAT104, IR1905-81-3-1, IR2793-80-1, IR32598-172-5, IR5533-PP856-1, Tetep, Ta-poo-cho-z, Tres Marias, BG367-7, Cheolweon 32, IR15314-43-2-3-3, ITA231, P1377-1-15M-4-1M-1, Suweon 300, 16877, 16879 (Col.)
1983	Carreon, Tetep, Ta-poo-cho-z, Suweon 300, 5287 (Col.)

[a]Underlined entries have been rated resistant in more than one year.

(1975-83) are listed in Table 3. Among those, the following were rated resistant at most sites and over different years:

Designation	*Resistant parents involved*
IR1416-128-5-8	Tetep
CIAT-ICA5	Tetep
IR1905-PP11-29-4	Tetep
IR4547-4-1-2	Tetep, Tadukan, Pankhari 203
IR5533-PP850-1	Tetep, Carreon
IR5533-PP855-1	Tetep, Carreon
IR5533-PP856-1	Tetep, Carreon
IR1820-52-2-4	Tetep
IR3259-5-160-3	Tetep
IR3259-8-172-5	Tetep
IR9660-00948-1	Dawn
5287 (Colombia)	
IRAT104	
Suweon 300	Tetep
Ta-poo-cho-z	
Huan-sen-goo	
Tadukan	
Tetep	
Carreon	

Most promising entries had Tetep as one parent. The other known resistant parents were Carreon, Tadukan, Dawn, and Pankhari 203.

Entries rated good in selected tests in high disease pressure sites (more than 50% of entries given scores of 5-9) are listed in Table 4. Among those, Tetep, Carreon, IR3259-8-172-5, IR5533-PP854-1, IR1416-128-5-8, Suweon 299, Suweon 300, IR46, and CIAT-ICA 5 were rated resistant in more than one test.

Many entries in the International Upland Rice Yield Nurseries (IURYN) have been tested in the IRBN. Thirteenof the 147 IURYN entries tested in the IRBN showed a high or moderate level of resistance to leaf blast (Table 5). These included two lines from West Africa (IRAT13, IRAT104), one from Bangladesh (BR319), and several from IRRI.

Entries rated susceptible at most sites over different years include B40 (susceptible check), Taichung T.C.W.C., Fanny, Kung-shan-wu-shan-ken, Aichi Asahi, Euribe, and TKM6.

Neck blast

Few tests were made to screen IRBN for neck blast tolerance. Screening results were reported from Pattambi (India) and Cañas (Costa Rica) in 1978; Mandya (India) in 1979; and Tsangwu (China), Mandya (India), and Shillong (India) in 1980. Entries rated good in different years are listed in Table 6. Those rated good more frequently included CIAT-ICA 5, IR4547-6-3-2, IR1544-238-2-3, IR32, IR45, Tetep, and Carreon.

Disease pressure in the screening test at Shillong in 1980 was high at both the seedling and flowering stages. Differences in reactions at the two stages were evident in some entries as follows:

- Resistant at seedling stage and susceptible at flowering: Pai-kan-tao, 74-5499, IR13484-66-2-3, Milyang 47, Suweon 235;
- Susceptible at seedling stage and resistant at flowering: Kataktara DA-2, IR1846-296-3, IR8, HR1619-6-2-4, Iri 326, Iri 342, Iri 346, IR20, JC99.

Reactions of variety Pai-kan-tao are in conformity with earlier findings (2). In general, there was a greater degree of correspondence in reactions at the seedling and flowering stages at most sites. However, the available blast nursery data did not provide any conclusive evidence on whether the same genes control resistance at both stages. Hashioka (5) and Padmanabhan (10) considered that resistance to leaf blast and neck blast might be independently controlled by different genes. Inoculation with known races under controlled environment conditions may provide some reliable information on the relationship of genetic control of resistance at the two stages.

Differential reactions

Variability in blast pathogen has been reported by several workers (1,3,4, 8, 9). Differential reactions at different test sites were evident in most IRBN

Table 4. International Rice Blast Nursery entries rated good at some sites where the disease incidence was high.

Year	Location	Best score	% entries rated 5-9	Entries given good rating
1976	Lampung, Indonesia	2.0	84	CIAT-ICA13, Suweon 235, IR46, IR4227-240-3-2, IR4712-233-2, Cuwini/Alupi, Kanto 51, Kataktara DA-2, Chokoto
1978	Hmawbi, Burma	1.0	51	H94 (9), B2039c-Kn-7-2-3-2-2, B2549b-Sm-Mr-5-5, B2550b-Sm-Mr-20-2, B2250b-Sm-Mr-68-1, IR3259-8-172-5
1978	Ibadan, Nigeria	1.0	52	Tetep, Carreon, IR1905-P11-29-4, IR11248-31-3-2, Tadukan, IR36
1980	Heho, Burma	1.0	68	Score 1.0 - TOS2259 Score 2.0 - Pai-kan-tao, IR1544-38-2-2, IR46, IR13149-71-3-2
	Nellore, India	2.0	58	Raminad Str. 3, Carreon, Tetep, IR4568-86-1-3-2, Suweon 285
	Raipur, India	1.0	61	IR36
	Hawalbagh, India	0.0	58	Tetep, IR1416-128-5-8
1981	Ponnampet, India	1.0	65	Khao-Tah-Haeng 17, Ciwini/ Alupi, Colombia II, Tetep, IR13146-41-3, IR13358-85-1-3, IR13427-40-2-3-3
	Hawalbagh, India	1.0	54	Caloro, BW246-10, CIAT-ICA5, IR9965-48-2, IR21912-131-3-3, Milyang 54, Pongsu Seribu, Suweon 299
	Suakoko, Liberia	3.0	83	Raminad Str. 3, IR1905-81-3-1, IR9660-00948-1, BG367-4, IR13538-48-2-3-2, Suweon 300
1982	Changsha, China	0.0	69	Tetep, Huan-sen-goo, IR1416-128-5-8, IR3259-8-172-5, IR5533-PP854-1
	Maros, Indonesia	1.0	63	IRAT104
	Los Baños, Philippines	0.0	74	IR5533-PP854-1, IR5533-PP856-1, C46-15, H114-5-5-1 -1 -1, Suweon 299
	Khonkaen, Thailand	0.0	57	CIAT-ICA5, IR1416-128-5-8, P1377-1-15M-1-2M-3
	Hawalbagh, India	0.0	54	Tetep, Ta-poo-cho-z
1983	Pingman, China	0.0	77	Carreon, Tetep
	Payakumbuh, Indonesia	2.0	74	BG379-2, DD-91, Hunan 14, Carreon, IRAT110, IRAT140, ITA123, ITA175, ITA232, P1034-6-4-2-3-3M, Suweon 300, Suweon 299, Suweon 303, Suweon 304, Suweon 305
	Rangsit, Thailand	1.0	87	IAC 25 dwarf (16856), Tetep dwarf (16890)
	Goiania, Brazil	0.0	60	Suweon 299

Table 5. Reactions to leaf blast of International Upland Rice Yield Nursery (IURYN) entries tested in the International Rice Blast Nursery (IRBN).

Designation	Year tested in IRBN	Score (% of sites)		
		0-2	3-4	5-9
IRAT13	1978	82	13	5
	1981	64	28	8
	1983	79	15	6
IR1544-238-2-3	1977	70	28	2
	1978	74	20	6
	1979	60	31	9
	1980	64	24	12
	1981	57	32	11
IR45	1978	73	23	5
	1979	56	34	9
	1980	55	30	15
IR52	1978	75	19	6
	1979	59	31	9
	1980	52	24	24
	1983[a]	67	22	11
IR5929-12-3	1979	50	34	16
IR5931-110-1	1979	58	30	12
IR7760-4-8-2	1978	66	31	3
	1979	47	41	13
IR7790-18-1-2	1979	61	30	9
IR9560-2-6-3-1	1978	54	36	10
MRC172-9	1978	58	35	8
BR319	1983[a]	66	29	6
IRAT104	1983	80	14	6
		70	19	11
UPL Ri-7	1983	44	47	8

[a] In 1983 the score groups were changed to 0-3, 4-6, and 7-9.

Table 6. International Rice Blast Nursery entries rated good for neck blast tolerance in different years and across sites.

Year	Entries
1978	Basmati 97, CIAT-ICA5, CIAT-ICA13, B2549b-Sm-Mr-5-6, IR2793-10-2, IR4432-28-5, IR1544-238-2-3, IR4547-6-3-2, IR4547-16-34, IR45, IR3525-46-1-4-3, IR3351-38-3-1, Dissi Hatif, Samba, Alupi, IR32
1979	Raminad Str. 3, Wagwag, CO 25, IR4227-18-3-2, IR1544-238-2-3, IR32, Tetep, IR4219-35-3-3, IR4547-6-3-2, IR6140-22-2, IR9669 sel., IR45, 5398, 5698, 5720, 5853, 5854
1980	PI4, CIAT-ICA5, Colombia I, Colombia II, IR946-14-3-3-2-3, IR1905-PP11-29-4-61, IR3259-8-172-5, IR5533-PP850-1, IR8192-31-2-1-2, IR14753-120-3, Suweon 286, Tetep, Carreon

entries (11). These could have been due to differences in races of pathogens prevalent at different test sites as well as due to environmental conditions. By inoculating with specific races and evaluating the reactions of different varieties, sets of differential varieties were developed in Colombia, India, Japan, Korea, Philippines, Taiwan (China), and USA. An international set was also developed through a cooperative project between Japan and USA. Several of the entries from the various differential sets are included each year in the IRBN. The reactions of those entries in the 1983 IRBN at sites with high average disease score are summarized inTable 7. Tetep was resistant at all sites whereas B40, Taichung T.C.W.C., and Khao-tah-haeng 17 were susceptible.

Moderate resistance

To identify varieties that may have field resistance to blast, the multilocation screening results were reviewed to find entries, given scores of 3-4 across sites. None of the entries in any of the years were in that category. A few entries given scores of 3-4 with highest frequency included NP 125, Y ashiro-mochi, B55, and Katachikon.

Comparative performance of Carreon and Tetep

Reactions of different selections from the cross IR9669 (IR8*3/Carreon) and the parents Carreon and IR8 at seven selected sites of 1976 IRBN, with good degree of disease pressure (Table 8) were compared. Carreon was resistant at all sites except at Parwanipur, Nepal. IR8 was susceptible at all sites except at Parwanipur. The progenies showed differential reactions at different sites. All seven selections included in the test were resistant at Parwanipur, indicating that they got the resistance from IR8. The differential reactions of the progenies at the other sites indicate that resistance in Carreon is possibly governed by few major genes and segregation of these major genes might have resulted in the differential reactions observed in the progenies. Resistant Tetep progenies from a straight cross with IR8 showed relatively less variability in reactions. They were resistant at most sites where Tetep was resistant. Possibly Tetep resistance is governed by a relatively lower number of major genes compared to Carreon.

Selections from the cross IR5533 which had two blast-resistant donors (Carreon, Tetep) in its parentage showed resistance at all sites except for one of the nine selections in the test, which was susceptible at only one site. This shows the usefulness of pyramiding of genes in widening the spectrum of resistance.

In the 1978 IRBN test at Hmawbi, Burma, Tetep and Carreon were susceptible but some progenies from IR5533 were resistant, suggesting the possibility of a complementary action of the genes derived from Tetep and Carreon.

Table 7. Reactions of some differential varieties to blast at selected test sites with high average disease score, 13th International Rice Blast Nursery 1983.

Designation	Blast scores at[a]									
	Pingman, China	Payakumbuh, Indonesia	IRRI, Philippines	Khonkaen, Thailand	Rangsit, Thailand	Nellore, India	Shillong, India	Onne, Nigeria	Goiania, Brazil	Guimanguillo, Mexico
Dular	S	–	R	R	S	–	M	M	M	R
Kanto 51	M	–	S	R	S	–	M	S	M	R
NP 125	M	–	M	R	S	M	S	S	M	M
Raminad Str. 3	–	S	M	R	S	S	R	R	R	R
Usen	S	M	M	R	S	–	M	S	S	S
Chokoto	S	M	S	R	S	–	S	R	S	M
CI 5309	S	–	R	R	–	–	S	S	R	M
CO 25	–	S	S	S	S	–	S	M	R	S
IR42	–	S	S	R	S	S	M	R	M	R
Kataktara DA2	S	R	R	R	S	–	M	R	M	R
Khao-Tah-Haeng 17	–	S	S	S	S	S	S	S	S	S
Pai-kan-tao	M	–	R	M	–	–	M	R	R	M
Peta	–	S	S	S	S	R	S	M	S	S
Taichung T. C. W. C.	S	S	S	S	S	–	S	S	S	S
Wagwag	–	S	R	R	S	R	S	S	S	M
Aichi Asahi	S	S	S	S	S	M	S	S	S	S
Fukunishiki	M	–	R	R	–	–	M	R	M	R
Tetep	R	R	R	R	R	R	R	R	R	R
Carreon	M	PM	R	R	S	R	R	M	R	R
Pankhari 203	M	S	R	R	S	S	M	M	M	R
Dawn	S	M	R	M	S	S	M	R	S	M
8-40	S	S	S	S	S	–	S	S	S	S

[a]R = resistant, S = susceptible, M = moderate.

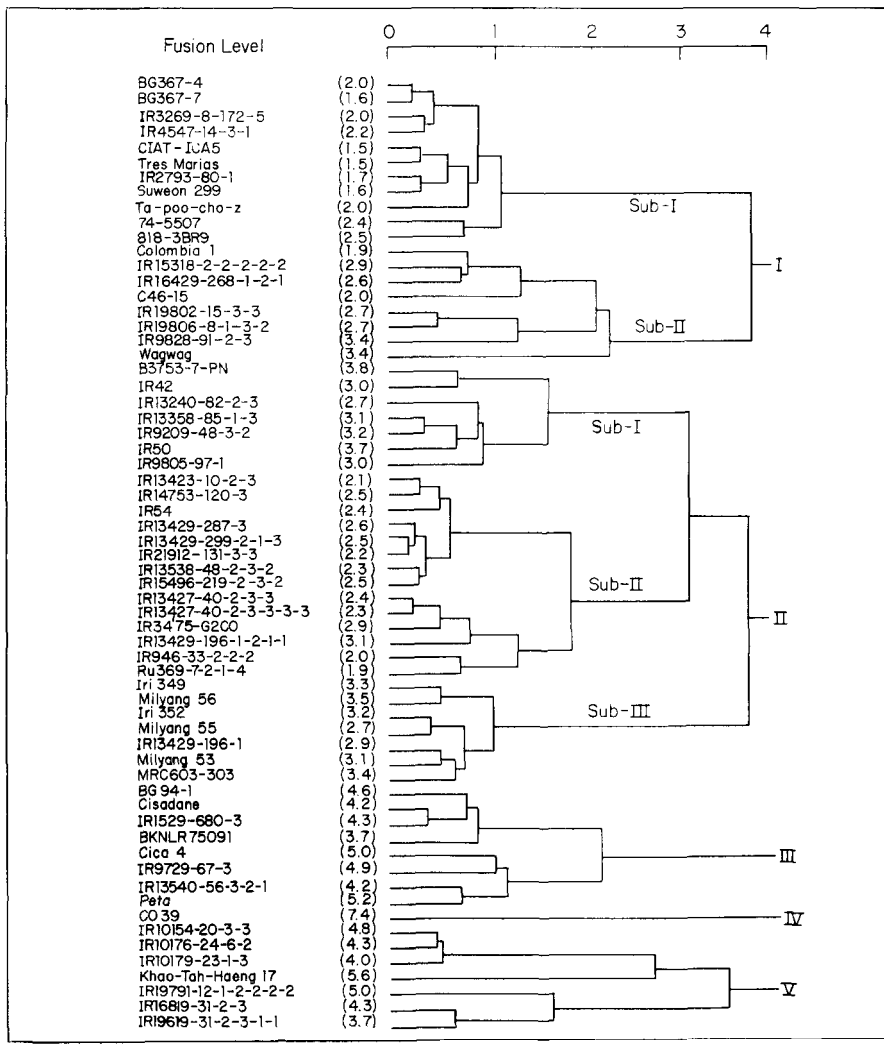
Table 8. Comparison of reactions to blast of Carreon, IR8, and their progenies, International Rice Blast Nursery 1976.

Designation[a]	Reaction to blast (score) at[b]						
	Indonesia		Leyte, Philippines	Rajburi, Thailand	Palmira, Colombia	Bumbong Lima, Malaysia	Patwanipur, Nepal
	Muara	Tamanbogo					
Carreon	R	R	R	R	R	R	S
IR9669-PP846-1	I	R	R	R	R	R	R
IR9669-PP836-1	R	R	R	R	R	R	R
IR9669-PP830-1	R	R	R	R	I	R	R
IR9669-PP823-1	S	I	S	R	S	R	R
IR9669-22-2-6	R	S	S	S	R	S	R
IR9669-23-12-7	S	S	S	R	R	R	R
IR9669-27-4-8	S	I	S	R	S	R	R
IR8	S	S	S	S	S	S	R
IR5533-56-1-12	R	R	R	R	R	R	R
IR5533-55-1-11	R	R	R	R	R	R	R
IR5533-15-1-1	R	R	R	R	R	R	R
IR5533-14-1-1	R	R	R	R	R	R	R
IR5533-13-1-1	S	R	R	R	R	R	R
IR5533-PP850-1	I	R	R	R	R	R	R
IR5533-PP854-1	R	R	I	R	R	R	R
IR5533-PP855-1	I	R	R	R	R	R	R
IR5533-PP856-1	R	R	R	R	R	R	R

IR9669 Parentage = IR8*3/Carreon, IR5533 parentage = IR8///IR8/Carreon//IR8/Tetep. [b]R = resistant, S = susceptible, I = intermediate.

Numerical analysis of IRBN data

One difficulty in interpreting and utilizing data from the IRBN is categorizing the type of resistance that different entries possess. Since it is expected that different races of *Pyricularia oryzae* predominate at different sites, the IRBN data should be useful in providing empirical information relative to the genetic grouping of entries in the nursery based on reactions to blast. The complexity of the host-parasite interaction in rice blast, however, makes it difficult to make an unambiguous classification of the types of resistance. The complicated race structure of the fungus population at particular sites, combined with environmental variability and the large diversity of IRBN entries, makes it difficult to form neat varietal groups.



1. Dendrogram of varietal comparisons for 63 IRBN entries in 1981 and 1982 classified by leaf blast reaction at 42 sites. Mean value of leaf blast score at 42 locations.

Numerical classification methods were used in an attempt to overcome these difficulties.

Initially, principal component and cluster analyses were performed for entries with complete data in 1981 and 1982. Nine major varietal groups were formed by cluster analysis for each year. It was noted, however, that many varieties which were included in both years did not belong to the same group each year (i.e., entries that were in a particular group in 1981 were not necessarily in the same group in 1982).

To gain more accuracy in the grouping, data from 2 consecutive years (1981-82) were analyzed. The dendrogram based on such an analysis is shown in Figure 1 for 64 entries that had complete data for both years. Groups I and II of this dendrogram, along with the corresponding groups assigned to individual entries in those groups on the basis of separate analyses of 1981 and 1982 data, are shown in Table 9. Of the 20 entries in

Table 9. International Rice Blast Nursery entries in two clusters (group I and II) based on combined analysis of 1981 and 1982 data on reactions to blast compared to the groupings based on individual year's data.

Group I entries (1981-82)	Group number based on single year data		Group entries (1981-82)	Group number based on single year data	
	1981	1982		1981	1982
BG367-4[a]	VII	I	BG3753-7-PN	I	III
BG367-4	VI	I	IR42	VI	II
IR3259-8-172-5 [a]	VII	I	IR13240-82-2-3[a]	IX	II
IR4547-l4-3-1 [a]	VI I	I	IR13358-85-1-3	IX	III
CIAT-ICA5	VI	I	IR9209–48-3-2[a]	IX	II
Tres Marias	VI	I	IR50 [a]	IX	II
IR2793-80-1[a]	VII	I	IR9805-97-1	IX	III
Suweon 299	VII	I	IR13423-10-2-3 [a]	IX	II
Ta-poo-cho-z	VII	I	IR14753-120-3	IX	I
74-5507	IX	I	IR54	IX	I
818-3BR9[a]	VII	I	IR13429-287-3 [a]	IX	II
Colombia I	VI	I	IR13429-299-2-1-3 [a]	IX	II
IR15318-2-2-2-2-2	VII	III	IR21912-131-3-3 [a]	IX	II
IR15429-268-1-2-1	VI	III	IR13538-48-2-3-2 [a]	IX	II
C46-15[a]	VII	I	IR15496-219-2-3-2 [a]	IX	II
IR19802-15-3-3	VII	II	IR13427-40-2-3-3 [a]	IX	II
IR19806-8-1-3-2	VII	II	IR13427-40-2-3-3-3-3	VII	II
IR9828-91-2-3	IX	III	IR34'75-G2CO	VII	II
Wagwag	VI	VII	IR13429-196-1-2-1 [a]	IX	II
			IR946-33-2-2-2	IX	I
			Ru369-7-2-1-4	VI	I
			Iri349	IX	IV
			Milyang 46	VIII	IV
			Iri352	IX	IV
			Milyang 55	IX	IV
			IR13429-196-1[a]	IX	II
			Milyang 53	VIII	IV
			MRC603-303	VIII	IV

[a]In the same group in all three classifications.

group I, 12 in 1981 and 14 in 1982 were in the same group and 8 of the entries were together in the same group based on 2-yr data and on individual year's data. Of the 28 entries in group II, 20 in 1981 and 15 in 1982 were in the same group and 12 were together in the same group both in 1981 and 1982. The 2-yr analysis appears to work well, since some of the known related entries (e.g., sister selections from the same cross) are generally grouped together. By extending this 2-yr analysis back to previous year's nurseries, entries that occur in consecutive 2-yr periods can be used as markers of a particular reaction pattern. This way, IRBN entries not necessarily grown in the same year can be grouped together by reference to another entry present in the same group. Such a grouping has been constructed for the years 1978-82 (Table 10).

Although the method appears useful for distinguishing broad varietal groups, its usefulness for studying resistance genes is questionable. The level of discrimination is probably not high enough to observe effects of individual genes. Initial studies with Philippine isolates indicate that the genetics of resistance is very complicated, and that different genes are responsible for resistance to the diverse blast races. Classifying the entries into broad varietal groups for cluster analysis, however, should allow easier interpretation and utilization of the large amount of information in the IRBN results.

Table 10. Summary of the varietal groups using dendrogram of IRBN entries from 1978 to 1982.[a]

1978-79	1979-80	1980-81	1981-82	Corresponding varieties
IV	VI	VI	I	TETEP GROUP (48 entries)
0	0	0	0	Tetep, IR1905-81-3-1, Carreon, Colombia II, Raminad Str. 3, IR1905-PP11-29-4-6-1, Ciwini/ Alupi, IR5533-56-1-12
0	0	0	0	Tres Marias, CIAT-ICA5
0	0	–	0	Colombia I
0	–	–	0	74-5507, IR279380-1
0	0	–	–	IR1416-125-5-8, IR4227-18-3-2, IR3271-PP134-68-3-1, IR9669-PP846-1, Tadukan, IR46
0	–	0	–	IR9802-10-3
–	0	0	–	Fukunishiki
–	–	–	0	Suweon 299, IR4547-14-3-1, IR9828-91-2-3
0	–	–	–	Dissi Hatif, IR4547-6-3-2, IR3259-PP11-186-4, IR9559-4-1-1, IR5533-13-1-1, IR9559-PP870-1, IR3271-760-1482, IR3273-289-2-1473, OS6, H5, M302, CIAT-ICA1, IR2588-5-1-2, IR4547-10180-20-7
–	–	0	–	IR5533-PP850-1, IR5533-PP854-1, IR9660-00948-1, IR9852-18-1
–	0	–	–	5287,5436, Pokhreli Masino, IR48, Milyang 46, Suweon 286

Table 10 continued.

1978-79	1979-80	1980-81	1981-82	Corresponding varieties
I	VI	V	II	CEYSVONI SML GROUP (41 entries)
0	0	0	0	IR54
0	0	0	–	IR1544-238-2-3
0	0	–	–	IR45, IR52, IR8192-31-2-1-2
0	–	–	0	Ru369-7-2-1-4
–	0	0	–	Milyang 47, TOS2259, Ceysvoni SM L
–	–	0	0	IR14753-120-3
–	–	0	–	IR3259-5-160-3, IR19774-23-2-2-2, IR19798-8-2-3-3, IR19799-17-3-1, IR13426-19-2, IR14632-22-3
0	–	–	–	IR38, IR4570-117-2-1-1, IR9209-181-2-2, IR9761-19-1, IR4563-52-1-3-6, IR2797-105-2-2-3, IR4432-285, IR4568-226-3-2
–	–	–	0	IR60, IR13429-287-3, IR13423-10-2-3, IR21912-131-3, IR13538-48-2-3, IR15497-219-2-3-2, IR13427-40-2-3-3, IR13427-40-2-3-3-3, IR3475-G2CO-CNT84-1-1, IR13429-196-1-2-1, Iri 349, Milyang 55, IR13429-196-1, Milyang 56, Milyang 53, Iri 352, MRC603-303
I	VI	V	II	PAI-KAN-TAO GROUP
0	0	0	0	IR34, IR36, IR456886-1-3-2, IR4432-103-6-4
–	0	0	0	IR42, IR50
0	0	–	–	IR44
0	–	–	–	BW246, Gama 318, IR32, IR3351-38-3-1, IR9761-75-3, IR9761-47-3, IR4432-52-6-4, IR1544-340-6-1
–	0	–	–	Suweon 287, Suweon 288, Iri 344, Iri 343, Iri 342, CO 25, IR43, IR9217-58-2-2
–	–	0	–	Pai-kan-tao, IR4227-164-1-1-1
–	–	–	0	B3753-7-PN, IR13240-82-2-3, IR13358-85-1-3, IR9209-48-3-2
III	II	II	V	KHAO-TAH-HAENG 17 GROUP (14 entries)
0	0	0	0	Khao-Tah-Haeng 17
0	0	0	–	Usen
–	0	0	–	Shin 2
–	0	–	–	Yamabiko
–	–	0	–	IR1846-296-3, Yashiro mochi, IR197748-1-3-3, Paro White
–	–	–	0	IR10154-20-3-3, IR10176-24-6-2, IR10176-23-1-3, IR19791-12-1-2-2-2-2, IR19819-31-2-3, IR19819-31-2-3-1-1
I	IV	IV	–	HANGANGCHALBYEO GROUP (2 entries)
–	0	0	–	Hangangchalbyeo
0	0	0	–	IR1721-11-5-3-2-3-1

Table 10 continued

1978-79	1979-80	1980-81	1981-82	Corresponding varieties
V	I	I	–	B-40 GROUP (2 entries)
0	0	0	–	B-40
–	0	0	–	Taichung T. C. W. C.
–	VI	III	–	PI-4 GROUP (7 entries)
–	0	0	–	Pi-4
–	–	0	–	Caloro, Chubu 22, Nongbaek, Minehikari, Jinheung Tsuyuake, CI 5309
II	VI	V	I	C46-15 GROUP (18 entries)
0	0	0	0	818-3BR9
0	0	0	–	T23
–	–	0	0	C46-15, IR19806-8-1-3-2, IR3259-8-172-5, IR15318-2-2-2-2-2, IR15429-268-1-2-1, IR19802-15-3-2
0	–	–	–	Basmati 370, 229/54
–	–	0	–	IR15314-30-3-1-3, IR3273-PP339-1, Huan-sen-goo, IR4547-16-1-5, IR4547-2-1-2, IR4547-5-3-6, CaMponi SML, IR1820-52-24-1
VI	V	IV	III	MILYANG 30 GROUP (18 entries)
0	0	0	0	IR 1529-680-3
0	0	0	–	IR20
0	0	–	–	IR9669 Sel.
0	–	–	–	BG35-2, IR3880-10, IR3839-1, IR3880-29
–	0	–	–	Milyang 30,Milyang 42, Milyang 45, Suweon 264, Suweon 285, Suweon 289, Iri 338
–	–	0	–	H97-(11)
–	–	–	0	BG94-1, Cisadane, BKNLR75091
–	–	–	0	BG94-1, Cisadane, BKNLR75091
VI	III	IV	III	PETA GROUP (11 entries)
0	0	0	0	Peta
–	0	0	–	IR8
–	–	0	0	Cica 4
–	0	–	–	Suweon 279, Suweon 281
–	–	0	–	MRI, Pelita I-1, Tongil
–	–	–	0	IR9729-67-3, IR13540-56-3-2-1

[a] The Roman numeral under each 2-yr period refers to the group number in that period. The "0" marks for each variety refer to the years the variety was included in the group. Dash (—)indicates that the variety was not included in the analysis in that 2-yr period.

FUTURE DIRECTIONS

The blast nursery has identified several improved varieties with specific resistance to different races of the pathogen. However, the sources of resistance involved in those entries were few (e.g., Tetep, Carreon, and Tadukan). Several additional sources of resistance must be identified and incorporated appropriately in improved agronomic background. Avail-

ability of additional sources of resistance and development of a pool of gene sources will help identify varieties for resistance to specific races on the one hand and plan appropriate pyramiding of genes, either to enhance the level of resistance or broaden the spectrum of resistance on the other.

The nurseries should include sets of entries targeted to different rice cultures, particularly the irrigated and rainfed upland. Selected entries from cold tolerance nursery should also be tested in the blast nursery.

Thus far, screening of IRBN for reactions to neck blast has been extremely limited. There is a need to intensify this effort through an appropriate methodology.

Selected entries from IRBN identified for their differential reactions under natural infection may have to be used for further studies under controlled environmental conditions to better understand the genetic variation in *P. oryzae* through artificial infection with various isolates of the pathogen.

ACKNOWLEDGMENTS

Contributions of the rice scientists who participated in the international blast nurseries from 1975 to 1984 are acknowledged with sincere thanks. Names of those scientists are listed in the individual IRBN reports published annually by IRTP. Thanks are also due the staff at IRTP headquarters who contributed in the organization of the nursery, data processing, and reporting of results.

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B. Pest management

EPIDEMIOLOGICAL INFORMATION AS AN AID IN PEST MANAGEMENT

J. KRANZ

EPIDEMIOLOGY: LABORATORY AND DISEASE CONTROL INTERFACE

Epidemiology is the branch of plant pathology that studies interactions of pathogen (or disease) populations and host plant populations in their environment and with the interference of man. These processes result in quantitative states and rates. States are plotted over time or distance, and rates describe the dynamics of these processes, such as disease progress curves or infection rates. Hence, epidemiology in plant pathology is essentially the science of population dynamics of diseases in crops and their resulting effects. It is thus more than the customary treatment of epidemiology in textbooks of disease cycles and the influence of climatic factors on disease.

Minimum or optimum temperatures for infection or sporulation are never the constants they are made to appear. They are variables affected by other factors including leaf wetness duration, disposition of the host, or inoculum density. Such compensation phenomena (5) are common and explain why disease outbreaks may occur under seemingly unfavorable environmental conditions.

The prime objective of epidemiology is to explain the behavior of plant diseases under given climatic and cropping conditions, and how to manipulate them toward a defined goal. Epidemiology permits design of novel tactics and strategies for pest management systems and resistance gene management. Tactics refer to disease control and management within a growing season, strategies are designs for long-range disease management.

DYNAMICS OF DISEASES IN TIME AND SPACE

Interactions between host plant development, weather, and disease often are difficult to disentangle. For management and control of a disease it may be essential to know how temperature, leaf wetness, and phase-dependent host

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resistance affect infection, latent periods, sporulation, and pathogen spread. Such clues may be used to develop the most effective interference with disease progress and spread, without undue side effects on the host plants, and without opening avenues for iatrogenic diseases (12). Systems analysis (17) is an appropriate way to approach this.

Interactions of host plant, weather, pathogen, and disease are best studied in a single field plot, large enough to be representative of a farmer's field, and equipped with meteorological equipment and spore traps. In such holistic field experiments, plant development, weather factors, and spore trapping results should be recorded daily. Records of disease intensity and sporulation, for example, as well as information on some host characters, are best noted as a subset of the total sample of tagged hills or tillers. This ensures correlation with daily weather data and spore catches. Once a week one returns to the same subsample of plants. These recordings can have varying thoroughness and precision, depending on the objective of the study, but they will invariably yield large bodies of data. Data acquisition and processing can become crucial and must be well organized before the experiment starts. Several selected publications, mostly on irrigated rice, are cited here to indicate the scope of the research (3, 4, 10, 13, 26, 28, 29).

SURVEILLANCE AND MONITORING

Supervised disease control and integrated pest management (IPM) are being used increasingly in rice production throughout the world. Both strategies are based on threshold levels of disease and pests in crops. IPM differs from supervised disease control by *ad hoc* decision making before, during, and sometimes after the crop growing season.

Disease assessment and sampling

Disease assessment and sampling techniques are paramount in all surveillance activities but are often unsatisfactory. Epidemiology must make disease assessment and sampling techniques meaningful, representative, and practical. This type of research, apart from disease assessment proper (e.g., standard diagrams, correction factors, linearizations) includes sampling methods (random, stratified, and systematic); sampling units (leaves, tillers, hills, plots); timing; sampling techniques (field or laboratory examination or both, tagged or removed); and sample size. The sample size must be practical, usually in the range of 15 to 50 sampling units per field or area. It depends on the variability of the disease, precision needed, and funds available. The basis for adequate sampling is the knowledge of the spatial distribution of a disease and its change during the epidemic.

Crop loss assessment methods

Crop loss assessment methods require close cooperation among plant physiologists, economists, and epidemiologists who contribute to disease

assessment technology. Any epidemiological field experiment lends itself to crop loss assessment modelling, provided yield data are taken from the sampling units (single plants or plots) for which disease progress was recorded at defined growth stages. This may do for loss magnitudes and loss equivalents (9), but for loss profiles (25), a more complex approach is needed. One example of published rice loss assessments is Padmanabhan (24).

Economic damage thresholds (EDT)

Economic damage thresholds include the economic determinant and the biological components (18). Biological components are based on loss equivalents for one unit of disease severity in a given growth stage. Susceptibility of a plant often changes with age, and hence impact of disease on yield formation will change as well. Consequently, economic damage thresholds change during a growth period. And as yield differs among fields, and prices between years, EDTs are, strictly speaking, only valid for a given field and year. With information on the most likely disease progress curve and the incubation periods of a disease, the control threshold can be established. In case of protective fungicide application, the control threshold is the disease severity at least one incubation period ahead of the time when curves predict that the disease progress will go beyond the economic damage threshold.

Risk analyses are useful, although widely neglected, tools for appraisal of the economic importance of a disease. Simple records of whether or not the disease exceeded the (assumed) economic damage thresholds over a number of years is all that is needed to establish probabilities of disease risks. These would also permit an economic analysis of various control strategies.

Strategies for gene management (race monitoring)

Control of rice diseases with resistance genes has been of prime importance for years, and will continue to be (23). This is particularly true for upland rice cultivars. However, most pathogens have the ability to adapt themselves to resistance genes in cultivars, which eventually leads to the cultivars no longer being protected. Various strategies have been suggested (14, 21) to overcome or obviate such an erosion or defeat of resistance genes. Practically all require a good understanding of the effects certain resistance genes have on race frequencies in pathogen populations as well as on various aspects of their shifts in time and space (1,2). Fruitful research has been done on wheat and barley powdery mildews and some cereal rusts. No doubt, these kinds of epidemiological studies will also help to explain the problems about *Pyricularia* races and their interactions with cultivars.

Apart from resistance genes proper, certain characteristics which describe plant type have an effect on disease intensities. Field resistance often appears to be rather conditioned by the morphology, anatomy, or some ontogenetic changes of the host plant and these factors may substantially affect disease progress.

FORECASTS

Forecasts, when feasible and available, are instruments for establishing a more rational crop protection program, and are essential in integrated pest management. Many types of forecasts exist or are possible (15). In disease control, forecasts for whether, and when, to control a disease are the most common. Forecasts imply aneconomic damage threshold and they require a practical monitoring system (19). Several rice blast disease forecasts are published (11, 20, 22, 27, 30) but few of them are in use. Obviously some did not comply with monitoring requirements, others were not developed using principles of epidemiological research as outlined above. A major shortcoming of most forecasts is they are based on too small a data base, and are not thoroughly validated.

DISEASE CONTROL METHODS

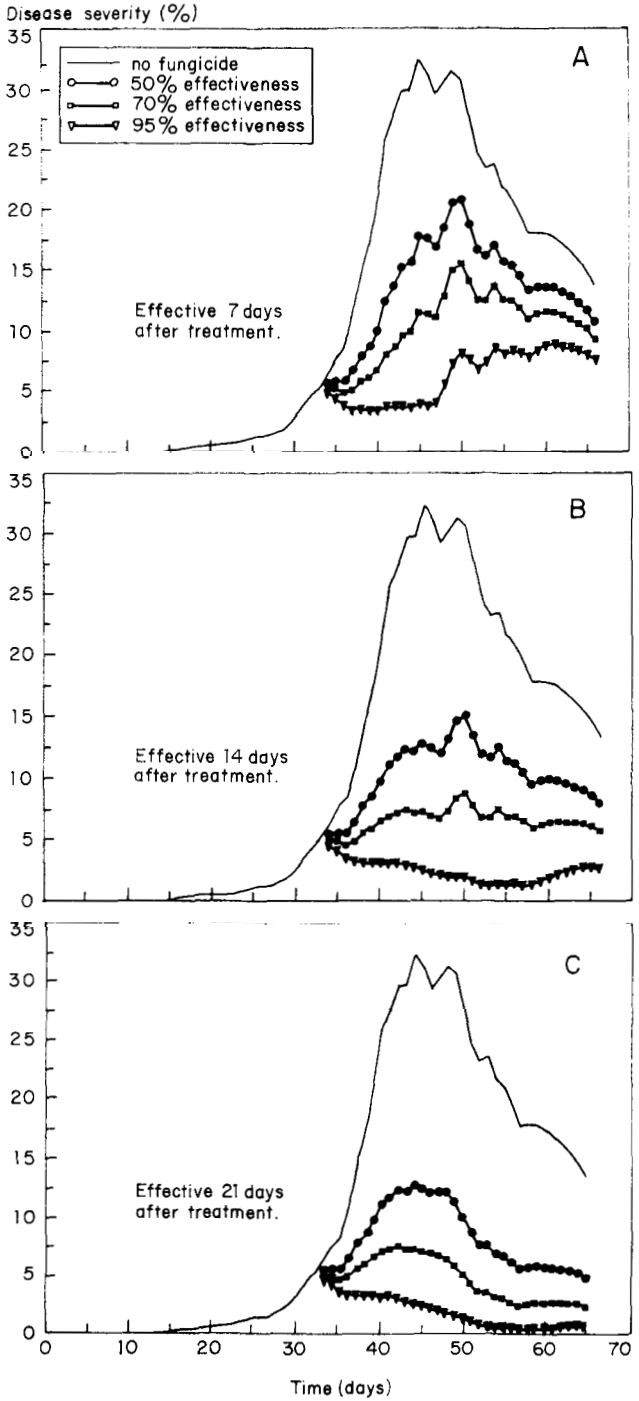
From field experiments, and systems analysis as described previously, weak points in the biology of the pathogen must be identified. Based on this information, models for control can be formulated and tested. From an epidemiological point of view, control measures affect either the size of the primary inoculum, or the infection rate, or both, and thus the final disease intensity in a crop.

Epidemiological studies can clarify the extent to which a certain control measure affects Yo, the primary infection at the onset of the disease, or r, the apparent infection rate. Models such as those shown in Figure 1 a-c can thus be instrumental in identifying the most effective control measures for a pathosystem under given conditions. This can save time and resources even if the most promising control measures are already known.

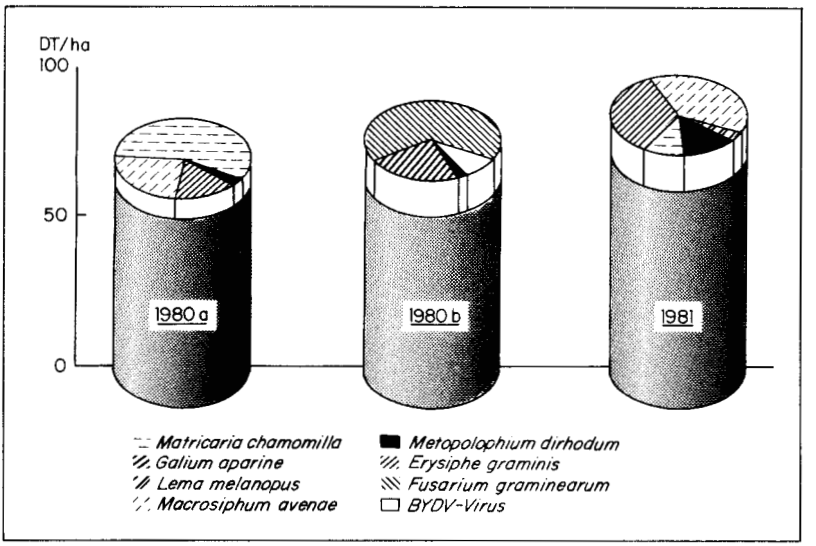
Field experiments based on epidemiological concepts may help to improve the efficiency of the control measures, or reveal why they fail to work.

DESIGN OF PEST MANAGEMENT SYSTEMS

Pest management systems are at present pragmatically designed and often successful; particularly if only one disease or pest is to be controlled, or where several single disease or pests occur in neat sequences. However, if several diseases or pests overlap in incidence or change in importance, pragmatic designs are likely to fail. For more scientifically based IPM systems, epidemiology must provide information on the interaction (possibly of all diseases, pests, and stresses occurring in a crop) and their effect on disease progress, and on yield (8). Information of this kind derived from such synecological studies supplements or corrects findings of the sort described previously and this facilitates better decision making. From the effect of all relevant constraints in the crop, its yield loss profile (see *Crop loss assessment methods*) may be computed (Fig. 2). Together with risk analyses and thresholds (see *Economic damage thresholds*) loss profiles would indicate



1. Simulated disease progress curves (from 6) of barley powdery mildew. The fungicide is assumed to be effective for 7 (a), 14 (b), and 21 (c) days after treatment.



2. Loss profiles (from 7) for three wheat fields. The height of the entire column gives potential yield of the field, the hatched portion the actual yield; the loss shared by the measured constraints is shown in the disc at the top.

to what extent control of an additional constraint is economically important. The amount of work needed for any synecological project in epidemiology is similar to the amount needed for a study of each of the pathosystems separately. It is essentially a matter of systems bounding which reconciles both the objective of the study and the feasible input in time, effort, and expense. To minimize systematic errors, a synecological project as outlined here should preferably be done by a single researcher, with consultation and the cooperation of specialists in pathogens, pests, and other related subjects.

DATA BASES

Future pest management will greatly rely on data bases comprising information as sketched in this chapter, together with information on weather, marketing, and many other relevant factors. Epidemiologists are becoming involved in developing concepts and procedures to create such computerized data bases.

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RICE BLAST MANAGEMENT UNDER UPLAND CONDITIONS

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Increased production of rice in upland areas is seriously constrained by frequent and intense blast occurrence because of edaphoclimatic conditions. Often, introduction of modern improved technologies achieved only limited success.

Nevertheless, a substantial increase and stabilization of production in upland rice at minimum input would have significant impact on total rice production in several regions (8) and would also help many subsistence farmers to benefit from modern technology.

RICE BLAST UNDER UPLAND CONDITIONS

The blast pathogen *Pyricularia oryzae* Cav. can survive much longer under dry conditions than under submerged or moist conditions (25). It may survive more than 2 yr in dry infected straw.

Rice plants grown under upland conditions are more prone to blast infection than those grown under irrigated conditions due to physico-chemical properties of soil, prolonged leaf wetness, and unbalanced nutrition uptake associated with drought (30).

Many known blast areas have common features such as infertile and acidic soil, low cation exchange capacity, sandy or light soil texture, and high humidity with low night temperature. Drought and Al toxicity are also common.

In blast-prone areas, yields often become a function of leaf and panicle blast severity (9, 27). Severe leaf blast infection reduces effective tiller numbers and plant height while panicle blast (including neck blast) affects grain filling and weight. Yield losses due to panicle blast are almost double those caused by leaf blast at the same severity level. Based on these observations, a new scale was devised for quantitative assessment of panicle blast severity (Table 1).

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Table 1. Scale for panicle blast intensity.

Grade	Description	Relative intensity value
0	No visible lesion or lesions on only a few pedicels	0
1	Lesions on several pedicels or secondary branches	10
3	Lesions on a few primary branches or the middle part of panicle axis	20
5	Lesion partially around the panicle base (node) or the uppermost internode (neck of panicle) or the lower part of panicle axis near the base	40
7	Lesion completely around panicle base or uppermost internode[a] or panicle axis near the base with more than 30% of filled grain	70
9	Lesion completely around panicle base or uppermost internode[a] or the panicle axis near the base with less than 30% of filled grains	100

[a] Infection is also found on the lower part of internode, which is covered by the leaf sheath. Proper evaluation time is around 24 d after heading.

PRINCIPLES AND PRACTICES OF BLAST MANAGEMENT

General concept of blast management

The primary objective of blast management is to keep damage from exceeding the level where profit, expected yield, or quality is significantly diminished (12). Yet total cost for disease management should be within an acceptable range (14).

Determining two critical points, damage threshold and action threshold, was suggested as an essential step for logical assessment of and proper use for control measures (35). This requires a well-designed and complicated series of epidemiological and economic analyses. In reality, however, rice farmers depend heavily on their own experiences and perceptions on disease level. Almost no critical research data on these parameters are available.

Under favorable upland conditions in Colombia, if 5% of leaf infection occurs during the active tillering stage, fungicide applications begin on susceptible varieties if subsequent weather is expected to be favorable for blast (5). Damage threshold for leaf blast was estimated at about 25% at the joint stage in the case of CICA 8. Determining an action threshold for panicle infection is difficult because of frequent early infection before heading.

A combination of measures that can significantly reduce the disease rate are preferred for leaf blast control. But for panicle blast, reduction of collar infection and protection of early emerging panicles are critical. Infection on the collar, a joint part between the leaf blade and the leaf sheath, frequently leads to panicle infection even before exsertion of panicles (8).

A cumulative disease curve representing leaf blast can be changed into a straight line by using an appropriate transformation (35). Two epi-

Table 2. Major effects of crop management components on epidemiological parameters of rice blast.

Components	Major effect on	
A. Farm site		
1. Prevailing climate	Xo[a]	r
2. Topography		r
3. Physicochemical properties of soil		r
B. Land preparation		
1. Soil amendments		r
2. Tillage level and depth of plowing	Xo	
3. Spacing and orientation of rows		r
C. Planting and crop husbandry		
1. Cropping system	Xo	
2. Variety	Xo	r
3. Seed quality	Xo	
4. Planting date	Xo	r
5. Seeding rate		r
6. Fertilizer rate		r
7. Weed control	Xo	
8. Use of fungicide	Xo	r
9. Removal of infected plants	Xo	
10. Handling of crop residue	Xo	

[a]Xo — initial inoculum; r — apparent rate of disease progress.

demiological parameters, an initial inoculum (Xo) and the apparent infection rate (r), are frequently used to characterize an epidemic. Many factors influence these parameters and thus the progress of the disease. Almost any farming activity can influence blast development, either directly or indirectly (Table 2). The relative degree of influence may vary greatly among countries as well as among regions.

Usually any single measure alone does not provide sufficient or stable control of blast, while a combination of several measures often is mutually enhancing.

Cultural practices

In the absence of immediate control measures, such as a highly resistant variety or chemical control, cultural practices have been one of the oldest and reliable methods to reduce blast damage (20). Unique combinations of traditional practices, such as low plant density and minimum use of N fertilizer, have evolved as a result of farmer experiences with traditional cultivars in a given upland environment.

Timely and uniform management of upland rice fields is difficult because of rolling or hilly topography and unpredictable rain distribution. In drought-prone areas of Central America, early planting is recommended to reduce drought injury during the period rice plants are vulnerable to the blast. In Quintana Roo, Mexico, drought injury is significantly reduced by constructing strong contour bunds (28).

Liming lowers soil pH and also Al toxicity. This practice also reduces leaf blast severity of moderately resistant varieties (1). Silica amendment is also known to reduce panicle blast (17).

Orientation of rows, spacing, and seeding rate influence microclimate within the rice canopy. Orienting the rows parallel to direction of prevailing winds lowers humidity within the canopy. Wider spacing and low seeding rates are common practices in drought-prone areas in Brazil.

Fertilizer and fungicide management

In the absence of high varietal resistance, proper use of fertilizer and fungicide is critical and often appears to be the only measure to sustain yields under high disease pressure.

A classic example of a high dose N and high blast damage relationship has been demonstrated repeatedly. Under prolonged drought in the Cerrado region of Brazil an application of more than 15 kg of N caused heavy blast (1 1). A heavy dose of N generally inhibits uptake of silica which is known to provide mechanical barriers against blast infection (2). Increased soluble N may favor the growth of the pathogen. Even in an area where rice plants seldom responded to N, increased application of N significantly reduced yield as blast increased (Tab1e 3). The effect of P and K on rice blast is not yet clearly understood.

