MAJOR RESEARCH IN

UPLAND RICE

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The responsibility **for** all aspects **of** this publication rests with the International Rice Research Institute.

Contents

about this bulletin

Scientists in the rice-producing nations can help both rural and urban populations by directing agricultural research to find ways to increase the yields of mitlions of subsistence rice farmers.

Among the poorest of these subsistence farmers are those who grow upland rice. Few share the benefits of the new rice technology.

This is partly because most – but not all – experiment stations have emphasized irrigated rice research. Significant research on upland rice has been conducted, however, at stations in Asia, Africa, and Latin America, as well as at the International Rice Research Institute.

Like the research itself, scientific literature on upland rice is scarce and scattered.

At IRRI, research on selected aspects of upland rice started from the beginning of our research program in 1962. The material included in this bulletin summarizes the results of these and other experiments conducted through 1973. This information was used to develop the future direction of our research on upland rice. We hope that scientists around the world find it useful for their own research programs.

IRRl scientists wrote chapters related to their particular fields. Our editorial staff coordinated and edited these chapters, and designed and illustrated the publication.

Like all of IRRI's scientific publications, the primary purpose of this bulletin is to help fellow scientists, both in the national programs and at **IRRI,** develop improved rice varieties and technologies for the world's millions of small and poor rice farmers.

chapter one

UPLAND RICE AROUND THE WORLD

Surajit K. De Datta[1]

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Upland rice around the world

Surajit K. De Datta

Upland rice, in this publication, refers to rice grown on both flat and sloping fields that are not bunded, that were prepared and seeded under dry conditions, and that depend on rainfall for moisture.

Upland rice **is** grown on three continents, mostly by small or subsistence farmers in the poorest regions of the world. Grain yields are generally low: from 0.5 to 1.5 tons per hectare (t/ha) in Asia; about 0.5 t/ha in Africa; and from 1 to **4** t/ha in Latin America.

But the area planted in upland rice is so large (nearly a sixth of the world's total rice land) that even a small increase in yield would substantially influence total rice production.

High yields under upland conditions are indeed possible. Under ideal conditions on experiment stations, yields of 7 t/ha have been recorded in the Philippines (De Datta and Beachell 1972). Yields of 7.2 t/ha have been recorded in Peru (Kawano *et al.* 1972), and 5.4 t/ha in Nigeria (Abifarin *et al.* 1972).

Much of the future expansion of the world's rice land will probably be in upland rice because most of the land suited to irrigated paddy culture is already planted in lowland rice. Such expansion is more feasible in some parts of Africa, and in the "cerrado savanna" area in Central West Brazil and the Amazon basin area of South America, than anywhere in Asia.

Upland rice grows under a wide range of conditions from shifting cultivation in Malaysia, the Philippines, West Africa, and Peru, to highly mechanized systems in parts of Latin America. Soil types vary: infertile acid sand in West Africa; oxisol in the Llanos Orintales region of South America; fertile acid soil formed from volcanic tuff in the Philippines; saline soil in coastal areas of India. Most upland rices are of the tall, lodging-susceptible, low-tillering type. They are either bred specifically for upland cultivation or selected locally on the basis of performance under poor moisture conditions.

Table 1. Total rice area and percentage of upland rice in selected Asian countries.

Country	Total rice area[a] (thousand ha)	Upland rice area[b] (% of total)
Taiwan	787	3
Ceylon	671[c]	2
Indonesia	7,348	21
Malaysia	448	5
Nepal	1,200	9
Bangladesh	10,200	23
Philippines	3,175[c]	20
South Vietnam	2,296[d]	3
Japan	3,281[c]	4
South Korea	1,236	1
India	36,000	n.a.[e]
Thailand	6,697	n.a.
Burma	5,057	n.a.
Mainland China (1952–1956)	29,597[f]	2[g]

[a]1967–1968 (U.S. Department of Agriculture 1968). [b]1960–1964 (Food and Agriculture Organization of the United Nations 1966). [c]1968–1969. [d]1966–1967. [e]n.a. = not available. [f]1952–1956 (Food and Agriculture Organization of the United Nations 1967). [g]Ting 1961.