Several chemicals are highly specific and effective in control of blast (15, 24). Efficiency of chemicals varies according to disease severity and weather conditions at time of application. Resistance of the variety also affects the result. Fungicide application when severe infection is compounded with drought often does not help (9, 11). Likewise, late foliar applications to control leaf blast or applications during heavy rain to control panicle blast after flowering do not give expected results.

Efficiency of chemicals is greatly improved by adjusting doses and number of applications according to resistance levels of varieties (21) and actual disease development (5). A practical method should be developed that permits making applications on the basis of need rather than on the calendar.

The scheme in Table 4 illustrates a concept of maximizing efficiency of chemical applications.

Table 3. Effects of N rates and chemical control on rice blast severity, plant height, and yields on CICA 8 under upland conditions (9).

Nitrogen rate (kg/ha)	Leaf blast [a,b] (%)		Panicle blast (%) [c]		Plant height (cm)		Yield (t/ha)	
	A	B	A	B	A	B	A	B
50 (40) [d]	6.9 a	30.1 a	0.3 a	22.2 a	86.7 a	74.4 a	5.2 a	2.8 b
100 (80)	8.5 a	28.5 a	0.5 a	34.3 b	82.7 a	75.8 a	5.0 a	2.5 b
150 (120)	7.6 a	41.2 b	2.3 a	39.7 c	86.8 a	68.8 a	5.1 a	1.8 c
200 (160)	8.9 a	35.4 b	3.5 a	42.2 c	87.8 a	66.8 b	4.6 a	1.6 c

A = with chemical control; B = without chemical control. [a] In a column, means followed by the same letter are not different significantly at the 5% level. [b] Evaluated 60 d after seeding, [c] Evaluated 25 d after flowering. [d] Amount given before 60 d after seeding.

Table 4. Chemical application scheme to control rice blast based on disease Progress at different growth stages of rice plants.

Quantitative resistance level	Disease level in previous season or stage and environmental conditions[a]	For leaf blast			For panicle blast		Total number of applications
		Seed/ Seedling	Active tillering		Booting	10 d after flowering	Min. ~ Max.
			Early	Late			
Low	I	O[b]	O	O	O	O	2 ~ 5
	II	O	X	X	O	X	
Intermediate	I	O	O			O	1 ~ 4
	II	X	X		O	X	
High	I	O	X		O	X	0 ~ 2
	II	X	X		X	X	

[a]I = high disease level, conducive conditions; II = low disease level, nonconducive conditions. [b]O = application; X = no application.

Some systemic fungicides are effective long enough to protect rice plants against leaf blast by seed treatment alone. Seed treatment has several advantages over foliar applications: relatively stable effect, less dosage and lower cost of application, and elimination of monitoring. Formulation improvements will facilitate safe use by farmers. However, wide and continuous seed treatment may require monitoring for potential occurrence of chemical-resistant strains of the pathogen.

Critical period for panicle blast control is the mid-booting stage rather than after heading (8). Infection on the collar of flag leaves is believed to lead to subsequent neck and panicle infection as panicle emerges. Thus, application of systemic fungicide during booting stages appears to be a logical approach. One additional application 10 d after heading can further protect late emerging panicles.

Combining chemicals is common in Latin America to protect the crop not only from panicle blast but also from other diseases such as leaf scald, sheath rot, or grain discoloration (33). Certain combinations enhance effectiveness of other chemicals (31).

DISEASE MONITORING

Monitoring of disease development aims to forecast and determine the time for control action as well as assess the effect of management.

Some countries in temperate regions, such as Korea and Japan, maintain extensive networks to monitor diseases (34).

For successful forecasting these prerequisites should be satisfied:

1) Appropriate disease management technology available on time.
2) Appropriate communication networks.

If simple and reliable methods for quantitative evaluation are not available, visual estimation with aid of pictorial scales helps reduce variation. A standard procedure for field assessment of blast is needed.

Race identification using known differential varieties is the popular method to monitor the shift of the pathogen. However, use of commercially important cultivars or parental breeding materials gives more meaningful information. The mobile nursery method employed for estimation of relative change of isolates virulent to specific cultivars can be a useful technique (4). Although virulence analysis is simple, the known methods are not fully satisfactory. Distortion of the frequency estimates is due to lack of genetic information on host resistance and pathogen virulence, sampling error, reasonable criteria for qualitative classification, and interference of unrecognized gene or gene interactions (29).

MANAGEMENT OF GENETIC RESISTANCE

An economical and practical blast management system invariably requires varietal resistance as its major component (16). Through a long coevolutionary process many upland cultivars might have acquired a sort of stable resistance in a given agroecosystem. Yet gradual intensification of farming and modification of traditional cultivars to increase production has further increased the potential risk of blast damage.

Virulence and resistance

Pathogenic variation of the blast pathogen is a well-recognized fact (18, 26). The pathogen population is capable of maintaining diverse combinations of different kinds of virulence factors. However, fitness of a race possessing single or combined virulence is highly influenced by cultivars and some unknown factors. Frequently, shifty nature of the pathogen population limits the effect of varietal resistance to only about 2 yr by increasing matching virulence (Table 5).

Resistance of rice plants is recognized either qualitatively or quantitatively (4). Qualitative resistance, typified by absence of sporulating lesions, is often controlled by one or few genes and is race specific. Thirteen different sources of qualitative resistance were identified in Japan (18).

Quantitative resistance is recognized by the slow progress of disease due to several factors such as reduction in infection efficiency, sporulation capacity, lesion size and infection period, and prolonged incubation period (3, 19, 32). Genetics of quantitative resistance is not yet clearly understood. Some sources for qualitative or quantitative resistance are widely effective against diverse races of blast (26).

Strategies for utilizing host resistance

Any genetic measures which will not allow a unidirectional shift of the blast pathogen in terms of virulence and fitness would lead to stability of varietal performance to the disease.

Many scientists agree that the only practical way of reducing vulnerability of a crop to shifty pathogen is to diversify host resistance in deliberate ways. Nevertheless, some combination of simple resistance factors would be

Table 5. Changes in blast reaction of commercial rice varieties in Colombia.

Varieties	Year													
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
IR8	O	Xo												
CICA 4			O	X										
IR22			O	X										
CICA 6						**O**	X							
CICA 7								O		X				
CICA 9								O	X					
CICA 8										O		X		
Metica 1													O	X
Oryzica 1														O

O = year released. X = year susceptibility.

effective against certain blast pathogens due to inability to generate matching virulence combinations or due to reduced fitness. Also recent progress in genetic engineering has increased the possibility of introducing immune systems from other plants to rice plants.

Many proposed genetic methods of blast management can be grouped, based on how the coevolutionary process of the blast pathogen in relation to host resistance is handled (Table 6). None of these strategies were successful in actual situations, although circumstantial evidence supports each strategy as a valid one. Long-term success of each method depends on how the two major selection pressures, i.e. directional and stabilizing selection, can be manipulated in favor of the rice plants (22).

Varietal mixtures can be adopted in numerous traditional upland areas to exploit high-yielding potentiality of modern varieties. Diverse genetic backgrounds of each component add further diversity besides distinct resistance. Preliminary trials show that leaf blast damage is significantly reduced by mixing lines that are agronomically similar but that differ in resistance to blast (9, 10).

Crucial for highly mechanized upland areas is uniformity of crop and grain quality. Development of composites using male sterility can be a good approach. Sequential release of improved varieties with distinct resistance factors could be another practical solution provided there is adequate supply of seeds on time.

Table 6. Classification of the utilization of genetic resistance in blast management.

Strategy	Tactic	Method
Cyclic disturbance of coevolutionary process	Recycling of R-genes or alternation with immune system (diversity in time)	• Rotation or sequential release of varieties with distinct R-genes • Crop rotation
Continuous disturbance of coevolutionary process	Simultaneous use of R-genes in an agroecosystem (diversity in space)	• Varietal mixture or composite • Multilines • Cultivation of varieties with different R-genes (gene deployment)
Delay or slow down of coevolution	Integration of different R-genes in a genotype (broadening the spectrum of resistance)	• Combining genes for qualitative resistance (pyramiding) • Use of quantitative resistance controlled by polygenes • Combining genes for qualitative and quantitative resistance
Complete blocking of coevolution	Transferring genetic immune system	• Incorporation of alien genes

Use of quantitative resistance, such as slow blasting ability, has been frequently mentioned, but practical use has been slow due to lack of proper screening methods. Slight modification of conventional uniform blast nurseries (6, 23) and use of the relative evaluation system (Table 7, 8) will accelerate this approach. Use of a race-specific nursery will provide stability estimation for slow blasting ability. A race-specific nursery can maintain a population of specific virulence(s) to particular host resistance(s), which are frequently used in breeding programs.

Table 7. Scale for the Relative Evaluation System.

Grade	Description
0	Careful observation of a plant or plot reveals no lesions or infected plants.
1	Rapid observation does not detect lesions or infected plants, but careful observation detects a few lesions or infected plants.
3	Rapid observation easily detects a few lesions or infected plants.
5	Disease level is between grades 3 and 7. Distribution of lesions or infected plants is fairly uniform.
7	Disease level is clearly less than that of the standard entry.
9	Disease level is similar to that of the standard entry.

Table 8. Procedure for the Relative Evaluation System.

Step	Procedure
1	Carefully observe all the entries. If several entries show disease levels higher than grade 3, proceed to step 2.
2	Select one entry with a higher level of disease at the time of evaluation, and assign grade 9. This entry is called the standard entry at the time of evaluation. This may vary from evaluation to evaluation.
3	Form a mental image of the standard entry, which serves as a guide for grade 9.
4	Evaluate individual entries comparing the relative level of disease with those of adjacent entries. Integrades 2, 4, 6, and 8 can be used when necessary.
5	For actual quantification of disease, evaluate 4 or 5 randomly selected entries for each grade using a pictorial guide or any available method to compute the value for each grade using either arithmethic average or regression.
6	Transform all the grades into quantitative terms for further analysis.

Physiological or architectural characters of the rice plant that might indirectly influence blast severity in a given agroecological condition should be further investigated. Vigorous regrowth of plants after a long dry spell and severe leaf blast and stem elongation well above the leaf canopy level could be considered as advantageous characters to reduce damage.

IMPLEMENTATION OF INTEGRATED BLAST MANAGEMENT

Integrated blast management maximizes the effect of individual control measures through harmoniously adjusting several efficient components into an overall local production system. While disease management is guided on a scientific basis, it is actually an art of manipulating all possible means and measures. Often a rigidly packaged control scheme has been criticized because of the view that farmers are losing the ability of rational decision making on their own (13). Management schemes should be simple, yet allow flexibility. Improved extension and training methods should be used to disseminate the advantages of employing integrated management for reliable and efficient protection against blast.

CONCLUSION

Various options and strategies are available for blast management. Nevertheless, due to heterogeneity of upland conditions, fine tuning can only be achieved in local environments of individual agroecosystems and socioeconomic situations. Accordingly, national research should concentrate on better understanding of blast environments of a given region including cultivars, pathogens, edaphoclimatic factors, cropping system, and their interactions. On the other hand, international agricultural centers should focus major emphasis on generation and dissemination of information on basic aspects of disease management strategies and related techniques. For better communication among concerned scientists, condition-specific rather than site-specific blast management research is highly encouraged.

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BLAST MANAGEMENT WITH UPLAND RICE CULTIVAR MIXTURES

J. M. BONMAN, B. A. ESTRADA, and R. I. DENTON

The management of blast disease in upland rice is a challenge to plant pathologists. Four elements that influence the development of plant disease epidemics — environment, host, pathogen, and man — all weigh heavily against effective disease management. The upland rice environment, compared with lowland, is highly conducive to blast, and because of immense variation in soils, topography, temperature regime, and rainfall, the disease is likely to be much more site specific than diseases of flooded rice. The host often shows susceptibility, especially when nitrogen fertilizer and dense plant spacing are used, and, unlike in less blast-prone environments, few durably resistant upland cultivars have been bred. The pathogen, too, is variable and notorious for evolving new races capable of attacking previously resistant cultivars. Man is the final important part of the blast disease equation and upland rice growers often have small, inaccessible farms, and cannot afford unsubsidized chemical control. For such an adaptable pathogen in a variable and often disease-conducive environment, the use of cultivar mixtures as a disease management approach should be tested.

MIXTURES IN TRADITIOSAL RICE CULTURE

During rice germplasm collection trips in Asia and Africa through the International Rice Germplasm Center at IRRI, cultivar mixtures were commonly encountered in all types of rice culture. On the high plateau of Madagascar, cultivars have been mixed for generations and the system even has its own name, Vary Tsindrilahy (literally, *rice mixture*). The mixtures usually comprise two or three distinct cultivars, but sometimes include five or more. According to local farmers, the mixed population provides a guaranteed yield.

Mixtures are common also throughout Indonesia. Generally, no more than two or three cultivars were found together and, in some cases, one

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cultivar was said to "improve" the performance of other varieties when included in a mixed stand. Because Indonesians are discriminating in their preferences for a particular grain quality, they usually mix varieties of the same grain type (for example, all glutinous, all aromatic, or all red kernel).

At the upper limits of rice cultivation in Bhutan, cultivar mixtures are less common because the number of cultivars adapted to such an environment is limited. However, in remote northeastern Bhutan at 2,150-m elevation, the cultivar Chhalangpa (literally, *mixture*) is grown, and is in fact two distinct types that are always grown together. When asked why they adopted such a practice, farmers replied that they had been doing so since "the beginning."

In Bangladesh, mixed stands appear to be taken for granted by local farmers and the whole population is often named after the predominant cultivar in the group. When the group is separated into the component types, though, each type is provided with a distinct name. In one field, six cultivars were collected and two others omitted because of their low frequency in the mixed stand.

Cultivars grown as mixtures generally tend to have similar growth duration and plant habit, and a whole field can be harvested in one operation. However, in some areas where panicles are harvested, cultivars of differing durations may be mixed and each harvested separately as it matures. In general, mixed cultivation of diverse genotypes seems to be the rule rather than the exception in traditional rice culture, and there would probably be no barrier to acceptance of mixtures of improved cultivars.

CULTIVAR MIXTURES IN MODERN AGRICULTURE

Cultivar mixtures are being used in modern, high-input agriculture in Europe, commercially with barley and experimentally with wheat. Barley cultivar mixtures have been planted by farmers in the United Kingdom for several years and the area is increasing. Interest in barley cultivar mixtures for disease control is great among agricultural scientists in eastern Europe (M. Wolfe, pers. comm.), presumably because the governments lack foreign exchange to purchase imported fungicides, an economic circumstance similar to that of many developing countries. In Malaysia, yields of lowland rice cultivar mixtures have been high and stable and blast disease has been controlled in experimental plots. Grain from mixed stands has the same cooking and eating qualities as that of the best component cultivar (2).

THEORY OF DISEASE RESPONSE IN MIXTURES

On the basis of degree of genetic similarity of the components, there are three categories of mixed plantings for a self-pollinated crop species: multiline, line, and cultivar mixtures. Multilines are the most uniform, each component being an isoline differing only in resistance (*r*) genes to the target pathogen. Line mixtures are more diverse in that the components are developed through only two or three backcrosses to a recurrent parent.

Cultivar mixtures are the most diverse because the components are distinct cultivars and not the products of backcrossing. Although the three types differ in degree of genetic diversity, the theory of how disease behaves in mixed stands is equally applicable to them.

When some components in a mixture are susceptible to some components of the prevailing pathogen population, disease progress in the mixed stand is slower than that in the susceptible pure stand (5). Such reductions in rate of disease increase result from:

- the intervening resistant plants acting as spore traps, thus reducing the number of pathogen propagules reaching susceptible components,
- greater distance between susceptible components in the mixed stand (1), and
- induced resistance to some diseases (3, 4).

Because disease is reduced in mixtures, the yield of mixed stands will be higher than the mean yield of pure stands when disease is present (6).

It is assumed that aside from reducing disease, cultivar mixtures will stabilize the virulence genes in the pathogen population, thus prolonging the usefulness of host *r*-genes (5, 6). The resistance of a mixture may erode in time, but presumably more slowly than in components deployed as single cultivars.

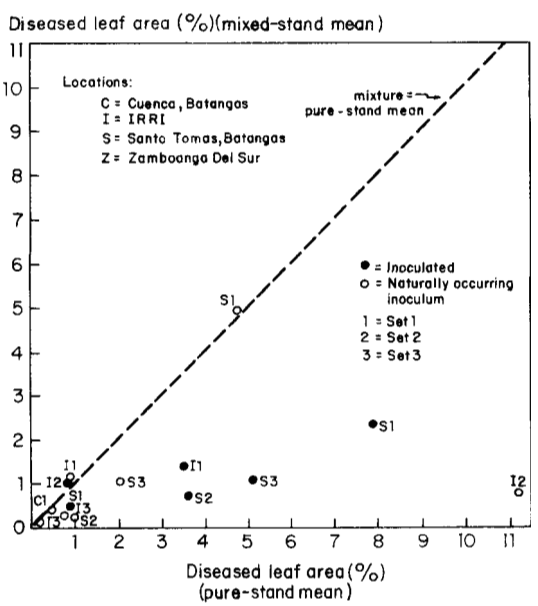
MIXTURES FOR BLAST CONTROL IN UPLAND RICE

In 1983, mixture experiments at four locations in the Philippines used three sets of upland rice cultivars and IR breeding lines. In each set, the mixtures were composed of equal proportions of each component line or cultivar. Set 1 was composed of the cultivars C22, UPLRi3, and UPLRi5; set 2 of the breeding lines IR3839-1, IR5931-110-1 and IR5929-12-3; and set 3 of the lines IR6023-10-1-1, IR6115-1-1-1, and IR10011-16-3. The three sets were included as part of uninoculated replicated yield trials by the IRRI Agronomy and Plant Breeding departments. In such small-plot yield trials, naturally occurring inoculum can move freely between plots and thus decrease the effectiveness of such treatments as cultivar mixtures or fungicides. Therefore, to reduce interplot interference in another set of inoculated experiments, each 3- × 5-m experimental plot was separated from neighboring plots by a 4-m border, in the center of which was sown a dense 1-m band of sorghum. Similarly, uninoculated experiments in farmer's fields using Set 1 in Zamboanga del Sur Province were space-planted with the farmer's cultivar sown between 5- × 5-m experimental plots.

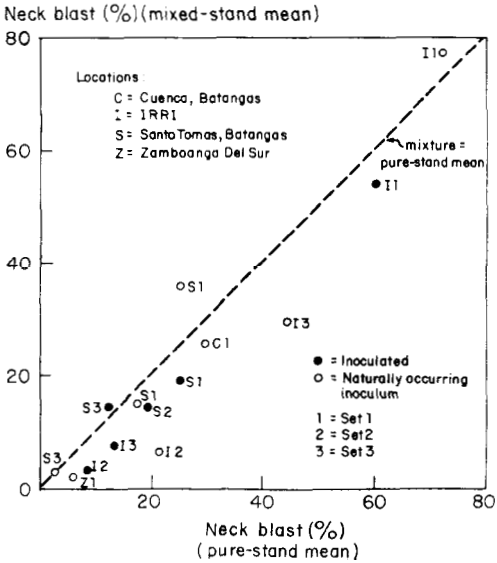
For the inoculated experiments, a Latin square experimental design with four replications was used. The seeding rate was 100 kg/ha and N fertilizer was applied at 80 kg N/ha as ammonium sulfate in three splits. Blast-infected seedlings were transplanted into the center of each plot about 1 mo after sowing. The percentage of diseased leaf area due to leaf blast was determined by visual scoring during the vegetative growth stage, and the incidence of neck blast symptoms was recorded at -harvest.

Leaf blast was significantly less in the mixed stands than in the pure stands of the most susceptible cultivar of each set, and was statistically equal to the amount of disease in the most resistant component in five of the six inoculated experiments. Results for leaf blast are summarized in Figure 1. Because of high variation between plots, leaf blast in inoculated experiments was significantly less in the mixed stand than the pure stand mean only for Set 3 at Santo Tomas. Neck blast in the mixtures was less effectively controlled than leaf blast (Fig. 2). However, in several 1983 experiments, neck blast data were taken late and symptoms were not incubated to confirm the presence of *Pyricularia oryzae.* At most sites incidence of neck blast was numerically less in the mixed stands than the pure stand mean. Mixture yields did not differ significantly from the pure-stand mean yields, but at higher yielding sites the trend was toward higher mixed-stand yields (Fig. 3).

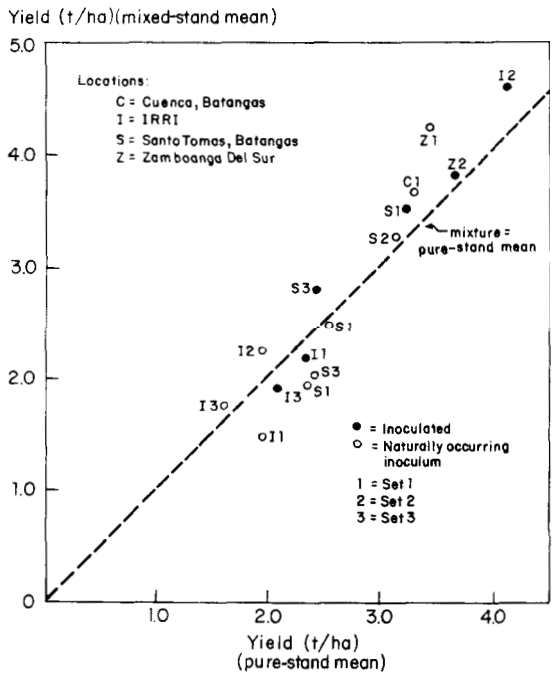
In the 1984 dry season, the cultivars C22 and UPLRi-3 and the breeding line IRl001l-16-3 were tested in mixed and pure stands using a line-source sprinkler system. The line-source sprinkler produces a linear decrease in the amount of water applied with increasing distance from the sprinkler line. Each treatment was sown in 2- × 14-m strips perpendicular to the line-source in 4 replications. Two rows of sorghum were sown in a 0.5-m border between strips. The strips were subdivided into 2- × 2-m plots and each plot was inoculated at the center with *P. oyzae-* infected leaves 28 d after seeding (DS). After uniform infection developed, the plots were irrigated before sunrise with the line-source sprinkler beginning 41 DS and continuing about every 4 d until 55 DS, when a heavy rainfall occurred. With this technique, a gradient of blast disease intensity was produced from low



1. Mixed-stand values vs pure-stand mean values for leafblast (% diseased leaf area) in 14 field trials.

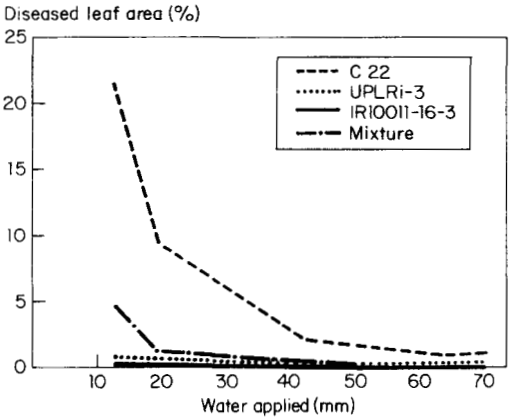


2. Mixed-stand values vs pure-stand mean values for neck blast incidence in 14 field trials.

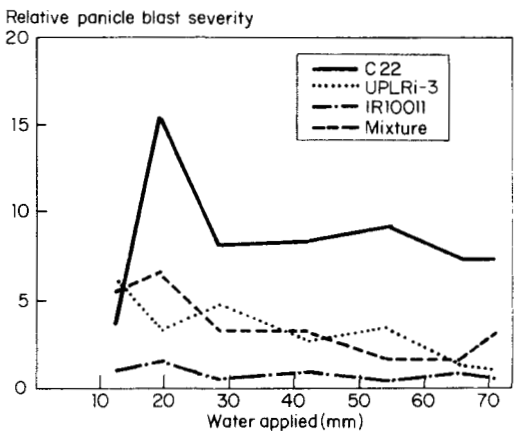


3. Mixed-stand values vs pure-stand mean values for yield in 15 field trials.

disease in the fully irrigated plot to high disease in the driest plot. The mixture performed well across this blast gradient and showed little disease even at the point where C22, the susceptible component, was badly blasted (Fig. 4).



4. Blast severity 64 DS in pure and mixed upland rice stands as affected by water applied from 41 to 55 DS.



5. Relative panicle blast severity in pure and mixed upland rice stands as affected by water applied from 41 to 55 DS.

Results for panicle blast, i.e. infection on the panicle base and branches, were not as consistent, perhaps because of the greater interplot interference later in the season and the uneven plant growth from variations in drainage and soil. Panicle blast intensity in the mixed stand was similar to that in UPLRi-3 (Fig. 5). Disease in C22 dropped at the end of the gradient presumably because of a low density of panicles due to damage from drought and blast sustained during the vegetative stage.

In both 1983 and 1984, experiments were in farmer's fields in Zamboanga del Sur Province, a blast-prone but otherwise highly favorable environment. One replicate was sown per field. After sowing, the farmer-cooperator managed the plots. Mixture Set 1 was used in the experiments and only C22 proved signficantly blast susceptible (Table 1). Leaf blast was not as severe as neck blast, especially in 1984. Panicle blast was significantly less in the mixture than in C22 and the mixture values were as low as the best of the pure stands. Yields of the mixed stands were equal to those of the best pure stand.

Table 1. Blast severity and yield of pure and mixed stands of 3 upland rice cultivars grown in farmer's fields in Zamboanga del Sur, Philippines. [a,b]

	Experiment 1		Experiment 2			Experiment 3		
	Panicle blast incidence [c] (%)	Yield (t/ha)	Leaf blast [d]	Panicle blast [e]	Yield (t/ha)	Leaf blast	Panicle blast	Yield (t/ha)
C22	18.1 a	3.1 a	0.9	27.6 a	3.0 a	0.3	14.7 a	3.7 b
UPLRI 3	0.4 b	3.4 a	0	1.0 b	3.5 a	0.1	2.4 b	4.8 a
UPLRI 5	0.1 b	3.3 a	0	3.7 b	3.3 a	0	2.4 b	4.8 a
Mixture	2.0 b	4.2 a	0.2	8.0 b	3.9 a	0.1	2.6 b	4.3 ab

[a] One replicate per field. Five replicates for experiments 1 and 2, 11 replicates for experiment 3. Experiment 1 conducted in 1983 and experiments 2 and 3 conducted in 1984. [b] Means in a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test. [c] Incidence of blast infection at the panicle base. [d] Mean percent diseased leaf area visually scored on the youngest 4 leaves of 20 plants/plot 8 wk after seeding. [e] Ratings are on scale of 0-100 based on incidence and severity of blast infection on panicle base and branches of at least 100 panicles/plot. All tissues showing symptoms were incubated in a moist chamber to confirm presence of *Pyricuiaria oryzae.*

CONCLUSIONS AND FUTURE RESEARCH

For upland rice, several topics are open for future work on cultivar mixtures. The three-component mixed stands used in these experiments reduced leaf blast to the level of the least susceptible component, but the mechanism(s) of this effect are unknown. It is also not known if such mixtures would be effective in more blast-intense environments. The blast encountered in many of the experiments was probably not as intense as that in other upland rice-growing areas. In further studies the line-source sprinkler technique might prove useful in simulating a range of blast environments.

Some results indicate panicle blast control in the mixtures was less efficient than leaf blast control, but it is uncertain if this observation is correct or if the decreased efficiency was caused by greater interplot interference during the panicle blast phase of the epidemic. Presumably, well-isolated plots are necessary in critically testing the efficacy of mixtures, and perhaps especially in testing their effects on panicle blast. Because error due to inoculum drift from other plots can greatly affect results, work on optimum field plot designs for evaluating mixtures is necessary. These field-plot designs could be valuable also for evaluating partial blast resistance.

The relationship between the proportion of the host population that is susceptible and blast disease development within the host population deserves close scrutiny. It could differ for leaf versus panicle blast, because the spore-trapping effect of intervening resistant plants is likely to change from vegetative to reproductive growth stages. Also, the level of partial resistance in susceptible components will have a large influence on disease development within the host population, and the partial resistance of the components will be an important variable in evaluating mixture experiments.

The effect of cultivar mixtures on the pathogen population is an important, yet difficult, area of research. It is important because the speed with which complex races evolve will greatly influence the durability of a given mixture set. The difficulties in studying changes in the fungus population mostly involve a lack of techniques for efficiently and accurately sampling the pathogenicity of a large number of individual spores. Perhaps the techniques used with other foliar diseases of cereals can be adapted to the study of rice blast.

The agronomic aspects of cultivar mixtures need further work. Theoretically, mixtures should give more stable yields across locations than single cultivars, but present data are inadequate to test this hypothesis. There is the possibility of a mixed-stand yield advantage not only when disease is present, but also when it is not, due to decreased interplant competition in mixtures. Perhaps interplant competition could be decreased and yield stability increased by choosing component cultivars that exploit different agroecological niches or respond differentially to environmental stress. Since no single cultivar will have all desired characteristics and be tolerant of all stresses, various components in a mixture might compensate for one another. Thus, mixtures may have an agronomic advantage over single cultivars in the often variable and unpredictable environments in which upland rice is cultivated.

Increased genetic diversity within stands of upland rice using multilines, line mixtures, or cultivar mixtures is by itself not a solution to the problem of losses from rice blast disease. Mixtures are one of a number of tools for managing blast. The most critical requirement for the effective use of various blast management tools such as cultivar mixtures is the existence of a dynamic breeding program that produces well-adapted cultivars with blast *r*-genes derived from diverse sources. Mixing poor germplasm will result in poor mixtures. Mixing good cultivars may prolong the commercial life of certain cultivars, make a sudden catastrophic breakdown in resistance less likely, and perhaps provide greater stability of yield over diverse environments.

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BLAST DISEASE MANAGEMENT IN UPLAND RICE IN BRAZIL

A. S. PRABHU and O. P. MORAIS

Rice blast (*Pyricularia oryzae* Cav.) is a limiting factor for upland rice production in Brazil. Efforts at the National Research Centre for Rice and Beans (CNPAF/EMBRAPA) have focused attention on developing integrated disease control for upland rice in the region that is dominated by savana vegetation known as cerrado, *Sensu lato.* Cerrado vegetation covers about 1.8 million ha, mainly in central Brazil. Annual rainfall varies from 1,000 to 1,700 mm, more than 90% of it occurring during the wet season, from October to April.

EPIDEMIOLOGICAL CONSIDERATIONS

Most rice is subjected to water deficits that result in short- to long-term drought periods, locally termed *veranicos.* Rice crops under moisture stress are predisposed to blast.

In central Brazil, wide differences in day and night temperatures result in long dew deposition periods in upland rice. Epidemiological studies (1976-84) identified weather variables favorable for leaf infection under field conditions in Goiânia. Healthy 30-d-old plants of susceptible cultivar IAC47 in 2 trays were exposed for 48 h to a natural source of inoculum over an unsprayed field of the same cultivar. After the exposure period, 1 tray was transferred to a moist chamber for an additional 16-h incubation and the other tray was transferred to a glasshouse bench. Successive batches of plants of the same age were exposed starting from 30 to 50 d after sowing until maturity. Lesion counts and weather variables during exposure were related. Lesion numbers increased with time in an exponential manner in plants with and without incubation for an additional leaf wetness period (Fig. 1). Rain did not significantly contribute to the infection. It was possible to estimate the lesion numbers on the basis of leaf-wetness period in the field. The study further showed that the viable airborne conidial population, estimated by leaf lesion counts, peaked at heading, independent of disease intensity in the field.

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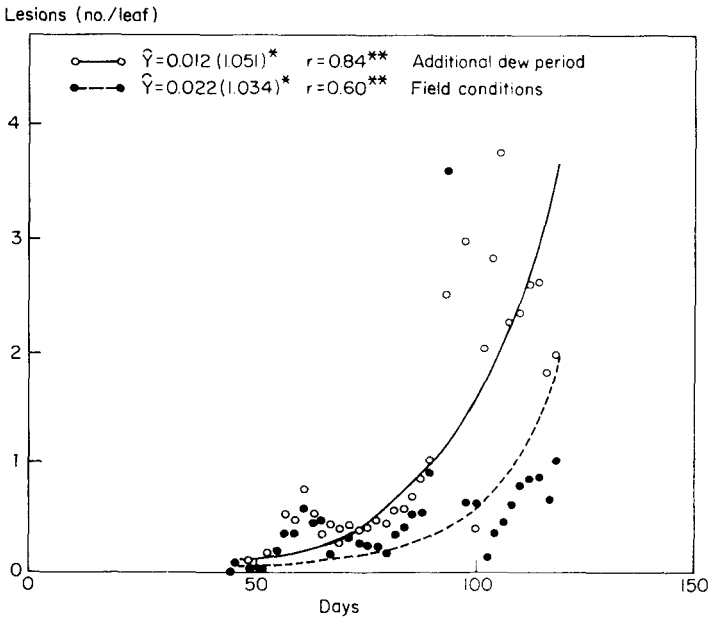
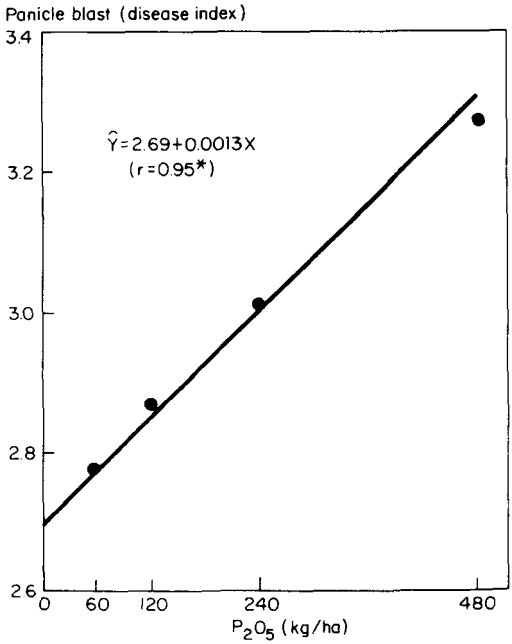


1. Relationship between lesion number/leaf of glasshouse-grown seedlings exposed for 48 h to natural inoculum over an unsprayed rice crop and number of days after sowing of the rice crop. After exposure, seedlings were placed directly in the glasshouse (------) or into dew chamber (▬▬) tor 16 h. (r = correlation coefficient). CNPAF/Goiânia, 1978-79.

The widely cited explanation for greater disease intensities in upland rice is the occurrence of long dew duration periods in upland rice than in irrigated rice. The altered metabolic changes in the plant tissues under water deficit have been overlooked. Investigations at CNPAF using rice cultivar IAC47 showed higher percentages of N in different parts of the plant for treatments subjected to moisture deficit of different durations during panicle emergence (8). Also, plants subjected to water deficit generally had a reduction in carbohydrate, accompanied by high soluble sugar content (2). Rice blast has been classified as a high sugar disease. The increase in N and soluble sugars in the leaf and panicle branches may be considered a major contributing factor for increased susceptibility under drought.

Plant susceptibility to blast is altered by the three major elements N, P, and K. N and P fertilizers are particularly interesting because they are essential for obtaining higher yields in cerrado. In drought-prone regions of upland rice, the increase in yield obtained by additional N is limited by blast incidence (1). In another experiment to determine the optimum P levels, panicle blast increased with increasing levels of P fertilization, with or without the influence of lime (Fig. 2). These results suggest the importance of balanced nutrition for blast control in cerrado soils.

Preventing introduction of inoculum through plant debris and aerial dissemination from the neighboring crop can reduce the disease to



2. Panicle blast severity in relation to rate of P fertilization (Panicle blast severity scale of the panicle affected): 1 = 0-5%, 2 = 25%, 3 = 50%, 4= 75%, and 5 = 100%. CNPAF/Goiania, 1982-83.

minimum levels at the vegetative phase of crop growth. The role of seed as a source of initial inoculum is of secondary importance. It has been observed that the fungus survives in the fallen infected culms for more than two cropping seasons. Delayed establishment of primary inoculum reduces the time for epidemic buildup.

Existing information on factors favoring and mitigating disease provide a basis for developing integrated blast disease management.

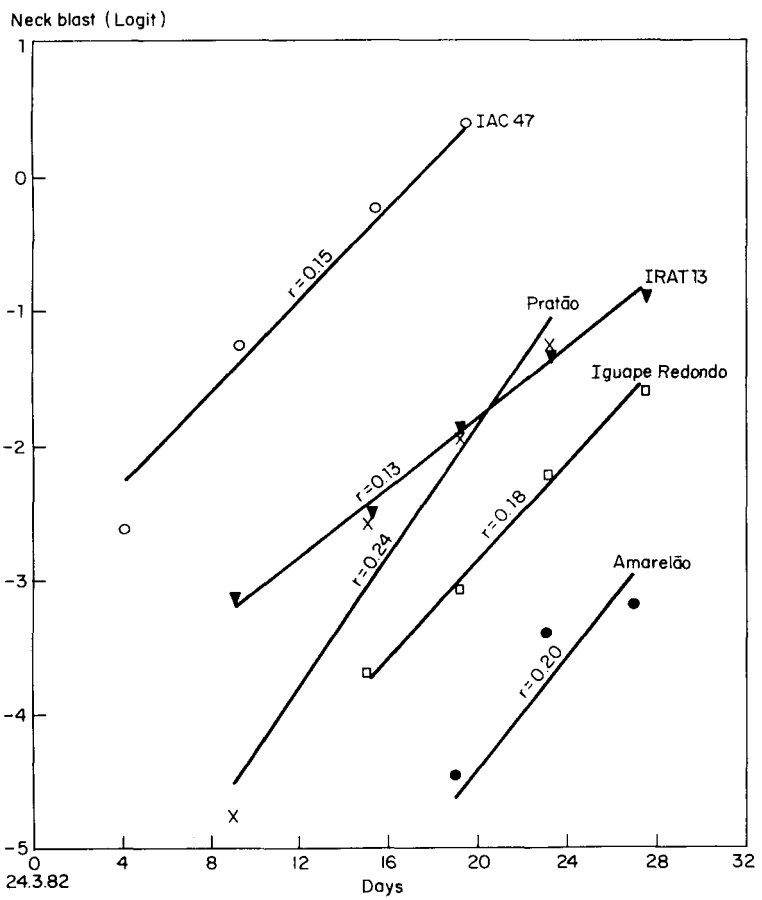
Genetic control

A resistant cultivar is a major component of an integrated disease management program. Many lowland rice cultivars have been bred with high degrees of resistance in different parts of the world. But the resistance has been short-lived because of rapid shifts in the pathogen population. Failures in earlier attempts at genetic control were attributed to faulty management of genes. Different breeding strategies have been proposed by breeders and pathologists. Their merits have been widely discussed. All require continuous search for resistant gene sources and development of resistant germplasm suitable for upland conditions in Brazil. The widely used blast-resistance gene sources in the breeding program originated from lowland rices, and no known sources of blast resistance exist in the upland germplasm collection of Brazil.

More than 200 entries from the Brazilian upland rice germplasm collection were evaluated in the blast nursery, as well as in field plots, to identify native land races that have higher resistance than commercial

cultivars. Two types of resistance among the land races under upland conditions have been identified and characterized as Amarelão and Paga Divida types. The Amarelão type is exhibited only under low disease pressure in the absence of alloinfection in tests using large plots (400-900 m^2). The delayed disease onset and the low neck blast severities in Amarelão and Iguape Redondo (Figure 3) suggest that they possess a relatively higher resistance than IAC47. Varietal differences have been noted in relation to culm blast (internodal blast). The low percentage of infected culms (Fig. 4) and slow leaf blast progress further proved that Amarelão and Iguape Redondo are superior to IAC47.

The type of resistance exhibited by Paga Divida functions in the same manner under low and under high disease pressures. The disease rating in the blast nursery varied from 4 to 5 in different years and locations. The slow rate of leaf blast progress and negligible proportions of neck and panicle



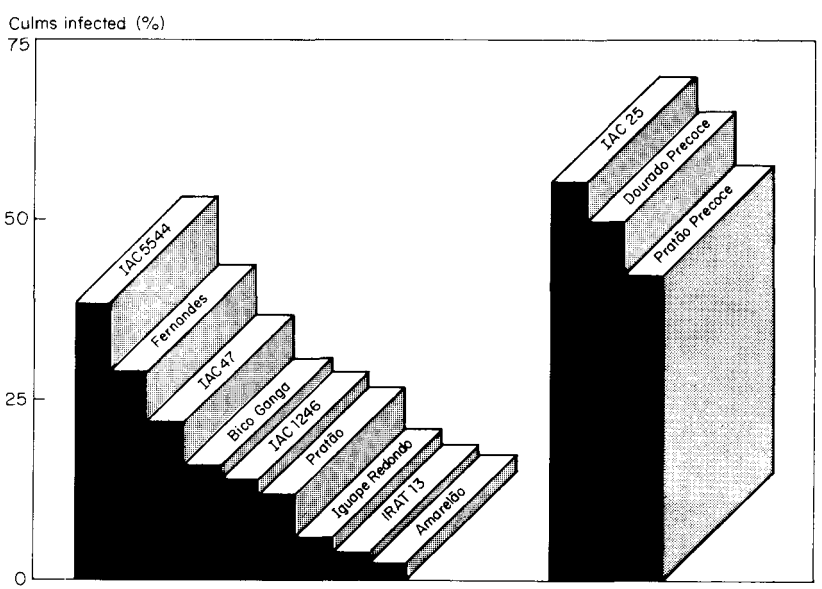
3. Neck blast progress over time in 5 upland rice cultivars (logit = Log_e (Y/1-y) where Y = disease proportion, r = apparent infection rate). CNPAF/Goânia, 1981-82.

blast are the characteristics of cultivars belonging to the Paga Divida type. This type of resistance is more desirable for upland conditions in Brazil where the blast disease stress is high.

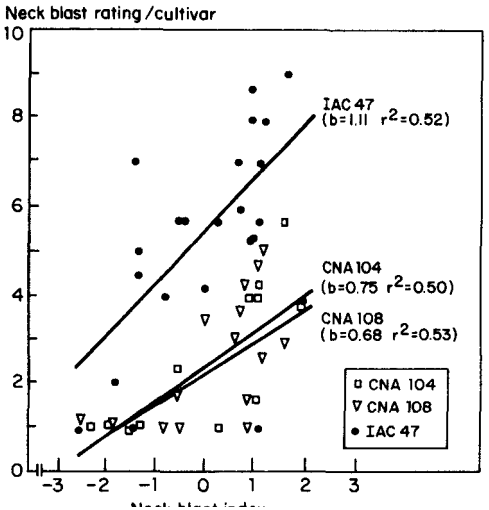
Several crosses were made at CNPAF to incorporate resistance genes in the agronomically desirable cultivar IAC47. The crosses made with IAC47 utilizing resistance sources originating from Korea and Nigeria resulted in several promising lines possessing consumer-preferred grain type combined with a high degree of blast resistance. Among them, the most superior lines are CNA104-B-2-43-2 (IAC47/SR2041-50-1) moderately resistant and CNA108-B-28-13-1 (TOS2578/7-4-2-3-B^2) resistant to leaf and panicle blast in the multilocational yield trials in central Brazil.

The genetics of resistance in these two cultivars is not known. But disease stability was evaluated by regressing neck blast rating of the cultivar in each experiment against disease index calculated by using data from 23 trials in the states of Goiás, Mato Grosso, Mato Grosso do Sul, and Minas Gerais. The index was calculated for each experiment by subtracting the mean disease rating of all trials from the average disease of a particular experiment. Slope of regression curves indicated that CNA108 and CNA104 had more stable disease resistance than IAC47 (Fig. 5). Also, the cultivar CNA108 outyielded IAC47 in all locations where neck blast incidence was high (Fig. 6).

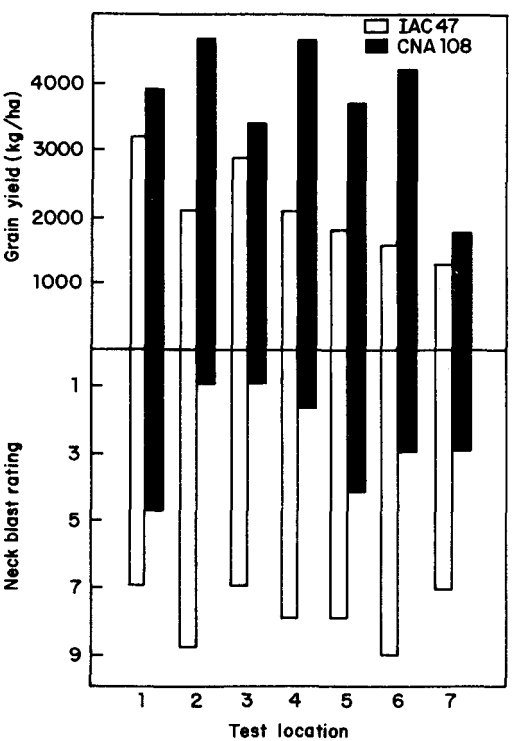
The realistic approach for blast control under upland conditions is varietal diversification. Ongoing resistance breeding in Brazil aims at developing large numbers of cultivars with different resistances so that some of them fit



4. Culm blast incidence in upland rice cultivars (left, medium-duration cultivars; right, short-duration cultivars). CNPAF/Goiania, 1981-82.



5. Regression of neck blast rating/cultivar (1-9 scale) on neck blast index (calculation based on the mean disease of 23 trials). CNPAF/Goiânia, 1983-84.



6. Grain yield and neck blast incidence of advanced promising line (CNA 108) and local check (IAC 47) in seven different trial locations in Brazil. (Neck blast scale: 1-9) CNPAF/Goiânia, 1983-84.

into a diversification plan. During 1981-82, a total of 82 crosses were made using local cultivars and different vertical resistant gene sources selected under Brazilian conditions (3). The failure of any one cultivar to occupy the entire rice-growing region results in automatic diversification of different

cultivars when available. The varietal diversification between farms and within the farm helps prevent large-scale blast epidemics. Results will be quick and easy to adopt in highly mechanized upland rice cultivation. The need for cultivars with horizontal resistance as the only solution has been overemphasized by several investigators. However, identifying horizontal resistance sources in the native germplasm and utilizing superior parents in resistance breeding are necessary and important.

Cultural control

In large farm holdings, rice sowing starts in October and continues until the end of December. Earlier plantings serve as foci of infection for latter ones. Four measures were recommended:

- Complete rice planting in minimum time possible.
- Orient successive plantings against predominant wind direction.
- Maintain wind barriers between different plantings.
- Sow early to avoid inoculum from neighboring farms (4).

With resistant cultivars available, a gene management scheme may limit the disease spread from early-sown to late-sown rice within and between farms.

The absence of adequate resistance in existing cultivars has placed a ceiling on N applications greater than 15 kg/ha at planting time. With availability of medium-tall cultivars resistant to blast, studies are being made to determine possibilities of increasing N fertilizer use for maximizing yields.

Avoiding practices that increase plant population, such as closer spacing, high seeding rate, and excessive use of fertilizer, results in significant reduction in initial leaf blast severity.

There are governmental incentives for supplementary irrigation for upland rice culture in Brazil. Overhead sprinkler irrigation at grain formation may offer promising results in reducing panicle blast to negligible levels possibly by preventing accumulation of soluble sugars and N in different parts of the panicle (5).

Chemical control

Many effective fungicides have been introduced and marketed in Brazil for rice blast control. In recent years, the fungicides indicated for blast control (benomyl, blasticidin-S, edifenphos, kasugamycin, kitazin, and triciclazol) are being used in combination with other products (e.g., maneb, mancozeb, captafol, cerconil, and ziram) with the object of controlling other rice diseases.

In general, one or two sprays are applied after heading for controlling panicle blast. One application of any of the tested fungicides at heading or flowering significantly increased yield over the untreated checks (7). Differences in grain yield were not evident with one spray between fungicides administered for neck blast control separately or in mixtures. The loss in grain weight was related to time of neck infection (6). There is a great need to protect the panicle until 12 to 15 d after heading. A single application

of systemic fungicide at heading increased yields 10-61 % in 7 sowings of IAC47 during 1983-84 (Table 1). The variation depended on influence of weather conditions following heading. It is difficult to predict panicle blast severity and the rate at which the disease progresses. The use of a routine spray constitutes a safeguard against heavy losses.

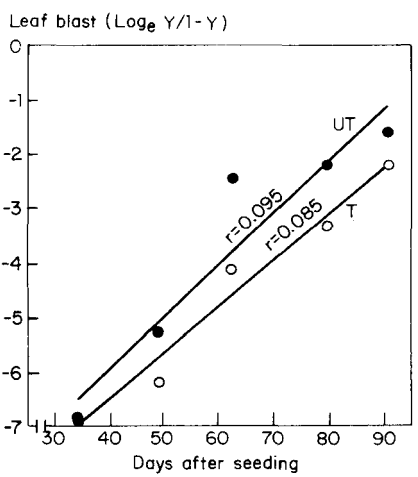
Controlling leaf blast with chemicals in upland rice is not common. In large farm holdings, in late-sown and dense planting with reduced spacing (35 cm) between rows, leaf blast is often serious. Spraying rice even at 7- to 12-d intervals failed to stop the leaf blast epidemic under severe drought conditions (Fig. 7). The plant recovers 60 d after sowing because of the resistance of the top leaves to new infections.

Considering the risk due to drought, the use of chemical sprays for leaf blast control is uneconomical in upland rice. However, seed treatments with highly potent systemic fungicides such as pyroquilon (CGA 49104) offer promise for leaf blast control at the vegetative phase. In the widely grown

Table 1. Effect of single fungicide[a] spray application on panicle on blast control and yield of upland rice cultivar IAC47.

Sowing date	Panicle blast (disease index)		Grain yield (t/ha)		Yield Increase (%)
	UT[b]	T[b]	UT	T	
03 Nov	1.90	1.31	2.1	2.3	10.2
10 Nov	2.37	2.15	1.3	1.6	27.0
17 Nov	2.20	1.60	1.4	1.9	35.6
24 Nov	1.87	1.67	1.7	2.0	21.4
01 Dec	2.43	1.68	1.2	1.9	61.4
08 Dec	2.09	1.71	1.2	1.4	15.7
15 Dec	2.37	1.91	0.8	1.1	31.6

[a]The systemic fungicide triciclazol was sprayed at heading. [b]UT= untreated, T = treated.

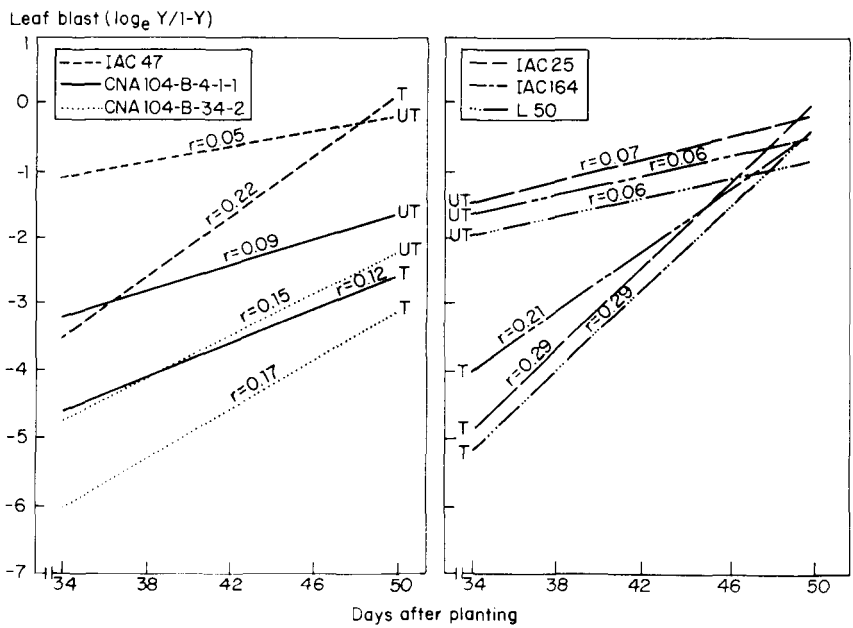


7. Leaf blast progress with time in fungicide-treated (T) and untreated (UT) plots. Plots were sprayed at 7- to 12-day intervals alternating with fungicides benomyl and kasugamycin until crop maturity. (Leafblast severities were transformed to Log$_e$ Y/l-Y where Y = disease proportion, r = apparent infection rate). CNPAF/Goiânia, 1977-78.

local cultivars IAC47 and IAC25, seed treatment with pyroquilon kept leaf blast infection significantly low until 38 d after planting; in the moderately resistant cultivar CNA104-34-2, it kept disease levels low until 50 d after planting (Fig. 8). Seed treatment of the late-sown susceptible or moderately resistant cultivars with pyroquilon will reduce losses caused by leaf blast in the vegetative phase in upland rice.

CONCLUSIONS

Upland rice farming in the main rice-growing states of central Brazil is mainly a commercial enterprise. Large investments are involved and risks are involved due to uncertain rainfall and rice blast. In the absence of blast, upland rice yield can be improved significantly in Brazil with existing drought-tolerant cultivars. Recently released blast-resistant cultivars should help stabilize yields and reduce production costs. Recommended cultural practices are only slight modifications of existing methods and are aimed to greatly reduce losses without additional expenditures. Fungicide use can be judiciously planned in conjunction with resistant cultivars and other cultural practices. However, further research on epidemiology and forecasting of panicle blast is necessary to optimize use of fungicides.



8. Effect of seed treatment with pyroquilon on leaf blast progress in three medium-(left) and short-duration (right) upland rice cultivars. (Leaf blast severities were transformed to Log, Y/1-Y where Y = disease proportion, r = apparent infection rate, UT = seeds untreated, T = seeds treated.) CNPAF/Goiânia, 1983-84.

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VIRULENCE ANALYSIS AS A TOOL IN DISEASE MANAGEMENT

K. M. CHIN

The frequent failure in agriculture of host resistance and pesticide application — two of the most potent methods of disease control - may be largely attributed to genetic adaptation by the pathogen. Variants in the pathogen population which are virulent on the new host resistance, or insensitive to the new pesticide, may be at a relative advantage compared with nonadapted genotypes. Selection for such genotypes ultimately results in their dominance. However, when these genotypes are less fit than nonadapted genotypes in a particular environment, the host resistance or pesticide will be observed to be durable (10).

The direction and result of selection for virulence in the pathogen population at any particular time will depend largely on the initial frequencies of virulent and nonvirulent genotypes and their relative fitnesses, the proportion of the host population carrying the resistance gene or genes, and the number of cycles of selection that have occurred (2).

It is therefore crucial in disease management to monitor the range of pathogenic variation faced by currently deployed host cultivars so that strategies may be developed early to counter changes in the pathogen population. It is also necessary to study the genetic structures of individual populations to determine the fitnesses of particular virulence genes and their combinants for exploitation through genetic manipulation of hosts.

PHYSIOLOGIC RACE SPECIALIZATION

The implications of genetic variability of pathogens for disease management and the need to characterize this variability led to the introduction of the physiologic race system of pathogen classification. The system is based on disease reactions of each race on a standard set of differential host cultivars, and has for some time been firmly entrenched in traditional plant pathology.

In recent years, as pathometric techniques have become more sophisticated, greater complexities of host-pathogen interactions have emerged and the shortcomings of the race classification have become more apparent.

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The system is simple to code and interpret for a limited number of races but rapidly becomes less manageable as virulence genes increase. For example, in Japan nine differential cultivars have been proposed for *Pyricularia oryzae* (12). Assuming a gene-for-gene interaction, a total of 512 races may be expected even if only 2 types of reaction, resistant and susceptible, were recognized. Van der Plank (1 9) pointed out that there were more than a million races of *Puccinia graminis tritici* to consider if a new race were created for every change in virulence.

Several systems code and describe races, ranging from virulence formulae (16), decanary (8), and octal systems (6). The major difficulty has been to develop a system that is informative and not unwieldy to use, yet flexible enough to permit addition of new differentials to cope with fresh pathogen variation.

Virulence frequencies

Virulence frequencies are easier to interpret and focus attention on crucial virulences, which are relevant to resistance genes in breeding programs and in currently important cultivars.

In the above example, the complex information from 512 races may be distilled into the relative frequencies of 9 virulence genes for studies of the population dynamics of the pathogen. An increase in frequency of a small number of relevant virulence genes or their combinations is more informative to a disease management program than complex changes in many largely irrelevant physiologic races.

Fewer tests are necessary, rare virulences may be more easily detected (Table l), and the flexibility of the system allows long-term comparisons. Wolfe and Schwarzbach (22) have listed other advantages of analyzing frequencies of virulences.

The study of virulence frequencies rather than physiology of races approximates the preference by population geneticists of gene frequencies over genotype frequencies and allows analysis by similar methodology (1).

Virulence analysis

As proposed by Wolfe and Schwarzbach (22) analysis of pathogen variation is based on the fundamental unit of virulence. In practice the unit may be between a pathogen isolate and a resistance source variety (phenotype-phenotype analysis) since detailed knowledge of the genes involved may not yet be available. The analysis is therefore particularly relevant to the study of rice blast in the tropics, where little is known about genetics of resistance.

P. oryzae also seems ideally suited for virulence analysis because of its reputedly high degree of variability. Ou (14) considered that most isolates were unstable and could not be maintained in pure culture thus posing a major problem for studies in classical genetics. Others have observed greater pathogenic stability (9, 13). Chin (1) proposed that the constant reshuffling of gene combinations in the organism affects race frequencies, but not virulence frequencies, and need not therefore be a problem in population studies.

Erysiphe graminis D.C., the causal organism of powdery mildew of cereals, also shows wide genetic variability and has been the subject of extensive virulence analysis by other researchers (22,24). The following illustrates use of virulence analysis mainly with examples from *E. graminis* and *P. oryzae.*

Range of pathogenic variation

Surveys of pathogenic variation should ideally be based on randomly collected samples. This is perhaps most easily achieved by sampling the general air spora. In cases where collections are made from specific cultivars the results should be weighted by the amounts of disease on individual cultivars. Van der Plank (18) has pointed out that the choice of host plant from which disease samples are collected substantially predetermines the result of a race survey.

Conventional spore traps are inappropriate as they do not easily permit the virulence testing of trapped spores. Spore traps have been devised by Schwarzbach (16) and Wolfe et al (23) for this purpose.

A modified mobile nursery technique, originally devised for studying *E. graminis* (5, 21), has been developed for studying *P. oryzae* (1). Seedlings of differential host cultivars, produced in a contamination-free environment, are exposed for up to 3 d at each test location. Following incubation, the numbers of lesions on each cultivar are recorded and scaled against infection on Mahsuri, a cultivar highly susceptible to all known isolates of *P. oryzae* in Malaysia. This calculation gives an estimate of virulence frequency as a proportion of total available virulence, which is independent of environmental variation between tests. Alternatively, spores may be trapped on mobile nurseries planted only with cv. Mahsuri, and multiplied on agar media before reinoculation of the differentials in a settling tower.

Table 1. Virulence frequencies of *Pyricularia oryzae* at 5 locations during 1982 and 1983, as detected by conventional race survey (122 isolates tested) and by mobile nurseries (3 mobile nursery tests per location).

Location[a]	Test	Virulence frequency									
		V_b	V_{i22}	V_{sg}	V_e	V_{pl}	V_{ta}	V_k	V_p	V_{ps}	r
1	Race survey	–	56	44	6	0	0	0	0	0	0.945[b]
	Mobile nursery	–	60	31	20	1	1	1	6	0	
2	Race survey	42	88	50	0	4	38	0	0	0	0.996[b]
	Mobile nursery	39	85	53	0	3	44	0	0	0	
3	Race survey	100	100	43	0	0	0	0	0	0	0.969[b]
	Mobile nursery	100	88	11	0	1	0	0	0	0	
4	Race survey	84	47	41	0	0	0	0	0	0	0.966[b]
	Mobile nursery	79	50	62	10	13	0	5	0	0	
5	Race survey	40	7	80	0	0	0	20	0	0	0.345 n. s.
	Mobile nursery	56	3	3	0	5	2	1	0	0	0.986[b] (without V_{sg} & V_k)

[a] Locations 1 and 2 in Seberang Perai, 3 and 4 in Kedah and 5 in Kelantan. [b] Significant at P<0.001; n. s., not significant.

Examples of results obtained from mobile nursery tests at five locations in 1982 and 1983 are presented in Table 1. As a comparison, results of conventional race surveys conducted during the same period are also tabulated. The race data has been reanalyzed in terms of virulence frequencies.

The data generally indicate a close correlation between mobile and race survey results. Notice, however, that:

1) because the mobile nursery technique sampled larger pathogen populations (1,200-1,500 propagules), compared with race surveys (12-13 single spore isolates) at each location, it was able to detect rare virulences that were not evident in the race survey;
2) a larger number of tests (single-spore isolation and inoculation) were necessary in the race study; and
3) biased results may be obtained because of sampling procedures as exemplified by results at location 5 (in Kelantan).

Unlike in the other surveys in which isolates for testing were randomly sampled from each location, the samples from location 5 consisted of 12 isolates from a single cultivar, MR42. Evidently, selection for V_{sg} and V_k on that cultivar resulted in a bias toward these virulences in the samples taken. This bias was not evident in the general population assessed by the mobile nursery method.

An examination of the relative areas planted to cultivars at the location suggests an answer to the apparent discrepancy. MR42 had then been grown on an experimental basis, occupying less than 0.1% of the rice area. Its contribution to the total air spora was therefore limited.

Isolations from particular cultivars must be weighted by their area of cultivation and relative amounts of disease if they are to be used for estimating the structure of the pathogen population in the region being surveyed.

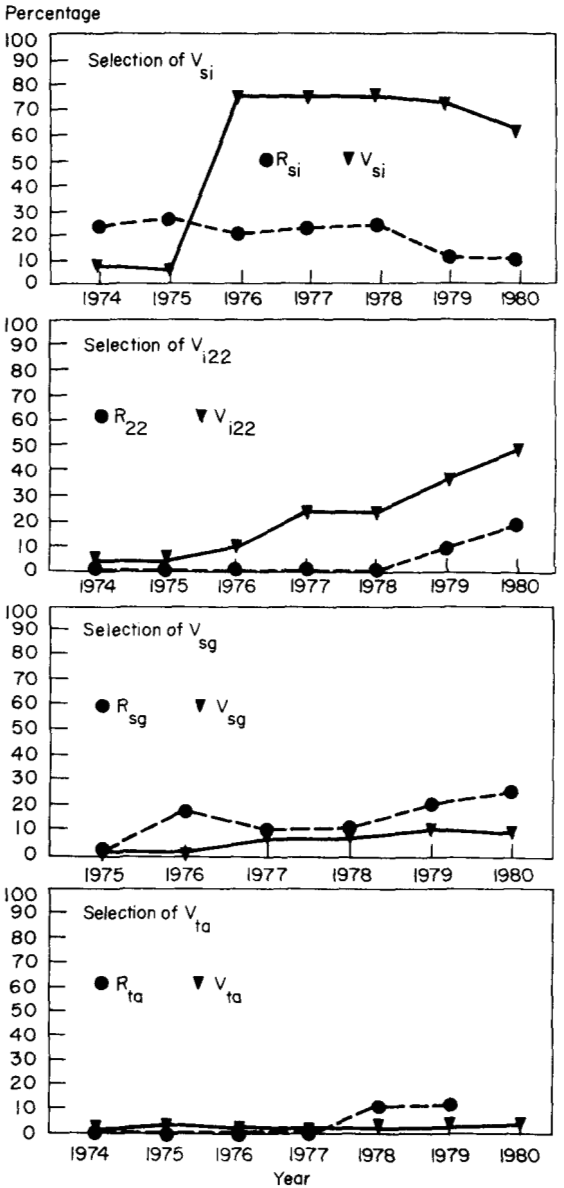
Population dynamics

Changes in pathogen populations may be followed by the use of mobile nurseries. Chin (1) plotted the changes in area occupied by each of four resistance groups (R_{si}, R_{i22}, R_{sg}, and R_{ta}) of rice in Seberang Perai, and compared them with changes in corresponding virulence frequencies (V_{si}, V_{i22}, V_{sg}, and V_{ta}) during 1974-80 (Fig. 1).

Data for 1974-78 were obtained by a reanalysis of results from the International Rice Blast Nursery during that period, separating the effects of the esodemic from that of the exodemic (15). Data for 1979-80 were obtained by mobile nursery tests, as described previously.

The data suggest that the pathogen population responded rapidly to selection by the resistance groups R_{si} and R_{i22}. Areas grown to R_{si} and R_{i22}, which exceeded 20%, resulted in more than 50% of the pathogen population carrying virulence for the corresponding group. Response to selection by R_{sg} and R_{ta} appeared slower, indicating a greater durability of resistance.

More recent information (Table l), however, indicates that the pathogen is able to develop forms better adapted to the two resistance groups.



1. Changes in the areas occupied by host resistance groups (R_{si}, R_{i22}, R_{sg}, and R_{ta}) and the frequencies of their corresponding virulences (V_{si}, V_{i22}, V_{sg}, and V_{ta}) in Seberang Perai during 1974-80.

Populations on matching and nonmatching hosts

Tests of populations from different hosts indicate the degree of selection against nonmatching virulences. Selection against unnecessary virulence has also previously (and erroneously) been termed stabilizing selection by Van der Plank (18).

For example during the 1983-84 main rice season at Bumbong Lima, the pathogen populations on each of the four resistance groups R_e, R_{sg}, R_{ta}, and

R_b were isolated and retested on all groups. The results (Table 2) indicate strong selection against V_{sg} on R_e and against V_e on R_{sg} and suggest that combinations of the two virulences may be associated with poor fitness attributes on either resistance group.

Tests of this nature are therefore useful for identifying sources of resistance which may be used in varietal diversification programs and in variety mixtures and multilines.

The results also show that unnecessary virulence genes are not always deleterious, and that the strength of a resistance gene *cannot* be defined (as suggested by Van der Plank (18)) by the degree of selection against the corresponding virulence when it is unnecessary.

For example, V_b is unnecessary on R_e, R_{sg}, and R_{ta}, but it is highly deleterious on R_{ta}, less so on R_e, and even favored on R_{sg}.

Virulence combinations and linkage disequilibrium

Estimates of frequencies of combined virulences employ a system of sequential testing and analysis of bulk pathogen isolates. An example of the sequential tests and analysis to determine all combinations of three virulence genes of *E. graminis* is given in Table 3 (adapted from Chin and Wolfe [3]).

Wolfe (20, 24) showed by phenotype-phenotype analysis that the frequencies of combined virulence factors in linkage equilibrium may be calculated from the product of their individual frequencies. Evidence came from data from wheat yellow rust, potato leaf blight, oat stem rust, and wheat and barley mildew.

Deviations from the expected frequency of occurrence of combined virulences (or linkage disequilibria) caused by selection may be of interest to breeders since they would indicate a deficiency in the pathogen. This deficiency should then be exploited by breeding the corresponding R-gene combination.

The test is valid only when isolates are collected from a single large pathogen population developing under a particular set of selective forces, when there is random and independent recombination of virulence genes, and when the effects of migration or hitch-hiking of genes may be excluded (17). Other sources of error include the influence of environmental factors on the selection of some virulence genes and sampling errors (11).

Table 2. Frequencies of virulence factors isolated from each of 4 resistance groups (R_e, R_{sg}, R_{ta}, and V_b) at Bumbong Lima, 1983/84 main season (matching virulence = 100)

Resistance	Virulence			
	V_e	V_{sg}	V_{ta}	V_b
R_e	100	0	76	41
R_{sg}	0	100	13	104
R_{ta}	35	19	100	13
R_b	14	7	14	100

Table 3. Scheme of repeated testing to obtain estimates of the relative frequencies of pathogen genotypes with different virulence combinations produced on cultivar Hassan in the mixture H : W : M.[a]

Tests										
Source of spore collection	Hassan									
Test I cultivars:	Wing	w *(h, m)* *hw (m)*	*wm (h)* *hwm*	Hassan	*h (w, m)* *hw (m)*	*hm (w)* *hwm*	Midas	m *(h, w)* *hm (w)*	*wm (h)* *hwm*
Relative number of mildew colonies:	12.6			100			9.9		
Test II cultivars	Wing	*w (h, m)* *hw (m)*	*wm (h)* *hwm*	Midas	*wm (h)* *hwm*	Wing	*wm (h)* *hwm*	Midas	*m (h, w)* *hm (w)*	*wm (h)* *hwm*
Relative number of mildew colonies:	100			0.6		2.1		100		

Analysis

Virulence combination	Calculation of frequency	Frequency (%)	
hwm	0.006 X 12.6 [from left of figure)	0.1	mean 0.1
	0.021 X 9.9 (from right of figure)	0.2	
hw (m)	12.6–0.1	12.5	
hm (w)	9.9–0.2	9.7	
h (w, m)	100–12.5–9.7–0.1	77.7	

[a]Adapted from Chin and Wolfe (3). Possible virulence combinations at each level of testing are given in brackets.

In 1983 mass isolations were made from an isolated crop of cv. Mahsuri in Seberang Perai. Inoculation in a settling tower on the standard set of differential varieties gave the overall frequencies of V_{sg} as 0.36 and V_e as 0.15. The expected frequency of V_{sg+e} was therefore 0.05.

Sequential testing of mass isolates from the resulting infection on R_{sg} and R_e revealed no V_{sg+e}, indicating again the inability of the pathogen to produce successful combinations of the two virulences. (X^2 test between observed and expected virulence numbers was significant at $P<0.05$). This apparent deficiency in the pathogen may be exploited by selecting breeding lines with the corresponding combination of resistance genes.

CONCLUSIONS

Determination of the overall structure of pathogen populations in particular regions allows breeders to anticipate pathogen changes and to rationalize the selection of resistance genes for incorporation into the local breeding program. In disease surveys to determine these structures, disease samples should be collected at random for testing to avoid biased results. Alternatively, samples may be taken from host cultivars without race-specific resistance genes, or the general air spora may be sampled. The mobile nursery techniques described in this paper largely satisfy these requirements.

The extreme variability of *P. oryzae* suggests that population dynamics of the pathogen can be studied most effectively by considering frequencies of individual virulences rather than their combinations. Tests made with bulk collections allow sufficiently large population samples to be studied and are therefore more sensitive to the presence of relatively rare virulence genes. The fitness of these virulences may be important in determining the fate of newly released cultivars.

Analysis of the structure of pathogen populations on individual cultivars allows test for linkage disequilibrium to be made on virulence gene combinations provided a number of assumptions (described above) are met. While in practice it is not always possible to satisfy all these requirements, analysis may still be useful, provided its limitations are clearly understood. Where cases of linkage disequilibrium are identified in the pathogen they can be of crucial significance to breeding programs for disease resistance and in the strategic use of host resistances.

While the concept of races as the phenotypic reaction of a pathogen isolate to a range of host cultivars will continue to be useful in plant pathology, in most population studies, frequencies of individual virulence genes will be increasingly preferred. A decade ago Day (4) foresaw that race designations would become “largely unnecessary” as the “frequency of certain critical virulence genes in the pathogen population” was more important information in disease surveys. Current trends in plant pathology are consistent with that prediction.

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UPLAND RICE INSECT PESTS. THEIR ECOLOGY, IMPORTANCE, AND CONTROL

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Upland rice fields are nonpuddled and nonbunded and not expected to impound water.

Information on insect pests of upland rice is limited but none worldwide in scope. The list of upland rice insect pests (Table 1) was gleaned from the literature or our observations.

PEST GROUPS AND THEIR ECOLOGY

Despite dryland habitats representing an extreme hydrological condition, upland rice is host to all but the most aquatic insect species (7, 102). Whorl maggots, caseworms, water weevils, and bloodworms require ponding. Many soil and seedling pests common in upland rice will attack a dry seedbed intended for planting in lowland rice fields. Deepwater rice is established in dry soil and, therefore, has more in common with upland and rainfed lowland than with irrigated rice, although water depths later may reach 1-3 m. Second only to deepwater rice, upland rice represents the most unstable environment to insects.

SOIL PESTS

Well-drained, nonpuddled upland rice soils favor pests that pass at least one growth stage underground. Soil pests feed on underground plant parts (seeds or roots) and develop entirely in a subterranean habitat, except during adult mating and dispersal flights. Soil pests include ants (Formicidae), termites (Isoptera), molecrickets (Gryllotalpidae), field crickets (Gryllidae), white grubs and black beetles (Scarabaeidae), root aphids (Aphididae), root-feeding mealybugs (Pseudococcidae), root-feeding bugs (Lygaeidae, Cydnidae), false wireworms (Tenebrionidae), wireworms (Elateridae), root weevils (Curculionidae), and soil-inhabiting cutworms (Noctuidae).

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Table 1. Insect pests of upland rice worldwide.

Order	Family	Species	Distribution[a]	Reference
Isoptera	Rhinotermitidae	*Coptotermes formosanus* (Shiraki)	Asia	53
		Heterotermes indicola (Wasmann)	Asia	50
	Termitidae	*Capritermes nitobei* (Shiraki)	Asia	50, 53
		Cornitermes striatus (Hagen)	LA	91
		Procapritermes mushae Oshima	Asia	50, 53
		Pericapritermes nigerianus Silvestri (= *socialis)*	Africa	5
		Macrotermes natalensis (Haviland)	Africa	53
		Macrotermes bellicosus Smeathman	Africa	53
		Macrotermes gilvus (Oshima)	Asia	103
		Odontotermes formosanus (Shiraki)	Asia	50, 53
		Procornitermes araujoi Emerson	LA	53, 112
		Procornitermes triacifer (Silvestri)	LA	112
		Trinervitermes ebenerianus Sjostedt	Africa	53
		Microtermes sp.	Asia	7, 93
		Syntermes molestus (Burmeister)	LA	24, 53, 112
		Termites unspecified	Asia	43
Dermaptera	Forficulidae	*Diaperasticus erythrocephalus* Olivier	Africa	20
		Doru lineare (Eschscholtr)	LA	108
Orthoptera	Gryllotalpidae	*Gryllotalpa africana* (Palisot de Baeuvois)	Africa	7, 18
		Gryllotalpa orientalis Burmeister	Asia	33, 43, 45, 52
		Neocurtilla (= *Gryllotalpa) hexadactyla* (Perty)	LA	49,89, 112, 117, 122
		Scapteriscus didactylus (Latreille)	LA	49
	Gryllidae	*Gryllus assimilis (= bimaculatus)* (Fabricius)	Asia, LA	45
		Brachytrupes portentosus Licht	Asia	*b*
		Brachytrupes membranaceus Drury	Africa	28
		Teleogryllus testaceus (Walker)	Asia	45, 103
		Teleogryllus occipitalis (Serville)	Asia	*b*
		Loxoblemmus haani Saussure	Asia	*b*
		Liogryllus (= *Gryllus) bimaculatus* (de Geer)	Asia	103

	Velarictorus aspersus (Walker)	Asia	*b*
	Euscyrtus concinnus (de Haan)	Asia	*b*
Pyrgormorphidae	*Atractomorpha burri* I. Bolivar	Asia	32
	Atractomorpha psittacina psittacina (de Haan)	Asia	103
Tettigoniidae	*Conocephalus longipennis* (de Haan)	Asia	103
	Conocephalus maculatus (Lethierry)	Asia	103
	Euconocephalus varius (Walker)	Asia	103
	Caulopsis cuspidatus (Scudder)	LA	39, 49
	Caulopsis oberthuri Scudder	LA	39
	Phaneroptera furcifera (Stal)	Asia	103
Tetrigidae	*Amphiotus* sp.	Asia	103
Acrididae	*Aiolopus thalassinus tamulus* (Fabricius)	Asia	103
	Acrida willemsei (Dirsch)	Asia	103
	Gesonula mundata zonocera Navas	Asia	103
	Gonista bicolor (de Haan)	Asia	32
	Oxya japonica japonica (Thunberg)	Asia	43,103
	Oxya hyla intricata (Stal)	Asia	103
	Oxya fuscovittata (Marschall)	Asia	47
	Oxya velox (Fabricius)	Asia	43
	Gastrimargus marmoratus grandis (Saussure)	Asia	103
	Xenocatantops humilis humilis Serville	Asia	32
	Hieroglyphus banian (Fabricius)	Asia	32, 43
	Hieroglyphus oryzivoros Carl	Asia	50
	Hieroglyphus daganensis Krauss	Africa	4
	Hieroglyphus nigrorepletus (I. Bolivar)	Asia	50
	Heteropternis respondens (Walker)	Asia	32
	Patanga succincta (Linnaeus)	Asia	31, 32, 53, 76
	Stenocatantops splendens (Thunberg)	Asia	32, 103
	Chondracris rosea (de Geer)	Asia	32
	Trigonidium cicindeloides Rampur	Asia	47
	Locusta rnigratoria manilensis (Meyen)	Asia	32
	Locusta migratoria capito (Saussure)	Africa	50
	Locusta migratoria migratorioides Reische et Fairmaire	Africa	19

Table 1 continued.

Order	Family	Species	Distribution	Reference
		Schisrocerca gregaria (Forskal)	Africa	19
		Schistotocerca americana (Fabricius)	LA	50, 112
		Valanga nigricornis (Burmeister)	Asia	50
		Orphulella intricata Scudder	LA	39
Homoptera	Coccidae	*Pulvinaria sorghicola* De Lotto	Africa	141
		Pulvinaria iceryi (Guerrin)	LA	108, 141
	Pseudococcidae	*Cataenococcus* sp.	Asia	70
		Chorizococcus ilu Williams	Asia	140
		Dysmicoccus boninsis (Kuwana) [c]	Asia, Africa, LA	140
		Dysmicoccus brevipes (Cockerell) [c]	Asia, Africa, LA	68, 117, 140
		Dysmicoccus oryzae (Wirjati) [c]	Asia	140
		Geococcus (= *Ripersia) oryzae* (Kuwana) [c]	Asia	140
		Brevennia (= *Heterococcus) rehi* (Lindinger)	Asia	43, 140
		Nipaecoccus graminis (Maskell)	Africa	140
		Planococcoides lingnani (Ferris)	Asia	140
		Pseudococcus saccharicola Takahashi	Asia	140
		Saccharicoccus sacchari (Cockerell)	Africa, Asia, LA	140
		Trionymus ceres Williams	Asia	69, 140
		Mealybug unspecified	Asia	52
	Aphididae	*Rhopalosiphum maidis* (Fitch)	Asia	143
		Rhopalosiphum padi (Linnaeus)	Asia	143
		Rhopalosiphum rufiabdominalis (Sasaki)	Asia, LA, Africa	37, 45, 72, 112, 117, 134, 143
		Tetraneura akinire Sasaki	Asia	143
		Tetraneura basui HilleRisLambers	Asia	143
		Terraneura nigriabdominalis (Sasaki) (= *Dryopeia hirsuta)*	Asia, Africa	5, 16, 45, 134, 142
		Terraneura radicicola Strand	Asia	143
		Paracletus cimiciformis von Heyden	Asia	143
		Geoica lucifuga (Zehntner)	LA	45, 112, 134, 143

	Geoica sefulosa (Passerini)	Asia	143
	Anoecia fulviabdominalis (Sasaki)	Asia	143
	Anoecia corni (Fabricius)	Asia	134,143
	Forda sp.	Asia	143
	Hysteroneura setariae (Thomas)	Africa, Asia, LA	5
	Sipha glyceriae (Kaltenbach)	Asia	143
	Root aphid unspecified	Asia	43, 51, 70
Cercopidae	*Deois schach* (Fabricius)	LA	34, 39, 111
	Sepullia (= Denoplux) nigropunctata Stal	Africa	20
	Tomaspis (= Deois) flexuosa (Walker)	LA	34, 37, 111
	Tomaspis (= Deois) flavopicta (Stal)	LA	34, 39, 111
	Tomaspis (= Deois) completa (Schmidt)	LA	39
	Tomaspis (= Zulia) entreriana (Berg)	LA	39
	Tomaspis (= Mahanarva) fimbriolata (Stal)	LA	39,111
	Tomaspis (=Aeneolomia) spectabilis (Distant)	LA	135
	Aeneolamia varia Fennah	LA	49
	Aeneolamia postica (Walker)	LA	117
	Abidama producta Walker	Asia	32
Delphacidae	*Sogatella furcifera* (Horvath)	Asia	33, 138
	Nilaparvata lugens (Stal)	Asia	16, 33, 43, 52, 138
	Sogatodes oryzicola (Muir)	LA	34, 38, 89
	Sogatodes cubanus (Crawford)	LA	89
	Peregrinus maidis (Ashmead)	LA	108
	Laodelphax striatellus (Fallen)	Asia	9
Cicadellidae	*Recilia dorsalis* (Motschulsky)	Asia	33,138
	Nephotettix nigropictus (Stal)	Asia	33, 138
	Nephotettix virescens (Distant)	Asia	33, 138
	Nephotettix modulatus Melichar	Africa	128
	Cofana spectra (Distant)	Asia	33, 138
	Graphocephala sp.	LA	34,37
	Hortensia similis (Walker)	LA	34, 37, 49, 89
	Exitianus obscurinervis (Stal)	LA	34, 37
	Balclutha sp.	LA	37
	Draeculacephala clypeata Osborn	LA	37, 49, 89
	Cicadulina bipunctella (Motsmura)	Asia	c

Table 1 continued.

Order	Family	Species	Distribution	Reference
Hemiptera	Lygaeidae	*Cymoninus turaensis* (Paiva)	Asia	103
		Ninus insignis Stal	Asia	103
		Pachybrachius nervosus Horvath	Asia	16
		Caenoblissus pilosus (Fabricius)	Asia	51
		Blissus leucopterus (Say)	LA	24, 49, 89, 117
		Blissus sp.	Asia	16
		Dimorphopterus cornutus novaeguineae Ghauri	Asia	48
		Dimorphopterus similis (Slater)	Africa	35
		Paromius piratoides (Costa)	Asia	103
	Cydnidae	*Pangaeus* sp.	LA	112
		Aethus indicus (Westwood)	Asia	103
		Geotomus pygmaeus (Dallas)	Asia	103
		Stibaropus molginus Schiodte	Asia	103
		Cyrtomenus bergi Froeschner	LA	117
		Cyrtomenus ciliatus (Palisot de Beauvois)	LA	117
		Cyrtomenus crassus Walker	LA	117
		Tominotus sp.	LA	117
	Alydidae	*Riptortus linearis* (Fabricius)	Asia	32, 103
		Leptocorisa acuta (Thunberg)	Asia	43, 47, 70, 125
		Leptocorisa biguttata (Walker)	Asia	125
		Leptocorisa oratorius (Fabricius)	Asia	33, 70, 114
		Leptocorisa chinensis Dallas	Asia	67
		Leptocorisa solomonensis Ahmad	Africa	114
		Leptocorisa spp.	Asia	31
		Stenocoris southwoodi Ahmad	Africa	4, 20, 50
		Mirperus torridus Westwood	Africa	4, 50
	Coreidae	*Cletus trigonus* (Thunberg)	Asia	103
	Corimelaenidae	*Alkindus atratus* Distant	LA	49, 89
	Pentatomidae	*Scaptocoris castaneus* Perty	LA	112
		Scotinophara tarsalis (Vollenhoven)	Asia	33
		Scotinophara scotti Horvath	Asia	70

		Stollia (= *Eysarcoris) ventralis* (Westwood)	Asia	103
		Dolycoris indicus Stal	Asia	47
		Macrina juvenca Burmeister	Africa	20
		Tanfia antiguensis (Westwood)	LA	108
		Tantia gelii Schout	Africa	20
		Tantia perditor (Fabricius)	LA	108
		Menida sp.	Asia	32
		Nezara viridula (Linneaus)	Asia, Africa	16, 20, 31, 32, 47, 49, 70
		Oebalus poecilus (Dallas)	LA	34, 37, 49, 112
		Oebalus ypsilon-griseus (de Geer)	LA	34, 37, 112, 122
		Oebalus grisescens (Sailer)	LA	89,112
		Tibraca limbativentris (Stal)	LA	34, 37, 49, 89, 112,135
		Aspavia armigera (Fabricius)	Africa	4, 50
		Diploxys fissa Erichson	Africa	4, 50
		Acrosternum marginatum (Palisot de Beauvois)	LA	108
		Acrosternum sp.	LA	108
Thysanoptera	Thripidae	*Frankliniella rodeos* ? Pergande	LA	34, 37
		Bregmatothrips venustos Watson	LA	39
		Stenchaetothrips (= *Baliothrips) biformis* (Bagnall) (= *Chloethrips oryzae* (Williams))	Asia	124, 136
		Haplothrips priesnerianus Bagnall	Asia	103
Coleoptera	Scarabaeidae Dynastinae	*Hetetoligus meles* Billberg (= *Heteroligus meles robustus* Prell)	Africa	20
		Alissonotum pauper Burmeister	Asia	50
		Alissonotum simile Arrow	Asia	121
		Dyscinetus dubius (Olivier)	LA	14, 112, 135
		Dyscinetus gagates Burmeister	LA	112
		Euetheola humilis Burmeister	LA	14, 49, 42, 117, 135
		Euetheola bidentata (Burmeister)	LA	117, 126

Table 1 continued.

Order	Family	Species	Distribution	Reference
		Heteronychus andersoni Jack	Africa	50
		Heteronychus bituberculatus Kolbe	Africa	50
		Heteronychus licas (Klug)	Africa	50
		Heteronychus mosambicus Peringuey (= *Heteronychus oryzae* Britton)	Africa	3, 4, 28, 50
		Heteronychus lioderes Redtenbacher	Asia	46, 50, 120
		Heteronychus arator (Fabricius)	Africa	50
		Heteronychus plebejus (Klug)	Africa	50
		Heteronychus pseudocongoensis Ferreire	Africa	18
		Heteronychus rugifrons Fairmaire	Africa	50
		Heteronychus rusticus niger (Klug)	Africa	50
		Lachnostera longipennis (Blanchard)	Asia	50
		Lachnosterna sp.	Asia	70
		Ligyrus fossator Burmeister	LA	50
		Ligyrus nasulus Burmeister	LA	117
		Ligyrus ebeninus (Erichson)	LA	112
		Ligyrus humilis Burmeister	LA	50
		Maladera castanea (Arrow)	Asia	50
		Maladera orientalis (Burmeister)	Asia	50
		Maladera japonica Motschulsky	Asia	50
		Phyllognathus dicnysius (Fabricius)	Asia	50
	Melolonthinae	*Exopholis hypoleuca* (Wiedemann)	Asia	68
		Leucopholis rorida (Fabricius)	Asia	50, 68
		Lepidiota blanchardi Dalla Torre	Asia	45, 50
		Leucopholis irrorata (Chevrolat)	Asia	45, 80
		Serica interrupta Walker	Asia	45
		Holotrichia longipennis (Blanchard)	Asia	71
		Holotrichia serrata Fabricius	Asia	71
		Holotrichia leucophthalma (Wiedemann)	Asia	50
		Holotrichia seticollis Moser	Asia	46, 47
		Holotrichia consanguinea Blanchard	Asia	71
		Stenocrates sp.	LA	39, 112

	Ataenius spp .	LA, Asia	117
	Phyllophaga aequata (Bates)	LA	117
	Phyllophaga caraga Saylor	LA	117
	Phyllophaga chiriquina (Bates)	LA	117
	Phyllophaga dasypoda (Bates)	LA	117
	Phyllophaga elegans Saylor	LA	117
	Phyllophaga hondura Saylor	LA	117
	Phyllophaga latipes (Bates)	LA	117
	Phyllophaga mentriesi (Blanchard)	LA	117
	Phyllophaga parvisetis (Bates)	LA	117
	Phyllophaga sanjosicola Saylor	LA	117
	Phyllophaga setifera Burmeister	LA	117
	Phyllophaga (= Holotrichia) helleri Breuske	Asia	50, 68, 94
	Phyllophaga sp.	LA	49, 89
	White grub unspecified		52
Rutellinae	*Lagochile trigona* (Host)	LA	50
	Anomala dimidiata var. *barbata* Burmeister	Asia	46, 47, 50
	Anomala humeralis (Burmeister)	Asia	45
	Anomala lurida (Blanchard)	Asia	45
	Anomala sulcatula (Burrneister)	Asia	45
	Anomala varians (Olivier)	Asia	50
	Anomala antigua (Gyllehal)	Asia	50
	Anomala pallida (Fabricius)	Asia	50
	Anomala polita (Blanchard)	Asia	50
	Adoretus caliginosus Bumeister	Asia	50
	Adoretus compressus (Weber)	Asia	50
	Papuana hubneri (Fairmaire)	Asia	50
	Papuana inermis Prell	Asia	50
	Popillia cupricollis Hope	Asia	47
Tenebrionidae	*Gonocephalum depressum* Fabricius	Asia	50, 68, 103
	Gonocephalum acurangulum (Fabricius)	Asia	50, 68
	Gonocephalum simplex (Fabricius)	Africa	50
	Epitragus sallei Champion	LA	117
	Anaedus punctatissimus Champion	LA	117

Table 1 continued.

Order	Family	Species	Distribution	Reference
	Elateridae	*Aetus* sp.	LA	112
		Agriotes sp.	LA	112
		Agriotes mancus Say	LA	117
		Conoderus sp.	LA	112
		Aeleoderma brachmana (Candeze)	Asia	*b*
		Wireworm unspecified	Asia	70
	Chrysomelidae	*Dicladispa viridicyanea* (Kraatz)	Africa	20
		Trichispa sericea (Guerrin)	Africa	7
		Oediopalpa sternalis (Weise)	LA	34, 37, 39
		Oediopalpa guerini (Baly)	LA	34, 37, 39
		Chaetocnema denticulata Stephens	LA	34, 37, 39, 49
		Chaetocnema basalis (Baly)	Asia	103
		Aulacophora sp. nr. *similis* Olivier	Asia	32
		Monolepta cavipenne Baly	Asia	32
		Monolepta signata Olivier	Asia	32
		Cerotoma atrofasciata Jacoby	LA	117
		Diabrotica adelpha Harold	LA	117
		Diabrotica balteata Leconte	LA	117
		Diabrotica graminea Baly	LA	117
		Diabrotica speciosa (Germar)	LA	34, 37, 39
		Diabrotica limitafa quindecimpunctata (Germar)	LA	112
		Diabrotica melanocephala (Fabricius)	LA	112
		Diabrotica sp.	LA	34, 39
		Altica sp.	Asia	103
		Epitrix cucumeris (Harris)	LA	117
		Epitrix sp.	LA	49
		Oulema oryzae (Kuwayama)	Asia	50
		Disonycha (= *Donacia)* sp.	LA	112
		Flea beetle unspecified	Asia	70
	Coccinellidae	*Chnootriba* (= *Epilachna) similis* (Mulsant)	Africa	4, 7

	Curculionidae	*Atactogaster inducens* Walker	Asia	107
		Hypomeces squamosus (Fabricius)	Asia	70
		Tanymecus discoidalis Gyllenhal	Africa	50
		Phaulosomus musculinus (= mus) Csiki	Africa	50
		Neobaridia amplitarsis Casey	LA	37, 39, 112, 135
Lepidoptera	Lymantriidae	*Psalis pennafula* (Fabricius)	Asia	68
		Laelia suffusa (Walker)	Asia	68
		Euproctis virguncula (Walker)	Asia	68
		Euproctis minor (Snellen)	Asia	68
		Euproctis xanthorrhoea (Kollar)	Asia	68
	Arctiidae	*Diacrisia obliqua* (Walker)	Asia	50
		Creatonotus gangis Linnaeus	Asia	50
	Limacodidae	*Latoia (= Parasa) bicolor* (Walker)	Asia	50
	Eupterotidae	*Nisaga simplex* Walker	Asia	105
	Noctuidae	*Sesamia nonagroides* botanephaga Tams et Bowden	Africa	4, 20
		Sesamia calamistis Hampson	Africa	4, 6, 7, 20
		Sesamia inferens (Walker)	Asia	33, 50, 52
		Spodoptera eridania (Cramer)	LA	89
		Spodoptera mauritia acronyctoides Guenee	Asia	16, 33
		Spodoptera frugiperda (J. E. Smith)	LA	14, 34, 37, 39, 49, 89, 112, 117, 121, 135
		Spodoptera exiqua (Hubner)	Africa	18,128
		Spodoptera exempta (Walker)	Africa	18, 20, 63, 128
		Spodoptera ornithogalli (Guenee)	LA	89
		Mythimna loreyi (Duponchel)	Asia	16
		Mythimna separata (Walker)	Asia	103
		Mythimna (= Pseudaletia) latifascia (Walker)	LA	112
		Mythimna (= Pseudaletia) seqoax (Fabricius)	LA	39
		Mythimna roseilinea (Walker)	Asia	*b*
		Mythimna yu Guenee	Asia	*b*
		Mocis frugalis (Fabricius)	Asia	16, 68

Table 1 continued.

Order	Family	Species	Distribution	Reference
		Mocis latipes (Guenee)	LA	37, 39, 88, 89, 117,135
		Agrotis ipsilon (Hufnagel)	LA, Africa	19, 39, 49, 89, 112,117
		Achaea janara (Linnaeus)	Asia	68
		Eldana saccharina Walker	Africa	20
		Armyworm unspecified	Asia	43, 52
	Pyralidae	*Cnaphalocrocis medinalis* (Guenee)	Asia	16, 26, 33, 43, 52, 138
		Marasmia bilinealis Hampson	Africa	20
		Marasmia trapezalis (Guenee)	Africa	18, 128
		Marasmia (= *Susumia) exigua* (Butler)	Asia	130
		Marasmia ruralis (Walker)	Asia	*b*
		Marasmia patnalis Bradley	Asia	*b*
		Marasmia sp.	Asia	*b*
		Leaf roller unspecified	Asia	
		Maliarpha separatella Ragonot	Africa	43
		Chilo parrellus (Swinhoe)	Africa	58
		Chilo polychrysus (Meyrick)	Asia	33, 43
		Chilo diffusilineus J. de Joannis	Africa	4, 15
		Chilo suppressalis (Walker)	Asia	33,43
		Chilo zacconius Blezrinski	Africa	4, 7
		Crambus sp.	LA	115
		Acigona loftini (Dyar)	LA	13
		Acigona chrysographella (Kollar)	Asia	50
		Scirpophaga incertulas (Walker)	Asia	33, 43
		? *Scirpophaga innotata* (Walker)	Asia	33
		? *Scirpophaga nivella* (Fabricius)	Asia	
		Elasmopalpus lignosellus (Zeller)	LA	14, 34, 37, 49, 89, 112, 117, 135
		Diatraea saccharalis (Fabricius)	LA	14, 37, 49, 89, 112, 135
		Stem borer unspecified	Asia	43

	Gelechiidae	*Brachmia arotraea* Mayr	Asia	32
		Brachmia sp.	Africa	18
	Hesperiidae	*Parnara guttata* Bremer et Grey	Asia	*b*
		Parnara naso Fabricius	Asia	32
		Pelopidas agna agna (Moore)	Asia	95
		Pelopidas mathias (Fabricius)	Asia, Africa	20, 92, 128
		Pelopidas conjuncta conjuncta (Herrich-Schaffer)	Asia	*b*
	Satyridae	*Melanitis leda ismene* Cramer	Asia	52,124
		Mycalesis asophis Hew	Asia	16
	Cecidomyiidae	*Orseolia oryzae* (Wood-Mason)	Asia	43, 55, 77
		Orseolia oryzivora Harris et Gagne	Africa	4, 7, 18, 129
Diptera	Chloropidae	*Mepachymerus* (= *Steleocerus) ensifer* (Thomson)	Asia	118
		Oscinella sp.	Asia	118
		Gaurax sp.	Asia	118
		Chlorops oryzae Matsumura	Asia	50
	Muscidae	*Atherigona oryzae* Malloch	Asia	16, 50, 68, 76
		Atherigona exigua Stein	Asia	50, 68, 103
		Atherigona orientalis Schiner	Asia	50
		Atherigona indicata Malloch	Asia, Africa	50, 118
	Diopsidae	*Diopsis macropthalma* (= *thoracica)* (Dalman)	Africa	7, 28
		Diopsis spp.	Africa	128
	Agromyzidae	*Pseudonapomyza asiatica* Spencer	Asia	124
		Pseudonapomyza spicata (Malloch)	Asia	*b*
		Agromyza oryzae (Munakata)	Asia	*b*
Hymenoptera	Formicidae	*Acromyrmex landolti bolzani* (Emery)	LA	34, 39, 112
		Acromyrmex landolti facticornis (Forel)	LA	34,112
		Acromyrmex heyeri (Forel)	LA	34, 39, 112
		Atta bisphaerica Forel	LA	34, 39, 112
		Atta capiguana Goncalves	LA	34, 39, 112
		Atta laevigata (F. Smith)	LA	34, 39, 112
		Atta opaciceps Borgmeier	LA	34, 112
		Solenopsis geminata (Fabricius)	Asia	*b*
		Pheidole sp.	Asia	*b*
		Pheidolegeton sp.	Asia	*b*
		Ants unspecified	Asia	70

[a]LA = Latin America. [b]Philippines, reported in this study. [c]Subterranean root feeders.

Ants

Species of terrestrial ants, notably the ubiquitous fire ant *Solenopsis geminata* and harvester ants *Pheidole* spp., specialize in feeding on ungerminated grass seed.

The upland rice environment is particularly well suited to ants because of lack of flooding. Frequent tillage also perpetuates grasses and granivorous species that are highly adapted to constructing new nests in recently tilled fields.

Damage is characterized by reduced plant stand, usually highly uneven (patchy) (70).

In Latin America, leaf-cutting ants (*Atta* spp. and *Acromyrmex* spp.) only occur in upland fields and defoliate rice plants (39).

Termites

Subterranean termites of the family Termitidae culture fungi in special underground cells — fungal combs made of half-digested plant material (68). The fungi, inoculated onto the combs, break down plant material into food that termites can digest. These grassland termites are permanent residents underground and build nests below the plow layer in upland rice fields. Damage will occur to newly planted crops where plant material has been removed by clean culture.

Infestations are worse in deep, light-textured soils with low moisture content. The first sign of damage is yellowing of older leaves (1 12). Termites feed on roots (to first cause yellowing, then wilting, and finally collapse of the plant) and on germinating seeds (to cause loss of stand), or at night the workers move above ground to cut seedlings at ground level to be covered with soil for later consumption.

Termites are more serious in Latin America where large rice fields are plowed with tractors, depriving termites of preferred food and forcing them onto living rice plants. In Asia, upland rice fields are typically small with large field border areas (ecotones) where termites can forage for preferred food other than growing rice plants.