UPLAND RICE IN ASIA

In Asia, upland culture is an important, although not the major, system of growing rice (Table 1). The largest areas of upland rice are found in India, Indonesia, Bangladesh, China, and the Philip pines. Varietal traits and production practices vary considerably, not only between countries but also within countries. For example, in Assam state, India, early maturing upland varieties that are tolerant to cold are grown in both hilly areas and in the valleys of the Brahmaputra and Surma Rivers.

India. Upland rice culture seems to be found in all rice-growing regions of Eastern India, including Assam, West Bengal, Orissa, and eastern Uttar Pradesh. Early maturing varieties are planted or broadcast-seeded in March and April and harvested in July or August in West Bengal, India. Upland rice is grown in some areas of Madhya Pradesh and Gujarat states during pre-monsoon rains. On the west coast of India, rice is seeded on dry soil in areas with a heavy but short rainy season. In the state of Kerala, dry soil is prepared with a country plow and rice seed are dibbled in. Yields average about 2.0 to 2.5 t/ha.

Indonesia. Indonesia has about 1.3 million ha of upland rice. distributed as follows: Java, 324,000 ha; Sumatra, 480,000 ha; Borneo (Kalimantan), 254,000 ha; Celebes, 91,000 ha; Moluccas, 5,000 ha; and other islands, 126,000 ha. The upland rice area is expanding gradually in the southern parts of Sumatra and Borneo. It may increase further if weeds such as *Imperata cylindrica* and *Cyperus rotundus* (nutsedge) can be effectively controlled.

In Indonesia, upland rice is grown under a variety of cultural and environmental conditions. Upland rice grows under shifting cultivation, in continually dry fields, and in dry and wet fields (where rice begins as an upland and is harvested as a lowland crop). It's usually planted in November or December, depending on the rain. Upland rice is often grown with other crops such as corn or cassava.

Upland rice is grown at altitudes ranging from sea level to 2,500 meters and higher, so varieties and cultural practices should be developed to suit both high and low temperatures, and to fit the varying rainfall patterns of Indonesia.

Bangladesh. Estimates of upland rice in Bangladesh range from 24 percent to 35 percent of the total rice land. Upland rice in Bangladesh is seeded in late March in dry soil. Monsoon rains and rivers provide moisture until vast areas are inundated. Late seeding on dry soil may continue until May, depending on moisture supply. Grain yields vary from 0.8 to 1.2 t/ha, with top yields reaching 2.5 t/ha.

Philippines. Estimates vary widely of upland rice areas in the Philippines. In 1966, the Food and Agriculture Organization of the United Nations estimated that 20 percent of the country's total rice area was upland (Table 1). But in 1972, the Philippine Bureau of Agricultural Economics estimated that roughly 366,200 ha were planted to upland rice, about 11 percent of the total rice area (Table 2). The province which produces the largest amount of upland rice in the Philippines is Cotabato, Mindanao, which has

Table 2. Total rice area and percentage of upland rice by legion. Philippines. 1972.[a]

Region	Upland rice area	Total rice area	Upland rice area (%)
Ilocos	4,030	145,610	2.8
Cagayan Valley	21,870	383,910	5.7
Central Luzon	3,260	671,070	0.5
Southern Tagalog	106,040	408,780	25.9
Bicol	32,950	273,560	12.1
Eastern Visayas	19,300	270,730	7.1
Western Visayas	36,610	424,950	8.6
Northern & Eastern Mindanao	47,480	229,860	20.7
Southern &Western Mindanao	94,660	437,910	**21.6**
Total in Philippines	366,200	3,246,380	11.3

[a]Source: Bureau of Agricultural Economics 1972, ***unpublished.***

115,926 ha of upland rice out of a total rice area of 251,279 ha (Table 3). In Batangas province, which has the second largest upland area, 49,000 ha are planted in upland rice, out of a total rice area of 70,000 ha. Much upland rice in Batangas is grown under coconut groves.

Nepal. Nine percent **of** Nepal's rice is upland. It grows under a wide range of ecological conditions, including both tropical and sub-tropical plains.