In Africa, termites can at times be important although fields are small and surrounded by perennial borders. These termite species perhaps selectively prefer rice to other available hosts.

Mole crickets

Nymphs and adult mole crickets are nocturnal and burrow through the soil profile feeding on roots of a wide variety of plants or forage above ground as predators of insects. Mole crickets prefer low-lying, moist upland soils with high organic matter (7, 49). Losses show as wilted plants (from root feeding) or reduction of stand (70). Damage is more common near field borders where mole crickets relocate after tillage operations (73).

Field crickets

Nymphs and adults of field crickets and mole crickets have similar nocturnal

habits and damage symptoms. They make subterranean nests and tunnel the soil profile to feed on roots.

Tunnel entrances surrounded by excavated soil are readily seen on the ground. Young plants are cut at ground level and stored in underground cells.

White grubs and black beetles

Scarab beetles that feed on living roots as larvae but not as adults are called white grubs or chafers (Melolonthinae, Rutellinae) while those that feed as adults on the crowns of the plants but not as larvae are called black beetles (Dynastinae). In the tropics chafers or white grubs have a 1-yr life cycle starting with adults emerging from the soil after the first downpours of the rainy season (80, 94). They lay eggs at the same time farmers sow upland rice. The rice passes its most susceptible stage, and damage is mostly avoided when white grubs are small. After several months, the long-lived white grubs become sufficiently large that two or three larvae can denude the root system of mature rice. This intensity of damage is rare but wilting occurs when root loss is combined with water stress.

Larvae need damp soil to survive and pass the unfavorable dry season 1-2 m underground. The first heavy rains of the season (20-30 mm/d) stimulate the grubs to resume activity. After several weeks they develop into pupae and adults, eventually digging their way to the surface and flying to nearby trees to seek food and mates. Grasslands may support large populations and therefore white grubs can be more abundant in newly planted upland rice fields that were previously fallow (49).

Black beetles live up to a year and as adults can attack a crop at any stage by burrowing under the soil surface (74) or feeding at the base of stems to cause whiteheads (120). Adults emerge with the early rains and, are more abundant on a young rice crop (49). Damage is most serious when a young crop with small root systems is attacked (21).

Root aphids

Several genera of migratory aphids feed on roots of upland rice (143). Population buildup is favored more in light-textured soils with high percolation rates. Tending ants — *Pheidole, Crematogaster, Tetramorium, Lasius, Tapinoma* — are necessary for root aphids to multiply. Ants harbor aphids in their nests over winter or during unfavorable periods, and relocate them on rice plants and dig tunnels along the root systems to allow these soft-bodied insects to penetrate the soil. Root aphids fly to rice plants at the beginning of the rice season and undergo several generations, continually developing winged forms to relocate on alternative grassy hosts until winter, when they move to perennial hosts, usually trees. Yield loss occurs mainly through reduced tillering, but infested plants become yellow and stunted, and, in extreme cases, wilt (133). As aphid population buildup is necessary for plant damage to occur, damage symptoms begin in the late vegetative and reproductive growth stages.

Root-feeding mealybugs

More than half of the mealybug species occurring on rice feed on roots (140). Mealybugs, as well as soil-inhabiting aphids, being soft-bodied, do not possess adaptations for living underground but are able to survive because tending ants (the same species as tend root aphids) dig burrows for them and move them from plant to plant.

The most common rice mealybug *Brevennia rehi* is a foliar feeder favored by lack of rain and apparently is responsible for high yield loss in northeast India and Bangladesh (N. Panda, pers. comm., as stated in IRRI [63]).

Root weevils

A few species of upland weevils, as larvae, attack rice roots, and, as adults, stems and leaves *(Hypomeces, Donacia, Atactogaster).* Damage is patchy in a field. The presence of upland weevil adults on rice foliage or on the soil surface indicates that the roots are being attacked by the grubs.

Root beetles

Soil-inhabiting *Gonocephalum* spp. false wireworms are reported in upland rice fields. The adults and larvae normally feed on decaying organic matter but after upland rice land preparation, these sources are removed and the larvae feed on the roots of seedlings or roam as nocturnal adults on the soil surface to cut off seedlings at ground level (50). This group of ground beetles is highly omnivorous as adults, even preying on stem borer larvae (106).

Root bugs

Upland rice seedlings can be attacked by adults and nymphs of chinch bugs *Blissus* and *Caenoblissus* and brown bug *Scaptocoris,* which feed on the roots with their sucking mouthparts (48, 51). These insects are large and can kill seedlings.

Cutworms

Soil-dwelling noctuid larvae during the day hide underground to avoid predation by birds and at night become active above the ground, cutting off young plants at ground level (hence the name cutworms). The severed plants are dragged into burrows made by the larvae.

FOLIAR PESTS

Other groups of insects are adapted to upland environments because they pass one growth stage underground, either as an egg (in hemimetabolous species) or as pupa (in a holometabolous groups).

Rice seedling maggots and leaf miners

Atherigona flies occur in nonflooded environments in Asia and Africa (104). Feeding by the larvae causes deadhearts, and only one larva occurs per tiller. *Atherigona* larvae feed on the decaying tillers while the larvae of stem borer moths actively feed on living tillers to cause deadhearts. Seedling maggots

will die if they cannot severe a tiller because they cannot feed on living tissues. Plants die under heavy attack while lighter infestations cause stunting, delayed maturity, and ragged leaves (137). Eggs are laid only on actively growing plants (29) and larvae pupate more in stems than in soil. Seedling maggot attack is highly seasonal (119), normally occurring in mid rainy season.

The rice stem maggot *Chlorops oryzae* is adapted to temperate upland and lowland rice growing regions of Asia. In Japan and China upland rice normally occurs in mountainous regions and is exposed to this chloropid fly. The larvae tunnel the stems. The stem maggot is more damaging during the seedling stage and the larvae hibernate in grasses over winter.

Leaf beetles

Several chrysomelid and coccinellid leaf beetles, either as larvae or adults or both, scrape or remove leaf tissue. This damage accelerates desiccation of plants. The larvae of some species are root feeders. *Epitrix* and *Chaetocnema* flea beetles and *Diabrotica* spp. root worms feed on rice foliage only as adults. Their root-feeding larvae have hosts other than rice. The adults and larvae of the hispa-1ike *Oediopalpa* spp. beetles of Brazil and *chnootriba* (= *Epilachna*) beetle of Africa feed on rice leaves. *Oediopalpa* spp. larvae are leaf miners. *Chnootriba* is also prevalent in lowland environments (7). Leafbeetles prefer vegetative rice (49). In Central Africa the hispid *Dicladispa viridicyanea* attacks upland rice in the vegetative stage as well as lowland rice in seedbeds. *Trichispa sericia* is reported on upland rice in West Africa.

The rice leaf beetle *Oulema oryzae,* much like *Chlorops oryzae,* is adapted to the temperate regions of Asia and is a pest of upland rice in the mountains (50). The adult hibernates on grasses throughout winter.

Armyworms

Species of the grassland-adapted *Spodoptera* and *Mythimna* larvae sometimes create widespread epidemics. The resulting defoliation of rice fields occurs generally in patches from early vegetative growth to harvest (23). Adults disperse over long distances to colonize even remote upland areas. They become more abundant than their natural enemies, particularly after favorable rains following a prolonged drought (113). The drought kills armyworms and natural enemies (mainly parasites) but causes armyworms to recolonize more rapidly.

The natural increase in soil fertility from mineralization of soil nitrogen over the drought period creates luxuriant plant growth to allow a rapid buildup of these highly fecund species. The preference for rice is further favored by removal of weeds from rice fields by farmers. The parasites normally return to control the armyworms but not after serious damage occurs. Outbreaks on upland rice have been reported in Ghana (2), Zanzibar (21), Central Africa (20), Panama (96), and Brazil (14). Damage is caused by severe defoliation, often leaving only the base of stems. Armyworm larvae hide during the day under litter or in soil cracks. At night they climb plants to feed. Larvae pupate in the soil.

Thrips

Although thrips frequently occur in upland rice (23, 124), reports of damage are fewer in upland rice than in lowland. Thrips larvae and adults rasp leafblades causing a characteristic stippling appearance. Thrips prefer vegetative-stage rice and their survival increases during drought (heavy rainfall washes them from foliage). When drought occurs in upland rice culture, the direct effects of water stress outweigh those of thrips damage. Drought and thrips cause leaf rolling in upland rice (136), and perhaps because of their small size, thrips have been overlooked.

In Latin America, *Frankliniella rodeos* attacks the panicles before emergence from the boot, causing sterile grains.

Stem bugs

Black bugs are the most common group of rice stem-feeding Hemiptera in Asia. Upland species — notably *S. tarsalis* and *S. scotti* — remove the sap from stems of grasses and upland rice.

In Latin America, a large pentatomid *Tibraca limbativentris* causes deadhearts and whiteheads on upland rice. Both adults and nymphs remove sap from internodes of plants older than 3 wk. Tillers are killed by mechanical damage and by the entry of secondary microbial infection. This damage is often confused with that of lepidopterous stem borers (135). Eggs are laid on the leaves and stems. Nymphs are gregarious and population buildup is reduced by drought.

Stem borers

Lepidopterous and dipterous stem borers are widely recorded on upland rice, however, their local abundance is highly influenced by cultural practices. The numbers of such stem borers, except *Elasmopalpus lignosellus,* usually build up toward the end of the crop growth cycle. Therefore, long-maturing varieties and staggered planting favor stem borer buildup. Many stem borer species lie dormant in the stubble after harvest and their survival is encouraged by panicle harvesting (leaving tall stems) and lack of tillage after harvest, which removes stubble and straw.

Stem borers have good dispersal powers and lay many eggs. Many successful upland rice species are polyphagous, however, the monophagous *Maliarpha separatella, Diopsis macropthalma,* and *Scirphophaga incertulas* can also be abundant on upland rice. *Chilo suppressalis* develops faster and becomes larger when reared on upland rice rather than on lowland rice (132).

The lesser corn stalk borer *Elasmopalpus lignosellus* is semisubterranean in habit and is perhaps the most adapted to upland rice. It is highly polyphagous being a pest of maize, peanut, and cowpea. It attacks seedling rice (one larva can kill up to four plants before maximum tillering) (112). *Chilo* and *Maliarpha* stem borers prefer older plants, but *Scirphophaga* spp. will attack young plants even in the nursery. *Elasmopalpus* larvae tunnel the stems at or below the soil level, causing typical deadhearts. Larvae are not found in their tunnels inside stems because when disturbed they retreat into

cases made from the soil tied together by silk. The lesser corn stalk borer is more abundant during drought and its damage is often confused with water stress (135). This species prefers sandy soils and its distribution within a field may be related to differences in soil texture (86).

Diatraea saccharalis, aside from the lesser corn stalk borer, is frequently mentioned as a stem borer pest in Latin America. According to Teran (135) rice and maize are more preferred hosts than sugarcane, its namesake.

Acigona chrysographella is a less known upland rice stem borer species in Asia with habits similar to *Elasmopalpus* (50) as it is not found in lowland environments. *Acigona* has grassy weed alternative hosts. As a moth it is often confused with the dark-headed stem borer *Chilo polychrysus* and striped stem borer *Chilo suppressalis.*

Other common upland rice stem borers are also reported in the lowlands. The dominant species in upland rice vary greatly with location. In Uttar Pradesh (47) and Japan (72), the pink stem borer *Sesamia inferens* is more prevalent.

In Kenya, the principal rice stem borer is *Chilo partellus* (58). The lowland Africa stern borers *Maliarpha separatella, Diopsis macropthalma,* and *Sesamia calamistis* are less abundant in upland than in lowland rice (128) but perhaps cause greater yield loss because plant injury is greater if combined with drought stress (58). *Diopsis* stalk-eyed stem borers are more prevalent in wet habitats (4, 7, 128). In Central and West Africa, *Maliarpha* and *Sesamia calamistis* are the dominant stem borers of upland rice (6, 7). *Chilo diffusilineus* and *Chilo partellus* inhabit the upland savannas whereas *Chilo zacconius* prefers the lowlands (7). Yellow stem borer can also be prevalent in upland rice (70). The sugarcane borer *Eldana saccharina* is so far only a potential pest of upland rice (57) in spite of Grist and Lever's (50) warning.

Grasshoppers, locusts, and crickets

Short-horned grasshoppers and locusts — *Locusta, Patanga, Schistocerca* — lay eggs in the soil, inhabit grasslands, and develop into swarms to inflict serious damage to upland rice from time to time (100). Large numbers can totally destroy a field, leaving only stubble. Even in low numbers, grasshoppers can cut the panicles (100). Farmers may not plant if locust swarms are imminent. As with armyworms, prolonged dry weather followed by favorable rains also create conditions favoring the development of large swarms (100). The breeding areas are normally the dry grasslands from which they disperse to agricultural land to attack crops, including upland rice (110). The eggs are susceptible to desiccation during drought but also die from inundation during seasonal rains in the locusts' breeding grounds. Egg survival is high during periods of favorable soil moisture and if sustained over several consecutive seasons, natural enemies cannot prevent a large population increase leading to the development of migratory swarms (36).

Most grasshoppers recorded on rice are adapted to the uplands (64), but lowland rice grasshoppers *Hieroglyphus* spp. and *Oxya* spp. occur only

occasionally on upland rice (1, 50). Their eggs are laid on rice foliage and their nymphs are semiaquatic.

The gryllid *Euscyrtus concinnus* is a pest of lowland and deepwater rice in Bangladesh and Thailand. In the Philippines, it damages upland rice grown in isolated pockets near lakes. The gryllid nymphs and adults feed on the central portions of foliage, leaving only the midrib and leaf margins.

Leaffolders

Pyralid moths, whose larvae fold leaves to make a feeding shelter occur worldwide (128) but are apparently more common in Asia. *Cnaphalocrocis medinalis,* the most known rice leaffolder in Asia, may actually prefer grassy weeds over rice (54). It is an early colonizer of upland rice. *Marasmia exigua,* a lowland species (130), prefers rice over grass species (54) and colonizes upland rice during the later growth stages. *Marasmia patnalis,* however, is the most commonly encountered species in upland rice in the Philippines. Its alternative host is perennial grass and it may survive year-round in upland rice environments. *Marasmia ruralis,* another leaffolder, is least abundant. Dormancy is unknown for leaffolders. *C. medinalis,* however, is known as a migrant (56). Damage is caused by removal of photosynthetic tissue, and attack during the flag-leaf stage is particularly injurious. Populations are normally held in check by natural enemies but leaffolders become particularly abundant in conditions of high plant fertility and shade.

Butterflies

Skippers *Pelopidas mathias* and *Borbo fanta* are more prevalent in African lowland than in upland habitats (4). But extensive studies in Japan and China showed *Pelopidas mathias'* preference for an upland habitat (92). *Parnara guttata* seasonally migrates between lowland and upland areas and is equally abundant in both environments (95).

Experience in the Philippines suggests that *Pelopidas mathias* and *Melanitis leda ismene* are often more abundant in upland rice habitats than in lowland. Bamboo *Bambusa* spp. annually sustains *P. mathias* populations in the Philippine uplands. Adults feed on nectar from flowers and migrate to upland rice during the late vegetative stage. Reports also state that the green-homed caterpillar *Melaniris leda ismene* is more abundant in lowlands (123). Butterflies in general, however seldom become numerous probably because of high egg predation. Parasitization of egg and larva often is low. They can readily disperse long distances to seek remote upland rice fields. However, they have low biotic potential, and even if predation rates were low, they would rarely become abundant. Observations show that adult butterflies rest in the shade during the day. Upland environments with their diverse microhabitats can provide more favorable sites than lowland rice plains, where they seldom are abundant.

The butterfly pests of rice have broad host ranges and become dormant during unfavorable times of the year.

Polyphagous lepidoptera

The larvae of many polyphagous moths are reported to defoliate upland rice: tussock moths *Psalis pennatula, Lailia suffusa, Euproctis virguncula, E. minor,* and *E. xanthorrhoea;* slug caterpillar *Laotia bicolor,* hairy caterpillar *Nisaga simplex* and wooly bears *Diacrisia obliqua,* and *Crearonotus gangis.*

Gall midges

The Asian rice gall midge *Orseolia oryzae* (55, 77) and its African counterpart *Orseolia oryzivora* Harris et Gagne (4, 7, 18, 128) prefer lowland rice to upland.

Foliar aphids

Reports of aphids attacking the aerial portion of upland rice plants are few (143). In the absence of maize, the maize leaf aphid *Rhopalosiphum maidis* attacks upland rice in the Philippines. In Sierra Leone, the plum peach aphid *Hysteroneura setariae* infests leaves and unripened grain (5).

Leafhoppers and planthoppers

Cicadellids and delphacids have good dispersal powers and readily colonize upland rice fields from nearby lowland rice areas or grasslands. A study in Sarawak (138) is typical and shows the similarity in species composition between upland and lowland rice. *Nephotettix* species dominated. The most prevalent species, accounting for 90-95% of the sweep net samples, were *N. virescens, N. nigropictus, Nilaparvata lugens, Sogatella furcifera, Cofana spectra,* and *Recilia dorsalis.* Their populations were higher in the lowlands. Katanyukul and Chandaratat (70) monitored hopper numbers in upland and lowland fields of northern Thailand with a sweep net and found similar results.

The smaller brown planthopper *Laodelphax striatellus* occurs in upland rice in Japan (9). It is an important vector of black-streaked dwarf and stripe viruses between winter wheat and barley to lowland rice. Early planting of lowland rice nurseries has encouraged the spread of these viruses but upland rice has remained uninfected.

In Latin America, *Sogatodes oryzicola* transmits hoja blanca virus disease but are rare in upland rice, except in favored upland areas of Colombia, Peru, and Venezuela (24).

Spittle bugs

Cercopid nymphs produce a protective frothy covering that looks like saliva. In Latin America, spittle bugs are important pests of upland rice. In parts of Brazil where upland rice fields are surrounded by pastures, severe damage occurs from migrating adults when the grasses become unfavorable hosts. An influx of adults can completely hopperburn a young rice crop within a week (112). The adults cause more damage. Nymphal populations rarely attain sufficient abundance to cause damage but their development is favored by regular rainfall (135).

SEED PESTS

Alydid and pentatomid bugs are seed pests of upland rice worldwide. In Asia, species of *Leptocorisa* prevail. The following habits make them particularly suitable as upland rice pests:

1) they feed on many grasses (therefore, can survive the early wet season before rice sets its grain);
2) adults are long-lived and mobile, behaviors that allow them to find isolated plantings of rice (besides seed bugs only birds and rats have this capability); and
3) adults aestivate in forested areas during the dry season when neither rice nor grassy weeds are present (115).

Rice seed bugs become concentrated on small upland rice fields, which they can actively search out. The prevalence of groves of trees, characteristic of upland environments, ensures nearby aestivation sites, keeping the seed bugs close at hand.

The lowlands of Asia are dominated by *L. oratorius,* which lays its eggs high on the foliage (115). *L. acuta* and *L. solomonensis* oviposit at ground level, the former on litter and the latter loose on the ground. These egg-laying habits explain their environmental preferences (125). In Japan, the postdiapause adults of *L. chinensis* migrate from mountainous areas to upland rice fields during the flowering stage (67).

Other pest species feed on flowers. In Mato Grosso, Brazil, and in Santa Cruz, Bolivia, the panicle weevil *Neobradia amplitaris* attacks upland rice at flowering (39, 135). The larvae are rice stem borers and the adults cause more damage by feeding at the base of spikelets, causing empty grains. Also in Latin America, the adult and nymph cydnid *Alkindus atratus* is a seed bug.

LIFE HISTORY STRATEGIES

Oryza sativa has a low tolerance for moisture stress; consequently upland rice is highly seasonal, being grown only during the wettest months of the year. This usually means that in a given location rice is present for less than half of the year. The resulting prolonged rice-free fallow poses serious problems of survival to upland rice insects, but they have evolved at least four mechanisms to overcome the cyclical lack of a host: 1) polyphagy, 2) longevity, 3) dormancy, and 4) vagility (dispersal).

Polyphagy

Polyphagy is having hosts of at least two botanical families, oligophagy of more than one genus, and monophagy as only in one genus (22) — in this case. *Oryza.* Most wild rices, however, are aquatic and therefore normally far removed from upland rice habitats, otherwise more would be alternative hosts for upland rice insects.

No doubt because of its limited temporal and spatial existence, upland rice has not favored the evolution of specialist species. There is no highly specialized upland rice pest. Lack of specialization for upland rice supports Chang (25) who shows evidence that upland rice has only been recently cultured by man from the lowlands and thus pests have had little time to fully adapt to the crop.

Most alternative hosts of rice pests are annual grasses, which also are seasonal. Upland rice is also host to the most highly polyphagous species: soil pests, grasshoppers, armyworms, *Heliothis,* and *Nezara viridula.* But rice is not these species' highly preferred host.

The dry season poses a great obstacle to an upland rice insect's survival and only some perennial plant hosts are suitable food during the off season. Polyphagy gives upland rice insects greater chance for survival during the rainy season when plants — both annual and perennial — are actively growing and therefore more nutritious.

Longevity

The ability of an individual insect to live 2-3 mo, without undergoing dormancy, helps such species as root-feeding white grubs (as larvae) and seed-feeding bugs (as adults) survive unfavorable periods. White grubs are not highly fecund and their life history strategy is to improve survival of their limited progeny. Their subterranean habitat hides them from many natural enemies but root tissue is not highly nutritious. Therefore, great quantities must be consumed and a large insect biomass is needed to digest it. Other soil-inhabiting, root-feeding insects have short life cycles as individuals but are more fecund.

Seed pests need greater longevity as adults to locate a host at early ripening to give its relatively sedentary offspring sufficient time to develop. Not many groups of upland rice insects live long in active development. Both polyphagy and longevity only increase survival during the rainy season. Other mechanisms are needed for survival in the dry season.

Dormancy

In the tropics the nonrice season is the dry season, while in temperate areas, the off-season is winter. Many upland rice insects undergo dormancy in the summer (aestivation) or winter (hibernation). Dormancy is simply inactivity and during winters with prolonged temperatures below 10°C, insects find shelter and cease activity. Activity is resumed with warmer temperatures.

Vagility

The ability to disperse, combined with high fecundity or short life cycles, enables some upland rice pests to better exploit this temporary habitat. Armyworms, skippers, and locusts, actively travel hundreds of kilometers in air fronts such as intertropical convergence zones to descend onto upland rice fields far from their breeding grounds (17). Several generations can

build up on alternative hosts in the grass family before rice is planted. These large insects are active fliers. Smaller insects such as thrips, aphids, and planthoppers passively migrate long distances carried by wind.

Stem borers, leaffolders, leafhoppers, cutworms, spittle bugs, leaf beetles, seed bugs, ants, and termites can readily travel tens of kilometers.

The least dispersive species are white grubs, mealybugs, seedling maggots, crickets, weevils, and gall midge.

Each species has evolved a unique set of attributes to enable it to survive and adapt to the changing upland environments. There are a number of possible evolutionary avenues to fitness and there is no reason to believe one set of attributes is better than another (131).

Other important characteristics of upland rice environments that affect insects are drought, area planted, and yield.

DROUGHT

Well-drained rainfed upland soils are subject to drought if rains do not occur within 2-3 wk. Prolonged drought followed by favorable rains stimulates armyworm and locust outbreaks but mealybugs, root aphids, and thrips become numerous only after short dry spells.

Two reasons favor the increase of mealybugs, aphids, and thrips.

- Heavy rain normally kills soft-bodied, foliage-feeding thrips and mealybugs, and soil-inhabiting root aphids and root mealybugs. An absence of rainfall eliminates this abiotic density-independent mortality effect.
- The rice plant responds to drought by breaking down proteins into soluble nitrogenous compounds that enter the phloem and are taken up by these sap-feeding insects (140). Greater nutrition, therefore, leads to greater fecundity.

SMALL RICE AREA

Except in highly mechanized, large land holdings of Latin America, upland rice fields typically are randomly dispersed in a mosaic of patches within a highly diverse flora. The small field sizes result in larger field borders than is in lowland rice. Upland rice fields themselves may be intercropped with cereals, legumes, or root crops. Mixed intercropping with a wide variety of species also occurs in tribal slash-and-bum agriculture (30, 44).

Some insect pests are favored by small fields. Some ant species for example, thus, can forage from more permanent field borders. Trees provide food and mating sites for white grubs (80) as well as aestivation sites for *Leptocorisa* spp. (115). Although all these factors appear to favor insect pest buildup, the contrary is actually true. Loevinsohn (82) showed that insect pest populations respond exponentially with the proportion of land devoted to rice up to about 75% of the area, then the rate of response declines. In most upland rice areas, because the rice crop occupies less than 50% of the area,

the potential for population buildup is low. This relationship may not be true for seed pests, which can actively seek and locate small rice fields.

LOW YIELD POTENTIAL

Most upland rice is grown on low-nutrient and mineral-toxic soils, which when combined with erratic rainfall, make the crop a highly risky crop for the farmer investing in costly soil amendments and land management. Often upland rice is grown far from markets, making inputs even more expensive. Because it is a subsistence crop, farmers will hesitate to invest in costly inputs to raise its yield.

IMPORTANCE OF UPLAND RICE PESTS

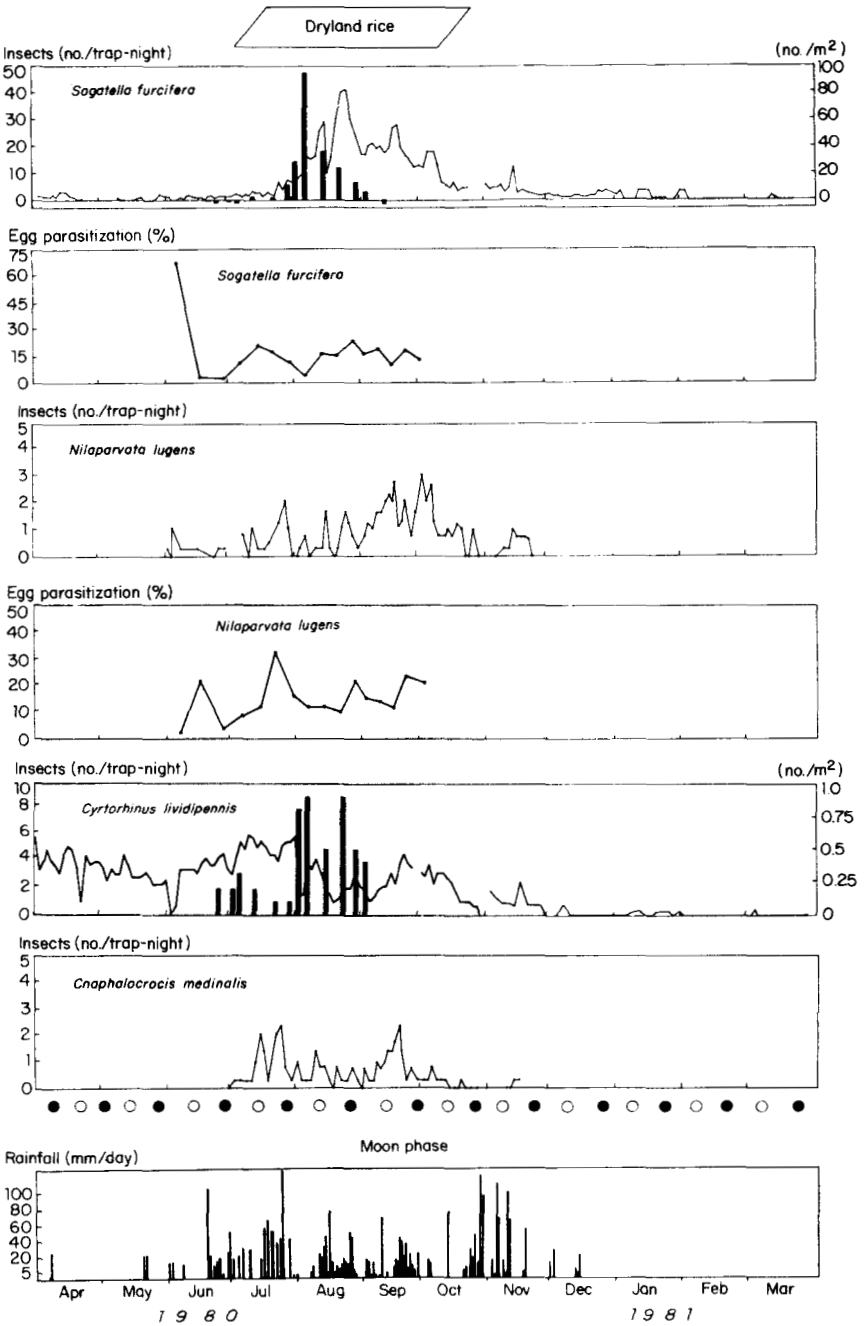
Visits to upland rice fields normally reveal low incidence of insect pests. Loevinsohn (82) and Loevinsohn et al (83) compared insect abundances using annual light trap catches in upland, rainfed lowland, and irrigated lowland sites in the Philippines. Unfortunately, only one upland site was studied, but the data showed that insect abundance in the upland site was less than or equal to that in rainfed lowland sites and lower than that in the irrigated sites.

The seasonal abundance of upland rice insect pests attracted to a light trap was graphed for crop year 1980-81 in Tanauan, Batangas (Fig. 1, 2). The WBPH was the most common rice hopper and its population peaked in the midgrowth stage of the crop as it does in lowland rice.

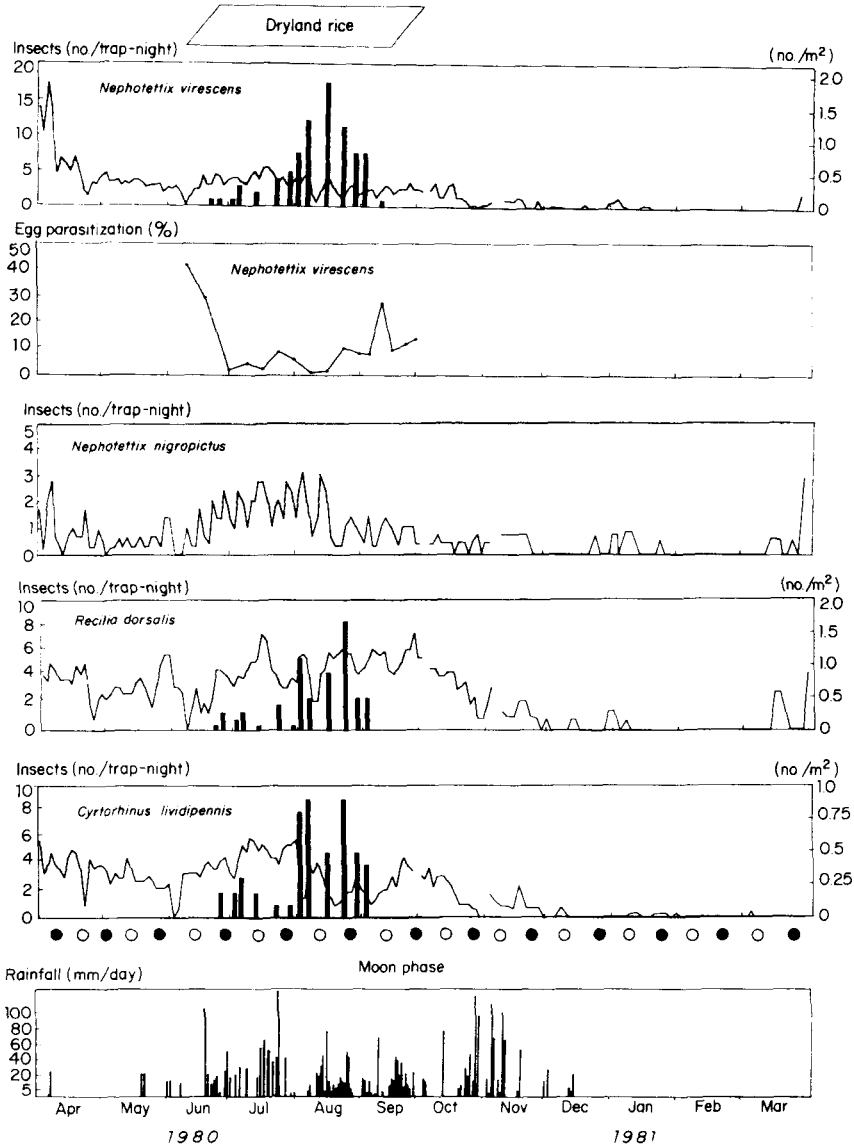
A review of the limited data available on upland rice shows an average of 21% yield loss from insect pests which is on a par with that of lowland rice determined by the same methodology (78).

Recorded yield losses were not related to yield potential (Fig. 3). Although percentages of yield losses of higher yielding crops might have been expected to be higher, they were not. At least two reasons explain the lack of a positive relationship between yield loss and yield potential. One is that insect damage exacerbates plant damage due to drought. The second reason concerns sown-seed pests that would have a greater impact on a low-tillering variety such as Dagge. Low-tillering varieties cannot fill in the space created by removal of seeds; however, UPRi5 is high yielding because it tillers actively and can close the canopy to provide an additional benefit of greater weed control.

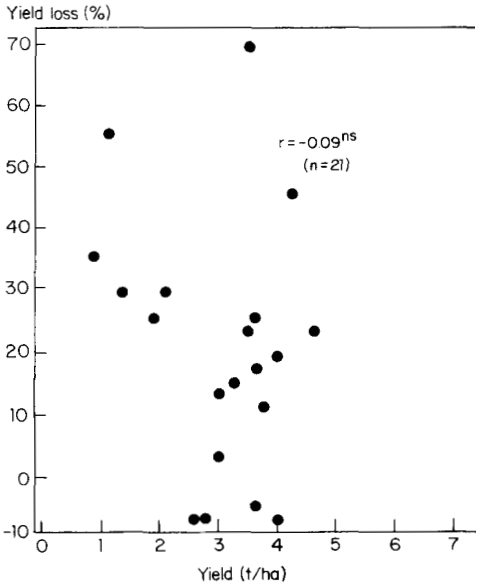
Insect complexes responsible for vegetative-stage yield losses in upland rice are entirely different from those in lowland rice. The key vegetative-stage pests in lowland rice are aquatic while those in upland rice are sown-seed (sown in soil), root, and seedling pests. The differences between the major pests of the two environments may explain why agriculturalists have overlooked the importance of upland rice insect pests. Many reports of upland rice pests in Asia have focused on major lowland species (27, 65).



1. Seasonal abundance measured by light trap and D-VAC suction sampler of whitebacked planthopper *Sogatella furcifera,* brown planthopper *Nilaparvata lugens,* and leaffolder *Cnaphalocrocis medinalis,* and planthopper egg parasites and mirid predator *Cyrtorhinus lividipennis* set against cropping pattern, daily rainfall, and moon phase. Tanauan, Batangas, 1980–81.



2. Seasonal abundance measured by light trap and D-Vac suction sampler of green leafhoppers *Nephotettix virescens* and. *P. nigropictus* and zigzag leafhopper *Recilia dorsalis,* their egg parasites and mirid predator *Cyrtorhinus lividipennis* set against cropping pattern, daily rainfall, and moon phase. Tanauan, Batangas, 1980-81.



3. Correlation between upland rice yield and yield loss caused by insects measured in 21 trials in the Philippines, Ivory Coast, and Brazil.

Measuring yield losses in upland rice environments is further complicated by a report from Brazil that yield losses that occurred in response to better insect control were greater. Treating seed with insecticide resulted in denser plant stands, which in turn created a more favorable environment for blast (40). This result was particularly exacerbated by use of carbofuran granules in seed furrows. The use of carbofuran may not only have increased plant stand but also augmented the level of N fertilizer, which in turn stimulated blast. In response it would be recommended to replace carbofuran with another insecticide or decrease the seeding and fertilizer rate, or both.

Other methods used to determine the impact of upland rice pests were to interview farmers or to develop single species correlations of population levels and yield loss. Ferreira (37) did both in Brazil. Most (75%) of Goias farmers reported insect losses in upland rice and 25% said those losses averaged 37%. This result is consistent with the yield losses measured by field trials in the same state. A 1% yield loss is predicted for every 10% of seedlings removed by leaf-cutting ants. Similarly, Ferreira (37) found that an average of 5.3% thrips/panicle before extension means 3 times more unfilled grains.

CONTROL

Cultural control

Cultural control practices should be considered first in a pest management program because they are broad spectrum and stable in their effect, pests having minimal capability to overcome them through selection of biotypes (82). On the other hand, some cultural control methods work only with the

high labor or power inputs and community-wide methods require coordination of many farmers — often difficult to accomplish.

Field level

Planting time. Shifting time of planting upland rice is open only to farmers in areas with a prolonged rainfall pattern, low cropping intensity, or mechanized land preparation. Generally speaking, any effort to plant as soon as possible with the beginning of the rainy season will result in lower populations of most insect pests.

Tillage. Light-textured upland rice soils can be plowed during the dry season to gain time so the crop can be planted with the first monsoon rains and to desiccate soil insects and weeds such as nutsedge. However, because most soil insects are below the plow layer, they are only slightly affected by dry-season plowing. Plowing when the soil is wet from the first monsoon rains will expose soil insects to predatory birds, chickens, dogs, and even man (field crickets, mole crickets, and white grubs are delicacies in traditional diets).

The greatest degree of insect control from tillage, however, will come from plowing soon after rice harvest. At this time, most soil insects are near the soil surface and other species such as stem borers are in the rice stubble. At rice harvest, white grubs are mature and tillage exposes them to predators. Timely control will protect the crop following rice and lower the population for succeeding years. Plowing under rice stubble aids its decomposition, killing larvae inside.

Frequent tillage destroys ant nests but has little effect on termites. Tillage and clean culture, however, remove food for termites, which then may attack a young rice crop. Scarab beetles also prefer to oviposit in recently tilled fields. No-tillage rice culture such as dibbling favors the survival of soil insects and those insects that pupate or lay eggs in the soil.

Planting method. Planting in furrows or broadcasting seed over the whole field is preferred to dibbling in hills to lessen the impact of soil insects. Often in dibbling the seed is not covered and is easily found by foraging insects, rodents, and birds.

Plant density. Increasing seed density protects the crop against seed and seedling pests, particularly if the crop germinates and emerges quickly. The beneficial effect of increasing the amount of seed will be negated the longer the seeds remain in a dry soil without emerging. Ants in particular are sufficiently abundant to be able to concentrate on a field and inflict serious seed losses.

Intercropping. Planting rows of companion crops has greater opportunities for upland rice than for lowland rice. In India, rice intercropped with cotton or pigeon pea had lower populations of GLH and WBPH than rice alone (116). Maize and upland taro are common in the Philippines. The change in pest status from intercropping is highly location-specific (79) and the net effect can either be no change, beneficial, or detrimental (109). For example, Batangas farmers intercrop taro in their upland rice fields. The taro

hornworm *Agrius convolvuli,* which normally feeds on taro, will feed on rice plants near the taro. It will not feed on rice when taro is not present in the field. Seed pests probably would be unaffected by intercropping. Seeds of preferred crops would, in any event, have to be protected with insecticide seed treatments. A companion crop planted with rice with greater tolerance for root damage or toxicity may act as a trap crop to root-feeding pests. Intercropping would affect most aerial feeding pests, particularly foliar aphids, leaf beetles, stem borers, and hoppers. On the other hand, intercropping may benefit the companion crop such as maize more than rice (81).

Weeding. Removing weeds is necessary for good crop growth. However, weeding, particularly during the first month after crop establishment, will force pests such as armyworms, which prefer grassy weeds to rice, onto the young crop. Soil insects active at this time will move to the rice crop as removal of weeds by hand will not kill them. Clean culture also may force termites to attack rice. Leaving certain weeds may be the optimal solution (8).

Fertilizer. Increasing rates of nitrogen fertilizer on the rice crop will favor higher populations of planthoppers, leafhoppers, and leaffolders. However, because upland rice yields are low and increased fertilizer levels make the crop susceptible to blast, inducing insect pests with increased fertilizer use will not be a widespread problem. However, in the favorable upland rice areas such as Batangas, the crop has high levels of whitebacked planthopper and rice leaffolder. The recommended method is to split the fertilizer into two or three applications to lessen insect buildup, but Batangas farmers do not apply fertilizer at the vegetative stage because the resulting tall crop easily lodges during even strong winds. Greater crop fertility increases insect survival, size, and fecundity (75, 87, 99). Not all insect species respond equally, however. Increasing rates of N, P, and K increased *Diatraea saccharalis* and *Chaetocnema* flea beetle but reduced thrips (37). Zinc reduced deadheart density from the lesser cornstalk borer.

Flooding. Although most upland rice areas would not have access to water, flooding has been recommended in appropriate areas of Brazil for control of root bugs and white grubs (112).

Crop rotation. Planting a crop after rice harvest will control stem borer and other pests remaining in the stubble if tillage is involved. Tillage to establish another crop will also unearth soil pests. Planting a nongraminaceous crop after rice is recommended for termite control (37). The beneficial effect of crop rotation to break crop cycles in upland rice culture is less than that in the lowlands because a crop-free period is assured in most rainfed upland rice areas, even after harvest of crops following rice.

Mulching. Vinyl plastic mulching designed for weed control in upland rice in Japan resulted in an unusually high infestation of *Chilo suppressalis* (59, 60, 61). Mulched upland rice grew more luxuriantly and attracted more ovipositing moths than unmulched rice. The rice and stem borers matured more quickly than in unmulched rice and a partial generation of young instars overwintered in the mulched rice stubble.

Community level

Early-maturing varieties. An early-maturing crop will minimize the number of pest generations that can build up. Rapid crop establishment with onset of the rainy season coupled with an early maturing variety will lessen white grub and stem borer damage in particular. White grubs are particularly destructive and stem borers build up in numbers slowly in a rice crop but can become quite abundant and cause whiteheads on a late-maturing crop. An early-maturing variety lessens the vegetative period and its impact is greatest against pests, which multiply over all growth stages.

Synchronous planting. Insects feeding on the aerial portions of rice plants disperse from an early- to a late-planted field. Insect pest buildup is favored in areas with staggered planting in neighboring farms.

Therefore, combinations of cultural practices — early planting, synchronous planting, crop rotation, and early-maturing varieties — give the greatest control of insect pests.

PLANT RESISTANCE

Root pests are normally costly to control with insecticides but resistant sources may be difficult to find. Painter (101), however, cites examples of varieties of crops tolerant of or resistant to root pests. Chinch bugs *Blissus leucopterus* and white grubs are the most relevant examples for upland rice. But because there are sorghum varieties that are high in cyanide, chemical resistance might be incorporated into rice if it can be crossed with sorghum.

The rice seedling maggot *Atherigona* spp. might be controlled through resistant varieties. A large breeding effort on a related species *Atherigona soccata* on sorghum has had fair success in developing resistant varieties (144). In a field trial, 10 upland rice varieties showed differences varying from 11 to 40% damaged tillers (127). A problem, however, may be that because there is a complex of *Atherigona* species, resistance to one species may not cross over to the others.

Stem borers are the main targets of breeders in Africa, but much of the screening is done under lowland conditions (7, 62, 129). Initial results show that cross resistance exists not only between African species but also with Asian species (58).

The work in Brazil perhaps typifies what is needed to develop insect-resistant upland rice varieties. Screening for insect resistance focuses on local pest problems. Varieties tolerant of *Elasmopalpus lignosellus* and resistant to *Diatraea saccharalis* have been identified (38). These insect pests cause high yield losses and are difficult to control chemically or by other means.

Perhaps the most cosmopolitan of all upland rice pests are the seed pests (ripening stage). Attempts at IRRI to find resistance to *Leptocorisa* rice bug have not been promising. Selecting for morphological characteristics that prevent bugs from feeding faces a number of problems; for example, pentatomids bore through the lemma or palea but hairy seeds or seeds with awns that deter bugs will promote complaints from people who thresh rice.

QUALITY OF NATURAL ENEMIES

Soil pests. Predators appear to be the most important group of natural enemies against social insects, ants, and termites. A number of predator species live in their nests mimicking their appearance and behavior. Introducing a more aggressive ant species to displace ant colonies is a possibility (98).

The nocturnal behavior and subterranean habitat of mole crickets and field crickets protect them from many natural enemies. There are only limited records of natural enemies for these groups of pests, mainly parasites.

White grubs have been serious enough to have been extensively studied for control by natural enemies (66, 84, 85). Scoliid parasites *Campsomeris* spp. have been introduced into the Philippines for control of *Leucopholis irrorata.*

The Japanese beetle in North America has been controlled by the commercially available bacterial preparation *Bacillus popillae* or milky disease (42). Spores sprayed on the soil and plowed under remain active for years.

Root aphids and mealy bugs readily succumb to predators and parasites once their tending ants are controlled. Baits treated with insecticide may be used to control tending ants by killing off their young (139).

Root-feeding bugs, false wireworms, wireworms, and root weevils are normally of such minor importance that the role of natural enemies has not been assessed.

Cutworms have a large number of natural enemies but they colonize the crop soon after land preparation at the beginning of the rainy season when natural enemy populations are low.

Foliar pests. The egg is the key seedling maggot life stage to focus on for natural enemy control by parasites or predators because it is highly exposed. Egg parasites or predators must be introduced from other countries, or if indigenous, be mass produced and released.

A eulophid wasp *Hemiptarsenus* sp. effectively regulates the leaf miner *Pseudonapomyza spicata* on wheat and rice and should be conserved.

Natural enemies of thrips on rice are little known. Normally, predatory thrips prey on herbivorous thrips. Egg parasites could either be introduced from other areas or mass produced and released.

Armyworms are normally held in check by activities of egg and larval parasites. In fact, it is when these natural enemies fail, usually because of drought, that armyworms become epidemic. It may be worthwhile therefore to release parasites during the rainy months following a drought.

Parasites have been traditionally considered for biological control attempts; usually exotic species have been released against stem borers (97). Because this approach has been unsuccessful, new avenues should be explored.

Grasshoppers have egg and nymphal/adult parasites. Among pathogens, protozoans have been recorded most frequently. Locust species would lend themselves to manipulation by natural enemies as work could be concentrated only on their habitual breeding areas.

Leaffolders have rich complexes of natural enemies, some adapted to upland rice (10, 13), ranging from egg predators, larval parasites, larval predators, to larval pathogens. Efforts to augment these natural enemies should focus on the egg predators (rear, release) and viral or fungal pathogens (culture, spray).

Parasitization of the large conspicuous larvae of skippers, greenhorned caterpillars, and other polyphagous lepidoptera by tachinids and chalcids is normally low. Egg parasites and predators perhaps are the key to their control.

Gall midges are parasitized by pteromalids and platygasterids that aestivate within their larval host between seasons. Foliar aphids are preyed upon by coccinellids, syrphids, and chrysophids.

Planthoppers and leafhoppers have egg parasites and predators as well as nymphal or adult parasites and predators. Their rich complex of natural enemies includes fungal pathogens. The principal egg parasites are mymarids and trichogrammatids. Egg predators are normally mirid plant bugs that suck out the yolk. Nymphal/adult parasites are dryinids on planthoppers, pipunculids on leafhoppers, and strepsiptera on both. Spiders dominate the nymphal and adult predators. Spittle bugs move to rice from pasture grasses and, therefore, can be suppressed by biocontrol only if it is carried out before the bugs immigrate to rice fields.

COMPARISON BETWEEN ENVIRONMENTS

Natural enemies perhaps face even greater constraints to survival and reproduction in upland environments than insect pests. They have adapted through their wide host ranges, ability to aestivate or hibernate over unfavorable seasons, ability to disperse, or other mechanisms to survive.

Anagrus optabilis, a mymarid planthopper egg parasite, is equally adapted to all Philippine rice environments. It is selective of planthoppers and even parasitizes the eggs of the maize planthopper *Peregrinus maidis* in upland areas. *Gonatocerus* sp. attacks eggs of green leafhoppers in all rice environments. It is also found parasitizing the eggs of the white rice leafhopper *Cofana spectra.*

Pipunculids are mainly parasitic on leafhopper. Each species has a unique environmental preference. *Tomosvaryella subvirescens* prefers species of *Nephotettix* and *Deltocephalus,* and is strangely most abundant in upland and irrigated lowland environments. *Pipunculus multillatus,* an upland rice parasite, attacks only *Nephotettix* species.

More than 17 recorded species of leaffolder parasites in the Philippines attack species of *Cnaphalocrocis* and *Marasmia.* Among the larval parasites, the braconid *Cardiochiles philippinensis* is most adapted to an upland environment.

Larval parasites of yellow stem borers are highly environment specific. The braconid *Stenobracon nicevellei* occurs only in upland rice but also attacks pink stem borers. *Temelucha philippinensis,* an ichneumonid, occurs in upland rice and also parasitizes the larvae of *Chilo suppressalis. Amauromorpha accepta metathoracica,* like *T. stangli,* is most adapted to the irrigated lowlands.

Predators as a group show more distinct environmental preferences. The nabid *Stenonabis tagalica* occurs only in the uplands and is also prevalent on legumes. The coccinellid lady beetles, wasps, and ants are more prevalent in upland areas. *Icraspis crocea* preys on a variety of aphids attacking legumes and maize. *Eumenes campaniformis,* a vespid mud wasp, makes nests in trees and therefore is most adapted to the more botanically diverse uplands.

Upland environments are habitats to arboreal carabid beetles. Three species of *Chlaenius* beetles prey on leaffolder larvae and are perhaps more important than parasites (13).

The gryllids and tettigoniids are widely adapted egg predators. They occur not only in rice but also on maize and legumes. They feed on eggs of most insects that are laid on leaves. *Conocephalus,* but not *Anaxipha* or *Metioche,* will eat egg masses covered with hair.

The spider community of upland rice environments is rich in species. In one site — Batangas, Philippines — 31 species have been recorded (11). Of the 176 spider species recorded from Philippine rice fields about half (82) also occur in upland rice. The spider species of upland rice environments overlap more with those in rainfed lowland than with those in irrigated lowland rice (12). Of the 10 most prevalent rice field spiders, 9 were abundant in upland rice, showing wide spider environmental adaptation. All three spider guilds — orb-web, space-web, and hunting spiders — were prevalent in upland rice fields.

As in other environments, *Callitrichia formosana* was the most dominant space-web spider, but its relative numbers were lower than for lowland sites. Among hunting spiders, *Oxyopes javanus* and *Lycosa leucostigma* were more abundant and *Lycosa pseudoannulata* less abundant in upland rice environments than in lowland.

Parasites, in general, do not appear highly effective by themselves against upland or even lowland pests. Among the various groups of natural enemies, parasites have attracted the most attention because they can be more readily assessed.

Predators and pathogens lend themselves better to management practices. Predators are probably the most important group of natural enemies acting in rice fields but are difficult to quantify. Pathogens on the other hand, are not important in the field but can be readily cultured and applied.

The natural enemy community of upland rice is rich in species and differs significantly from that of lowland rice. To the greatest degree possible, these beneficial organisms should be conserved by applying insecticides judiciously, particularly sprays. Seed or soil placement of chemicals minimizes exposure to natural enemies. The strategy to derive the greatest benefit from

the activity of natural enemies is to allow the greatest number of beneficial species to thrive. The abundance of each species is highly dynamic within and between years. Conserving the greatest number of species increases the probability that at least one species will be effective against each potential pest at any given time.

Programs to introduce exotic species or mass produce indigenous ones are more ambitious and expensive because trained people are needed to carry them out on a sustained basis.

CHEMICAL CONTROL

Insecticides offer rapid and efficient control of insect pests and should be used only after other control measures have been considered. Insecticides are not used on most upland rice fields because of cost (18); upland yields normally are too low to justify the expenditure. Also most upland rice is grown as a subsistence crop and cash inputs are not considered alternatives as they would be for cash crops.

However, insecticide usage has been justified when a crop is threatened by epidemics of locusts or armyworms. New technology stressing greater efficiency has minimized insecticide cost.

Seed treatment is normally inexpensive and can be economically justified in many cases (37). Treating seed with systemic insecticide (126) but not chlorinated hydrocarbons (142) is the most effective way to control seedling maggots. Foliar sprays must be repeated to obtain control and often are washed off by frequent early-season rains. Granular insecticides are effective but normally the required dosages are too expensive to justify except under heavy infestation (142).

Seed treatment is also effective against ants and may be cheaper than increasing the seeding rate.

Baits can be an inexpensive way of controlling ants, mole crickets, and field crickets. Made of locally available material, baits impregnated with insecticide can be sparingly distributed, taking advantage of the pests' ability to disperse and encounter bait sites.

The new models of low-volume, hand-held, controlled-droplet sprayers may offer an advantage over high-volume knapsack sprayers for controlling foliar pests. Canopies in upland rice are more open than those in lowland rice and better droplet penetration should result. Controlled droplet applicators would be ideal for seedbugs and defoliators.

CONCLUSION

Upland rice is attacked by a wider array of insect pests than are prevalent in lowland rice, mainly because of the addition of soil pests.

Yield losses from insect pests in upland rice often are comparable with those of lowland rainfed or irrigated rice (0-30%), but usually from different groups of pests. The principal pest groups are, foremost, the soil pests

feeding on sown seed and roots, followed by seedling pests. These groups have largely gone unnoticed, leading researchers to conclude that seed bugs and stem borers are the most important pests. Yield loss trials that pinpoint major pests need to include seed treatments. Granules applied in the furrow may not give adequate protection from many seed pests.

Upland rice has no arthropod specialists. The monophagous pests that occur on upland rice prefer the lowlands where rice evolved. Rice in the uplands exist only because of man, and although lowland rice predates upland rice, there was sufficient evolutionary time for rice specialists to evolve. After all we see evolution at work every time a new BPH biotype evolves or a rice insect develops resistance to the latest insecticide in Japan. Wheat, maize, and sorghum do not have monophagous pests, leading us to conclude that there is no evolutionary advantage for insects to have narrow host ranges in upland graminaceae.

Pests have not only adapted to the uplands by having wider plant host ranges but also by having long life cycles, undergoing dormancy, or being dispersive. Each pest has a unique life history strategy which, under a highly unpredictable environment, is the best strategy. In any given year, some insect species can better exploit upland rice as a food resource. No pest is a serious pest every year on upland rice, because if that were so, evolutionary adaptation would cost more than development.

The low yielding potential of upland rice means not only less quantity and lower quality of food for pests to exploit but also less incentive for farmers to undertake control measures.

The most effective control measures would be early and synchronous planting of early-maturing upland rice varieties to prevent insect pest build-up. Breeding for insect resistance should initially focus on stem borers as they are the most difficult to control by other means. Biocontrol efforts should first stress conservation of natural enemies, but augmentation should focus on predators and pathogens rather than parasites. Efficient chemical control is seed treatment or baits for seed, seedling, and some root pests, and controlled droplet sprayers for spot treatment against foliar pests and seed bugs.

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INTEGRATED WEED MANAGEMENT PRACTICES FOR UPLAND RICE

S. K. DE DATTA, K. MOODY, and S. SANKARAN

Weeds are a major limiting factor of upland rice production in the world. Yield reduction due to unchecked weed growth varies from 40 to 85% (48) but with severe weed competition complete loss is possible (17, 66). Weed management in upland rice involves the use of more than one method to minimize damage. Effective control measures are integrated and applied with consideration for economic, ecological, and sociological consequences (21). This paper deals with some technologies for controlling weeds in upland rice and how integrated weed management (IWM) is successfully accomplished.

TECHNOLOGY FOR CONTROLLING WEEDS IN UPLAND RICE

Preventive measures

Some measures to prevent weeds from setting seeds or becoming established in upland rice are: use of weed-free crop seeds, clean equipment, and prevention of soil runoff to check the spread of weed seeds.

Tillage and crop establishment

Methods of seedbed preparation. Preparation of seedbeds is one of the indirect methods of weed control. Moody (50) noted that disc plowing followed by disc or spike-tooth harrowing gave a suitable seedbed for upland rice establishment. Soil should be left as loose and uncompacted as possible because weed seed germination is favored by a firm compacted seedbed. A rough seedbed is also desirable in many tropical areas because this greatly reduces structural breakdown under highly erosive rains.

Thorough land preparation reduces the weed problem in dry seeded rice (60). In China, intense land preparation by rototilling and maintaining the field as clean fallow during the dry season are two successful methods of weed control in upland rice (86). However, negligible areas are devoted to

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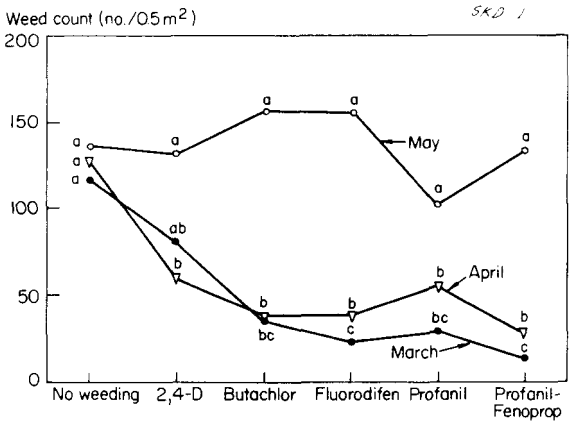
upland rice in China. At IRRI, Lopez et al (39) reported that increasing the number of rototillings reduced the weed population and biomass and weeding time.

Effect of deep tillage. Use of deep plowing as an effective method of weed control has been reported for upland rice. Uichanco (81) reported increased tillering, plant height and yield, and better weed control with deep plowing of 20–25 cm. Curfs (12) found less weed growth on soils that were plowed deep and rotovated with a high-powered tractor than those that were shallow-plowed or zero-tilled. Pande and Bhan (62) also showed the effectiveness of deep tillage (28 cm) in reducing the weed population and dry matter significantly, compared with tillage at 7-, 14- and 21-cm soil depths.

Effect of the stale seedbed technique. Another approach to weed control is the stale seedbed technique. After land preparation, weeds that emerge following rain are destroyed by chemicals such as paraquat (1-1'-dimethyl-4-4'-bipyridilium ion) or by cultivation. The rice is then seeded with minimum soil disturbance. Later weedings may be reduced or delayed using this method (66). According to Uichanco (81) the usual practice in the Philippines is to allow weed seeds to germinate after the last plowing before harrowing the field, a practice which reduces the amount of labor required for weed control. The use of the stale seedbed technique at IRRI resulted in weed weight reduction but rice yields were not significantly different between weeded and unweeded plots (30). Castin and Moody (8) reported that easier-to-control broadleaf weeds were predominant in stale seedbed plots compared to the conventionally prepared and zero-tilled plots. When herbicides were applied for postplant weed control, significantly higher yields were obtained from stale seedbed plots than from the plots prepared conventionally and zero-tilled. However, in a subsequent study (5) they observed that eliminating a particular weed species or a group of weed species resulted in the buildup of other weed species.

Effect of reduced tillage. Results with minimal and zero tillage techniques in upland rice in the tropics have not been consistent. Wijewardene (1986) reported successful establishment of upland rice with zero tillage in Nigeria. Zero tillage failed to control weeds successfully in upland rice in the Philippines (56). Lacsina (37) found that rice crops in reduced-tillage plots that were treated with a herbicide failed to produce any yield because of heavy weed infestation, whereas conventionally tilled plots that were weeded twice yielded between 1.0 and 2.4 t/ha. Lack of success with reduced tillage techniques has been attributed to the rapid regeneration of perennial weeds and failure of herbicides to control them (8, 53).

Time of seedbed preparation and weed emergence. Upland rice cultivation at different periods of the year influences weed emergence, degree of infestation, and dominance of a weed species in a community (32). Studies at IRRI during the 1979 wet season by Castin and Moody (6) showed populations on land prepared during May were higher than on land prepared in March or April irrespective of weed control treatment (Fig. 1). Plowing immediately after harvest of the previous crop at the end of the wet



1. Weed count (no./0.5 m²) 2 wk after emergence as affected by the time of land preparation and weed control methods used. IRRI, 1979 (7).

season when the soil is still moist may be more advantageous than preparing the land at the beginning of the rainy season. Repeated tillage during the fallow period prevents weeds from seeding and exposes vegetative propagules to drying, besides improving soil moisture conservation (9).

Off-season management of upland rice fields. Keeping rice fields as weedy fallows in the off-season creates difficult weed problems when the rice crop is grown the following rainy season. Postharvest tillage of upland rice fields was suggested by Moody and Mian (56) to prevent weeds from seeding and to expose underground rhizomatous organs to drying so that a significant reduction is achieved in weed seed reserves in the soil. Dry season tillage is also reported to be effective for upland rice weed control in the Philippines (77), China (87), and Indonesia (65). Castin and Moody (8) observed that weekly harrowings in the dry season gave good tilth and it was also conducive to better rice seed emergence and weed growth. However, the efficiency of herbicides and grain yields were better in the plots that received repeated harrowings compared with plots kept as weedy fallows.

Blind cultivation. Cultivation after rice is sown but before the seedlings have emerged is sometimes practiced in upland rice to break the soil crust, to create conditions favorable for rice emergence and stand establishment, and to kill young weed seedlings (74). Shallow cultivation is best. Deep cultivation turns up weed seeds that have been dormant at greater depths and thus creates conditions favorable for them to germinate, grow, and compete with the crop. Greater destruction of germinated rice seeds also occurs with deeper cultivation.

Crop competition methods

The choice of cultivar, seed rate, seeding method, and row spacing are some factors that influence weed incidence in upland rice fields.

Row seeding and weed control. Tosh et a1 (81) showed that seeding rice in rows resulted in higher plant population, lower weed dry matter accumulation, and higher grain yield than did broadcast seeding. Merlier (46)

observed that maintaining optimum plant density with high seed rate helped in suppressing the vigorously growing weeds in the early stages of plant growth.

Effect of cultivars on weed growth. Moody and Mukhopadhyay (57) suggested that rice cultivars that emerge rapidly have high seedling vigor, rapidly develop canopy, and compete more successfully with weeds than cultivars lacking these characteristics. However, studies by Lopez et al (40) show that rice cultivar types had no effect on weed control as they did not influence either weed population or weed dry weight.

Little has been done on utilization of genetic variability, inherent with specific rice cultivars, as a means of enhancing the competitiveness of upland rice with the weed flora. Intensive research in this area will provide a viable means of enhancing the IWM concept.

Cropping systems and weed control. Growing the same crop of dry seeded rice continuously on the same land tends to increase a particular group of weeds. Suitable rotation of crops reduces infestation of weeds (34). Castin et a1 (10) found that planting maize or mungbean during the dry season resulted in less weed growth, reduced weeding time, increased herbicide performance, and increased rice yields in the subsequent season compared with plots previously maintained weed-free or as weedy fallow.

The frequency and intensity of weeding operations in a rice-based cropping system also influence the weed growth and competition with rice. Navarez et a1 (60) studied the changes in weed population brought about by weed control practices used continuously in an upland rice-mungbean cropping pattern at IRRI Farm. The population of dominant annual itch grass (*Rottboellia exaltata* L. f.) was considerably reduced in the third year of cropping when the plot was kept weed-free by 3 hand weedings in rice and 2 hand weedings in mungbean during the first 2 yr. Reduction in the weedings from three to two and to one brought less control of the predominant weed.

Merlier (47) reported that regular use of herbicides on rice and other crops, as well as soil maintenance between two cropping periods, greatly reduced the weed infestation in upland rice fields.

The interrelationship of row spacing, seeding rate, and canopy influence on crop-weed relationships has been investigated in a limited way in upland rice systems. There is evidence that these factors can be successfully manipulated to give a competitive advantage for the rice crop, often at the expense of the weed flora. Judicious manipulation of these factors can be a highly effective component of an IWM system.

Fertilizer management on weed control

Among plant nutrient elements required for both the rice and weeds, N is the most important. The extent of competition due to weeds differs with the time and method of fertilizer application.

Time of N application. Moody (53) observed that fertilizer application to rice should be timed to prevent weed proliferation and yet obtain maximum benefit for the crop. Matsunaka (42) recommended that in situations where

effective weed control is not possible, N application should be delayed until the quantity of N uptake is reduced and more will be taken up by the competing crop. Ahmed and Moody (2) found that a delay in N application until the first weeding resulted in reduced initial weed growth and increased grain yield. However, Riyanto (69) reported that varying the date and time of N application had no effect on the weed biomass. Yield reductions due to weeds ranged from 71 to 80% whether all the fertilizer was applied before planting or split applications were used.

Method of N application. Method of nitrogen placement has been reported to influence weed growth to a great extent. Noguchi and Nakayama (62) found that weeds grew better within the crop rows than between crop rows when fertilizer was band-placed in the rows but better between rows when the fertilizer was broadcast. The growth of certain weeds was better when fertilizer was broadcast than when band-placed.

Rate of N application. The rate of N application to a rice crop has a significant influence on competition for nutrients. It is better to apply fertilizer at some lower rate than needed to produce maximum yields when weed control is inadequate (14). Greater yield losses due to weeds have been observed at low and high rates of applied N than at intermediate levels (36, 64, 68). At low N levels, plants compete first for N and later for light whereas with an adequate supply of N, plants compete primarily for light (35, 36). In the absence of weeds, as the rate of fertilizer application increased, rice yield also increased (20). A similar trend in rice yield was generally maintained even in the presence of weeds. However, the extent of increase was higher in weeded plots than in a weedy check. In most cases, grain yield of nonweeded fertilized plots was considerably lower than that of weeded plots to which no fertilizer had been added (14, 52). It appears that manipulating N application in upland rice offers the most potential in the IWM system. However, it requires a high level of management in matching it to the specific needs of upland rice, weed problems, soil conditions, and other weed management techniques.

Manual and mechanical weed control methods

Manual and mechanical weed control methods include hand weeding, use of mechanical weeders, intercultivators, and mulching materials. Among these, hand weeding is the most widely used traditional method of weed control in upland rice.

Hand weeding. One hand weeding, no matter how properly timed, will not provide season-long weed control in upland rice (67). When upland rice fields are moderately infested with weeds, two weedings, one at the third and the second at the fifth week after sowing, are generally sufficient. However, when weed growth is severe 3 weedings during the first 8 wk of crop growth may be required for satisfactory control (55). Several workers have reported hand weeding is more efficient compared with other methods of weed control (21, 27, 70). Although hand weeding is the best method of weed control, it is tedious and time-consuming (3, 19) and requires much labor

(19, 58). Further, by the time hand weeding is undertaken the weeds have competed with the crop and reduced yields (11).

Hoe weeding. Among types of mechanical tools available, hoes are faster and more efficient (13), and hoeing can be done at an earlier stage of rice growth (50). However, hoes are suitable only for small farms. More time is needed for their use (13) than for other mechanical weeders, and they can be used only in drilled rice, not in a broadcast-seeded crop.

Interrow cultivators. When row spacing of dry seeded rice is sufficiently wide, interrow cultivation by horse-drawn implements has been successful in Fiji (66). However, attempts to use animal-drawn equipment have not succeeded in Malagasy Republic (39), Ivory Coast (67), and in Nigeria (27). Uprooting of or severe damage to the rice plants occurred when intercultivation was too near the rice row. Thus, weeds within and near the rows, which are the most deleterious with regard to weed competition, are not controlled (50). At IRRI, Singh et al (75) showed that interrow cultivation followed by a light hand weeding in the crop rows was better than the conventional labor-intensive hand weedings.

Herbicide technology

Experiments at IRRI show that chemical weed control in upland rice is not only possible but also effective and economical (18). It is the only method of weed control suitable for large-scale rice production (50).

Herbicides for upland rice. The hormonal herbicides 2,4-D (2,4-dichlorophenoxy acetic acid) and MCPA (4-chloro-2-methylphenoxy acetic acid) are the most widely used in upland rice in several countries. Sanchez and Nurena (72) reported that these herbicides were highly effective in controlling broadleaf weeds that emerged immediately after clearing the forest for upland rice production. These postemergence herbicides have shown good performance in India (4), Fiji (11), Philippines (44), and Indonesia (70) at rates ranging from 2 to 4 kg/ha.

Preemergence butachlor (N-butoxy-methyl-a chloro-2’,6’-diethyl-acetanilide) at 2 kg/ha is reported to give effective weed control in upland rice (15, 59, 79, 83) but it caused phytotoxicity when the chemical was applied soon after seeding (28).

Preemergence thiobencarb (S-4-chlorobenzyl diethylthiocarbamate) at rates ranging from 1.5 to 2.5 kg/ha is reported to be as good as 2 hand weedings in upland rice (24, 71, 83).

Oxadiazon (5-tert-butyl-3 (2,4-dichloro-5-isopropoxyphenyl)-1,3-4-oxadiazol-2-one) has performed well in upland rice at 1 to 3 kg/ha (30, 41, 47).

Postemergence application of propanil (3’4’-dichlorophenylpropionanilide) at rates ranging from 3 to 4 kg/ha gave effective weed control in India (79), Philippines (45), Nigeria (28), and tropical Africa (83). However, a single application of propanil gives inadequate weed control in upland rice (3, 18, 51). Sequential treatments made at 3-wk intervals in fields infested with grasses are likely to give better results but such treatments might not be economical (43).

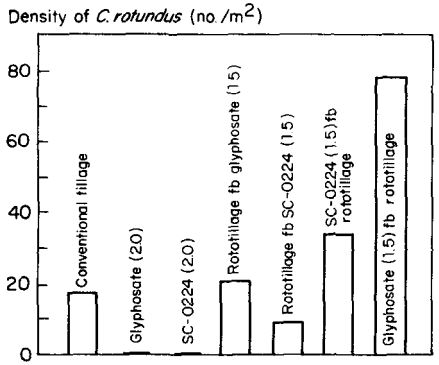
Herbicide combinations and mixtures. The best weed control in rice is obtained with sequential application or herbicide mixture because they increase the weed control spectrum. Propanil mixed with either 2,4-D or MCPA is reported to give excellent weed control (44, 67, 83). Some of the other useful mixtures with propanil are thiobencarb (41, 47), fluorodifen (4-nitrophenyl 2-nitro-4-trifluoromethyl-phenyl ether) (47, 51, 85); bentazon [3-isopropyl-1*H*-2, l,3-benzothiadiazin-4 (3H)-one 2,2-dioxide] (47, 83), oxadiazon (47), and butachlor (27, 51, 85). One disadvantage of these treatments is that if rain falls soon after application, weed control will be poor. Merlier (47) noted that repeat applications are needed if rain falls within 5-6 h after treatment.

Improved application technique. Method of herbicide application substantially affects herbicide efficiency. IRRI (30) reported the degree of weed control achieved with oxadiazon, pendimethalin, and butachlor differed only slightly regardless of application method, with controlled droplet applicator or boom sprayer. However, in another study at IRRI, the Birky (low-volume pneumatic sprayer), the Micronherbi (a battery-operated ultralow-volume spinning disc applicator), and the single-nozzle knapsack sprayer performed similarly. However, only the Birky performed significantly better than the conventional knapsack sprayer with boom (32). Merlier (47) noted that with the increasing use of low-volume sprayers, which are rapidly replacing other types of equipment in West Africa, synthetic phytohormones such as 2,4-D have been abandoned for rice because low-volume spraying makes them highly phytotoxic.

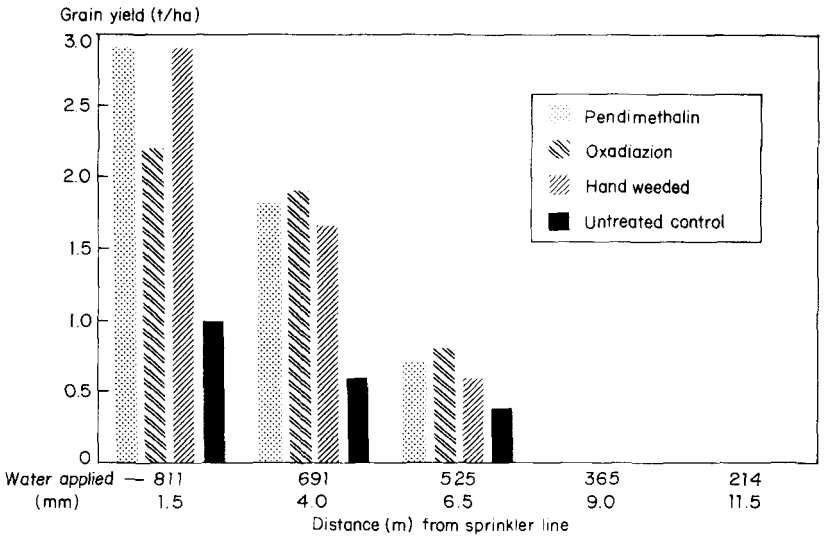
Control of problem weeds in upland rice. Cyperus rotundus L. is one of the most difficult to control weeds in upland rice throughout the world. Applying 1.0 kg 2,4-D/ha 20 days after emergence (DE) of rice in plots with different preplant weed control treatments (preplant application of either 2 kg glyphosate or the coded herbicide SC-0224 per hectare) gave complete control of the weed (Fig. 2).

Rottboellia exaltata is potentially a dominant grass weed in upland rice. A tank-mix application of pendimethalin and fluazifop-butyl (1.0 + 0.08 kg ai/ha) 12 DE provided excellent *R. exaltata* control and significantly increased rice yield compared with the untreated and hand-weeded checks or a single application of either herbicide (32).

Soil moisture-herbicide relationship. Soil moisture status governs the success of chemical weed control in upland rice. At IRRI, Sankaran and De Datta (73) used a line source sprinkler system to regulate soil moisture while evaluating the effectiveness of pendimethalin and oxadiazon. With both herbicides, IR36 yields were similar to those of the hand-weeded check at high moisture levels (811 and 691 mm). But when moisture dropped below cumulative pan evaporation (668 mm), yields with chemical and hand weeding were similar to those in the unweeded check (Fig. 3). Below the 525 mm water application, there was no grain yield although herbicide and hand weeding effectively controlled weeds. Results indicate that herbicide application is wasteful unless adequate water is available for crop growth.



2. Effect of herbicides and their combination with cultivation on the control of *Cyprus rotundus* in upland rice. IRRI, 1973 wet season (32). fb = followed by.



3. Effect of herbicides on grain yield of upland rice (IR36) at different soil moisture regimes (73).

Biological control agents

Little published information is available on biological weed control in upland rice. A study in the United States by Smith (80) showed the usefulness of an endemic fungus *Colletotrichum gloesporioides* Penz. in controlling a leguminous weed *Aeschynomene virginica* L. in a flooded rice field in 5-wk time. Biological agents, however, have the disadvantage of controlling only one specific weed which may be predominant in the crop field. This can lead to a shift in weed flora which may result in new weed management problems. In spite of this limitation, biological control offers an important approach for the future with advantages such as the lack of harmful residues in the crop and in the environment.

INTEGRATED WEED MANAGEMENT

An efficient weed management system *integrates* preventive measures such as land preparation, manual and mechanical weeding, crop rotation, soil and fertilizer management, use of natural enemies, and herbicides (17, 22). The primary objective of integrating control measures is to exert such pressure that growth of the crop is favored over that of the weeds (84). The integrated control system must be compatible with other management practices to increase production, and maintain a quality environment.

In upland rice, integrating weed control methods has proven effective and is suggested by various workers to be the best weed control system (16, 40). This approach can reduce buildup of difficult-to-control perennial weeds caused by the continuous use of the same herbicide, control method, and cropping system (16). Most weed control trials in upland rice have dealt with a single practice without considering other control methods. Only in recent years has a combination of two or more weeding methods been evaluated for controlling weeds in upland rice. Kolhe and Mittra (37) reported that in the integrated approach, a postemergence application of propanil at 20 DAS, followed by hoeing between the rows and hand weeding within rows at 40 DAS, minimized crop-weed competition thereby increasing grain yield significantly.

Combination of control methods

Research results on weed control in upland rice indicate that there is no complete control for all weeds with a single pre- or postemergence herbicide application. An application of a combination of herbicides followed in 3 or 4 wk by hand or hoe weeding gave satisfactory weed control in several countries. A list of successful combination methods of weed control reported is in Table 1.

Propanil, 2,4-D, butachlor, and pendimethalin applications have shown good results when a hand weeding followed herbicide application. All these treatment combinations gave not only satisfactory weed control but also high grain yields compared with the repeated hand-weeded check.

CONCLUSION

The integration of control methods is a desirable development for weed control in upland rice because no single method can satisfactorily solve all weed problems. Significant contributions will result by increasing the knowledge on such aspects of weed science as weed-rice competition, damage and yield losses from weeds, emergence patterns of weed communities, the life cycle of weeds, and the ecological and physiological nature of weeds and cultivar differences in tolerance for herbicide toxicity. Herbicides will continue to be the key components of IWM systems. Therefore, more selective and cost-effective herbicides will be needed to control existing weed problems and newly emerging weed species in upland rice ecosystems.

Table 1. Successful herbicide followed by hand or hoe weeding combinations reported in various upland rice areas of the world.

Treatment[a]	Application		Reference	Country
	Rate[b] (kg ai/ha)	Time[c]		
2,4-D Na salt fb 1 RW	1.0	PS fb 28 DAS	29	Philippines
2,4-D/MCPA fb 1 HW	2.2	PS fb 21 DAS	48	India
2,4-D Na salt fb 1 HW	1.0	PS fb 28 DAS	78	India
Propanil fb 1 hw and HW	2.0	20 fb 40 DAS	37	India
Propanil fb 1 hw	3.0	14 fb 28 DAS	23	Nigeria
Propanil fb 1 HW	3.0	40 fb 35 DAS	21	India
Propanil	3.0	20	15	Philippines
Butachlor fb 1 HW	2.0	PE fb 30 DAS	1	Bangladesh
Butachlor fb 1 HW	2.0	PE fb 35 DAS	76	India
Butachlor fb 1 HW	2.0	PE fb 30 DAS	25	Philippines
Butachlor fb 1 HW	2.0	PE fb 45 DAS	26	India
Butachlor fb 1 HW	2.0	PE fb 40 DAS	12	Philippines
Butachlor fb 1 HW	2.0	PE	15	Philippines
Pendimethalin fb 1 HW	2.0	PE fb 40 DAS	73	Philippines

[a] fb = followed by, HW = hand weeding, hw = hoe weeding, RW = rotary weeding. [b] ai = active ingredient. [c] DAS = days after seeding, PE = preemergence, PS = presowing.

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Preproduction testing and production programs

A. Ecological, social, economic, technical, and training aspects

ECOLOGICAL ISSUES IN PREPRODUCTION TESTING AND PRODUCTION PROGRAMS INVOLVING UPLAND RICE

J. L. McINTOSH

Rice is a key food commodity in upland mixed farming systems in most humid areas within the tropics. This does not mean that upland rice is the main crop in terms of food production or cash returns (Table 1). Upland rice, however, is a key crop in that it provides a desired food commodity, provides a ground cover, and is well adapted for growth during the rainy season. The straw is used for animal forage and bedding and may become a soil amendment by direct incorporation or as a mulch.

It is important that upland rice production be stable and sustainable in upland mixed farming systems. In this paper, experiences with farming systems research and development in Indonesia are used as bases for discussion of ecological issues relevant to wide-scale testing and implementation of national production programs involving upland rice.

FARMING SYSTEMS RESEARCH AND DEVELOPMENT

Many food crop commodities and agricultural enterprises play significant roles in the small-farm economy (Table 1). Past research has developed strategies for year-round crop production. The systems developed are acceptable to farmers and are reasonably stable and sustainable although need to improve soil fertility and conservation practices is continuous. Stability of production of each crop or commodity in the system must be further improved. Recent cropping systems research has focused on deficiencies in food crops production. Furthermore, farming systems scientists working in upland areas view long-run food crop components of the farm systems as primarily for subsistence.

Even under present conditions and constraints, 0.5 ha of land appears adequate to meet this need. Consequently, present and future farming systems research will be directed toward stabilizing production of the principal food crops within the patterns, improving soil fertility and

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Table 1. Analysis of upland rainfed farming systems. Two-hectare farm on infertile red-yellow podzolic soils. [a]

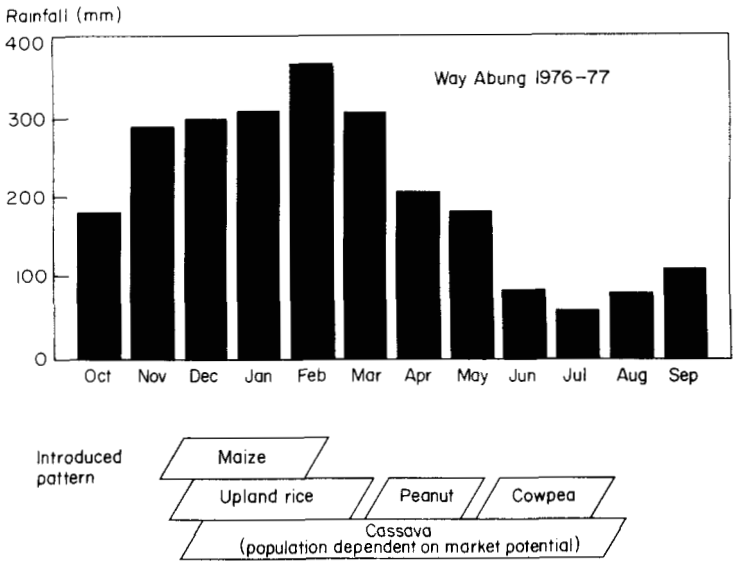
	Present situation without use of new technology			Within 2-5 yr implement and refine existing technology		Within 5-8 yr develop and implement new technology	
	Price[b] (Rp/kg)	Yield (t/ha)	Value[b] (Rp/ha)	Yield (t/ha)	Value[b] (Rp/ha)	Yield (t/ha)	Value[b] (Rp/ha)
Food Crops Production							
Maize +	125	0.4	50,000	1.0	125,000	1.0	125,000
Upland rice +	150	0.8	120,000	1.5	225,000	2.5	370,000
Cassava+	10	1.0	70,000	7.0	70,000	10.0	100,000
Peanut (pod) -	400	0.4	160,000	1.0	400,000	2.0	800,000
Cowpea	200	0.2	40,000	0.4	80,000	0.6	120,000
Total for 1 ha			440,000		900,000		1,520,000
Total for 0.5 ha			220,000		450,000		760,000
Animal Production							
Small ruminant (5 adults)	40,000/ animal	—	—	6	240,000 food	10 units	400,000 food
Poultry (10)	—	—	—	—		–	
					240,000		400,000
Perennial crops [c]							
Rubber (1.5 ha)	800	—	—	0.6	480,000	10	800,000
					720,000		1,200,000
Total gross income	(2.0 ha)		220,000		1,410,000		2,360,000

[a] Source: Upland Rice Research Project Proposal, AARD/IRRI. [b] US$1 = about Rp 415. [c] Credit needed for establishment. Production figures given are for years 5 and 8. respectively.

conservation practices, and increasing cash income through better utilization of land and labor resources. The animal and perennial crops components of the farming systems must be further developed.

Cropping systems

Long-term soil and crop management studies began in 1973 in central Lampung in Sumatra on farmers' fields that had been cultivated for 20 yr. The studies showed that infertile and acid soils (Tropudults pH 4.3), could produce 2-3 t rough rice/ha with moderate rates of fertilizer (70 kg N and 45 kg P_2O_5/ha for the rice crop). A year-round cropping pattern, based on existing farmers' patterns, was designed and tested. This cropping pattern consists of maize plus upland rice intercropped with rows of cassava spaced 2 m apart. After harvest of the maize and rice, a sequence of peanuts followed by rice bean (or cowpea) was interplanted between the rows of cassava (Fig. 1). This pattern (M + ULR + Cv + Pnt - CP) was found much more productive and profitable (Table 2) than a random planting of the same crops as practiced by farmers as well as a sequence of upland rice followed by maize followed by rice bean (ULR - M - Rb).



1. Monthly rainfall distribution and year-round cropping pattern commonly tested on Red-Yellow Podzolic soils. Source: McIntosh et a1 (2).

Table 2. Average yield of crops and approximate net returns for check and full treatment plots. Cropping Systems Research, Bandarjaya, Central Lampung. 1973-74.[a]

Fertility treatment	Dry grain[b] (kg/ha)				Cassava fresh root (t/ha)	Approximate net return (RP/kg)[c]
	Maize	Upland rice	Peanut	Rice bean		
			Mixed cropping			
No lime + no NPK + no mulch	467	690	161	55	12.7	65,000
Lime + NPK + mulch	1,165	1,358	356	248	28.3	132,000
			Intercropping			
No lime + no NPK + no mulch	455	769	222	93	14.6	91,000
Lime + NPK + mulch	1,350	2,724	567	627	23.2	265,000
			Sequential planting			
No lime +no NPK + no mulch	606	850	–	153	–	(-6,000)
Lime + NPK + mulch	2,935	3,536	–	723	–	74,000

[a]Source: McIntosh and Effendi (3). [b]Yields subsequently have varied due to pests and management but have remained basically the same. [c]US$1 = ca. Rp 415.

This same general cropping pattern has been tested in experiment stations and farmers' fields in major upland agricultural areas of Indonesia. Upland farmers almost always grew the first crops in the pattern, upland rice, maize, and cassava, in some arrangement. Sometimes farmers grow legumes in this combination. In areas with short rainy seasons (<4 mo) farmers may not be able to plant and grow legumes after harvest of the maize and rice. This is a

necessary adaptation of the cropping pattern not only for drier regions but also during drought years in the wetter regions. Even under these situations, the cassava will produce some yield and provide food subsistence.

Subsistence

Intuitively farmers develop strategies for food subsistence. This is particularly true where upland rice is a major component of the farming systems. Farming systems research, particularly in newly developed areas, has developed strategies for production of sufficient food to provide the basic food and economic needs of the families. Research concentrates on development of cropping patterns and component technologies to provide stability and sustainability to these food production systems. Certain components of the systems are weak and need strengthening, e.g. the need to know more about soil fertility, fertilizer efficiency, and soil conservation. However, a primary need is to develop crop varieties with yield stability. Present yield potentials are satisfactory but better varietal adaptation to cropping patterns, soil, and climate is needed. Better insect and disease resistance, especially for upland rice, is needed.

The amount of land used for food crops depends upon such things as yields, labor supply, and infrastructure. From work in new transmigration areas in Indonesia, 0.5 ha has been found to supply sufficient food grain and legumes and some surplus to sell. This food source is usually supplemented with vegetable, seed, and fruit products from home gardens. In many instances small ruminants are included in the farm system. Table 1 gives some idea of the production and income that can be derived from these subsistence systems.

Labor becomes a constraining factor for increasing the land area under cultivation. For the subsistence system described, family labor can usually cultivate only about 0.7 ha/yr. Farmers are reluctant to hire labor or add extra power (draft animal or mechanical) because of the costs and risk involved in food crops production. Usually alternative agricultural enterprises or off-farm work opportunities are sought to raise the family income.

Cash economy

Many farmers in upland areas have between 2 and 3 ha of land. Consequently, in these cases farmers have food self-sufficiency and, at the same time, the potential for additional income from other agricultural enterprises. For some farmers this may mean increasing the land area in upland rice and other food crops. Soil productivity and availability of markets are important to farmers in determining the strategy for determining use of land, labor, and capital. The potential for cassava production is great. Marketing constraints can usually be overcome through planning and development of processing facilities. Soybeans can be successfully grown in many places and the long-term market potential appears good. In both these instances soil conservation and fertility constraints affect the sustainability of production of those crops over time.

Perennial crops. Farmers plant perennial crops to provide shade, fuel, fodder, seeds, fruit, exudates, spices, and lumber. Most importantly, these crops increase production and economic stability of the farming system. These plantings are usually random in terms of species as well as arrangement, and more research is needed to develop strategies for better use of the plants that farmers are now using.

Information about varieties, cultural practices, unit production, and price of products is available for many perennial crops. This information must be systematically collected and evaluated, and models must be developed for the best adapted and most economic species that could be grown and the proportions of each that could most effectively be included in a farming system.

Upland rice will also find a use as a cover crop in early stages of these plantations. Periodic rejuvenation by cutting and replanting will be needed. Thus, within a farming system, food crops may be grown alone in a cropping pattern, in combination with perennial crops, and as a cover crop.

Livestock. The range of animals from fish, poultry, and goats to large ruminants offers many options for use of farm resources and increasing farm income. Farmers can quickly develop an enterprise that can convert low-grade forage, fodder, and crop residues into marketable meat products. The larger ruminants offer additional value as sources of milk and power. The species and their relative proportions in a farm system must also be known. An approximation can be made by determining the labor and forage available within the farming system and the labor and feed requirements for each animal unit.

Rural industry. A successful upland agriculture economy is primarily dependent upon stable and marketable production. Special circumstances in tropical upland agriculture reduce production stability. Farms are usually small and rainfall-dependent with erosive and infertile soils. The farm system must be developed but always in conjunction with development of the area in general. A stable upland farm system will likely include off-farm labor as well as nonagricultural but on-farm labor opportunities,

PARTITIONING THE TARGET AREA

Initial national production programs involving lowland rice, such as Masagana 99 and BIMAS, were effective although the recommendations tended to be general.

Commodity-specific recommendations with little regard for local biological and sociological conditions tend to be much less effective for cropping systems involving upland rice than for those involving lowland rice. On the other hand, production programs cannot be developed and adapted for every field situation. Initially, fitting varieties and crop management to some natural soil and climatic conditions with the target area is desirable. Further refinement and local adaptation can follow from field experience.

Categories and cropping patterns

Many classifications have been developed to characterize rice-growing environments. IRRI scientists suggest a simple classification, principally for breeding purposes, for upland rice (1):

- Favorable upland with long growing season (LF).
- Favorable upland with short growing season (SF).
- Unfavorable upland with long growing season (LU).
- Unfavorable upland with short growing season (SU).

For this paper, we may use the classification system proposed by IRRI as a basis for partitioning upland rice-growing areas of a country according to prevailing biological and climatical conditions. Before this, however, the prevailing socioeconomic conditions of the target area must be evaluated to determine the appropriate degree of intervention. In all cases the assumption is that appropriate soil conservation practices will be followed.

Low-input systems (LIS). Production programs and associated technology packages are often unacceptable because farmers either lack the money or the desire to assume risks. Under these conditions, about the only new technologies that farmers can accept are new varieties and soil fertility management practices that involve green manuring and improved crop residue management.

Furthermore, local or locally improved varieties of upland rice will likely be most appropriate. In all cases, upland rice will be one crop component of the whole upland cropping system. Major efforts should be made to increase the cash income and stability through animal and perennial crops production.

I. *LIS - LF*

Upland rice + maize - peanut or maize or greenbeans - cowpea soybean mungbean

II. *LIS - SF*

Upland rice + maize ≠ cassava or pigeon pea or sesame ≠ cowpea

III. *LIS - LU*

Upland rice + maize ≠ cassava ≠ peanut or soybean - cowpea or cover crop

IV. *LIS - SU*

Upland rice + maize ≠ cassava or pigeon pea or sesame ≠ cowpea or cover pea

These low input cropping patterns involving upland rice will require substantial amounts of animal or green manure. The model described in Table 1 may be used to illustrate a procedure to follow where new lands are being opened or other situations where farmers have 2-3 ha of land. The use of 1 ha of land for an interculture of perennial crops and food crops could produce enough food for subsistence and products for cash sale. The perennial crop could be rubber, coconut, oil palm, spice crops, or tree crops for fruit, fuel, or lumber. These kinds of systems fill the needs of the farmer and meet the requirement of being environmentally benign.

Moderate input systems (MIS). Most production programs include recommendations for fertilizer and other inputs especially needed to raise rice yields above 2-3 t/ha. But before these recommendations can be applied, stable, responsive, and high yielding varieties must be developed. Initially modifications of existing local varieties might improve yield potential and stability while new improved varieties are being developed. But in the long-run, a series of varieties with blast and brown planthopper resistance, earlier maturity, and higher yield potential will be needed if upland rice is to remain a major source of food production.

All precautions and efforts to increase cash income and improve stability of the farming systems for low input systems also apply to moderate input systems. It is assumed that these farmers will be more inclined to assume risk and, consequently, will use more fertilizers, pesticides, and other production inputs.

V. *MIS - LF*

Upland rice - peanut or soybean - cowpea

VI. *MIS - SF*

Upland rice - maize ≺ cover crop

Upland rice + maize ≺ pigeon pea or cassava or sesame

VII. *MIS - LU*

Upland rice+ maize ≺ cassava ≺ soybean or peanut

+ means planted with
≺means intercropped with
- means followed by

VIII. *MIS - SU*

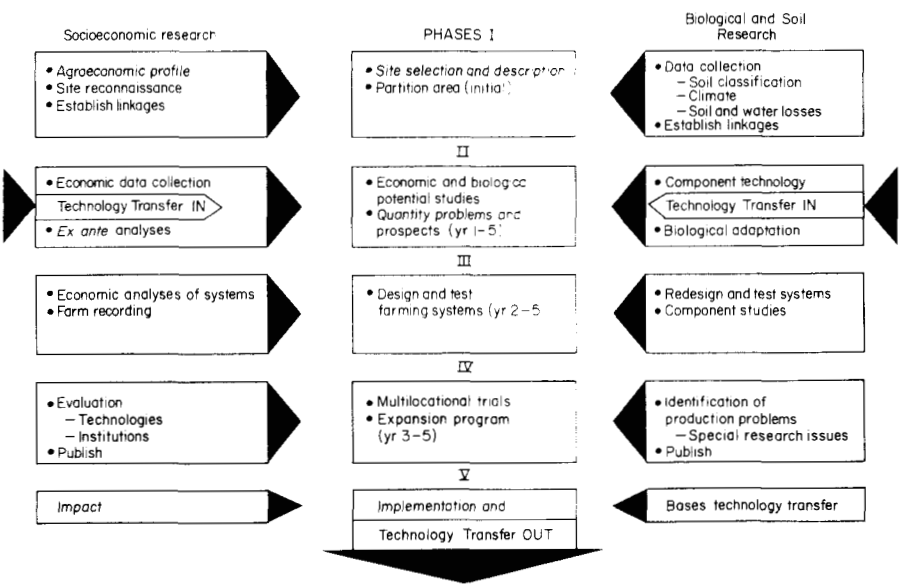
Upland rice + maize → pigeon pea or cassava

Upland rice + maize - peanut or cowpea

Over time, where inputs are available and used, the cropping patterns tend to become more uniform within any climatic or topographic area. Effects of the soil fertility factors are minimized and patterns become stable. Efforts must be made to stabilize the soil through terracing and perhaps developing land-use patterns that involve more tree crops, as in low input systems.

PREPRODUCTION TESTING

Figure 2 shows steps usually followed in conducting a cropping/farming systems research program. Research is done as much as possible under farmer conditions so the technology developed may be relevant not only to the target area in general but also to the specific conditions of the research site. After 2 or 3 yr of component and systems studies, enough technology is



2. Parallel biological and socioeconomic activities required for the 5 distinct research and implementation phases of a farming systems program with little inflow of technology.

usually generated to backstop multilocational trials that may be established to further test the technologies over a wider area. In Indonesia, the Directorate of Food Crops Production conducts verification trials for all new technologies related to food crops production. It routinely carries out interdisciplinary cropping systems verifications trials. Similar organizations do this for the other agricultural commodities. Consequently, a division of responsibilities is based on commodities. This can make integrated and interdisciplinary on-site farming systems preproduction testing difficult.

TECHNOLOGY TRANSFER

Efficient technology transfer is important within the government bureaucracy, from research to extension, or from one site to another within country, region, or throughout the world. The suitability of technology depends upon socioeconomic as well as biological criteria. Simple but effective systems of characterizing the research sites and possible transfer locations are needed. In Indonesia, a simple format characterizes the soil and climatic environments of farming systems research sites. To this is added information concerning institutions, timing, indexing phrases, and an abstract of the research progress for each farming systems research site (Table 3). The usefulness of these descriptions depends upon availability and use of long-term climatic data and soil characterization through an internationally accepted system of classification, such as Soil Taxonomy. The numbers of wet (>200 mm) and dry (<l00 mm) months with some indication of distribution (bimodal, for example), the latitude and elevation and the various kinds of information that may be derived from soil classification provide information to identify prospective target areas for technology transfer. On-site research is still needed to verify and refine the technology.

Table 3. Sample research brief. Cropping/farming systems research sites that have been completed and those that are ongoing, AARD.

Site location	Edaphic condition	Months with rainfall (no.) >200 mm and <100 mm		Most probable soil classification or type	Latitude: Elevation:	Year		Institution
						Started	Stopped	
Bandar Agung and Komering Putih, Central Lampung, Sumatra	Rainfed upland	5	2	Typic Tropudult, clayey, mixed isohyperthermic	4° 40's ± 40 M	1975	1978	CRIFC

Descriptive phrases: Cropping systems, interdisciplinary, integrated and on-farm research; food crops and economic component studies.

These sites are similar in many respects but were intended to represent "old opened" and "newly opened" land, respectively. Newly opened land in the target area is mainly settled by transmigrants from Java while the "old opened" areas are settled by indigenous people. It was not feasible to work with both groups at the same time because of differences in cultures as well as farming systems. Both sites selected were settled by transmigrants but Bandar Agung had been opened for about three years while Komering Putih was newly opened.

Research followed the strategy developed in Indonesia and modified by contacts through the Asian Cropping Systems Working Group. Surveys were conducted in the target and adjacent area to develop an agroeconomic profile. Year-round cropping patterns based on the Farmers Cropping Pattern (FCP). Farmers Cropping Pattern without Constraints (FCP, w/o C), and Introduced Cropping Pattern (ICP) were tested in farmers' fields. Ancillary component technology studies were on weed control, soil fertility, varietal testing, entomology, and farm record keeping. The basic cropping pattern developed in Bandarjaya was found to be acceptable in these areas with some options for flexibility in populations of crop species in the basic pattern of maize plus upland rice intercropped with cassava (after 30 days) and then peanuts followed by cowpea planted between the rows of cassava after harvest of the maize and rice. This pattern is illustrated by C + U LR + Cv + PNT - CP.