Sri Lanka. In the northern part of Sri Lanka's Jaffna district. rice is seeded in October on well-drained to moderately drained fields which may or may not be bunded, but it may be harvested under partially flooded conditions. The grain yields vary from 1 to 2 t/ha. Rice production in these areas depends on rainfall distribution and the yield potential of early maturing varieties.

Burma. Most of Burma's 400,000 ha of upland rice is grown on rolling land in the northern states. It is planted in May and harvested in October-November, with average yields between 0.75 and 1.1 t/ha.

Thailand. Hill tribes grow upland rice under shifting cultivation in Thailand. Upland rice **is an** insignificant part of Thailand's

Table 3. Philippine provinces with at least 5,000 ha **of** upland rice.[a]

Province	Total rice area (ha)	Upland rice (ha)
Albay	50,476	13,213
Aklan	24,150	5,668
Antique	39,978	9,009
Batangas	69,799	48,995
Bukidnon	23,556	18,980
Camarines Sur	112,117	43,554
Capiz	54,214	11,123
Cavite	34,557	14,705
Cotabato	251,279	115,926
Davao	43,991	25,282
Iloilo	157,700	32,962
Isabela	112,879	16,536
Lanao del Norte	24,852	16,784
Lanao del Sur	54,416	32,694
Leyte	74,689	11,125
Masbate	28,602	11,132
Mountain Province	56,035	8,483
Negros Occidental	83,477	27,516
Oriental Mindoro	45,957	16,046
Palawan	19,853	16,236
Pangasinan	124,902	9,031
Quezon	60,634	21,302
Samar	102,133	22,616
Sulu	14,917	14,144
Tarlac	97,114	7,926
Zamboanga del Norte	18,548	8,806
Zamboanga del Sur	68,349	41,274
Total	2,730,394	713,347

“Source: 1960 Census **of** Agriculture (Philippine Bureau **of** Census and Statistics [Undated]).

total rice area of 6.7 million ha. In May, tribesmen dibble rice seeds about 3 cm deep in dry soil with bamboo sticks. In southern Thailand, rice is grown under rubber trees, as well as with other upland crops such as corn and cassava, on newly opened land cleared by the "slash and burn" technique.

South Vietnam. In South Vietnam, mountain farmers use traditional methods to grow upland rice from Quang Tri south through the central highlands (Table 4). Upland rice covered 70,000 ha in 1972. Production was previously higher but extensive warfare has reduced the areas planted to upland rice. Efforts are now being made to increase both the range and the productivity of the upland areas through improved varieties and cultural practices.

Table 4. Area planted to upland rice by province in South Vietnam.[a]

Province	Area planted (ha)
Quang Tri	200
Quang Ngai	366
Quang Tin	150
Binh Dinh	20,000
Kontum	7,200
Pleiku	5,500
Phu Bon	3,700
Darlac	17,000
Quang Duc	1,943
Tuyen Duc	2,600
Lam Dong	2,000
Phuoc Long	4,160
Binh Long	2,300
Binh Tuy	278
Long Khanh	3,000
Total	70,397

[a]Source: Directorate General of Agriculture, 1972.

Table 5. Total rice area and percentage of upland rice in West Africa.[a]

Country	Total rice area (thousand ha)	Upland rice (thousand ha)	Upland rice (% of total)
Sierra Leone	320	194	60
Guinea	280	168	60
Nigeria	160	100	62
Ivory Coast	290	260	89
Mali	190	–	–
Liberia	280	280	100
Senegal	90	–	–
Ghana	42.5	32.5	76
Gambia	28	3	10
Upper Volta	45	5	11
Togo	29	28	96
Niger	13	–	–
Dahomey	2	1.8	90
Mauritania	0.5	–	0
Total[b]	1770	1072	60

[a]Adapted from Food and Agriculture Organization Inventory Mission 1970. [b]Statistics are not available for upland rice for several countries.

UPLAND RICE IN AFRICA

About 75 percent of Africa's total rice is upland, planted in the humid regions of West Africa. Yields average only about 0.5 t/ha (Abifarin *et al.* 1972). All of West Africa's 1.77 million ha, however, comprises only 1.4 percent of the world's rice area. The important upland rice-growing countries are Sierra Leone, Guinea, Nigeria, Ivory Coast, and Liberia (Table 5). The dates of planting and times when upland rice is grown depend entirely on the rainfall patterns. "Slash and burn" clearing of the land, followed by intercropping of upland crops, is common in the forest belt; shifting cultivation is also common. In Liberia and Sierra Leone, upland rice is intercropped with cassava. Yams are grown with u p land rice in Ghana, Togo, Dahomey, and Nigeria. Both cassava and yams are widely intercropped with rice in the Ivory Coast.

Land preparation in Africa is primitive. Only about 2 percent ot the total area is prepared with animals or equipment; female laborers are the primary source of power. Annual rainfall exceeds 1,500 mm in about 60 percent of the rice fields. Rice seeds are broadcast on dry soil and covered with a short-handled hoe. In other rice areas, seeds are dibbled with a stick or a narrow blade (Food and Agriculture Inventory Mission 1970).

Table 6. Total rice area and percentage of upland rice in key Latin American countries.

Country	Total rice area[a] (thousand ha)	Upland rice area[b] (% of total)
Brazil	4,979	77
Colombia	275[c]	65
Guyana	138[d]	55
Mexico	167[c]	25
Panama	130	95
Ecuador	105	63
Peru	50	21
Central America	140	90
Venezuela	139	80
Total – Latin America	6,123	75

[a]1967–1968 (U.S. Department of Agriculture 1968). [b]1960–1964 (Sanchez 1972). [c]1968–1969 (U.S. Department of Agriculture 1968). [d]1966–1967 (U.S. Department of Agriculture 1967).

UPLAND RICE IN LATIN AMERICA

About 5 percent of the world's total rice is grown on 6.5 million ha in Latin America. Brown (1969) reported that about 65 percent of Latin American rice is grown under upland conditions; Sanchez (1972) estimated 75 percent (Table 6). Although it may seem insignificant compared with the rice produced and consumed in Asia, rice is an important ingredient in Latin American diets. Perhaps more important is the potential for increased rice production – especially of upland rice – in Latin America. Vast areas suitable for rice, if brought into production, could help meet future world demands. But the present picture of rice production in Latin America is not particularly bright. Grain yields average only about 1.3 t/ha. Hundreds of thousands of families are involved in the small upland rice operations (CIAT 1973).

Rice is the second most widely consumed food crop in Brazil (next to cassava). Brazil, the largest country in Latin America, also has the largest area of upland rice, about 3.5 million ha out of 5.2 million ha (De Datta and Beachell 1972).

Most of the upland rice in Brazil is grown on small and medium-sized farms with somewhat rolling topography. In these areas, the average yields are low, from 1.2 to 1.5 t/ha. Table 7 shows the relative importance of rice-producing states in Brazil for 1970. In the northern states, including Maranhao and Para, upland rice is grown under shifting cultivation and in mixed cropping patterns with corn, beans, squash, bananas, and cassava. About 15 percent of Brazil's total rice is produced in the northern and northeastern regions. In central-west "cerrado savanna' area in Brazil which includes portions of Goias, Minas Gerais, Sáo Paulo, Maranháo, and Mato Grosso states, rice culture is semi-mechanized; rice is of-

Table 7. Area planted and production under upland and lowland rice culture in states of Brazil, 1970.[a]

State	Production (000 tons)	Area planted (000 ha)	Culture
Rio Grande do Sul	1543	431	lowland
Goiás	1217	1098	upland
Minas Gerais	1165	877	upland
São Paulo	1053	703	upland
Maranhão	675	553	upland
Mato Grosso	616	321	upland
Paraná	590	432	upland
Santa Catarina	214	86	lowland
Pari	73	75	upland
Bahia	58	39	upland-lowland
Total	7553	4979	

[a]De Souza 1973.

ten the first crop on newly cleared savanna lands. This area, about 3.7 million ha, is probably the world's largest continuous upland rice-growing area. It produces 70 percent of Brazil's rice.