Crop yields and net returns were consistent with data from previous trials. Some management techniques and "rules of thumb" for management began to be apparent. These were:

- *Imperata* is not a problem after initial land opening if the food crops are grown in year-round cropping patterns and receive fertilizer.
- Shoot fly (corn), seedling fly (upland rice), and agromyza (legumes) are serious pests and must be controlled. The best control measure was found to be carbofuran applied with seed.
- The soils require phosphorus fertilizer, most effectively applied in the row with seed.
- Neck blast on rice is a major problem. Local varieties less affected. Rates of nitrogen should not exceed 60 kg/ha on susceptible varieties.
- Must use DRM varieties of maize.
- Farmer and family have difficulty cultivating more than 0.5 ha of land when first opened and 0.7 ha later.
- Cassava grows well but difficult to market. Population of cassava in pattern must be synchronized to marketing situation.
- Not difficult to produce yields and gross returns (present prices) as follows:

	Farmers' pattern			Introduced pattern	
	Price (Rp/kg)	Yield (t/ha)	Value (Rp/ha)	Yield (t/ha)	Value (Rp/ha)
Cropping pattern					
Maize +	125	0.4	50,000	1.0	125,000
Upland rice +	150	0.8	120,000	1.5	225,000
Cassava +	10	7.0	70,000	7.0	70,000
Peanut (pod) -	400			1.0	400,000
Cowpea	200			0.4	80,000
Total for 1 ha			240,000		900,000
Total for 0.5 ha			120,000		450,000

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ECONOMIC ISSUES IN RESEARCH INVOLVING UPLAND RICE

B. HARRISS, J. HARRISS, and A. PAIN

Economic evaluations of the social rates of return from public investments in agricultural research suggest high profitability. Returns up to 30-60% are three times greater than typical investments in other economic sectors (20). Despite impressive achievements of food grains research since 1960, several major gaps remain (40) with upland rice as one (30). Upland rice is relatively neglected by national and international rice research programs (34, 36).

Moormann and van Breemen (45) have written that " . . . general use of terms such as upland rice . . . is semantically and technically incorrect . . . (there) are not different rices in most cases for different landscapes . . . . " We have seen on the Monitoring Tour that though there are different rices for different environments, the semantic problem and the problem of biophysical environmental classification remain. Furthermore, if improved production technology has not raised rice production in minimally altered environments (i.e. unbunded, unleveled lands) of low rainfall then it is likely to be for ecological, socioeconomic, and institutional reasons. Hence, the importance to study these aspects of rice culture. Also, since upland rice production has not yet been transformed through technology transfer, we are forced into addressing issues of research and development before preproduction testing of technology.

Comparatively little is known in the Consultative Group on International Agricultural Research (CGIAR) system about the economics of upland rice, at least in South Asia (60). The first part of this paper, therefore, discusses economic issues considered relevant to the evaluation of technologies being developed by IRRI and ICRISAT, whose mandates cover the crop and the ecosystem in South Asia. This is followed by comments and a suggestion for an additional or alternative approach.

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ECONOMIC ISSUES IN TECHNOLOGY DEVELOPMENT

Earlier experience is useful for formulators of research projects for new crops and regions. However, seldom is it possible to ascertain whether IRRI's impressive body of economic research is carried out for its own legitimate and intrinsic merit, or if it precedes and is closely integrated with research and development in applied biology or if it is carried out ex post. The following relevant issues in the applied economics of rice are listed in an order reflecting historical sequencing (37).

1) The economics of rice production with special reference to the analysis of farm level and institutional constraints to increases in production.
2) Resource productivity or the economic returns of factors of production: land, labor, and capital, including new equipment, machinery, and inputs. Such research defines the sociospatial distribution of demand for technological components that raise productivity.
3) The economic evaluation of the impact of new technologies and components (fertilizer, insecticides, pesticides, seed, mechanized production, and postharvest processes) upon cropping systems and factors of production. Here technology developed or transferred via International Agricultural Research Centers (IARCs) are taken as exogenously given and assessed in terms of costs and benefits.
4) Explanations for existing cropping patterns and systems, research responding to recognition of the complexity of farming enterprises within which rice is located.
5) The economics of newly designed cropping systems. These simulated systems tend to have a small number of objective functions to maximize. They require costing to assess the relative efficiency of resource use compared with that of existing systems.
6) The economics of rice policies such as prices, subsidies, credit, marketing institutions, technology for storage, processing and transport, employment, energy, and land tenure (36). This research stems from recognition that macrolevel economic policy shapes the sociospatial diffusion of new technology. Leverage to change macrolevel national policies is not within the brief of the IARCs. But to point out the social costs of interventions that constrain the diffusion of yield enhancing or stabilizing technology is relevant to IARCs' mandates (5, 36).

For reasons elaborated later, research in all areas except perhaps item 5 should precede and accompany crop research in upland rice.

ICRISAT's research in the economics of dryland agriculture helps characterize the ecological regions where upland rice is cultivated in South Asia. ICRISAT's economics research (59) has focused on these issues:

- human nutritional needs in relation to crop breeding priorities, and economic aspects of the nutritional characteristics of given crops;
- the economics of the resource endowment of semiarid environments, focusing on the economics of key production factors: water, labor,

common property resources, and the economics and energetics of animal draft power;

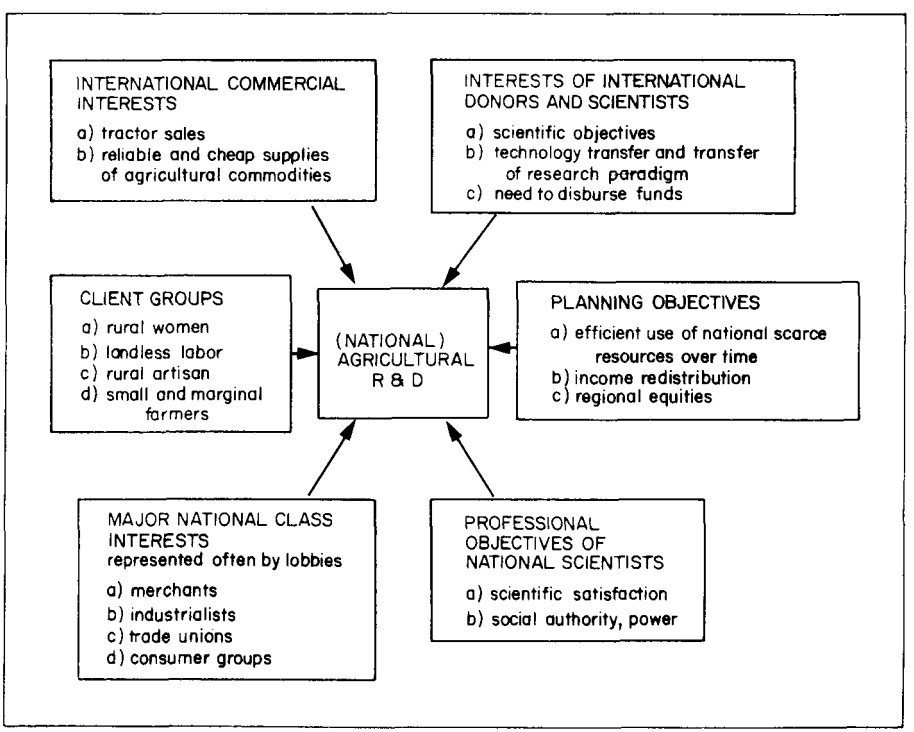
- crop production under conditions of risk and uncertainty, the impact of income fluctuations, the determinants of fertilizer use, responses to drought;
- the economics of marketed surplus, of agricultural markets, and the interrelationships between marketing and production; and
- the establishment of performance parameters and the economic evaluation of prospective technologies developed by ICRISAT.

All the first four sets of issues above are relevant to upland rice research.

COMMENTS

Experience and research priorities of IARCs are part of several forces acting on research and development (Fig. 1). In the case of upland rice, a frequent lack of power of local advocacy has resulted in low priority for its upgrading, suggesting the need for help by outside interests (such as IARCs).

Over the last 20 yr, the substance and the role of economic research on agriculture have developed and changed. At first, producers were evaluated as poor but efficient (56). Their productive capacity could be transformed by



1. Determinants of agricultural research and development (R&D). (expanded from Biggs [7], p214)

the transfer of technology. Biological scientists saw little need for economic research which was perceived as 1) location specific and therefore not internationally replicable, and 2) unnecessary, given the evident yield superiority of transferable technologies (32).

But research on agrarian economies was directed, often independently of the IARCs, to analysis on issues such as

- production costs;
- constraints to transfer of technology (21) and yield gap analysis;
- the diffusion and impact of new technology (25, 49);
- risk aversion and optimizing behavior (42);
- crop production trends and instability (29, 47); and
- the demolition of the protein myth (55).

These led to a redirection of agricultural research, notably toward increasing yields of energy rather than of protein, toward yield stability.

Further analysis of

- the distributional impact of new technology (see 12 and 13 on class formation; 24 on regional impact; 1 and 43 for impact on the gender division of labor);
- the evaluation of failure of extension programs (52, 36, 44 on T and V);
- research showing that technology could not be transferred without adaptation, carried out by farmers when not carried out by national or international institutions (8, 22, 53); and
- ex ante research alerting controllers of research resources to relative and macro level imbalances between resources allocated to agricultural research and the economic importance of crops (9, 10)

have provoked biological research on new crops and regions.

The *modus operandi* for determining research priorities is being altered as a result, among other things, of this body of social science.

The diffused origin of research funding and the highly diffused potential beneficiaries from innovations in agricultural production technology represent a problem of accountability to scientists in IARCs. These scientists naturally tend to resolve this problem by directing much of their discourse (as here) to their scientific peers rather than to a constituency with which they rarely have direct contact (41).

Certain analysts of agricultural research institutions especially at national levels have suggested that an expansion of the ex ante role of the social scientist improves communication, feedback, and interaction between biological and farming systems scientists and their farming constituency. This expanded role consists of socioeconomic research into existing farming systems, and into farmers' own means of articulating problems associated with increasing crop production and improving levels of consumption. The socioeconomist, in conveying such ideas to rice researchers, can be productive in shaping ex ante prioritization of biological research, especially in its applied aspects (2, 6, 8, 11, 14, 26, 32, 57).

This expanded role for the social scientist is the more important considering:

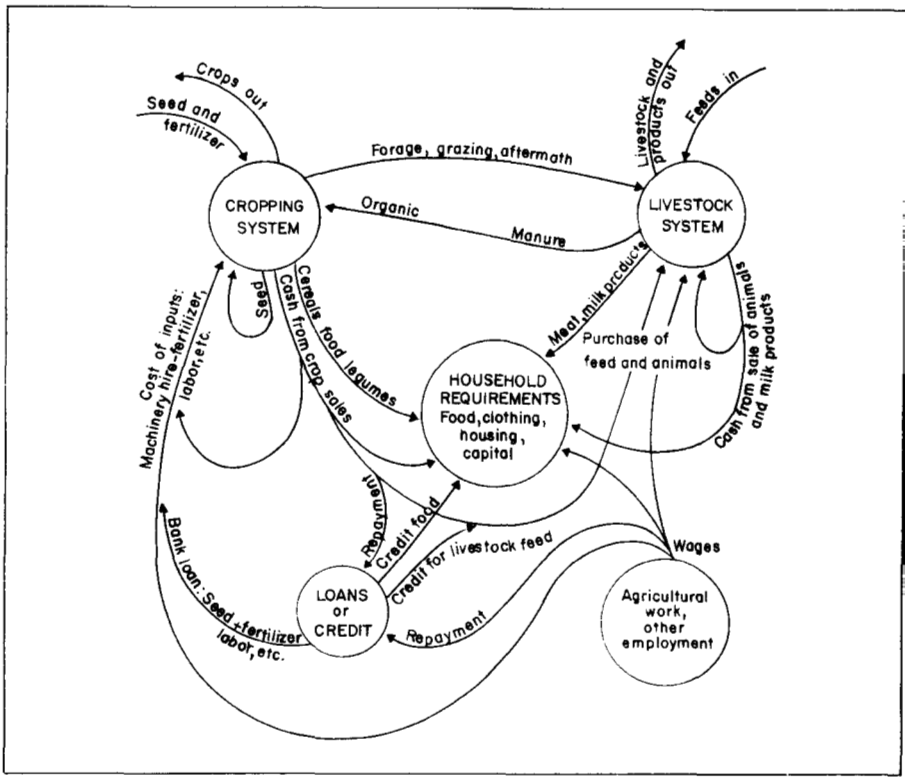
- the complexity and diversity of physical-biological environments, of farming systems, and of goals of agricultural research which include upland rice (19, 31, 38, 50),
- the apparent lack of investible surplus among most upland rice farmers in West Africa, and in South and Southeast Asia. The last characteristic would constitute a powerful constraint to the adoption of standard technological packages involving cash inputs (31, 46, 50; R. Wiley, ICRISAT, 1984, pers. comm.). These problems reinforce the need for new and decentralized approaches to improve production technologies focusing on breeding for a wide range of stresses and also on changes in management and in land use. In such a context feedback and interaction are vital. Innovations in management and planning of such research need to be examined experimentally.

Farming systems research (FSR) is one such development, most aptly called a movement. Its objectives consist of "farm level research through a farmer/researcher partnership in problem identification and farm-level testing of improved technologies." It is farmer centered, holistic, problem solving, interdisciplinary, committed to on-farm research, iterative, and continuous. The farming system is analyzed in terms of resources used in activities of representative households, resulting in outputs, which may be quantified physically, or in terms of energy flows or economic costs (3, 4, 24, 33). CGIAR crops may be components of much more complex systems, outputs, and activities that may not necessarily be agricultural, but affect production of crops and animals.

Determinants of such farming systems are physical, biological, exogenous social institutions and forces (land tenure, off-farm opportunities, credit, markets, prices, inputs and the modes of surplus extraction) and endogenous (household structure, health and nutritional status, education, food behavior and control, perceptions of risk [Fig. 2]). FSR methodology consists in classification, diagnosis of improvable components of the system, generation of recommendations to biological researchers and from them to farmers, and finally implementation and evaluation.

On-farm research (OFR), another outcome of the reevaluation of the social scientist's role, may be nested methodologically within farming systems programs (7, 51). It involves a radical change in the concept of preproduction testing (Fig. 3). Informal surveys bring social and biological scientists into direct contact with farmers, leading to the expansion of on-farm experimentation, which is determined from dialogue with farmers, not imposed by researchers, and uses large numbers of simple unreplicated trials, not only a few complex replicated trials.

OFR is claimed to be more appropriate for problem identification and for the qualitative evaluation of alternatives rather than for testing products of research or for estimating optimal inputs for technology considered best by researchers (60). Whereas work on the design and simulation of cropping systems has been found to be highly location specific and not necessarily "international," it is claimed that the latter type of OFR is capable of



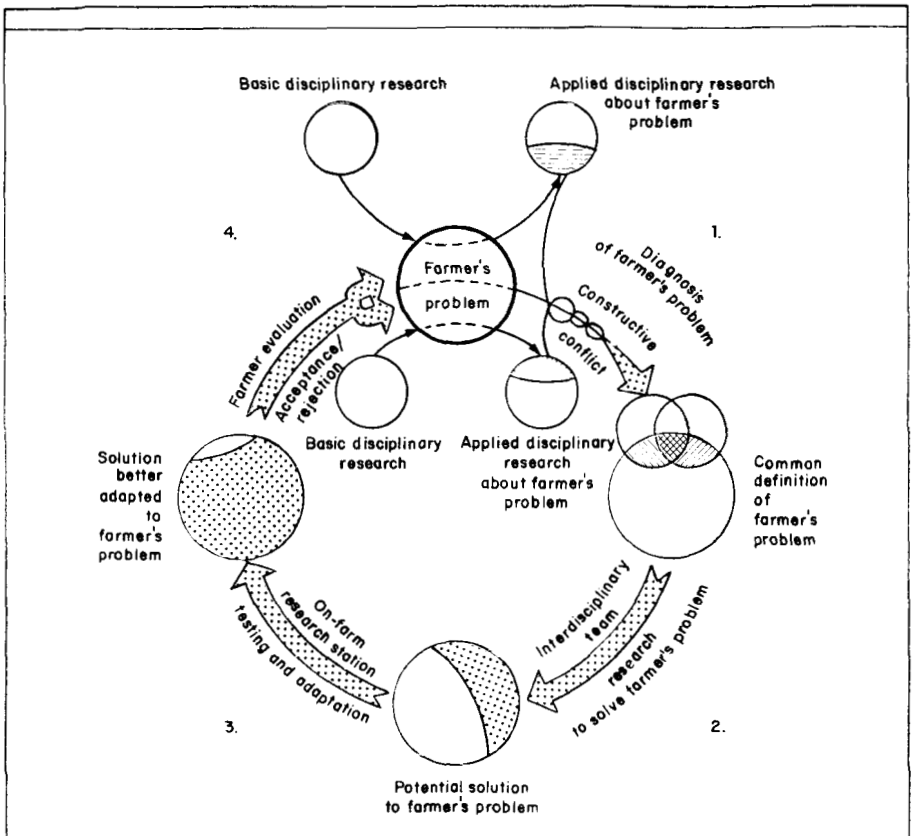
2. Some farm system interrelationships. Source: (25).

generating both new and widely replicable technologies and research results (32).

However, both OFR and FSR confront difficulties of time, expense, communication barriers (between researchers rather than farmers because of specialist disciplinary terminology), problems with objectives (because of different disciplinary values and standards), and methodological problems because so-called "traditional" farming systems are commonly in the process of continual change rather than static equilibrium. Clearly resources need to be expanded, research management and communication techniques have to be developed, and disciplinary blinkers taken off. We believe these approaches to have special relevance to the revival of biological research on upland rice.

We tentatively propose the following topics in multidisciplinary farming systems research as relevant for upland rice.

- The ecological and economic relationships of upland rice need to be integrated analytically with other elements in the farming systems of which it is a part to appreciate the role of upland rice in complex agrarian systems, the constraints under which various classes of cultivators operate, and the implications of changes in the different



Activity	Goal
1. Diagnosis of farmer's problem	Common definition of problem by farmers and scientists
2. Interdisciplinary team research to solve farmer's problem	Identify and develop a potential solution to the problem
3. On-farm testing and adaptation	Better adapt the proposed solution to farmer's conditions
4. Farmer evaluation	Understanding farmer acceptance or rejection of solution

3. Farmer-back-to-farmer--a model for generating acceptable technology (adapted from 53). Source: (33).

component parts of the system. Diversity in enterprise patterns (monocropping, intercropping, crop rotations, shifting cultivation) on plots of different soil (moisture) types and on the holdings of different types of upland rice farming households has to be quantified. Q-analytical algorithms are now available for the analysis of complexity at different levels of combinatorial aggregation (17, 39 for explanations of theory, scope, and methodology; 19 for an application to complexity in dryland agriculture).

- Specific botanical and economic characteristics of rice varieties actually cultivated, soil moisture regimes, nutrient cycles, inputs, residues, and losses need to be specified or estimated. Methodologies from the ecological analyses of natural habitats can be applied to farming systems. Plots can be studied using comparative statics at various stages over a complete rotation cycle, with different crops and different management practices. Simple gravimetric soil sampling might be appropriate for estimates of soil moisture reserves. From such an ecological analysis, the capacity of the existing system to maintain itself may be better understood.
- The degree to which the farming system, of which upland rice will be a component, is commercialized is an important issue; first, because the extent of commercialization indicates the social role of cash, and demand for cash inputs would be expected to increase with the adoption of modern technology. Second, the process of commercialization will reveal nonlocal physical and financial flows, therefore the extent of the regional market. Analysis of the farming system needs to include by-products, now being recognized as potentially important raw materials for agroindustry although technologies available have often required direct or indirect subsidies or operation at low capacity utilization because of supply constraints. This situation often indicates an inappropriately low degree of commercialization for these technologies. Thus, the commercialization of by-products is as important as that of rice proper and the economics of by-product utilization can determine the profitability of modern rice milling technology. The economics of the use made of broken rice, husk, bran, and straw are thus important empirical issues. The importance of upland versus other rice in the supplies to agroprocessing industry needs assessment. But it is also necessary to separate the economic analysis of commercialized products from a physical analysis of the nonmonetized uses of noncommercialized products of the rice plant.
- IRRI has emphasized the need for research on the livelihoods of people dependent on rice-based agricultural systems, especially of women (36). Thus labor inputs, the forms of organization of labor and its remuneration, the social distribution of incomes generated, and the sexual distribution of control over incomes are relevant issues. It is necessary to examine the impact of seasonality upon all these (see 15).
- The social outcome of a farming system is indicated by the health and nutritional status of those participating in production. Health and nutritional status are also inputs into the farming system and possibly a constraint on production (34). Nutritional status needs to be explained in relation to aggregate income, seasonal fluctuations, food security, and entitlement in relation to the human energy requirement of the farming system for upland rice (see 48 for an argued statement for the importance of this research).

AN ADDITIONAL APPROACH

The substantive discourse between scientists in conference proceedings such as this, and the existing priorities and research methods that we have discussed would be made considerably more relevant to those whose agriculture this research is to benefit if the role of social scientists, including economists, were allowed to expand through field research in one further way, prior to research and development and prior to or accompanying preproduction testing of technology.

Much more account could be taken in agricultural research than has been the case in the past, of the language and understanding of farmers themselves (11, 54). This is both because of the desirability of understanding farmers' perceptions of the constraints under which they operate, and of the appreciation that cultivators may have knowledge which is no less valid than that of research scientists and unknown to the latter.

We need to investigate farmers' and farmers' wives' understanding of the characteristics of different rice varieties; of soils and growing conditions; of insects and diseases affecting the rice plant; of water management; of control of pre- and postharvest crop control losses; of the nutritional properties of rice; and the relation between food, work, and health. The calendrical knowledge of rural men and women and their experience of contact with the instruments of state intervention in agriculture are also important empirical issues (16, 18, 27, 28, 57). Techniques such as repertory grid analysis can be used (53). It is useful to understand and to observe reasons for differences in farming practices and practices of resource conservation between individuals. The consequences of these actions on yields and other production variables may be better understood (58). Farmers' own observations of constraints, their articulation for change in technology may be located conceptually in a way that has distinct practical spin-off in improvements in extension communication, and training.

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SOCIOLOGICAL AND ANTHROPOLOGICAL ASPECTS IN PREPRODUCTION TESTING AND PRODUCTION PROGRAM INVOLVING UPLAND RICE

J. JIGGINS and L. FRESCO

Development of agricultural technology for upland rice environments confronts researchers with particular problems. In irrigated, and, to a lesser extent, in rainfed lowland production environments, soil-water-plant relations are relatively homogeneous, and predictable; physical and biological regularities justify use of rather simple research tools and concepts such as constraints analysis and cropping systems research. But the diversity of upland rice environments, ranging from favorable to unfavorable with great variation in growing season (13), does not allow easy transfer of research methods developed for other conditions.

The gap between research station yields and small farmers' yields is not diminishing except in a few areas in Southeast Asia. In fact, difficulties involved in development of upland rice technology reveal some inadequacies underlying the whole technology design process being practiced at the IARCs. Inadequacies at the preproduction testing stages of the process reflect, and are in part the consequence of, inadequacies at earlier stages; for example, in the derivation of design criteria and the specification of what is to be tested. Attempting to address sociological and anthropological issues *only* at the later stages thus would be ineffective.

DIMENSIONS OF THE PROBLEM

The large-scale application of public funds to science-led agricultural production increases is a recent phenomenon. For centuries, producers and consumers have developed, through a delicately balanced process of purposive experimentation, trial-and-error, imitation, and serendipity, specific (rather than general) combinations of cultivation practices, and land races (20). Only recently have outsiders with little practical knowledge of cultivators' and consumers' environments been involved in designing new technology. Their design criteria, demonstrably, reflect scientific concepts brought to the definition of the problem statement and the organization of the research process. Some key assumptions might be stated as follows:

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Definition of technology

Technology usually is seen by researchers as a product that changes physical input-output relations. Improved genotypes have always received the most attention. Recently, researchers have concentrated on cultivars that are resource neutral as well as scale neutral and are said to be appropriate for a wide range of farming systems. Unfortunately, the criterion of neutrality holds within only extremely narrow specifications, precisely because the benefits of the new cultivars are not totally embodied in the seed or fertilizer. They require changes in labor allocation and inputs and crop management and hence in household management and in the organizational and institutional infrastructure. Thus, a definition of "technology" must encompass the social organization of production, at farm, household, regional, or other levels. Moreover, since technology is an artifact of its time and environment, neither an increase in supply per se in the range of technological choice nor the existence of an opportunity or need perceived as acute by policy makers and researchers is sufficient to generate items that are significant and meaningful to users.

Adaptations

Fitting technology to users or users to technology? The history of technological innovation suggests that success requires close attention to innovation processes, that is, to utilization and to users, from the beginning of the research process. But international agricultural research center (IARC) researchers have tended to define adaptation as eliminating error of fit at the *end* of the technology development process.

Illusion of the smorgasbord

Researchers have aimed at producing two types of choices: a range of characteristics built into plant genotypes and a wide range of cultivars. Implicitly, it is assumed that 1) what is offered is appropriate and highly desired by users; 2) producers and consumers are in a position to make informed choices; and 3) the range of choice effectively is accessible to users. Rarely, and then only for particular minorities, do these conditions hold simultaneously (10, 16).

Myth of the entrepreneur

Researchers have tended to predicate their work on a model of the farmer and the farm as a petty capitalist enterprise managed by an independent entrepreneur. They have assumed a single decision-maker, usually male, and have ignored the limits to free individual action set by the networks of intrahousehold and interhousehold relations in which small-scale production and consumption in developing countries are still largely embedded.

Reification of technology

In the process of agricultural technology generation, the IARCs have tended to abstract items of technology from their production or consumption

context. This abstraction allows the belief that technical instruments by themselves bring about development. A. N. Whitehead (22) labeled this kind of scientific reductionism "the fallacy of misplaced concreteness" and it has received much attention from social scientists disturbed by an approach to material development that treats people as objects of manipulation rather than as human beings.

Given these kinds of underlying assumptions, researchers have tended to react to the difficulties of upland rice environments by increasing the complexity of the research process, elaborating more detailed procedures, widening the number of experimental factors and the components in component technologies. Multidisciplinary exploratory and validation surveys, the inclusion of social scientists in design teams, recognition of multiple objectives within the farm household, the evolution of multiphased and multilocational trials, have led to research structures and processes that are more difficult to manage, less transparent to the end beneficiaries or to researchers themselves, and scarcely cost effective.

Farming systems research (FSR) has emphasized the detailed definition of homogeneous producer categories to reduce diversity to manageable proportions and, recognizing the limitations of a purely technocratic view of the world, has sought the participation of social scientists. However, social scientists have limited their participation largely to postevaluation and testing of finished or semifinished technologies whose fundamental architecture has been set. Where they have been let loose in the diagnostic phases of FSR, there have been major problems of incorporating their insights into agricultural scientists' work, especially in translating their description of social factors and farmers' priorities into agronomic definitions. Social scientists have been assigned the role of "those who know what farmers want" in contrast to agricultural scientists, "those who know what farmers need" and both the information and the methodologies used by social scientists have appeared inaccessible and often illegitimate to the latter.

REFORMULATING RESEARCH CONCEPTS

Developing diversified technology for upland rice farming systems thus forces us to look again at agricultural research concepts and processes and to formulate new paradigms. To be effective in terms of research process, reformulated concepts and new paradigms necessarily involve changes in mentalities. These are not easily achieved but they are not beyond reach (4). The following three points would seem to describe the more important shifts in outlook required:

1. Upland rice technology development, unlike pure plant science, encompasses problems that, in mathematical jargon, are described as "ill-posed," i.e. — problems whose solutions require knowledge derived from methodologies other than science (mathematics) and from spheres other than that which is the focus of attention.

2. Upland rice agriculture represents more than primary production in the rural areas of developing countries; it is the source of livelihood for many who have no direct role in either management or labor. A concern for livelihood potential necessarily involves a concern for biomass and its utilization. This implies that yield must be measured in terms of total usable matter, including grain, fiber, stalk, forage, and others.
3. "Development'' is undoubtedly associated with increased efficiencies; the IARCs have concentrated on increasing production efficiencies rather than human or societal efficiencies. In irrigated and a few lowland rainfed environments, it has been possible for researchers to assume as given or as inducible the concommitant efficiencies in human and institutional behavior required for the optimal performance of the new technologies (although these have been rather less impressively forthcoming than researchers' models assumed and subject to instability over time, to the extent that the validity of the assumption itself has been brought into question). In the socially and economically more marginal environments where upland rice is grown, the assumption clearly is unreasonable, even as a theoretical entry point. Both the existing efficiencies of human and social behavior in upland rice areas and awareness of the limits to induced change would seem to offer more fruitful perspectives.

It does not seem either sensible or practically possible for these conceptual formulations to be regarded merely as areas of research and analysis, which might be *added on* to existing assumptions and outlooks. Their value-orientation, and the breeding criteria and research process that might flow from them are distinct from the main body of current thinking and practice at the IARCs. Nor will recruiting a few sociologists and anthropologists in itself achieve much. What is needed is a willingness on the part of researchers to move toward an integrative rather than additive approach to problem definition and problem solving.

RESTRUCTURING THE RESEARCH PROCESS

If sociological and anthropological issues are to be addressed, the research process should be directed toward increasing users' options for responding profitably to - and surviving - changes in opportunity. Technology, thus described, is that which increases resilience and flexibility over time rather than a one-time hit that monopolizes resources to the point where only a limited range of options can be pursued profitably within rather inflexible boundary conditions, The research process that might produce the preferred technology has been well proven in spheres outside agricultural technology generation in the IARCs. Its characteristic features are as follows:

Trying out

By *trying out* is meant a preference for testing over analysis, a preference for testing diagnostic conclusions over increasingly detailed specification of

what the problems and opportunities might be. "Getting on with it, especially in the face of complexity, simply comes down to trying something" (17). There seems to be abounding virtue in numerous, iterative cycles with producers and consumers, of experimental action, analysis, and reflection and, in the sphere of technological innovation, comparatively little in linear and deterministic models and experiments that do not include users. Obviously, it is more cost effective to try something out than to try to analyze everything in advance, hoping among numerous potential products to hit on a few that might at least have utility for someone, somewhere. Yet the IARCs' testing and evaluation procedures are largely after-the-fact experiments determined by scientists; IRRI's constraints (yield-gap) analysis explicitly excludes plant materials not yet released and available locally: sound logic in terms of its own model but unhelpful in the cost-effective development of technologies.

Quick, numerous, and inexpensive

If upland rice breeding programs are to base their design more closely on markets, then the willingness to submit semifinished products to user trials must commensurately increase. Studies of technological innovation, both historical and contemporary, suggest that opportunities exist in the present, if they exist at all, and that the identifiable starting point is an immediate application within a specific (even if wide scale) context. To capture these opportunities, then, successful experimentation is based on the frequency in time and location of tests of numerous technologies in numerous agricultural (as opposed to experimental and research station) trials, i.e. it is the overall number of technologies tested that counts and not the number of replication experiments for any one technology. Suppose the chances of any one trial proving a cultivar to be useful are only 10%. If trials of 10 cultivars are conducted, by the laws of probability the chance that at least one will prove useful rises to 65%. If 25 trials are conducted, the chance of at least one proving useful rises to 90% and the odds that two will prove so are almost 75%. However small the odds seem that any one technology will work, the odds of one technology striking home are the higher the larger the total number of trials. IRRI, for example, has access, through its seed collection and testing program and the Asian Farming Systems Network, to an unmatched resource with which to conduct quick, numerous on-farm agricultural trials with users. It also has a large stock of partially developed cultivars which have never been tested with users for their agricultural potential. Outside the IARC circuit, much has been done at the local level to improve the productivity of farming systems by swapping plant materials and husbandry practices between users, exploiting the existing and available genetic variability.

A return to the simple and idiosyncratic

"Trying out" is not an approach easily managed by a large scientific bureaucracy; it is predicated on multiple actions conducted by small,

flexible units of dedicated staff elaborating and testing ideas and technologies against agricultural realities. Formality, organizational rationality, and intellectual tidiness are not its hallmarks. It requires an efficient administrative and scientific back-up service. It requires intensive, person-to-person communication and reporting of trial results. It requires disciplined adherence to schedules at which results are reviewed, and trials continued or aborted. Mistakes in initial judgments and diagnosis must be seen as tolerable, inevitable, acceptable.

The user linkage

In general, the IARCs have two outlets: 1) national agricultural research structures and through them farmers; and, 2) national seed multiplication programs. Each encompasses a range of specialized, distinct end uses and users, i.e. "markets". The more that interest is focused on the poor, the remote, and the unstable climatic and agronomic conditions that characterize most upland rice areas, the more diversified are these markets. Procedures for identifying and specifying the boundaries of homogeneous uses and groups of users (i.e. recommendation domains) are needed then. The only cost-effective way to do this is by market research on the ground. Office analysis of census-type data collected through instruments such as quantitative surveys is also necessary but will never by itself provide enough of the right kind of information in a timely fashion to support technology development and innovation.

In terms of the research and development process itself, once recommendation domains have been identified, user participation fits into the following phases:

- *The diagnostic phase* with homogeneous groups of ultimate users (producers and consumers).
- *The resting and evaluation phase* with users in on-farm and in-the-kitchen producer and consumer trials. The practice has been to select typical producers and consumers, by which is meant the average, modal, or representative. Others have pointed to the importance of selecting users who represent the range of conditions within the recommendation domain. Yet others have stressed the additional necessity of identifying at any point on the range the lead users, who have in their own practice a preference for experimentation. There is no reason to believe that experimentation is not normally distributed among producers and consumers; unfortunately, the inventions of the poor and needy have tended to be unsought and unperceived by researchers. (Furthermore, the propensity to experiment has usually been confused with the propensity to adopt and, specifically, to adopt the technologies offered by outsiders. The two are distinct. Until experimentation is grounded in the agricultural reality of the range of farmers, this distinction will continue to hold).
- *The production phase.* Once a technology has shown advantages for some users within a recommendation domain, it should be tested over a more

extensive population, including populations in similar domains, where intermediate users and intermediate organizations might in the future play an important role (19). Agricultural extension services have in some cases, for single commodities, played such a role in agricultural technology generation. In French-speaking Africa, development organizations have successfully linked researchers and users at this stage of the process (2). FSR projects recently have played intermediary roles but their contribution necessarily remains small scale, unless and until they can link to government extension or community development services or to nongovernment and community organizations (3, 14).

IMPLEMENTATION: CHANGING DAY-TO-DAY PRACTICE

The reformulation of research paradigms and the restructuring of the research process must be translated into day-to-day practice. For upland rice research, it includes the following:

Recommendation domains and diagnosis

The definition of upland rice environments and evaluation mainly on the basis of agronomic (12, 13) or economic criteria (7, 23) implicitly assumes that technology problems and opportunities lie solely or determinantly in those spheres. IARC researchers recently have come up with a number of key socioeconomic variables (5, 18). Helpful as these checklist guidelines are, they not only raise doubts as to why some variables are included and not others; they each leave out some dimensions that other social scientists no doubt would consider essential. Further elaboration would produce unusable, complex methodological handbooks. To reduce complexity to the manageable, agronomists and other researchers themselves must pay attention to four sets of relations extended over two dimensions, viz: access, availability, distribution, exchange, extended over time and space:

1. the actual access of producers and consumers to resources and (decision-making) powers, within the household and in the wider community;
2. the availability of resources to consumers and producers in any local situation and the transaction costs involved in making them available;
3. the pattern of distribution of resources and outputs and the rules governing the allocation; and
4. the social and economic forces governing exchange of inputs and outputs within the household and between household members and the wider community.

The condition of any set of relations is held to be variable over time, which in itself has a number of aspects (such as the moment and duration of the domestic life cycle, the culturally determined period for the intracommunity settlement of debts, secular socioeconomic trends, short-run climatic crises, seasonalities of various kinds, and so on). It is also held to modify its meaning and significance according to the level at which it is analyzed (e.g. at the level

of the individual, the household, the community, the national economy and so forth). Spatial variability includes variations in environment and natural resources.

Another approach to increasing the sensitivity of technology development to human environments is to model the farm household but what is lacking is any general framework incorporating the diversity of household structures and formations, and their internal and external relations. Overly simplistic models form the basis of most economic and FS research at the IARCs (6). However, the idea is not to complicate the models by disaggregating data, for example, by sex and age, but to accept that a model is only a guideline tool which must be tested for its utility. Testing a model against the four variables (access, and so forth) and two dimensions, outlined above, produces more appropriate models without increasing complexity.

Upland rice lends itself to analytic models of intrahousehold and interhousehold dynamics because of the diversity of labor allocation and decision-making arrangements and control mechanisms in production; see (1 5) for a Timorese example. Dey (8) has documented some of these for West Africa. There, the general trend appears to be that, in forest areas, men are responsible for clearing and fencing, while women select and store seeds and carry out all remaining cultivation, including that of interplanted crops. Among the Gourou, for example, rice is stored in the husband's granary; he dispenses rations of rice to his wife.

If there is a surplus, women will sell the rice but they are expected to surrender the money to their husband (who might return to their wife a percentage). In some cases, women might also clear a separate field for themselves to grow rice which they primarily keep for themselves but which they might also give in part to their husband in return for other services. Similar ambiguity (regarding, for example, the determination of any single "decision-maker") is evident also with respect to disposal of the output among the Bete, among whom both men and women sell rice at different moments throughout the season and for different purposes.

Exploring the suggested four sets of relations over two dimensions for the case briefly outlined above might raise the following kinds of questions:

- Do female producers have equivalent access to production resources as males?
- If not, how does this condition their management and crop performance?
- Does access to resources vary, for either men or women, over time? (e.g. is access conditional on the age of marriage)?
- Are there any cycles in resource utilization (e. g. tied to household life cycles or to the season)?
- What rules govern distribution of resources and product among household members and between households?
- Are they stable or do they depend on, for example (autonomous or state-induced) changes in the rules governing land tenure and membership in marketing organizations?

Table 1. An example of a diagnostic matrix for the definition of upland rice RDs.

Upland rice growing environments	Socioeconomic criteria			
	SD L[a] etc.	Access to inputs	Access to services	Distribution of output
LF				
SF				
LU				
SU				

[a]Sexual division of labor (decision-making, income, and expenditure)
With the help of such a matrix, applied locally at different sites, both the boundaries of recommendation domains and preliminary diagnostic patterns are made apparent.

- Which arrangements governing intrahousehold and interhousehold exchange of goods and services are inflexible and which are already being modified by secular changes in roles and expectations?

These kinds of questions may be asked by agronomists themselves.

While more specialized (social) scientists might be needed to test which investigative diagnostic tools work in any particular context, a simple tool such as the diagnostic matrix may help to refine diagnosis of upland rice production at the household level at an early stage (Table 1).

With the help of such a matrix, applied locally at different sites, both the boundaries of recommendation domains and preliminary diagnostic patterns are made apparent.

Breeding criteria

Recent advances in biotechnology and in in vitro techniques may change the role of plant breeding in the overall process of agricultural technology development (2). There will be more scope to diversify the breeding process and to bring it physically closer to local circumstances and, thereby, to facilitate the inclusion of users' own criteria alongside "objective'' agronomic criteria in the development of new cultivars. Yet methods have hardly been developed for translating users' criteria with respect to the crops they grow and consume into agronomic criteria and this is one area where social scientists might usefully collaborate (i.e. in the development and testing of procedures). (Ashby [1] illustrates one set of usable techniques).

In any recommendation domain, it is possible to find a mixture of rice crops grown for different end uses and under different management regimes. By far the major effort in breeding programs has been devoted to only a few of these uses and to genotypes that are both highly responsive to their environment and have high input requirements. Translated into social terms, the major effort has concentrated on marketed production of male-controlled crops. Yet by applying the kind of diagnostic approach advocated here, different kinds of breeding criteria might be expected to emerge (Table 2). Because great differences in end utilization occur between upland rice grown by women and men, it is usually essential to complement

Table 2. An example of a breeding criteria matrix: crop production criteria.

Type of rice crop	Upland rice growing environment			
	LF	SF	LU	SU
Mainly subsistence	Yield stability	Drought avoidance	Adverse soils tolerance	No added investment in labor or land
Female crop [a]	Ratoonability	(as above)	Fitness for mixed cropping	No added investment in labor or land
Male crop [a]	Soil management	(as above) and recovery	Short duration	No added investment in labor or land
Cash crop only	Semidwarf HYV	Short duration	(as above)	No added investment in labor or land

[a] Female and male refer to management and resource utilization during crop production. Because great differences in end utilization occur between upland rice grown by woman and men. It is usually essential to complement agronomic (crop production) breeding criteria, such as those defined.

Table 3. An example of a breeding criteria matrix; postharvest utilization criteria.

Desired characteristics for postharvest uses	Rice biomass utilization	
	Men	Women
Breeding potential (rice wine)	X	-
On-farm storage	-	X
Puffing	-	X
Thatching straw	X	-
Threshing quality	X	-
Mat weaving	-	X
"Fit" with cooking technology	-	X

agronomic (crop production) breeding criteria, such as those defined above, with criteria pertaining to postharvest utilization of the crops, covering their total biomass (Table 3).

Even this simple example illustrates the importance of recognizing that producers are 1) not necessarily primarily concerned with changing the input-output relations of grain production; and 2) might be satisfied with genotypes that exhibit more yield stability and less environmental responsiveness than modern cultivars typically do, since they are selecting for other characteristics than yield maximization.

Testing and evaluation

Given the need for quick, numerous trials based on agricultural realities and strong user participation, the following principles should be incorporated:

1. *Representativeness.* In their own experimental traditions, producers often are interested more in representative rather than random samples, concentrating their experiments on a small number of individual plants rather than on a whole field. They are usually acutely

aware of individual plant performance and compare experimental growth with the norm in the same situation, treating contextual factors as exogenous parameters. The underlying presumption is their interest in security within the limits of stability known to them through their own experience of their environment, rather than in statistical probabilities.

2. *Replication.* Replication trials, used by researchers to sort out the influence of exogenous variables and to check regularities against a statistically respectable sample (and often, implicitly as demonstrations), may have little meaning for users who in their own types of single split-plot trials, designed to test factors important to themselves, are using different criteria for "success" than scientists typically use.
3. *Low-input environments.* Research station selection has produced survivors accustomed to high-input environments. Since there are practical limits to simulating low-input environments on research station sites, experimental sites that offer low-input environments rather than approximating research-station conditions must be used for both selection and testing.
4. *Recognizing trade-off.* Since there are differences in objectives, end uses, and crop management between households and between household members in any RD, testing and evaluation explicitly has to recognize these differences. What is likely to emerge is not a single index of success or profitability but the identification of a range of niches and situations recurring over time in which the technologies usefully could be adopted.
5. *Testing and evaluating institutional behaviors.* The IARCs and national systems have been slow to recognize that access and availability, distribution and exchange, are all seriously compromised by institutional design and that service structures necessary to the profitability of a new cultivar are as much in need of testing and experimentation as the cultivars themselves. There are precedents to draw on. The Guided Change project in northern Nigeria (11) and French FSR in, for example, Senegal, under the Unites Experimentales, deliberately set out to test organizational and institutional design and the limits to the adaptations of human and institutional behaviors (9).

Intermediate organizations

Just as there are factors and causative relations that are not perceivable by producers, so are there factors not readily perceivable by agricultural researchers. Discerning the complementarities and bridging the gaps between producers and researchers seem activities in which intermediate organizations could usefully and cost-effectively participate. A prerequisite to their involvement is the breakdown of the institutional isolation with which many research stations have surrounded themselves. Intermediaries could be useful particularly in the conduct of integrated producer-consumer trials and evaluation. Usually these have been carried out through analysis of

prices, sales, and purchases. As a result, the important roles of intra-household and primary marketing networks and the influence of postharvest technologies on biological technologies and crop husbandry have been ignored.

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TECHNOLOGICAL ISSUES IN DESIGNING CROP PRODUCTION PROGRAMS

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For rural areas of Asia, where the primary source of livelihood is farming, improvement in farm productivity has been and continues to be one of the most effective tools for development. Development programs whose primary focus is the improvement of farm productivity shall be referred to in this paper as production programs.

A production technology that is substantially superior to the existing farmers' practice is an essential component of a production program. By hastening farmer adoption of the new and more productive technology, productivity in the target area is expected to increase.

This paper focuses on production technology. The criteria for technical superiority, the procedure for testing such criteria, and our implementation experience in the Philippines will be discussed.

REQUIREMENT FOR TECHNICAL SUPERIORITY

A new technology (NT), to qualify for use in a production program, must satisfy two requirements: 1) higher productivity, and 2) farmer acceptability.

Higher productivity

A superior technology must increase the productivity of the most limiting farm resources. Land, labor, and cash capital are usually the limiting resources of small farms in Asia. Hence, productivity can be measured as the amount of output per unit of land, labor, or capital.

A NT, to be superior, must increase productivity by at least 30% in one or more resources without an accompanying decrease in productivity with respect to the other resources. For example, Table 1 shows the productivity of three new technologies and an existing farmer practice. Of the three NT,

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only one (NT3) is more productive with respect to all three resources, including a labor productivity that is more than 30% better than the farmer's practice. Note that NT1 and NT2 are inferior to the farmer's practice with respect to at least one resource.

Acceptability

A NT that is more productive and profitable may not necessarily be acceptable to the farmers. Three important factors affect acceptabi1ity. *First* is social acceptability. The NT must violate neither the local norms nor the preferences of the farm households and the community. In highland areas of the Philippines, for example, traditional cold-tolerant rice varieties were used for making wines intended for local festivities. When new high-yielding rice varieties were introduced, their acceptability was sporadic mainly because they could not be used for wine making. *Second,* NT must not require a large amount of new resources. NT with lower added cost for input and labor would be easier to adopt than NT that requires more. For example technology 1 in Table 1 has a much lower added cost than technology 3. Consequently, farmers may find this alternative much easier to implement. *Third,* the NT must be easy to learn. Ease of adoption is related to the simpleness of the technology. A technology familiar to the farmer is most likely acceptable relative to one with unfamiliar innovations.

PROCEDURE FOR TESTING SUPERIORITY

For most traditional experiments, it is assumed that superior performance in research station will automatically result in a corresponding superiority in farmers' fields.

Recent findings have put this assumption in doubt. Technologies that perform excellently in a research station are mediocre in farmers' fields. Farm practices that perform poorly at a research station may show suprising stability on an actual farm. Existing farm practices are location specific. They are most productive in the locality where they are practiced.

Table 1. Comparative productivity of new technologies over current farmers' practice (hypothetical example).

Technology	Product gross value (P/ha)	Cost of production		Productivity[a]	
		Labor (P/ha)	Cash (P/ha)	Labor	Cash
1	3500	1300	900	2.7	3.9
2	3600	1500	1000	2.4	3.6
3	5300	1600	1200	3.3	4.4
Farmer's practice	3000	1200	750	2.5	4

[a] Ratio of the gross value product and the resource cost (i.e., labor and cash cost).

Consequently, alternative technologies must not be evaluated at an experiment station or a well-selected farm, but at farms that represent the location where these practices are expected to be adopted by farmers.

The Philippines in 1982 established a network of on-farm trials primarily to verify the superiority of NTs to existing farmer practices directly on actual farms. The network, being implemented through the Regional Integrated Agricultural Research Systems (RIARS) of the Ministry of Agriculture and Food (MAF), consists of 71 outreach sites, each covering 2 or 3 barangays (villages). On the average, a test site has about 750 ha of land and about 500 farm households. Two or three technicians, termed a Provincial Technology Verification Team (PTVT), are assigned to each outreach site to conduct the on-farm trial.

Generally, these five steps were used to test the superiority of a technology:

1. *Selection of target area.* Target areas were selected to represent a priority agricultural problem situation in a region or province. The potential for improving existing productivity must be substantial. Because rainfed areas were prevalent (about 80% of the cultivated area), the network focused on rainfed rather than on irrigated culture.
2. *Site description.* Secondary data on soil, climate, and other agricultural statistics about the province and the target area were gathered. Then a farm survey of 200 sample farmers was conducted. They were asked about their farm resources, practices, production, and problems.
3. *Technology design.* On the basis of the site description, existing farmer cropping patterns (EP), and the currently known technology, an alternative cropping pattern (AP) with the corresponding management practices was designed. Modifications on variety, fertilizer use, insect control, and weed management were the most common. In most cases, AP had additional crop(s) either as sequence crop or intercrop.
4. *Testing and evaluation.* The designed AP were planted and compared with existing farmer practices in four to five test farms in the outreach site. Performance of existing farmer practices was measured from plots actually managed by the farmers. The basic data collected for both the AP and FP plots included climatic data, management practices, yield, and cost of labor and material inputs. Analysis was done for each crop and for the whole cropping pattern. Annual research review was conducted to evaluate the performance of the AP, and modifications were made when necessary.
5. *Pilot production program.* APs that satisfied the minimum requirement for superiority and farmer acceptance were identified and entered into a barangay pilot production program. The production programs are done within the outreach site where the agronomic trials were conducted. Expansion in the succeeding year will depend on rate of adoption in the pilot barangay.

EXPERIENCES IN THE PHILIPPINES

Although our network of farm trials involved many crops, for this section we shall focus only on the upland rice.

Site description

Among the 71 outreach sites in the country, 10 tested cropping patterns involving upland rice.

These outreach sites had annual rainfall that ranged from 1200 mm to 2600 mm with a rainy season of 4-6 mo. Soils were clay to clay loam, that are usually acidic to slightly acidic. Soil fertility varies, some sites having moderate organic matter content and others being P deficient (Table 2). Average farm size varies from 1 to 2.5 ha at an average of 1 to 2 parcels/farm.