Colombia, Guyana, Panama, Ecuador, Peru, Venezuela, and several Central American countries are other important upland rice-growing countries. Twenty-one percent of Peru's rice crop comes from upland rice grown under shifting cultivation in the Amazon basin (Sanchez 1972; Cha 1967). In this vast ecological region, which covers half of Peru's land surface and extends deeply into Brazil, Bolivia, Colombia, and Ecuador (Sanchez and Nureña 1972), upland rice is grown on both flat and ,sloping areas. The main cropping system is locally known as "altura" or "tacarpo" (meaning "using a pointed stick") because it involves cutting and burning of mature secondary forests during the drier months, from July to September, then dibbling seeds into holes made with a "tacarpo" (Sanchez and Nureña 1972). Grain yields are extremely low, from 0.5 to 0.7 t/ha.

POTENTIAL FOR IMPROVEMENT

We can see that upland rice production is an important component of the agricultural economies of many countries. The yields are generally low, but can be increased by the development of improved varieties and cultural practices to suit the soil, climatic, and social conditions. These improvements are entirely possible through research and extension, and through changes in national policies.

chapter two

CROP ENVIRONMENT OF UPLAND RICE

Climates of upland rice regions
Surajit K. De Datta[1] and Benito S. Vergara[2]
Soils on which upland rice is grown
Surajit K. De Datta and Reeshon Feuer[3]
Growth-limiting factors of aerobic soils
Felix N. Ponnamperuma[4]

The crop environment of upland rice must be thoroughly understood before one can explain the variability in grain yields and find ways to increase production. In this chapter, the crop environment includes the weather, the soil, and the biotic factors that affect upland rice.

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Climates of upland rice regions

Surajit K. De Datta and Benito S. Vergara

RAINFALL

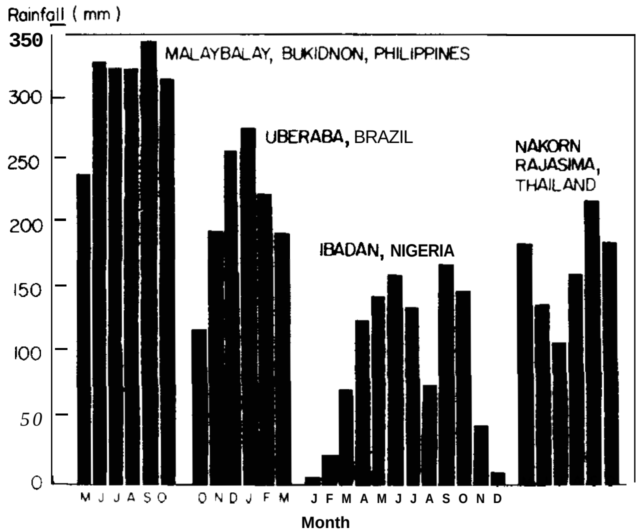
Availability of water is more uncertain for upland than for lowland rice because upland fields are not bunded. Because upland rice depends entirely on rain water, both the amount and the distribution of rainfall are important. Low rainfall during the growing season generally means decreased rice yields. But research at IRRI and other experiment stations and in farmers' fields indicates that the distribution of rainfall is also a major influence on yields, even in areas with as high as 2,000 mm annual rainfall (Jana and De Datta 1971; De Datta *et al.* 1974*a*).

Amount of rainfall. In monsoon Asia, the amount of rain and the duration of the rainy season vary not only between countries but also within countries. Upland rice is grown under heavy rainfall in Assam and West Bengal states of eastern India, and along the coastal areas of Kerala. It grows under low rainfall conditions in Madhya Pradesh. The growing season is extremely short and rainfall is highly variable in eastern Uttar Pradesk The upland areas in Bangladesh are similar to those of eastern India. In the upland rice areas of northern Sri Lanka, from 875 to 1,000 mm of precipitation falls during **3%** to 4 months of the year. In the upland areas of Burma, rainfall from May to November can be as low as 500 mm or as high as 2,000 mm.

In Indonesia, rainfall is well distributed in the humid and semihumid western regions. The rainy season is very short and the rainfall is unevenly distributed in the eastern regions. Upland yields are very unstable in these areas. Varieties with growth durations of from 90 to **135** days are highly desirable for all of Indonesia.

Thailand's rainy season lasts from May to October, indicating that varieties which are medium in growth duration and slightly sensitive to photoperiod may be desirable (fig. 1).