Cropping pattern design

Upland rice (UR) is usually planted with these cropping patterns: 1) UR alone, 2) UR followed by upland crops such as maize, 3) UR relayed with root crops such as sweet potato, and 4) UR intercropped with other annual crops (maize) or with perennial crops like banana. On the other hand, the designed AP usually includes additional crops either as sequence crop or as intercrop.

The varieties used for upland rice in the AP were UPL Ri-5 and UPL Ri-7, and fertilizer applications varied from 40-60-0 to 60-30-30. Insecticide application, if any, was minimal and weed control was the farmer's usual practice. For other upland crops not planted previously by the farmer, existing recommended practices were used.

Performance of cropping patterns. Results from on-farm trials of selected UR-based cropping patterns are in Table 3.

Several AP show higher yield than the FP. Similarly, favorable net return and marginal benefit cost ratio (MBCR) was realized for the AP. However, there were also sites with negative returns. One of the reasons was the nonharvest of other crops in the pattern because of insects and diseases. Generally, the UR component of the AP had more favorable performance than FP.

In terms of gross return per hectare and return to labor and power cost, all APs evaluated were superior to the FPs (Table 4) while APs tested in Negros Occidental and Sorsogon showed inferior performance in terms of return to material cost. Only the cropping pattern in Antique had proven its superiority over the farmer pattern. If these 1984 results are confirmed by the 1985 trials, we could start implementing a pilot production program in the Antique outreach site by 1986.

Table 2. Description of RIARS outreach sites with upland rice cropping systems.

Site characteristic	Trece Martires, Cavite	Manito, Albay	Hamtic, Antique	Kabankalan, Negros Occidental	Jamidan, Capiz	Naval, Biliran	Curuan, Zamboanga	Castilla, Sorsogon
Annual rainfall (mm)	1520	2480	2635	3694	1338	2478	1155	2622
Wet months (2700 mm)	May-Oct	Oct-Jan	Jun-Oct	Jun-Oct	Jun-Dec	Jun-Oct	Jun-Oct	Jul-Jan
Dry months (100 mm)	Nov-Apr	Feb-Jun	Dec-Apr	Dec-Apr	Jun-Apr	Jan-May	Nov-May	Feb-Apr
Soil type	Clay loam	Clay loam	Clay	Clay	Clay	Clay	Clay	Clay loam
Soil pH	4.4-4.8	4.5-5.5	5.4	5.2-5.8	5.4	6.9	5.4-6.6	5-5.9
Organic matter (%)	1.0-2.0	3.0-4.5	1.0-2.0	1.5-2.0	2.3	6.5	2.5	.73-1
P (ppm)	6-36	2.3-4.5	5.0-13	7.12	16.14	trace	12	2.0
K (ppm)	187-612	6.0-2.5	320-540	40-65	585	376	–	44-455
Household members (av no.)	6	5.8	7	7	6.3	5.3	4	6.2
Av farm size (ha)	2.59	0.96	1.47	1.75	1.5	1.04	2.5	1.9
Parcels (av no.)	1.69	1.20	2	1	–	1.4	1.3	1.85
UR cropping pattern in the outreach site	Banana + UR (40%)	UR/S. Potato (80%)	UR-maize (5%)	UR-fallow (18%) UR-maize (16%)	UR-fallow (18%)	UR-fallow (19%)	UR-fallow (13%) Maize-UR (6%)	UR-fallow (8) Cassava (18) S.Potato (17)

[a] Figures in parentheses are percentages of farmers reported planting the cropping pattern in the largest parcel during the preliminary survey.

Table 3. Performance (P/ha) of upland rice-based cropping pattern tested in RIARS outreach site, Philippines, 1983-84.

	Trece Martires, Cavite[a]	Manito, Albay	Castilla, Sorsogon	Hamtic, Antique	Jamindan, Capiz	Naval, Biliran	Kabankalan, Negros Occidental
1. Alternative CP	Banana+(UR-Pn)	Sweet potato-UR	UR-bush sitao	Ipil-ipil + (UR-C+Pn)	UR-C + mung	UR-mung[b]	UR-C+Pn
a. Gross return	10 370	8 842	18 628	17 112	7 345	2 980	12 590
b. Total variable cost	8 690	6 466	7 600	7 600	5 290	3 053	3 975
Labor and power cost	4 290	2 630	3 066	4 620	3 495	2 080	1 815
Material cost	4 390	2 100	3 400	2 980	1 795	973	2 160
c. Net return	1 690	4 115	10 362	9 510	2 055	-73	8 615
2. Farmer's CP	Banana+(UR-Pn)	UR/S. Potato	UR-fallow	UR-fallow	UR-fallow	UR-fallow	UR-C
a. Gross return	4 480	5 421	1 530	3 510	2 399	3 140	3 340
b. Total variable cost	6 355	2 635	1 191	2 190	1 588	1 730	1 018
Labor and power cost	4 385	2 192	1 017	1 400	1 425	1 560	603
Material cost	1 975	442	174	790	163	170	415
c. Net return	-1 875	2 786	339	1 320	811	1 410	2 322
3. MBCR	2.5	1.63	2.9	2.5	1.33	-	3.12
4. % increase in TVC	367	79	440	24 7	233	76	290

[a] Gross return does not include harvest from banana. [b] No harvest on mungbean because of fusarium wilt.

Table 4. Performance (P/ha) of promising UR-based cropping pattern in three RIARS outreach site, 1983-84.

Site cropping pattern	Gross return	Productivity criteria[a]		Increase in cost of AP over FP[b]		
		Labor and power cost	Material cost	Labor and power cost	Material cost	Total variable cost
1. Castilla Sorsogon						
UR-bush sitao (AP)	12 633	4.5	3.9	2 049	3 226	5 275
UR-fallow (FP)	1 530	0.5	7.8	(200)	(1 800)	(440)
2. Hamtic, Antique						
Ipil-ipil + (UR-C+Pn)	17 112	2.7	4.7	3 220	2 190	5 410
UR-fallow (FP)	3 510	1.5	3.4	(230)	(277)	(247)
3. Kabankalan, Negros Occ.						
UR-C+Pn (AP)	12 590	5.9	4.8	1 212	1 745	2 957
UR-C (FP)	3 340	4.5	7.0	(200)	(420)	(290)

[a]Computed as a ratio of gross return and resource cost (i.e. labor and power cost and material cost). [b]Figures in the parentheses are percent increases in cost of AP over FP.

B. Case studies of preproduction testing and production programs

ADAPTIVE RESEARCH, PREPRODUCTION TESTING, AND PRODUCTION PROGRAMS IN PHILIPPINE UPLAND RICE

H. J. NESBITT

In the Philippines, upland rice is referred to as rice that is dry seeded into unbunded soil and relies on rainfall for moisture. It constitutes a small percentage of the area sown to rice but because farmers have received few incentives in the form of its new component technology or financial subsidies, the potential for improving its production is immense.

Upland rice is grown under conditions ranging from steep slopes to gently undulating land that has been cleared for centuries. Soil types vary considerably within the country as do rainfall patterns. Hence considerable adaptive research and preproduction testing are required before technology developed abroad or in Philippine research centers can be recommended to the farmer.

UPLAND RICE PRODUCTION IS PERSPECTIVE

Rice production in the Philippines has increased considerably over the past three decades. In the 1970s the annual increases reached 6%. Some of the increases resulted from the development of new irrigation schemes, as illustrated by the increase in irrigated area shown in Table 1. Much of the land may be cultivated to rice two or more times a year. The primary source of improved production was the more than 50% increase in irrigated-rice yields over the past decade (Table 1), attributable to farmers' adoption of modern varieties (MVs), improved technology, and better management techniques.

The area planted to upland rice appears to have decreased in the past 5 yr (Table 1) while yields have remained constant. In 1970, 13% of the area planted to rice was attributed to upland cultivation, which constituted 8% of total production. In 1983, only 5% of the rice area and 2% of the total production in the Philippines were from upland sources.

Provinces producing the largest amount of upland rice in the Philippines are in the southern island of Mindanao, where upland rice as a percentage of

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Table 1. Rice production in the Philippines, 1970-83.

Year	Irrigated		Rainfed		Upland		% Upland	
	Area (million ha)	Yield (t/ha)	Area (million ha)	Yield (t/ha)	Area (thousand ha)	Yield (t/ha)	Area	Production
1970	1.3	2.1	1.3	1.5	420	1.0	13	8
1971	1.5	2.0	1.3	1.6	370	1.0	12	7
1972	1.3	2.0	1.5	1.4	370	0.9	11	6
1973	1.2	1.9	1.4	1.2	440	0.8	14	8
1974	1.5	2.1	1.5	1.5	420	1.0	12	7
1975	1.4	2.2	1.7	1.4	460	0.9	13	7
1976	1.5	2.3	1.7	1.5	400	0.9	11	6
1977	1.5	2.4	1.6	1.6	430	1.0	12	7
1978	1.5	2.6	1.6	1.6	430	1.1	12	7
1979	1.5	2.8	1.6	1.7	420	1.1	12	6
1980	1.6	2.9	1.6	1.7	370	1.0	10	5
1981	1.6	2.8	1.5	1.8	240	1.0	7	3
1982	1.7	3.0	1.5	1.9	240	1.0	7	3
1983	1.7	2.9	1.3	1.8	150	1.0	5	2

[a] Source: Bureau of Agricultural Economics, Ministry of Agriculture, Philippines.

total production is high because of the less intensive nature of agriculture. A high proportion of upland rice is intercropped with coconuts.

In the past, little attention has been given to research for improving upland rice production in the Philippines. The University of the Philippines at Los Baños (UPLB) has bred a number of improved rice varieties but the breeding program is constrained by financial limitations. Developing other components of technology received low priority because of the small and decreasing importance of the crop on a national scale.

More recently IRRI has expanded its research program on upland rice because of its worldwide importance. Upland rice is grown on almost a sixth of the world's total rice land and this area is likely to expand as land suited to irrigated rice becomes fully utilized.

High yields were possible under upland conditions with existing varieties in the late 1960s and early 1970s. More than 7 t/ha was recorded in experiments during this period in the Philippines (1) and in Peru (2). Cropping system studies and crop protection are now part of the centralized research program administered from Manila.

In 1984, the national program of adaptive research and preproduction testing of upland rice was limited to widespread assessment of varieties. It was coordinated through the Ministry of Agriculture and Food with the assistance of the Philippine Council of Agriculture and Resources Research and Development (PCARRD) and IRRI.

There are no national programs for encouraging upland rice production in the Philippines. Upland farmers receive no government subsidies in the form of cheap credit, or operating costs as do farmers in the irrigated areas, and they face all the implicit tariffs on rice production inputs (4).

On a bilateral aid program in the Mindanao Province of Zamboanga del Sur, agronomists conducted some basic and adaptive research before testing

the technologies in farmers' fields. Credit in the form of inputs was also provided to farmers to encourage them to grow high-yielding rice varieties using the technology package developed by the research program. In the absence of a larger production program in the Philippines, the project and its results are described.

PADAP'S MULTIPLE CROPPING PROJECT

The Philippine-Australian Development Assistance Program (PADAP) in 1972 identified the province of Zamboanga del Sur as worthy of assistance. The program was named the Zamboanga del Sur Development Project (ZDSDP). Initial assistance was in road construction, village water supply, and construction of an irrigation system for lowland rice. It was also considered necessary to help the small upland farmers of the province. To achieve this, an agricultural development program was begun in 1976.

Initially, technology for growing crops with credit was introduced into the province from other islands. It soon became obvious that use of technology adopted from elsewhere was not satisfactory in Zamboanga del Sur and a research program was started in 1978 to generate, adapt, and prove annual cropping technology specifically applicable to the agroclimatic conditions prevailing in the province. Because of their economic and social importance to the province, adaptive research, preproduction testing, and production of upland rice constitute a major proportion of PADAP's agricultural program.

Upland rice is a significant source of rice grain production in Zamboanga del Sur. Land planted to upland rice made up 24% of the total area devoted to rice production during the first cropping of 1982 (Table 2). When a crop intensity factor of 1.7 was used for irrigated rice and 1.3 for rainfed areas (3) the percentage of land cropped to upland rice was 6 times the national average during the same year. However, yields were low, (average, 1.2 t/ha or less).

Conditions in some parts of the province are particularly suited to upland rice. Zamboanga del Sur is in western Mindanao, out of the typhoon belt, and little of the grain is downgraded because of weather damage. Crops are sown early in the rainy season, after which there is a high probability of 4 mo

Table 2. Land use, cropping intensity and crop area of rice in Zamboanga del Sur during 1982.[a]

Rice crop	Land-use area		% of province	Av yield (t/ha)	Production		Cropping intensity	Crop area	
	thousand ha	%			thousand t	%		thousand ha	%
Irrigated	24.4	32	3.3	4.2	102.5	43	1.7	41.5	40
Rainfed	33.4	44	4.5	3.4	113.5	48	1.3	43.4	42
Upland	18.6	24	2.5	1.2	22.3	9	1.0	18.6	18
Total	76.4	100	10.3		238.3	100		108.5	100

[a] From an evaluation of land resources of Zamboanga del Sur (3).

drought-free period. The major soil type is Alfisol, which has good texture and a pH between 5.5 and 6.5. Concentrations of the macroelements necessary for good plant growth, particularly N and P, are low.

ADAPTIVE RESEARCH

Crop production problems of upland rice in the credit program were numerous at the beginning, 1978, and agronomic research covered all facets of agronomy. It was necessary to select suitable varieties, determine optimum fertilizer regimes for different soils, improve land-preparation techniques and crop protection, and develop more efficient cropping systems.

Varieties

Upland rice variety evaluations started in 1979 with establishment of a small-plot trial containing 60 varieties selected by IRRI personnel with potential for use in the Zamboanga del Sur Development Project. IRRI, UPLB, Bureau of Plant Industry, and local varieties were included. Similar evaluations were conducted near the same site during 1980,1981, and 1982 after a large number assessed in 1979 were excluded. The top 10 rice yields from 1980 to 1982 are shown in Table 3.

Interestingly, a variety bred for the lowland (IR54) was the highest yielding selection evaluated in a 3-yr period. IR54 was also the highest yielding variety in 1983 and 1984. These results reflect the province's excellent conditions for growing upland rice.

IR54 and many other rice varieties succumbed to rice blast *(Pyricularia oryzae)* in some production areas during 1982. In 1983, a multitiered evaluation system was installed in different parts of the province. It began with project selections, IRRI observational nurseries, seed production increases, single-line observations in farmers' fields, and variety trials under

Table 3. Yields of rice varieties (1980-82).

Variety	Yield (t/ha)			
	1980	1981	1982	Av
IR54	3.10	4.24	4.08	3.81
Ri 5	3.61	4.55	2.54	3.57
Gama 318	3.13	3.81	3.74	3.56
IR3646-9-3-1-9	2.60	3.85	3.08	3.16
IR2061-522-6-9	3.00	3.48	2.95	3.14
IR 1579-2	2.69	3.73	3.71	3.04
IR3880-10 (FT3-366)	2.65	3.49	2.78	2.97
Kn 96	3.01	2.44	3.40	2.95
IR3880-13	2.80	2.84	3.22	2.95
IR3839-1	2.23	3.33	3.24	2.93

Fertilizer rates: 1980-81, 60-60-60 kg NPK/ha; 1982, 100-40-0 kg NPK/ha.

farmer management. This approach was used for evaluating both MV and local varieties.

The variety C22 was recommended for distribution in the production program during 1979, 1980, and 1981. In 1982, IR54 and Ri 5 were also included.

Time of planting

Upland rice was planted once a month for 2 yr to ascertain the optimum planting time. The variety C22 was sown into rows spaced 25 cm apart and fertilized with N, P, and K at 60 kg/ha. To achieve the highest yields in Zamboanga del Sur, farmers must plant early in the rainy season. Rice yields decrease after planting in April because of reduced solar radiation during June, July, and August.

Fertilizer recommendations

Fertilizer application recommendations for rice were formulated after a microelement study on maize in 1979. The experiments indicated no micronutrient deficiencies in any of the three major soil types on which both maize and upland rice grow. But N and P were needed to ensure good yields. Although the reaction to N and P was variable on different soils, one recommendation was given to farmer cooperators in the program. For MVs it was 16-20-0 (N-P-K) at 200 kg/ha applied basally and urea at 100 kg/ha side dressed at 55 days after emergence. The amount recommended for use on local varieties in 1984 was reduced to 40 kg N and 20 kg P_2O_5/ha.

Land preparation

After plowing the soil twice with a buffalo-drawn single moldboard plow, Zamboanga del Sur farmers traditionally harrow the land once and hill the rice seed at approximately 40-cm spacings. For a more even plant distribution, the interrow spaces are reduced to 25 cm and seeds are drilled along the row. This technique usually results in more tillers per unit area.

Crop management

Crops were generally weeded late, and the delay resulted in substantial yield losses (5). Weed competition was even greater in lowland varieties, which have an upright habit.

Experiments by the Multiple Cropping Project (MCP) confirmed the need to weed early. If crops were kept weed free the first 6 wk, later competition was reduced and yield losses were negligible. To achieve this effect throughout the crop area, it was necessary to speed the weeding process. Agricultural engineers developed hoes for this purpose. Although the hoes reduced weeding time by more than 50%, farmers preferred the hand-held knife. However, on-farm demonstrations convinced them of the advantages of early weeding and farmers generally hired extra labor to remove weeds at this stage. Other crop protection techniques were adapted from national recommendations.

Most upland rice crops in Zamboanga del Sur are harvested by hand and threshed by foot. New threshing methods were assessed under different conditions to reduce harvest time and improve recovery rates. A pedal thresher developed by IRRI and the Philippine Institute of Agricultural Engineering and Technology was modified in the MCP for this purpose. It is fast, efficient, cheap, and acceptable to farmers.

Cropping systems

After technology packages were developed to maximize yields through the use of appropriate varieties, fertilizer levels, good land preparation, and crop management, research concentrated on increasing crop production with improved cropping systems. Experimental cropping systems included legume rotation, direct sowing of crops into rice stubble, and intercropping with other annuals and under coconuts. This research is continuing during 1985.

PREPRODUCTION TESTING

Preproduction testing of upland rice in the Philippines is currently being developed through the Ministry of Agriculture and Food (MAF), universities, and IRRI. One such program is the Inter-agency Rice-Based Cropping Systems Preproduction Evaluation Program, established to test the performance of varieties recommended by the Philippine Seed Board over a range of environments. In addition to national evaluations, the MCP tests its own technology in farmers' fields. Farm labor is used but with research supervision. The ability of selected farmers to fully utilize the technology is then monitored. If chances of success are considered high, demonstrations are established and used to extend the improved practices to the farming community.

This routine is used for crop management practices and cropping systems. A multitiered varietal screening system involves replicated research trials at several sites, crop development trials in farmers' fields, and single-row observational plantings spread throughout the rice-growing areas.

Varieties are also milled and examined by traders before being considered for production. This step was included in the preproduction phase after Ri7 was dropped from the production program in 1983 because of its poor milling characteristics.

PRODUCTION PROGRAM

Recommendations

Initially the technology package for growing MVs in the upland areas was derived from "best bet'' recommendations suggested by MCP, IRRI, and UPLB staff members. Farmers were directed to sow the cultivar C22 at 60 kg/ha in rows spaced 40 cm apart and to apply urea at 100 kg/ha basally and 100 kg/ha at 50 d after emergence.

Farmers were also requested to weed the crops at least twice before maturity. Insect pest control was similar to that for the lowland crop. If rice blast was a problem, farmers were to apply benomyl to reduce its severity. These recommendations progressively changed as more information became available, both from national sources and through project research.

In 1984, two loan levels were released by the project. Farmers could grow either MVs or local varieties. The high-technology package included an MV (C1528-32-2) to be grown with 16-20-0 (N-P-K) at 200 kg/ha and urea at 100 kg at 25-cm row spacings with insecticides and fungicides. The crop was insured. A cash portion was supplied in the budget, if required, for employing labor to weed the crop.

Farmers were also given the opportunity to grow a local variety at half the fertilizer rate. No allowance was made for purchasing insecticides or fungicides. This budget halved the total variable costs and reduced the risk of the farmer's incurring financial losses in the event of a poor harvest.

Credit

Loans for growing both MV and local upland rice varieties are released for a minimum of 0.5 ha and a maximum of 2 ha. To qualify for a loan, farmers must own a carabao or have easy access to one and ensure they have resources to carry out the required cultivation. Because there are no collateral requirements, many tenant farmers take part in the scheme. From 1979 to 1984, approximately 40% of farmer cooperators were owner-operators and the remainder either share-cropped or paid cash rental. Some of these farmers become part-owners in 1984.

Loan releases are made through the banks, the amount of the loan is determined by project team members after an extensive budgetary analysis. Costs for seed, fertilizer, pesticides, insurance, and emergency expenses are totaled and farmers pay bank interest rates on this amount. The technicians collect repayments and submit them to the banks. All repayments are to be completed 6 mo after the loan release. If a farmer does not repay during this period he becomes ineligible to apply for further loans.

To promote better repayments, some farmers were organized into groups of three to seven, jointly responsible for each other's loans. After 1983, some of these groups were recognized as a legally constituted body to streamline the organization and distribution of inputs. Individual liability remained, but farmers could not remain in the group and retain borrowing status without group agreement.

Input organization

Inputs for the program are organized by extension supervisors. The variety to be used is decided upon 6 mo before release and bulked in the lowland during the dry season. Experienced seed producers are commissioned to ensure the production of good-quality seed. The seed allocation is then delivered to distribution points at the village nearest the farmers. Fertilizers and pesticides are released by input dealers when chits are submitted.

Extension

Extension of new technology to farmers is organized through technicians who reside in the same districts as the farmers. Technicians also handle both the issuance and collection of loans. Hence they have close contact with the farmers.

Most new technicians are fresh graduates from provincial universities or agricultural colleges before being employed by the MAF for the project. Training begins with their attendance at a multiple cropping training course conducted by senior ZDSDP and MAF staff members.

After being assigned to an area, the technicians are required to establish a quarter-ha demonstration plots of the recommended technology package of each MCP crop. This serves as training for the technician and as a base for holding field days and recruiting farmers. In their second cropping, new technicians may have 10 or less loan releases. This farmer limit is increased to 60 in subsequent seasons (8).

All technicians attend monthly multiple cropping meetings during which problems are discussed. Topics cover the availability and timing of input supplies, pest and disease outbreaks, difficulties in marketing, and monitoring loan repayments.

Seminars are often conducted, and speakers from other institutions such as IRRI provide special lectures. Some technicians also attend training courses at other institutions or are included in interprovincial educational tours.

Maintaining a well-trained technical team is the basis for the extension to farmers of up-to-date technology. To ensure resolving problems early, supervisors from the central MAF office visit each technician weekly.

RESULTS OF THE PROGRAM

When credit was first made available for growing MVs, the yields jumped from the 1978 survey estimate of 1.0 t/ha to more than 3.4 t/ha (Table 4). In 1982, the estimated average yield dropped below 1.8 t/ha because of a severe rice blast outbreak. These yields compare favorably with those of small-plot trials at the MCP research station (Table 5). In 1979 and 1980 IRRI-recommended fertilizer rates at N levels well below those recommended by

Table 4. Rice production in the multiple cropping production program (MCPP).

Year	Farmers (no.)	Av yield (kg/ha)	Loan payment (%)
1979	4	3403	100
1980	141	3710	83
1981	723	3363	87
1982	429	1765	53
1983	490	3158	90
1984	796	1792[a]	73

[a] Local varieties. [b] As of September 1984.

Table 5. Rice yields of research trials (RT)[a] and production areas (PA)[b].

Year	Yield (t/ha)											
	C22		Ri5		IR54		Ri7		C1528-32-2		Local	
	RT	PA	RT	PA	RT	PA	RT	PA	RT	PA	RT	PA
1979	1.7	3.4	1.0	-	1.9	-	-	-	-	-	-	-
1980	2.4	3.7	3.6	-	3.1	-	-	-	-	-	-	-
1981	3.5	3.4	4.6	-	4.3	-	-	-	-	-	-	-
1982	2.8	2.2	2.5	1.8	4.1	1.1	-	-	-	-	-	-
1983	-	-	4.8	-	5.2	-	4.9	3.2	4.4	-	3.5	-
1984	-	-	-	-	-	-	-	-	-	3.0	-	1.8

[a]Fertilizer rate - 60-60-60 kg NPK/ha. [b]Fertilizer rate - 100-40-0 kg NPK/ha.

MCP were used (Table 4). The moisture content of farmers' yields are higher than the standard 12%.

Rice also grows extremely well under partial shading. Several production crops under coconut trees yielded as much as rice growing nearby in unshaded areas (6). Many farmers accept rice as the production crop best adapted to growing under coconuts and the area of native and improved rice varieties in these areas has visibly increased in the 1980s.

A high loan repayment rate was associated with the good MV yields from 1979 to 198 1 inclusive and in 1983. Over 83% of the loans were repaid during these years. In 1982 the loan repayment was lower because of poor harvest (7).

Despite good yields and high loan repayment rates, approximately 47% of the cooperators leave the MCP at the end of each season. A survey in 1983 indicated that most farmers considered upland rice the more profitable of the five MCP crops (upland rice, peanut, mungbean, maize, and soybean). However, 75% of the respondents left the program to grow local varieties (8). The major reasons given for discontinuing use of MVs were fear of too much credit or crop failure and the crop's high labor requirements. More than 34% of the respondents considered the premium price paid for local rice a good reason for growing it.

In 1984 when farmers were given a choice between MV or local upland rice, most opted for local varieties.

Even after being told that the MVs were more profitable to grow (Table 6) farmers stood firm on their choice. To encourage greater adoption of MVs, varieties must be developed that are more resistant to diseases, particularly to rice blast, are more competitive with weeds, resistant to drought, and have what people in this area consider to be better flavor.

Although most farmers interviewed during 1983 preferred to grow their own local rice varieties, there is considerable evidence that they accepted readily other portions of the technology package (7). For example, farmers who left the program applied fertilizer but at a reduced rate; many maintained the drilling of seed in rows spaced 30-40 cm apart and

Table 6. Budgetary analysis for MCP, MV, and local rice, Sep 1984 prices (ha).

		cost (₱) [a]	
		MV	Local
Gross receipts	(HYV = 3 t/ha at ₱ 2.30/kg)	6900	
	(local = 1.5 t/ha at ₱ 3.00/kg)		4500
Variable costs	(includes seeds, fertilizer [c] pesticides, hired labor [b] interest repayments, and insurance)	3106	1720
Net cash receipts		3794	2780
Imputed costs	(labor and buffalo)	1095	870
		2699	1910

[a] Approved loan ceilings for May 1984: local = ₱1300, MV = ₱2400. $US = ₱20. [b] Hired labor costs calculated on 1/10th harvest share.

understood the need to spray insecticides at the correct time and concentration. Farmers also attempted to weed earlier to reduce yield losses from weed competition.

CONCLUSIONS

Upland rice crops in the Philippines are subject to yield reductions from disease, drought, and, occasionally, rat damage. Few production programs use MVs. Farmers grow crops with a small number of inputs and use native varieties to achieve low but reasonably dependable yields.

The experience of the MCP in PADAP indicates that farmers are not prepared to risk their financial security to achieve high yields with MVs and high technology. The MCP technology package was extremely viable but the varieties used were susceptible to rice blast, tended to be less competitive with weeds, were not drought resistant, and had less flavorful grain than local varieties.

When farmers realized how much at risk their livelihoods were with MVs, many reverted to local varieties but retained other parts of the technology package presented with the loan. With a low-technology package, yields were increased by 70%.

In the Philippines, the farmers' risk of losing a crop can be reduced through development of varieties that resist rice blast and drought. Until the varieties are developed, a national two-tiered production program can be supported by the Government to increase upland rice production. Where the incidence of rice blast is low (coastal areas) MVs can be grown. In other areas, local varieties can be grown with reduced inputs. The MCP of PADAP has shown that yield increases and good repayment rates are possible if loans are made available through the banking system.

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ADAPTIVE RESEARCH, PREPRODUCTION TESTING, AND PRODUCTION PROGRAMS IN BRAZIL

F. M. DALL'ACQUA, O. P. DE MORAIS, E. T. DE OLIVEIRA, and J. KLUTHCOUSKI

How can research institutions assure that agricultural research results more rapidly benefit rural producers for whom the research is intended? This question has recently started to receive special attention in Brazil.

The Brazilian agricultural research system was developed under the influence of the diffusion model imported from the more developed countries (5). The model implies a freedom of choice in research projects so that scarce resources can be allocated to a broad range of research topics depending on the investigator's decision. The tendency to develop research activities oriented toward solving real problems was supposed to result from pressure by farmers on government research agencies.

Extension services were seen as the means of bridging the gap between research agencies and farmer fields. The challenge of making research results from the literature available to farmers in usable form was placed almost exclusively on the shoulders of the extension services.

This institutional system was, in fact, found to *increase gradually* the gap between the amount of research results and that part which crystallized into new technologies adapted to farm conditions. Farmers were not organized well enough to orient research activities toward solving their real problems. Scientists went their own way, doing the work they were interested in, rather than directing it toward the solution of problems noted in the field. Researchers and extension personnel did not work together to adapt research results to farmer's conditions. Extension services were limited to gathering what they could from wherever they could find the information.

This agricultural research system was not homogeneously inefficient (3, 4). A dependence on imports, which characterized the Brazilian pattern of capital accumulation, made governments more responsive to export crops (coffee, sugarcane, cotton, and soybeans) than domestic crops (rice, beans, cassava, and maize). In this sense, research on rice had never been given high priority, despite its importance in both the diet of the Brazilian population and agricultural income and employment. Rice is the principal source of

CNPAF/EMBRAPA, Brazil.

calories and the third and fourth most important crop in terms of cultivated area and value of production in Brazil. A limiting situation was experienced in upland rice, which in the 1960s represented about 80% of total Brazilian rice area and 70% of production.

Research institutions were unable to attract financial resources for upland rice research. Almost all information on this crop was produced by only one agency: the Agronomic Institute of Campinas. The location-specific nature of results made it difficult for extension services to adapt the results generated for the state of São Paulo to farmers' conditions elsewhere in Brazil. Average rice yields dropped from 1.6 t/ha in 1938-42 to 1.4 t/ha in 1968-70.

The 1960s were characterized by food shortage and political instability. A sharply rising cost of living led to growing social discontent. Increased political activity of urban and rural workers created a situation of profound instability and transformed the food crisis into a political crisis. The government became aware that food-price inflation was an important factor contributing to social disturbances.

APPLIED RESEARCH UNDER EMBRAPA

Increasing political pressure to raise agricultural yields and production created a favorable climate for a profound restructuring of the existing research apparatus. In late 1972, the federal government launched a massive reform in the research system. The Brazilian Agricultural Research Enterprise (EMBRAPA) was created to do research at the federal level and to coordinate and supervise state-level agencies. Applied research directed toward solving immediate production problems was explicitly defined as the major philosophy of EMBRAPA agencies, including the National Rice Research Center. Research was to focus on problems noted in the field to generate technologies for prompt incorporation into existing production systems. Once technology was chosen, it would be tested in farmers' production systems. The test was a cooperative effort of applied researchers and extension personnel. Problems were fed back to research scientists to redesign their experiments for new answers. In brief, agricultural research was to be a process that starts with the farmer's problem and ends only when the newly developed technology has been adopted.

I will quickly review development of this applied research program at CNPAF, then conclude with a description of adaptive research, preproduction testing, and production programs on upland rice under way in Brazil.

THE TECHNOLOGICAL PACKAGE PROGRAM

In 1975, CNPAF/EMBRAPA, in cooperation with the Rural Extension Service (EMBRATER), organized the Technological Package Program. Emphasis was on disseminating existing technological information. The premise was that sufficient technological knowledge to overcome important

production constraints was available but was not being used by farmers for whom it was intended. If farmers accepted these technologies, a significant impact would result in improved agricultural yield and production.

The Technological Package Program was organized at meetings of researchers, extension personnel, and local farmers in the main production regions. This group defined the best practices for three levels (subsistence, intermediate, and high technology) of each aspect of crop management, such as mechanization, fertilization, weed control, and insect control, under existing conditions. Some questions were:

- What are the best crop varieties for the region?
- What is the recommended NPK application?
- Which insect pests are important constraints to production?
- Which insecticides perform best against the limiting insect pests?
- When and how many insecticide applications are required for control?
- What is the best weed control practice for the region?
- Which herbicides best control weeds in upland areas?

The resulting pieces of information were brought together in a *technological package,* which was distributed to local farmers for adoption.

Although the program produced more than 1,200 packages for diverse crops, its usefulness was not formally evaluated (1). Field tests originally planned were rarely conducted. The feeling is that the proposed program had little effect of changing the inadequate technological level under which most of the upland rice crop was grown in Brazil, before the 1970s. One support for this argument is that upland rice yield decreased 10% in the 1974-84 period.

Reasons for this unfavorable performance include the following:

1. Lack of sufficient technological knowledge which could be readily transferred to upland rice farmers;
2. Inability of the institutional system to ensure complete profit incentives to intended users;
3. Profit potential was insufficient to overcome climate risk and managerial deficiencies associated with the transitional purpose of upland production; and
4. Farmers were more willing to substitute one isolated practice rather than the full system.

Most upland rice production in Brazil comes from the transitional purpose system in which farmers do not look for an adequate rate of return in the upland rice crop, but for a cost reduction in the process of clearing areas for other purposes. Rice is chosen as transitional crop because of its 1) good performance in poor soil, 2) low level of investment and low production cost, and 3) easy adaptation to newly opened areas (2).

RICE RESEARCH UNDER CNPAF

Parallel to the technological package effort, the National Rice Research Center (CNPAF), established in 1975, immediately began work on rice

research. According to the philosophy underlying EMBRAPA, the National Rice Research Program is a cooperative effort between CNPAF and state research agencies. Since then, research specifically in this program has been directed toward assessing and studying major constraints to farmers' productivity. This information is used at research meetings to define regional and national priorities. State agencies are responsible for testing any pertinent technology under diverse conditions in farmer fields or other predefined areas. Thus, applied-research results generated at CNPAF are transferred to state agencies for local-adaption testing. Results from adaptive trials go into the existing organization for a National Production Program for rice farmers.

Under this system, breeding work at CNPAF has produced the best results. Unfortunately, in other disciplines, efficient coordination of basic and applied research effort has not been achieved. Appropriate methodological techniques are also factors limiting further development of adaptive research program.

Breeding program and preproduction testing

The varietal improvement program of the National Rice Research Center has identified high yield or stability of yield, and disease and insect resistance across all rice environments as breeding objectives. The breeding program provides varieties for more than 6 million ha of Brazil's extremely diverse rice-growing environments. Because it is impossible to breed a single variety suitable for the diverse Brazilian environment, research goals were set by regions. Brazil was divided into three regions for evaluation trials of elite germplasm.

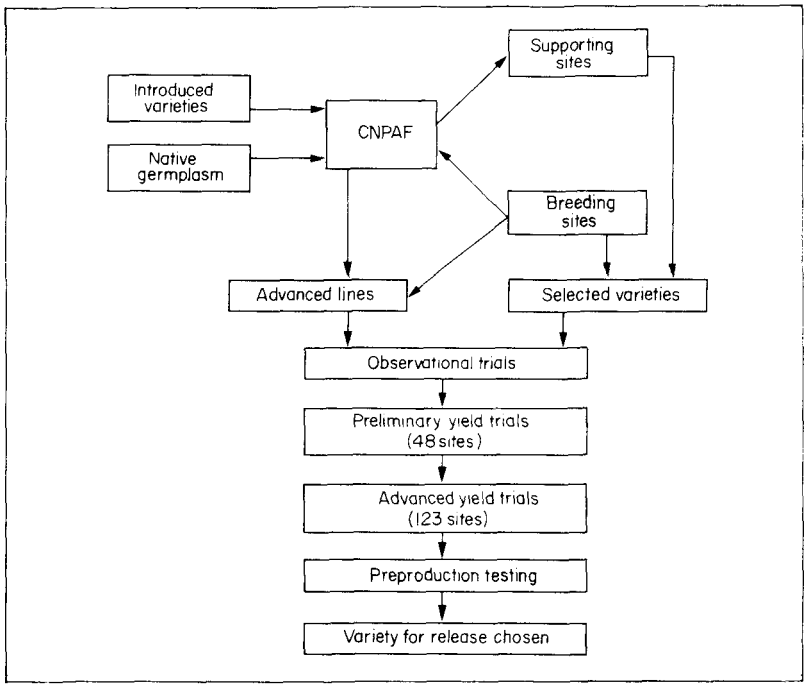
Region I — Rio Grande do Sul and Santa Catarina
Region II — South-East and Center-West States
Region III — North and Northeast States

The program is coordinated by a team of breeders at CNPAF closely linked to state research agencies in each region. Extension services, in general, participate only in preproduction testing. An organization chart (Fig. 1) shows the steps in developing new rice varieties.

The observational plots, composed of material from foreign countries and other national institutions, are in selected localities of each region. Promising lines from these trials are then included in preliminary yield trials to identify good performers in each environment. Experimental trials, statistically designed with two or three replications, are conducted as a cooperative effort between CNPAF and state research agencies.

The most promising lines in each state or region based on preliminary observations are included in advanced yield trials and tested for 2-3 yr before release for preproduction testing. The most promising advanced lines for preproduction testing are jointly decided by CNPAF and state representatives at the Annual Rice Researcher Meeting.

Preproduction testings are organized as a cooperative effort between CNPAF, state researchers, and local extension services. The most promising

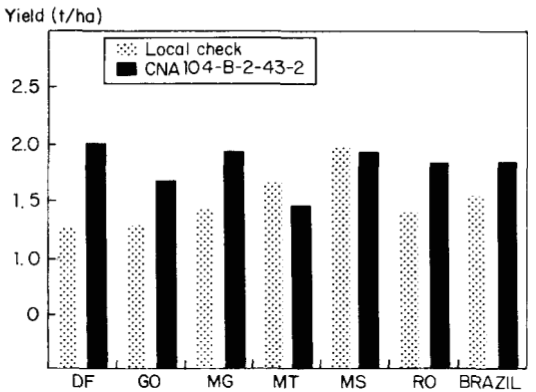


1. Step in developing new rice varieties.

lines are tested under diverse conditions in farmer fields against a popular local variety as a check. Crop management (including input level decisions) is fully by the farmer.

Performance of the promising lines is evaluated based on data from 2-3 yr advanced yield trials and collaborating farmers' opinions. Parallel to preproduction testing, the breeders increase seed at CNPAF. A minimum of 50 kg seed is made available to the Basic Seed Production Service which provides it to registered farmers for multiplication.

Actual CNPAF experiences in using this methodology will illustrate the procedure. In 1982 after identifying three promising lines (CNA 104-B-4-1-1, CNA 95-BM30-BM9-11, and CNA 104-B-2-43-2) in experimental yield trials, CNPAF suggested that state researchers and extension services evaluate the lines in farmer fields. Trials were planned by local agencies in six states in the central part of the country. Results were obtained from 52 of 70 farmers selected for the research. CNA 104-B-2-43-2 had an average production advantage of about 0.3 t/ha over the traditional varieties IAC 25, IAC 47, and IAC 46 (Fig. 2). The average productivity of upland rice in Brazil is only 1.2 t/ha. Additionally, 85% of the producers who used CNA 104-B-2-43-2 had equal or better grain quality and disease resistance than those who used traditional varieties. The farmers' opinions and results of advanced yield trials led to release of CNA 104-B-2-43-2 in 1984.



2. Grain yield of advanced promising lines in comparison with local check in farmer fields in six Brazilian states. DF = Distrito Federal, GO = Goias, MG = Minas Gerais, MT = Mato Grosso, MS = Mato Grosso do Sul, RO = Rondonia.

An experience in adaptive research

Methodological techniques have limited more rapid development of adaptive trials at the state level. A new program proposed in 1984 was a cooperative effort of CNPAF, state agencies, and extension service to determine:

1. The best land preparation method for rice under upland conditions;
2. The differences between five upland rice varieties; and
3. The effect of planting another rice crop or other crops (e.g. soybeans), after a rice crop under upland conditions.

Special attention for both methodological aspects and precision in gathering data was attained by limiting initial trials to three sites over a representative area of upland rice production. The 4-yr program is now in its second year.

The first and second objectives were partially achieved in the first year.

One method of land preparation differed greatly from the others (Table 1). Preincorporation followed by plowing in moist soil produced almost 2 t/ha more than heavy harrowing (Rome plowing), the traditional method in the region, or direct plowing and preincorporation in dry soil. This result is impressive considering that the regional upland average yield is only 1.1 t/ha. All five varieties were tested only with preincorporation followed by plowing in moist soil. IAC 47 produced 0.3-1.2 t/ha more than IAC 165, CNA 791059, CNA 104-B-34-2, and CNA 790954. However CNA 104-B-34-2, which produced 2.6 t/ha, has more blast tolerance which may prove to be an advantage.

This work had its greatest impact in central Brazil where the three research areas of the project are located. After broadcasting the results on television, CNPAF received more than 20,000 letters from farmers asking for more information. Farmers have been quick to adopt preincorporation followed by plowing in moist soil because the method is not more expensive.

Production pilot unit and production programs

Often, problems noted in farmer fields are not of production, but of credit, marketing, management, and others. The close association of both kinds of

Table 1. Grain yields (t/ha) for five varieties and four land preparation methods (6).

Variety	Heavy harrowing[a]	Direct plowing	Preincorporation/ plowing in dry soil	Preincorporation/ plowing in moist soil
IAC 47[b]	1.10	1.21	1.23	3.11
IAC 165[b]	—	—	—	1.92
CNA 791059	—	—	—	2.47
CNA 104-B-34-2	—	—	—	2.84
CNA 79054	—	—	—	2.20

[a]Local traditional method. [b]Popular varieties.

problems at the farm level implies that any recommended agricultural technology evaluated only in terms of production may not be adopted by producers.

A goal of the production pilot unit is to identify institutional constraints in facilitating the dissemination of new technologies generated by CNPAF. Essentially we evaluate the institutional capacity in providing full profit opportunities from the use of the recommended new technology.

The production pilot unit is a 400-ha testing area in which the CNPAF experimental station simulates farmer management. Testing new technologies in this environment enables researchers to evaluate, for example, the effect of credit and market conditions on profitability and opportunity for utilization of the technology. Changes in agricultural policy can then be recommended on the basis of the limiting effect of these institutional variables. Modification of the credit system to meet the timing of capital needs and repayment capability associated with the use of rock phosphate fertilizer in upland rice illustrates the kind of information derived from the analysis of the production pilot unit.

Unfortunately, results from this research have not been fed to the government for a national production program for rice farmers. In fact, the official programs for the agricultural sector have not contributed to the increase in rice production in Brazil in the last few years.

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ADAPTIVE RESEARCH AND PREEXTENSION TESTING: THE CASE OF UPLAND RICE IN WEST AFRICA

T. P. FOTZO, D. S. C. SPENCER, and A. S. SANDHU

When WARDA was established in 1971, it was assumed that IRRI's high-yielding rice varieties could be imported and screened through the Coordinated Variety Trials (CVTs) carried out in member states. It was also assumed that IRAT program on upland rice at Bouaké, Ivory Coast, would produce improved varieties for WARDA and national programs (3). Because of its disappointing experience with the direct importation of new rice varieties from IRRI and heavy reliance on IRAT/IDESSA's (Institut de Recherche en Agronomique Tropicale (Research Institute for Tropical Agriculture)/Institut des Savanes (Savannah Institute) program at Bouake, WARDA, in 1981, launched the Technology Assessment and Transfer (TAT) program at all special research project sites in Sierra Leone, Mali, Senegal, and Ivory Coast. (Because of staffing and funding problems, TAT programs did not start at the same time at all sites; the TAT program at Bouaké, for example, started in June 1983.)

For the first time it was recognized that improved rice development programs to be successful should consider the existing cultural and socioeconomic situation under which the farmers operate. Also, as part of the technology development process, potential techniques should be tested on farmer fields to see if they could be economically adopted by farmers. By this process, technology appropriate to farmers' conditions and packages for easy transfer could be developed (1).

OBJECTIVES OF THE TAT PROGRAM

An important factor in the improvement of rice production in West Africa is to develop improved technology and to get it effectively used by rice farmers. Research scientists are becoming more conscious of the fact that the impact of a new technology is measured not by its performance in experimental plots but by the extent to which it is adopted by farmers on their farms.

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There is empirical evidence that when agricultural research is undertaken on crops without high levels of environmental control, substantial yield variations between the experiment station and farmer fields can be expected. There also is a gap between availability of improved technology from research stations and its actual application on the farms. Many research recommendations are not adopted by farmers and those that are adopted often fail to yield as high as they had on the research station.

There are many possible reasons for these yield gaps and the gaps between availability of the technology and its adoption. Although there is no agreement about the nature and relative importance of these causes, there is general consensus that some technologies evolved by agricultural scientists are not in line with farmers' objectives and may not fit into the social, economic, and production constraints especially in view of farmer attitudes, risk potential, and limited availability of most production inputs such as capital and labor.

There is growing concern regarding the need to extend the research process, to include assessment of the technology under farmer's socio-economic and production constraints. Feedback from farmers enables a direct farm-level input into technology design as well as testing the new technology under the different farm conditions in the target area. This also helps improve understanding of the technology-generating process. Such procedures are therefore important in developing production packages for dissemination by extension education agencies.

Technology assessment is especially important in African countries where communication links between farm and research is weak. Farmers often do not have the information and management experience and risk orientation to conduct and modify various technology components to suit their own environment, production systems, and socioeconomic constraints and personal preferences. The extension education system in most African states is generally weak and inadequate, and lacks facilities for experimentation and research to evolve an extension strategy for communicating improved technology to farmers. It is therefore necessary that the technology assessment phase also include designing and testing an extension approach for successful use by the national extension services, for the transfer of improved technology to farmers.

Thus the concept of technology assessment and transfer has twin objectives: evaluating the improved technology for suitability to farmers' socioeconomic and production needs; and devising and testing an extension education strategy for use by the extension organization of a country for transfer to farmers. The objectives of the TAT program can be summarized as follows:

- To systematically assemble information on the West African upland rice farmer;
- Collaborate with other scientists of the WARDA Station at Bouaké in designing and testing appropriate technological packages under farmer conditions for each rice production system and estimate the potential economic profitability of such technological packages;

- Monitor and evaluate the adoption of WARDA improved technology in development projects;
- Identify and examine major extension problems of rice industries of member countries and work with national extension services in solving such problems; and
- Encourage the establishment and efficient functioning of national seed multiplication projects for production of certified upland rice seeds and to supply those projects with good quality foundation seeds (3).

Methodology

Based on the above needs, the West Africa Rice Development Association (WARDA) has developed a TAT model which contains four phases (Fig. 1).

Phase 1 is a survey and analysis of basic background information on existing farming systems especially on the social, economic, and production constraints faced by rice farmers, as well as a prior evaluation of new technology.

Phase 2 and 3 identify the technological packages for each rice ecology in the region from research at the regional research station and various national programs operating in the region and tested under farm conditions against a set of evaluation criteria specifically developed for the purpose.

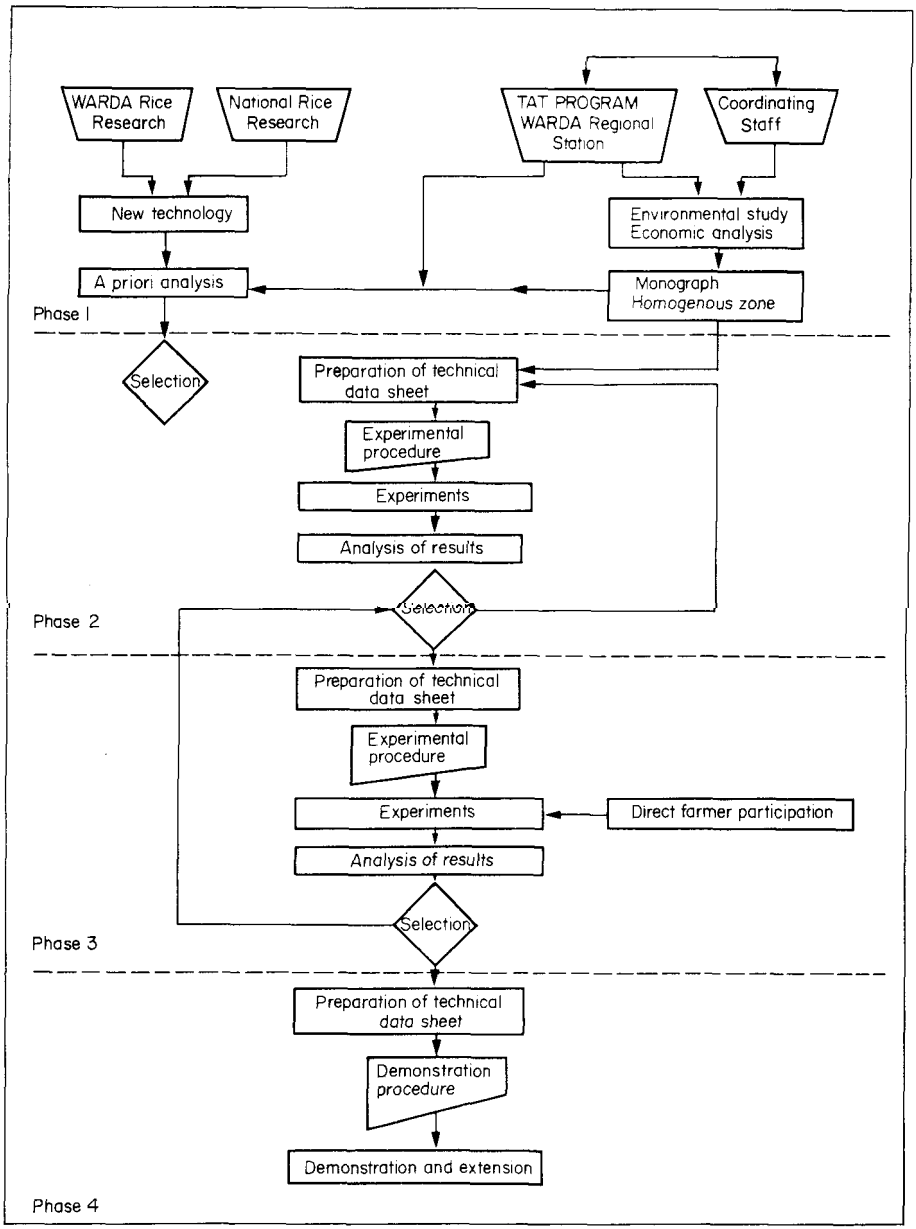
A 3-point criteria was developed for evaluating performance of the technology package: yield comparison, economic benefits, and socio-personal consideration, including labor use compatibility and general acceptance by the farmers. Furthermore, the package must prove it has good prospects to qualify for governmental assistance as needed when taken up by national extension services, and that necessary inputs in sufficient quantities will be available to farmers when needed.

Phase 4 involves designing and testing extension education strategy and farm demonstrations in collaboration with the national extension services in the member countries for communicating the tested technology to farmers. At that point, member countries take over the task of actual extension work.

Because most upland rice environments common to West Africa are in Ivory Coast, this country was used extensively (but not exclusively) during the first two phases of the TAT program. A three-pronged approach was used in the constraint identification phase:

- Collecting background information on farmer's environment from secondary sources such as research institutes and government reports.
- Exploratory field surveys involving personal interviews with farmers and input suppliers. Information on the rice production processes was obtained from local and regional institutions as well as from observations in farmer fields and their surroundings.
- Detailed socioeconomic surveys involving visits to farmers throughout the cropping season to complete the survey questionnaire. The frequency with which the farmers were formally interviewed depended on the type of information.

Testing innovations (i.e. design and analysis of on-farm trials), a series of steps was involved which subjects the technology being tested to the good



1. Functional analysis of TAT project.

and the bad that farmers are going to give it when, and if, it is adopted. The steps were designed to protect the collaborating farmers from risk when they participate in the evaluation of the new technology. Initially, researchers manage the trials (verification trials [VT]). In the final stages, farmers are the primary managers of the trials (adaptive trials [AT]).

The nature and design of on-farm trials change as we move from verification trials to adaptive trials. Critical variables considered include: number of treatments, plot size, number of replications, number of sites, type of management, control of variation, measurement of sources of variation, biologic precision and discrimination among variables, ability to test socioeconomic interaction, number of farmers, farmers' investments, and extension interaction with research.

Table 1 illustrates the differences between VT and AT.

AT are designed such that the farmer can do essentially all the management. The year after the AT, the TAT team can return to find out whether the previous year's collaborating farmers have used the new technology on their own initiative. Based on this simple survey, an *acceptability index* can be calculated. Data from VT and AT are analyzed by modified stability analysis, budgeting and partial budgeting, and in some instances, linear programming tools.

MAJOR CONSTRAINTS TO UPLAND RICE PRODUCTION

Upland rice production problems include the following:

1. Land
   - soil erosion, a problem throughout the subregion. It forces farmers to abandon their fields after cultivating them for only a few seasons;
   - inadequate water to grow rice due to drought which has been reoccurring in some parts of the subregion. Some farmers, particularly in the Sahel areas, have abandoned rice cultivation in favor of crops that can better withstand inadequate water supply, such as sorghum and millet; and
   - lack of inputs in some countries. In Ghana and Senegal, for example, some farmers have abandoned rice cultivation mainly because farm inputs such as implements and fertilizers are not available (1).

Table 1. Differences between verification trials (VT) and adaptive trials (AT). Adapted from (6).

Variable	VT	AT
1. No. of treatments	High	Low
2. No. of replications	High	Low
3. No. of sites	Low	High
4. No. of farmers	Low	High
5. Plot size	Low	High
6. Farmers' investment	Low	High
7. Extension interaction with research	Low	High
8. Control of variation	High	Low
9. Measurement of source of variation	Low	High
10. Researchers' management	High	Low
11. Farmers' management	Low	High
12. Biologic precision and discrimination among variables	High	Low
13. Ability to test socioeconomic interaction	Low	High

2. Paddy yield. Problems related to paddy yield are the same as those related to land. There are other factors responsible for low paddy yield:
   - Technical problems
     - lack of improved cultural practices, for instance, inadequate weed control and poor land preparation (1, 4),
     - inadequate use of modern and improved inputs, such as good quality seed, fertilizers, and chemicals for seed treatment, because of nonavailability, and
     - widespread crop damage caused by insects and diseases resulting from inadequate crop protection.
   - Institutional, infrastructural, and economic problems
     - poor extension services,
     - inadequate mechanization facilities to support land preparation, and
     - inadequate credit facilities for the predominant small-scale farmers to purchase modern and improved inputs.

UPLAND RICE TECHNOLOGICAL PACKAGES UNDER TEST

WARDA has established a regional upland rice research station at Bouaké, Ivory Coast, to research upland rice for the West African region (March 1983). In addition, it collaborates with IDESSA, whose Food Crop Department has been responsible for the rice improvement program. As a result of this collaborative work, seven varieties (IRAT 144, IRAT 104, IRAT 112, IRAT 109, IRAT 170, IRAT 136, and IRAT 13) have been recommended for upland cultivation. Some of these varieties are now being multiplied by Development Corporations in the Ivory Coast for use by farmers who are still using Moroberekan, Iguape Cateto, and Dourado. Elsewhere in the region, varieties recommended as a result of WARDA research included: 63-83, DJ8-341, LAC 23, LAC 23 (white), IRAT 8, IRAT 9, IRAT 10, and OS6. For most of these varieties, little empirical evidence is available as to the gap between existing practices on West African rice farms and available technologies. With establishment of the upland rice research program at Bouake, the TAT program is designed to provide information on the actual gap under farmer conditions, for different ecologies and intensification levels. Research on significant aspects including varietal improvement, agronomy, insects and diseases, weed control, etc. is done under farmer conditions. The following packages have been identified in 1983 for testing in VT in 1984.

- Low level input technology
  - Land preparation: hand tools.
  - Varieties: IRAT 112, IRAT 104, and IAC 164.
  - Fertilizer: urea (75 kg/ha in 2 applications).
  - Other practices: Farmers' practices in the area (1, 5).

- High level input technology
  - — Land preparation: animal traction or use of tractors.
  - — Varieties: IRAT 109, IRAT 170, IAC 164.
  - — Weeding: use of herbicide (4 liters Ronstar/ha).
  - — Fertilizer: NPK (10-18-18) (150 kg/ha) and urea (75 kg/ha).
    Note that in both levels of technology, 4 seed rates (60 kg/ha, 80 kg/ha, 100 kg/ha, and 120 kg/ha) were used.
- Other practices: Farmers' practices in the area (2, 5).

The trials were distributed across various ecological zones (Table 2).

However, many problems and constraints are not being tackled through ongoing research, for example, long-term soil and crop management practices, long-term yield maintenance studies, rice interaction with other crops. Furthermore, during the 1985 cropping season, the technological packages to be tested will be broken into four subpackages: (1) improved variety only, (2) improved variety + fertilizer, (3) improved variety +fertilizer + herbicide, and (4) improved variety + fertilizer + herbicide + mechanical land preparation (Farmers often adopt new improved technology in bits and pieces).

CONCLUSION

The demand for rice as a staple food in the West African region has tremendously increased. To meet this increased demand, WARDA is doing research in four major rice ecologies of the region, mainly mangrove, swamp rice, deep water and flooded rice, upland rice, and irrigated rice. Major emphasis is now on upland rice research. Because detailed results of the 1984 trials are not yet available, little can be said about the performance of the packages tested. There is no substitute for adaptive research in increasing the probability of adoption of improved technology. Adaptive research should be part of the various research institutes, and not left for the extension services.

Table 2. Distribution of trials in Ivory Coast, 1984 (2).

Site	Latitude and vegetation	Rainfall pattern	Trials (no.)	Input level
Guiglo	6° 50' forest	1600-1800 mm bimodal	6	Low
Man	7° 20' forest	1600-1800 mm monomodal	6	Low
Touba	8° savannah	1300-1500 mm monomodal	18 → 10	Low
			→ 8	High
Odienne	10° 20' 9° 40'	1200-1400 mm monomodal	12 → 4	Low
			→ 8	High
Boundiali	9° 50'	1200-1400 mm monomodal	12 → 5	Low
			→ 7	High

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RESEARCH AND PRODUCTION OF UPLAND RICE IN COSTA RICA

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Rice is an important component in the Costa Rican diet; per person consumption is 52 kg of milled rice per year. Rice self-sufficiency has been a concern of all governments since the beginning of this century. But it was not until the 1940s that rice research and crop management began, infrastructure and mechanization were developed, and credit and production and marketing policies were established.

Rice research was initiated in 1940 when the Ministry of Agriculture and Husbandry created the Socorrito Experimental Station in Puntarenas Province, a main rice area of the country. Later the research activities were moved to the Enrique Jimenez Nuñez Experiment Station in Cañas, Guanascaste, where the rice program continues and includes pathology, entomology, mineral nutrition, weed control, and basic seed production.

This paper discusses Costa Rica's rice zones and production systems, objectives of rice research programs, the impact of modern varieties on production, and production and marketing policies.

PRODUCTION ZONES

Costa Rica has concentrated rice production in three zones, two on the Pacific Coast and one on the Atlantic Coast.

Northern Pacific zone

Classified as tropical dry forest, the northern Pacific zone has two defined seasons, one dry from December to April, and the other wet from May to November with 1800 mm of rainfall although short periods of drought may occur in July and August. The soils are alluvial along the Tempisque river valley and its tributaries. Vertisols occur in the remainder of the area; texture varies from sandy loam to clay with an average pH 6.2.

Sixty percent of Costa Rica's total rice area (88 351 ha in 1983) is in this zone.

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Southern Pacific zone

The Southern Pacific zone is classified as tropical humid forest with an annual average rainfall of 3500 mm. Soils are of alluvial origin, flat and deep, brown and moderately clayed. In some areas soils have high copper concentrations toxic to rice.

This zone accounts for 30% of the total rice area.

Atlantic zone

The Atlantic zone is classified as tropical humid forest, with 2500-3000 mm of rainfall from May to February. Soils are of alluvial origin, flat and deep, and moderately clayey in texture. Ten percent of the total rice area is concentrated here.

PRODUCTION SYSTEMS

Mechanized upland

More than 95% of the rice area in the country is upland rice and is highly mechanized on large holdings.

Seeding and basal fertilization are drilled with subsequent practices (weed control, N fertilization, and fungicide and insecticide applications) carried out by terrestrial equipment or airplanes. When wet soil conditions do not permit use of terrestrial equipment for seeding, it is done by broadcasting dry or pregerminated seed by airplane. Harvesting is completely mechanized using different types of combines.

Manual upland

A system representing less than 2% of the total rice area consists of small farmers who manage the crop manually. This system is concentrated in undulating areas between 500 and 1000 m elevation. Farmers do not use inputs and production is for subsistence.

Irrigated

The irrigated system is about 3% of the total rice area and is completely mechanized in large holdings. On dry soil, dry seed is directly seeded; on wet soil, pregerminated seed is broadcast by airplane.

OBJECTIVES AND RESEARCH ACTIVITIES

The main objective of the rice program in Costa Rica is to achieve self-sufficiency through development and use of appropriate technology for upland areas and to increase and stabilize production and productivity.

To accomplish this objective, research activities focus on accomplishing the following.

1) Develop varieties for the upland system with:
   - high efficiency at low input levels;
   - increased resistance to pests, including blast *(Pyricularia oyzae)* and leafhoppers *(Sogatodes oryzicola);*

- resistance to lodging and shattering;
- early maturity (110-120 days) and good milling and cooking quality;
- tolerance for short drought periods.

2) Study and establish economic damage caused by diseases, insects, weeds, and soil nutritional problems, and
3) Develop integrated management to overcome production constraints.

RESEARCH PROGRAMS

Varietal improvement

In Costa Rica, varietal improvement has been fundamental in trying to attain self-sufficiency.

Most resources were devoted to evaluating, selecting, and testing segregating and advanced materials introduced from international institutions, mainly from CIAT and IRRI. Help of these international centers permitted selection of promising materials for direct use as varieties and to identify entries with specific characteristics for breeding.

The program has evaluated 5658 entries and selected 376 from IRTP nurseries of IRRI and CIAT since 1977. Most were discarded due to instability under upland conditions. However, from germplasm introduced since 1982, a total of 49 promising entries (Table 1) were selected for further tests.

Farmers participate in regional trials. They provide land and its preparation and finance all management practices from seeding to harvest. These regional trials are in different ecologic sites of the country's main rice areas.

Nomination of varieties

When materials superior to commercial varieties are identified by evaluation and selection, a best line is nominated to be designated a variety. A qualifying committee studies all information available about the potential new variety. Upon approval the committee recommends official release of the new variety by the Board of Trustees of the National Seed Unit. This Unit proceeds then to produce registered and certified seed for commercial production.

In the 1970s, first quinquennial, the rice program recommended IR8, IR22, and CICA 4, and in the second quinquennial CICA 6, CICA 7, and CICA 9 were recommended. At the same time CR 1113 and CR 5272 were released by the program. These two varieties were selected from segregating material introduced from CIAT. Also, from these materials the program selected the variety CR 201 released in 1981 and anew variety, CR 1821, for official release in 1985.

Crop management

Laboratory, greenhouse, and field tests were conducted to determine critical levels and economic dosages of fertilizers. For N, for example, the critical

Table 1. Promising materials selected from IRTP nurseries for Latin America to be evaluated in 1985 regional trials in Costa Rica.

C. R. No.	Pedigree	Origin
1827	P 1386-2-6M-5-1B	VIOAL-SNF, 1982
1828	P 2053 F4-14-2-1B	VIOAL, 1982
1830	P 2053 F4-169-8-1B	VIOAL, 1982
1831	P 2057 F4-88-3-1B	VIOAL, 1982
1834	P 2217 F4-1-1B	VIOAL, 1982
1835	P 2220 F4-28-1B	VIOAL, 1982
1838	P 1383	VIPAL, 1980
1864	P 2058 F4-47-3-1B	VIOAL, 1983
1867	P 2060 F4-49-4-1B	VIOAL, 1983
1873	P 2053 F4-99-44-1B	VIOAL, 1983
1884	P 3293 F4-96	VIOAL, 1983
1885	P 3295 F4-94	VIOAL, 1983
1892	P 3081 F4-58	VIOAL, 1983
1895	P 3082 F4-4	VIOAL, 1983
1898	P 3983 F4-61	VIOAL, 1983
1901	P 3084 F4-34	VIOAL, 1983
1906	IR 13358-67-3-2	VIOAL-SNF, 1983
1913	P 2231 F4-138-2-1B	VIRAL-T, 1983
1914	P 2231 F4-138-2-1B	VIRAL-T, 1983
1918	P 2231 F4-45-83-3-1B	VIRAL-T, 1983
1919	P 2057 F4-88-3-1B	VIRAL-T, 1983
1921	P 2231 F4-4-7-1B	VIRAL-T, 1983
1922	P 2060 F4-2-5-1B	VIRAL-T, 1983
1929	IR 4427-3 15-2-3	VIOAL-HB, 1983
1976	P 2231 F4-13-2-1	VIOAL, 1984
1993	P 2060 F4-49-4-1B	VIOAL, 1984
1995	P 2862 F4-119-2	VIOAL, 1984
2017	P 3059 F4-91-2	VIOAL, 1984
2019	P 2867 F4-47-1	VIOAL, 1984
2022	P 2867 F4-52-2	VIOAL, 1984
2025	P 2862 F4-53-4	VIOAL, 1984
2047	P 2231 F4-13-2-1B	VIOAL, 1984
2055	P 2153-276-1-10-PR 509	VIOAL, 1984
2056	P 2231 F4-45-5-4	VIOAL, 1984
2077	P 3282 F4-33-2	VIOAL, 1984
2098	P 2192 F4-39-5-1B-1	VIOAL, 1984
2106	P 3081 F4-58-3	VIOAL, 1984
2108	IR 19670-263-3-2-2-1	VIOAL, 1984
2112	P 3082 F4-18	VIOAL, 1984
2125	P 2867 F4-1-3	VIOAL, 1984
2129	IR 27315-19-3-3	VIOAL, 1984
2141	PNA 235 F4-66-1	VIOAL, 1984
2142	P 3082 F4-73	VIOAL, 1984
2148	P 2054 F4-26-4	VIOAL-SNF, 1984
2149	P 2056 F4-59-2	VIOAL-SNF, 1984
2197	P 2231 F4-138-6-2-1	VIRAL-T, 1984
2199	P 2057 F4-88-3-1B	VIRAL-T, 1984
2201	P 2231 F4-138-2-1B	VIRAL-T, 1984
2202	P 2231 F4-128-6-1B	VIRAL-T, 1984

levels varied with varieties and soil fertility. Split applications are basic in upland conditions. In general, dosages in the range of 80-30-0 and 150-60-30 are recommended for the rice crop in Costa Rica.

Deficiencies and toxicities of certain nutrients are under study. Deficiencies of S, Fe, Zn, and Mn have been observed. Cu toxicity is being observed in rice areas planted to banana previously where heavy applications of Cu compounds were made to control banana diseases.

Gramineous weeds (*Echinochloa colona* and *Rottboellia exaltata*) and cyperaceae (*Cyperus rotundus*) are a serious problem in upland rice in Costa Rica. Several pre- and postemergent herbicides and mixtures for control were tested and farmers make use of ensuing recommendations. Also, timing applications of postemergent herbicides were studied.

Varietal resistance has been the main factor to control diseases and insects. However, chemical control was studied as a complementary and preventive measure to diminish blast incidence. Results with some fungicides demonstrated increased productivity and better grain quality when two applications of fungicides were made, one at flowering initiation and the other 10 d after flowering.

PRODUCTION OF CERTIFIED SEED

In 1978 a National Seed Unit for seed certification was established. This institution initiated production and rice seed certification beginning with CR 1113. Basic seed of rice varieties produced by the program at the Experimental Station is handled through the National Seed Unit to produce registered and certified seed through the National Production Institute or private enterprises. Use of certified seeds has diminished problems of varietal mixtures, red rice, and noxious weeds which affected production severely.

Table 2 presents the utilization of improved and certified seed of different varieties from 1970 to 1983.

IMPACT OF MODERN VARIETIES

Introduced rice varieties during the first half of this century in Costa Rica were susceptible to blast and *Sogatodes.*

During the 1950s several varieties, known as Americanas, were introduced from the United States. They were grown only for a short period because of their susceptibility to blast and hoja blanca. Later, in the 1960s, Surinam varieties (Tapuripa and others) were introduced for commercial production but they were susceptible to *Sogatodes,* hoja blanca, and lodging.

At the end of the 1960s IR8 was introduced. It created a true revolution in productivity and farmers were forced to modify their concepts and management methods to obtain maximum yield potential from this variety. Farmers were so influenced by IR8 that even now they have little interest in tall varieties which are susceptible to lodging.

Table 2. Utilization of improved seed for commercial production from 1970 to 1983 in Costa Rica.

Year	Main variety	Improved seed (t)
1970	Tapuripa	780
1971	IR8	1910
1972	IR22	2287
1973	CICA 4	2469
1974	CICA 4	4060
1975	CR 1113	6753
1976	CR 1113	6770
1977	CR 1113	6057
1978	CR 1113	7569
1979	CR 1113	7841
1980	CR 1113	8152
1981	CR 1113	7338
1982	CR 1113	9050
1983	CR 1113	8847

Sources: National Seed Unit and National Production Institute.

Table 3. Rice area, production, and productivity in Costa Rica, 1957-83.

Year	Area		Production		Yield	
	Annual average (thousand/ha)	Increase (%)	Annual average (thousand/ha)	Increase (%)	Annual average (t/ha)	Increase (%)
1957-59	40.8	–	36.1	–	0.83	–
1960-64	49.7	21.6	47.0	30.2	0.95	8.0
1965-69	44.8	– 9.8	54.0	14.9	1.21	27.4
1970-74	72.8	62.6	101.0	87.0	1.39	14.9
1975-79	79.1	8.5	189.0	87.1	2.39	71.9
1980-83	80.5	1.8	219.0	15.9	2.72	13.8

The rice area and production during 1957-83 are presented in Table 3. Surinam varieties replaced American varieties from 1960 to 1964. This adoption increased the area (21.6%) and productivity (8.0%). As a result of IR8 adoption during 1965-69, area decreased (9.8%) but production increased substantially (14.9%) and productivity went up (27.4%) in comparison to 1960-64.

During 1970-74, IR8 continued and IR22 and CICA 4 were introduced. Largely because of these varieties, increases in area (62%) and in productivity (15%) were recorded. During this period droughts and blast severely affected rice production and farmers were forced to change varieties. They adopted CR 1113, released by the program in 1973. The adoption of CR 1113 during 1975-79 increased production by 87.0% and productivity by 72.0% in relation to 1970-74 period.

The increase of production and productivity during 1980-83 are due to high adoption (85-97% of total area) of CR 1113.

Table 4. Distribution and yields of main rice varieties cultivated in Costa Rica, 1970-83.

Year	Total area (thousand/ha)	Main variety	% of total area	Average national yield (t/ha)
1970	62.7	Tapuripa	35.45	1.14
1971	64.3	IR 8	65.81	1.44
1972	86.1	IR 22	43.55	1.13
1973	71.5	CICA 4	76.04	1.63
1974	79.5	CICA 4	84.43	1.59
1975	87.1	CR 1113	94.74	2.25
1976	80.1	CR 1113	94.46	1.87
1977	71.0	CR 1113	95.69	2.37
1978	75.7	CR 1113	77.92	2.59
1979	81.2	CR 1113	62.84	2.92
1980	84.6	CR 1113	85.06	2.88
1981	72-3	CR 1113	97.92	2.79
1982	76.6	CR 1113	94.86	1.94
1983	88.3	CR 1113	89.64	3.17

Source: National Production Institute and National Seed Unit.

Table 5. External marketing of milled rice (thousand t) in Costa Rica, 1955-83.

Year	Imports	Exports	Balance
1955-59	28.3	-	- 28.3
1960-64	1.0	0.9	- 0.1
1965-69	23.5	7.2	- 16.3
1970-74	23.1	12.0	- 1.1
1975-79	0.7	130.6	+ 129.9
1980-83	25.2	94.2	+ 69.0

Source: Economic and Statistics Department, Ministry of Agriculture and Husbandry.

Table 4 presents the distribution and yields of main varieties cultivated during 1970-83.

Use of high-yielding varieties, certified seed, good management, adequate infrastructure, and good production policies are the main factors that contributed to Costa Rica's self-sufficiency in rice since 1975, enabling it to export surplus production and maintain modest and sufficient reserves for calamities and stabilizing internal prices (Table 5).

PRODUCTION POLICIES

Considering that rice is basic in the diet of Costa Rica's population, the government established certain policies to increase production and achieve self-sufficiency. These policies are related to farmer's credit, crop insurance, support prices, and marketing. The national monetary banks assigned

annually a credit representing 66% of production costs. To provide this credit, banks demand that farmers insure their crop. This insurance is given by a National Insurance Company to farmers who signed a contract for utilizing the recommended technology making emphasis in the use of certified seed.

The support price policy is fixed annually by government before planting time. Thus, rice farmers know in advance what price they will get for the paddy production. Rice marketing is done directly by farmers with private enterprise in charge of processing and milling, or with the official entity, the National Production Institute, purchasing the paddy.

TRAINING IN UPLAND RICE

P. C. GUPTA, J. C. O'TOOLE, and S. K. DE DATTA

Information on upland rice is scanty and variable because of the diverse nature of the crop's environment. Due to the diverse environment, technologies that have evolved are limited to a specific agroecosystem. Most of such technologies are confined to isolated pockets. Recent efforts by the International Rice Research Institute (IRRI) and other national and international centers to spread technologies in similar areas of the world have broadened the scope for improving upland rice productivity.

The development and spread of appropriate technologies call for human resource development. Trained manpower — for both upland rice research and extension — is limited. The upland rice training program at IRRI basically aims at strengthening the human resource development of various national centers involved.

Historical background

Training in upland rice is a recent endeavor. Previously, it was only a small portion of general rice production courses offered by many international agricultural research centers (IARCs). Courses on general rice production were given by IRRI, IITA, CIAT, and WARDA prior to the Upland Rice Workshop, Bouaké, Ivory Coast (4-8 March 1982) (1, 2, 5, 7, 10). Rice production training program (RPTP) of IRRI is almost 20 yr old now.

The duration of these rice production courses varied from a few weeks to nearly 6 mo. Rice production under different ecologies: irrigated, rainfed, and upland conditions, was emphasized. In certain cases, trainees were given a basic concept of rice production (multidisciplinary phase) for some time and later they branched into different specialized areas (specialized phase) for individual internship (2). In other cases, rice production courses were conducted off-site in collaboration with national agencies (5).

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A regional training course on improved cultural practices for upland rice was organized at Chiang Mai, Thailand, 5–23 October 1981. The course was jointly organized by the United Nations Development Program (UNDP), Food and Agricultural Organization of the United Nations (FAO), and Northern Region Agricultural Development Center, Thailand. The objective was to provide orientation and information on the latest developments in the practical aspects of upland rice production in the region. Sixteen participants from seven countries of South and Southeast Asia: Bangladesh, Burma, India, Indonesia, Malaysia, Philippines, and Thailand attended the course (3).

The Upland Rice Workshop, Bouake, Ivory Coast (9) recommended strengthening the existing training programs in upland rice. Three levels of training programs were visualized:

- Training for farmers and junior officers must be conducted by national programs.
- Training programs for intermediate and junior researchers and senior extension officers must be conducted by national and regional organizations and by the international organizations situated in upland rice areas.
- Training programs at a high scientific level (MS, Ph D) should be conducted by International and national institutes such as IRRI, IITA, GERDAT, and at African, Asian, European, and American universities.

The workshop also recognized IRRI's proposal to establish an upland rice training course at IRRI to train the trainers and to develop training methodology. The workshop also emphasized the need to take upland rice–based farming systems as the basis of training and wanted the national governments to develop incentives to strengthen and stabilize the rice research staff. It also made an appeal to the donors to finance the national programs on upland rice training.

Upland Rice Training at IRRI

IRRI provides two types of training for upland rice researchers:

1. Research oriented, (postdoctoral fellowships), and degree programs (MS, Ph D)
2. Formal course.

Research-oriented training program

IRRI postdoctoral fellowships provide scientists from national crop improvement programs an opportunity to update their skills, techniques, and knowledge on research in rice and rice–based cropping systems. A survey of IRRI annual reports (6, 7, 10) provides data on research-related training courses for upland rice. Thirteen postdoctoral fellows have worked on upland rice–related problems up to 1983 (Table l), four in agronomy, five in plant pathology, one in multiple cropping, and three in plant physiology. In addition, nine research fellows/post master fellows researched upland

Table 1. Summary of participants in research oriented training programs related to upland rim at IRRI, 1962-83.

Department	Level of research				No. of participants (total)
	MS	Ph D	Research fellow /postmaster	Postdoc	
Agronomy	8	3	4	4	19
Plant Breeding	2	-	-	-	2
Plant Pathology [a]	6	1	3	5	15
Multiple Cropping	3	1	1	1	6
Plant Physiology	-	-	1	3	4
Agricultural Economics	2	-	-	-	2
IRTP	1	-	-	-	1
IRGC	1	-	-	-	1
Total	23	5	9	13	50

Source: (6, 7, 10). [a] Mainly on blast. No distinction is made between upland and lowland rices.

rice in the departments of agronomy, plant pathology, multiple cropping, and plant physiology.

Most masters (MS) and doctor of philosophy (Ph D) study programs are planned with the University of the Philippines at Los Baños (UPLB) or with other universities with which IRRI has cooperative arrangements for degree training. The general policy is that the MS students complete course work at universities in developing countries with which IRRI has cooperative arrangements for graduate programs, but selected Ph D students requiring more specialized courses take either their entire or part of course work at universities in developed countries.

As a general policy all thesis work is done at IRRI. On recommendation of IRRI advisers, however, students may conduct their research in their home countries or at outreach sites in the Philippines where IRRI has experiments (8).

During 1962-83, a total of 23 students worked for their MS degree in upland rice-related problems (Table 1). The largest number, eight, was in agronomy, followed by six in plant pathology, three in multiple cropping, two each in plant breeding and agricultural economics, and one each in IRTP and IRGC. Five students worked for their Ph D degrees, three in agronomy and one each in multiple cropping and plant physiology.

Formal training course in upland rice (URTC)

As a follow-up of recommendations of the Upland Rice Workshop, Bouaké, IRRI developed a 16-wk formal training course in upland rice. It is designed to provide training in the principles of rice production and research under upland conditions with emphasis on varietal improvement through increased resistance to/tolerance for drought, rice blast disease, and problem soils; crop management, and knowledge of specific soil and water management problems.

The first upland rice training course was from 23 May to 8 September 1983 and the second course from 23 July to 8 November 1984.

Participants

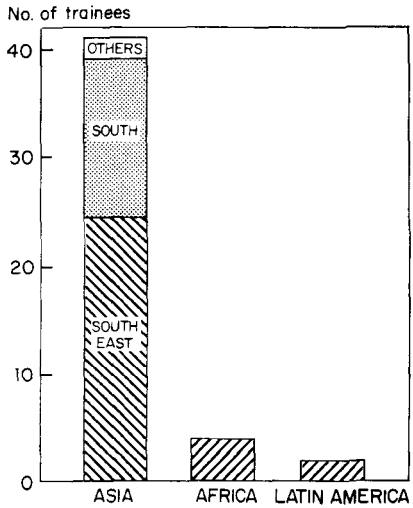
Twenty-eight agricultural scientists from 15 countries participated in the first (1983) upland rice training course and 18 agricultural scientists from 9 countries took part in the second course in 1984 (Table 2). Most of the trainees, 82% in the first course and 94% in the second course, were from Southeast and South Asian countries (Fig. 1). In the 1983 course three trainees were from Africa and two from Latin America; in the second course only one trainee came from Africa and none from Latin America.

Qualification of participants ranged from high school diploma to Ph D degree. On an average 76% of the participants had BS or MS degrees. Thirteen percent had Ph D degrees and 11% had less than a BS degree (Fig. 2). Most participants (48%) claimed to be working in agronomy at their home stations, 17% in plant breeding, 15% in agricultural extension, 7% each in plant physiology and pathology, 4% in entomology, and 2% in agricultural engineering (Fig. 3).

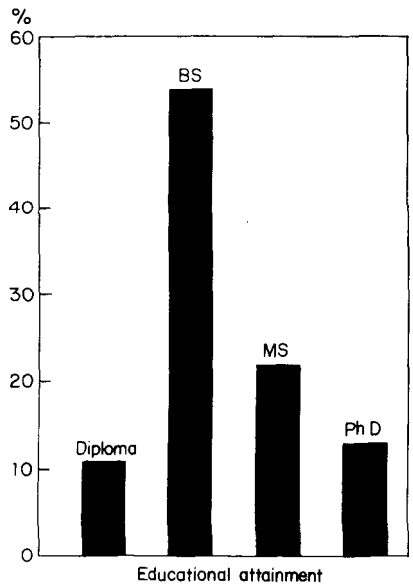
Participants' age ranged from 24 to 51 yr in 1983 and 27 to 49 yr in 1984. More than 50% of all the participants were 30-40 yr old, 28% were less than 30 yr old, 17% were 40-50 yr old, and 2% were more than 50 yr old (Table 3).

Table 2. Participants in first and second upland rice training courses at IRRI.

Region/country	Number of participants		Total
	URTC-83	URTC-84	
Asia			
Bangladesh	1	–	1
Burma	2	1	3
India	5	4	9
Indonesia	3	3	6
Iraq	1	–	1
Malaysia	1	1	2
Nepal	1	2	3
Philippines	4	3	7
Sri Lanka	2	–	2
Thailand	2	2	4
Vietnam	1	1	2
Africa			
Sudan	1	–	1
Nigeria	2	–	2
Kenya	–	1	1
Latin America			
Brazil	1	–	1
Mexico	1	–	1
Total	28	18	46



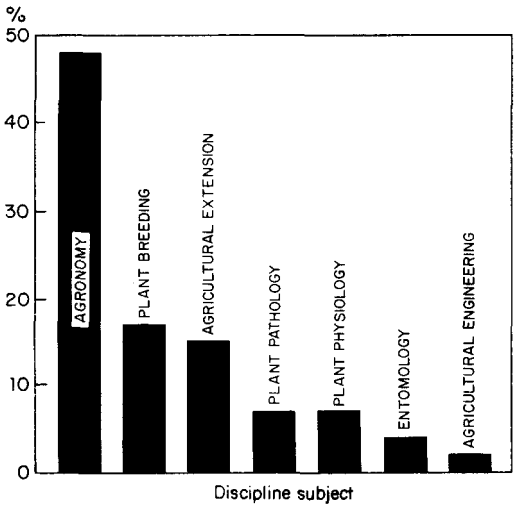
1. Total number of URTC trainees from different regions, 1983-84.



2. Distribution of URTC trainees by educational attainment, 1983-84.

Table 3. Age group of URTC participants.

Age group	Number of participants		Total	%
	URTC-83	URTC-84		
Below 30 years	9	4	13	28
30 - 40	16	8	24	52
40 - 50	2	6	8	17
above 50	1	–	1	2



3. Distribution of trainees by discipline, 1983-84.

Course

The course is organized into these major disciplines:

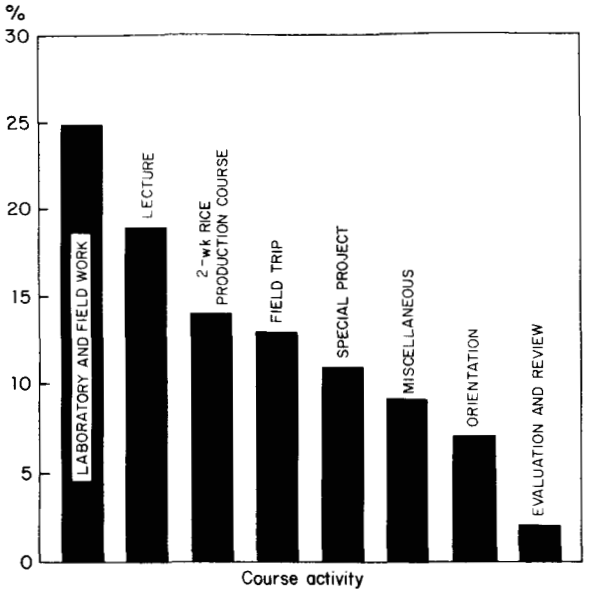
- upland rice distribution,
- upland rice-based cropping systems,
- upland rice environment,
- upland rice soil,
- varietal improvement,
- soil management,
- plant physiology,
- agronomic practices,
- farm equipment,
- disease management,
- insect pest control,
- agricultural economics,
- field experimentation, and
- communication.

Each discipline was further organized into lectures and laboratory or field exercises (4).

Organization and implementation

Training activities were organized into:

- classroom lectures,
- laboratory/field exercises,
- field work,
- observation and evaluation of upland rice varieties and experiments at IRRI farm,
- field trips to upland rice growing areas and experiments in the Philippines, and
- special project work.



4. Distribution of total training time by activity, 1983-84.

Training activities were grouped into a general package of interdisciplinary subject matter given to all trainees, and a special project designed to increase the skill and technique of individual trainees in their specialized area of research. In special project work every trainee is assigned to a scientist working in the same area of specialization. The trainee under the guidance of the scientist plans and conducts a small experiment to learn the modern methods and techniques of research.

A comparison of hours devoted to different activities in Table 4 shows about 500 h for different training activities in 1983 and 1984. Laboratory exercises and field work took the maximum time in both courses. Overall, 25% of the time was devoted to laboratory and field work, 19% to lecture, 13% to field trip, 11% to special project work, 14% to 2-wk rice production course, 9% to miscellaneous work, 7% to orientation, and 2% to evaluation and review (Fig. 4).

Evaluation and grading

Objective evaluation was an integral component of the upland rice training program. It provided grading of the trainees and also helped the training staff to continuously update the training material. Trainees' performances were evaluated in the following:

1) Bench mark test. This was administered at the beginning of the course and was not included in the grading.
2) Written test. The written tests included short quizzes, midterm, and final examinations. They constituted about 30% of the final grade.
3) Field and laboratory exercises. Trainees were graded in the laboratory and field practicals which constituted about 25% of the grade.

Table 4. URTC activities by hours.

Activity	1983		1984	
	Hours	%	Hours	%
Orientation	32	6	35	7
Two-week rice production course	70	14	70	14
Lecture	117	23	78	16
Laboratory exercises and field work	153	30	100	20
Special project	24	5	91	18
Field trip	56	11	70	14
Evaluation and review	7	1	15	3
Miscellaneous (classbriefing, country seminars, report writing, etc).	44	9	42	8
Total	503		501	

4) Special project reports. Advisers of special projects evaluated the performance of trainees in conducting the experiment and presenting the results in the form of a report. This constituted 25% of the final grade.
5) Performance in a 2-wk rice production course was given a weight of 10% of the final grade.
6) Another 10% of the grade was for oral presentation of reports, attitude, and general interest of the trainee.

Three types of achievement certificates were awarded:

Completed with distinction. All trainees who achieved excellence in their performance were awarded this certificate.

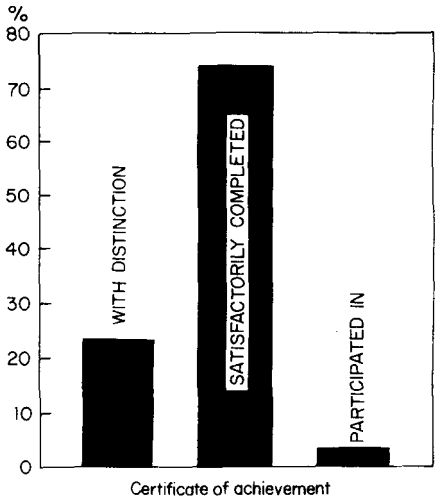
Satisfactorily completed. All trainees who achieved average performance were awarded this certificate.

Participated in. All trainees who merely went through the course were awarded this certificate.

The percentages of achievement certificates of 1983 and 1984 upland rice course trainees are in Figure 5. The performance in both years was similar.

Resource persons

Most of the resource persons for both courses were IRRI senior and junior staff. In the 1983 course, four guest speakers, one each from IRAT, IITA, WARDA, and EMBRAPA (Brazil), presented the information on upland rice in their respective regions. Three speakers were invited from the University of the Philippines at Los Baños. In the 1984 course, guest speakers also from IITA, WARDA, IRAT, and EMBRAPA lectured to the trainees an upland rice problems and prospects of their respective regions. One lecturer, who worked as a private consultant in agriculture, spoke on hill agriculture in Nepal. Slightly more than 50% of lectures and exercises were handled by senior and guest speakers in 1983 and 1984 courses.



5. Distribution of achievement certificates of URTC trainees, 1983-84.

Two-week rice production course

A 2-wk rice production course, emphasizing management strategies of rice under lowland conditions, is also integrated with the upland course to expose trainees to production problems under all ecologies — lowland and upland. In many countries trainees are concerned not only with upland ecology but also with other rice ecologies. In the 1983 course, the 2-wk rice production course was given at the beginning, right after the orientation program, while in the 1984 course it was given near the end.

Evolution of training literature

One constraint observed in the upland rice training program was unavailability of published information on upland rice. We started to collect all the available information on upland rice in the world irrespective of publication or language status shortly after the completion of the first course. We wrote to upland rice workers throughout the world to share their information with us. This information has been abstracted and a book on upland rice will be published shortly by IRRI.

Effective learning also requires organizing the material into learning sets called discipline modules. The discipline modules are further organized into performance or learning objectives. These performance objectives bind the trainees to learn the concepts behind them. Performance objectives for the upland rice training course have been prepared with the help of the resource persons of the first course and IRRI has published *Performance Objective: Upland Rice Training Course.* The performance objectives and the upland rice book, together will greatly help in teaching the upland rice course.

Feedback

A dynamic approach continuously updates the course content at IRRI. At the end of each course, the trainees evaluated the course content. Based on

this evaluation, the next course content was updated. Based on trainee suggestions from the first course, the lecture component of the second course was reduced from 23% to 16%. The time allocation for special projects in the second course was increased from 5% to 18%.

The trainees appreciated the participation of scientists from international agricultural research centers in conducting the upland rice training courses at IRRI as the information available is mainly for South and Southeast Asia. Guest speakers from IITA, IRAT, WARDA, and EMBRAPA (national center of Brazil) explained the problems and prospects of upland rice production in their respective regions to the trainees. This exposed the trainees to different environments and management constraints in which upland rice is grown in the world.

Suggestions and issues for consideration

Upland rice technologies are globally variable. For realistic training in upland rice the trainees should be exposed to management problems of different environments. The experiences gained in conducting the first and second courses at IRRI provided some insight into this. The following issues need consideration:

- Increased intercenter collaboration in upland rice training in terms of guest lecturers and exchange of training materials.

URTC has been developed with the collaboration of IARCs working on upland rice. IITA, WARDA, and IRAT provided their scientists as speakers for the first and second courses. EMBRAPA (national center of Brazil) also provided a speaker. CIAT could not provide a speaker. While coverage of upland rice information from the African region was inadequate, that from Latin America was less so. Ways should be found to further strengthen intercenter collaboration in sharing information.

Seeds of important cultivars were obtained from IITA, CIAT, IRAT, and EMBRAPA for the URTC varietal trial. This provided the trainees an opportunity to observe and evaluate upland rice cultivars grown in different environments all over the world. This collaboration should be continued further with the sharing of new cultivars and breeding lines developed by IARCs. The IARCs can also help in upland rice training by sharing the technical information on upland rice. IRAT provided two publications: *Upland Rice* and *Rice Blast and its control* for distribution to the trainees. These are excellent reference materials and were well received by the trainees. This should be further strengthened.

- Increasing participation of trainees from West Africa and Latin America.

  The number of trainees from Latin America and West Africa has been less than the available slots. In the first course, only two trainees from Latin America and two from West Africa participated, although there were four slots for each region. In the second course no one from Latin America or West Africa participated despite allocations of four for Latin America and three for West Africa. We should find ways to

increase the number of trainees from Latin America and West Africa.

- Strengthening national and regional courses in upland rice as a complementary to URTC at IRRI.

Upland rice is grown in diverse environments, hence national and regional training programs should be developed and strengthened to focus attention on local problems. The course at IRRI should provide training to upland rice workers more at the principles and generalization level. Local problems should find places in regional and national courses. The training courses at IRRI and national and regional courses should form a network for the exchange of information and training materials.

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WORKSHOP RECOMMENDATIONS

Group 1. Environmental Characterization

In agreement with the Bouaké recommendation and follow-up action taken (including meetings of working groups) it is recommended that:

1. In classification of upland rice environments the primary division must indicate the presence or absence of a water table;
2. Bouaké recommendations 2, 3, 4, 6, and 7 are synthesized into a practical work plan describing environmental inventory and classification methods;
3. Bouaké recommendations 8 and 9 are to be incorporated into a project proposal. This proposal was endorsed by the meeting;
4. Bouaké recommendation 10 is to be addressed upon completion of the work specified by the above recommendations;
5. Work should be initiated with plant pathologists to study macro and micro-meteorological aspects of rice disease/weather relations (particularly for blast and helminthosporium);
6. Recommendation 1 of Bouaké is virtually complete, and now superseded by more specific goals. Recommendation 5 is well advanced for Asia and Latin America but must be continued for Africa;
7. Working groups should meet to review progress at regular intervals.

Group 2. Integrated Upland Rice Farming Systems

Because of the great diversity in upland rice environments among different continents, regions, and countries, it is necessary that appropriate technologies for upland rice-based farming systems be developed or improved to meet location-specific requirements within national program capabilities. We recommend that efforts be directed to:

1. develop or improve soil, crop, and residue management practices to minimize drought stress, blast, weed infestation, and soil erosion; improve soil fertility; and give sustainable productivity and income;

2. develop or improve appropriate energy (and time?)-saving implements to minimize seeding and weeding labor requirements;
3. expand the exchange and testing of rice germplasm, especially of the improved materials, now being implemented through IRTP, to include sites where severe climatic, edaphic, and biotic stresses prevail. International centers should assist in implementing such specialized nurseries with the cooperation of the national programs;
4. develop a Global Rice Farming Systems Network to include upland rice-based farming systems patterned after the global IRTP. The network will be jointly administered by IITA, WARDA, and IRRI in Africa and CIAT and IRRI in Latin America.
5. strengthen socioeconomic research
   a. at the international level, on methodologies for analyzing complex systems and policies, and coordinating results;
   b. at the national level by involving social scientists in specifying technological objectives, conducting field research involving entire household, using interrelationships and conservation and the experimental capacity of farmers.

General recommendations

1. The Upland Rice Newsletter should be continued, contributions from various institutes encouraged, and the periodicity and distribution of the newsletter improved.
2. The first two upland rice conferences were held in Africa and Asia. The third should be held in Latin America in 1988, and give greater emphasis to socioeconomic analyses of the integrated system.

Group 3. Biological Stresses

Diseases

The group observed that blast continues to be one of the most important biological constraints to rice production in most upland rice growing areas.

Recommendations of the 1982 meeting at Bouaké, Ivory Coast, were reviewed:

- The need for collaboration between plant pathologists and breeders in blast control should be extended to include agronomists, soil scientists, plant physiologists, and agrometeorologists;
- Future International Rice Blast Nurseries (IRBN) should include methodology for evaluating panicle blast resistance. Efforts should be made to characterize blast pathogen populations at different testing sites;
- The need to create a center at Montpellier for the maintenance of a *Pyricularia oryzae* race collection was reemphasized. The group expressed appreciation for IRAT's successful efforts to obtain funds for the project;

- Studies on crop losses from blast in upland rice should be accelerated to provide basis for estimating realistic threshold levels to be used in integrated disease management. A comprehensive data base on all factors influencing the disease should be established at IRRI and the information made available to all collaborators;
- Studies on host-blast pathogen interactions will be continued, with greater emphasis on genetics of resistance;
- Chemical control measures should be an integral part of IPM programs with the view to minimizing costs and reducing the possibility of pathogen adaptation to single control measures;
- Epidemiologic baseline studies relating blast disease to weather, cultural practices, soil, and nutritional factors should be conducted and reported in the next IURRC;
- Emphasis should be given to screening germplasm for resistance to other diseases including brown spot (*Helminthosporium oryzae*), leaf scald (*Rhyncosporium oryzae*), and grain discoloration (caused by a range of fungal pathogens). Cultural and other appropriate control measures should be developed for sheath blight;
- New methods of disease management, for example through variety mixtures, should be explored.

Insects

The group observed that the list of important upland rice insect pests has been extended since the 1982 conference and endorsed the recommendations made during that meeting, and recommended that more importance be given to reporting on insect pests at the next meeting.

Weeds

Weed management was considered one of the most important agronomic practices in upland rice production and should receive greater research priority. Improved cultural practices and breeding for varieties better able to compete with weeds and control with weedicides, should be given more emphasis at the 1988 meeting.

Birds and rodents

Recommendations of the Bouaké meeting on birds and rodents were endorsed, and reports were requested from various organizations (including FAO, OCLALA, GTZ) for the 1988 conference. Information on crop losses should be included.

General recommendations

1. The IURRN should be incorporated into the IRRN because of the relevance of findings in upland rice to irrigated rice and to facilitate information distribution.
2. The next IURRC should be in Latin America in 1988 so as not to coincide with other conferences scheduled for that year.

Group 4. Preproduction Testing and Production Programs

RESEARCH PRIORITY

The group felt that there are some methodological questions in upland rice systems research related to:

- adaptive research,
- preproduction testing, and
- production programs.

Researches proposed

1. Study the experiences of national programs and private organizations and use these to develop alternative strategies for methodological questions;
2. Evaluate (if possible) effectiveness of various alternative strategies;
3. Disseminate information to potential users.

Implementation

The group recommends that IRRI and other relevant International Centers within the next 18 mo identify funding sources and commission appropriate comparative studies as indicated in the research proposed. A workshop should be held in Africa to discuss strategies for adaptive and preproduction testing.

NEXT MEETINGS

The next meeting should be held in Latin America in 1988.

NEWSLETTER

The Upland Rice Newsletter should be continued and the mailing list increased. The newsletter should contain more information from a social economic point of view.

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