Upland rice yields in the Philippines are closely associated with climatic zones and rainfall patterns. Yields average only 0.66 t/ha in the low rainfall areas (where rainfall is sufficiently distributed,



1. Rainfall patterns of selected upland rice regions.

but with a maximum period of 4½ dry months). Average yields reach 1.1 t/ha in high rainfall areas (where rainfall is evenly distributed throughout the season, but with 3 dry months). The national average of upland rice in the Philippines is about 0.9 t/ha (De Datta *et al.* 1974*b*).

In West Africa, where most rice is upland, both the amount and the distribution of rainfall are of paramount importance. The West African rainy season may be continuous, or it may be interrupted, depending on the latitude. It may begin anytime from March to July (it begins later at higher latitudes). Rainfall distribution is unimodal (having one peak) in areas with short rainy seasons, but it is bimodal (having two peaks) with a 1- to 2-month break from July to August, in areas with long rainy seasons. The region of bimodal rainfall includes southeastern Ivory Coast, southern Ghana, southern Togo and Dahomey, and southern Nigeria, up to a maximum latitude of 7°N (fig. 1). Less important areas of bimodal distribution include southeastern Guinea and northeastern Liberia. In areas of less than 1,000 mm annual rainfall, the rainy season lasts from June to October. In areas of more than 1,800 mm annual rainfall, it may begin as early as late March (Food and Agriculture Organization Inventory Mission 1970). These rainfall data indicate the need to develop varieties with wide ranges of maturity and cultural practices that conform with rainfall distribution patterns.

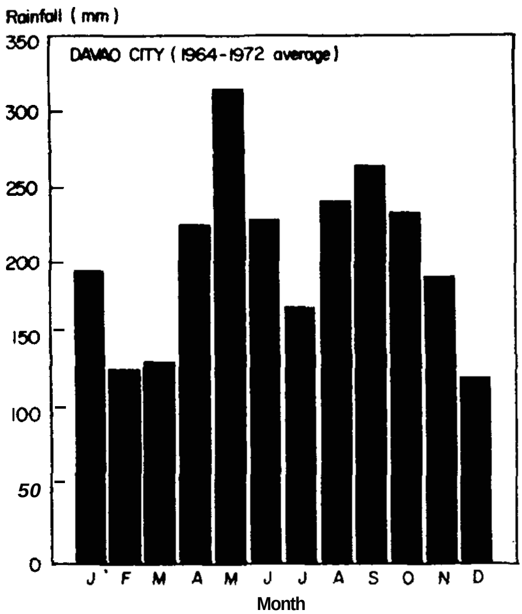
For Latin America, Brown (1969) reported that 1,000 mm of annual rainfall, with 200 mm monthly rainfall during the growing season, is adequate for growing upland rice.

Brazil, which has, by far, the largest upland rice area in Latin America, has a distinct rainy season which begins in October and ends in April (fig. 1). The average annual rainfall varies from 1,300 to 1,800 mm; 70 to 80 percent of the rain falls during the upland rice-growing season. The rainfall tapers off in February, leading to an ideal harvesting period during the drier months, resulting in milled rice of better quality (de Souza 1973).

Rainfall in most of the Amazon basin of Peru ranges from 2,000 to 4,000 mm annually, far more than enough to grow one upland rice crop (Sanchez 1972). Kawano *et al.* (1972) reported yields of more than 4 t/ha in Peru's Amazon basin, with rainfall averaging 200 mm/mo. during the growing season, confirming Brown's contention.

Rainfall pattern and distribution. The daily rainfall is actually more critical than the monthly or annual rainfall. Moisture stress can damage or even kill plants in an area which receives as much as 200 mm of precipitation in 1 day, and then receives no rainfall for the next 20 days. A precipitation of 100 mm/mo., distributed evenly, is preferable to 200 mm/mo. which all falls in 2 or 3 days.

We examined the rainfall patterns of some upland rice areas taking 200 mm/mo. as the base line (fig. 1). In some areas, such as Uberaba, Brazil, the rainfall pattern is unimodal and of short duration. Varieties that mature in less than 100 days would be practical for upland conditions. In other areas, such as Malaybalay, Bukidnon, Mindanao, Philippines, the rainfall pattern is also unimodal but the duration is long; varieties that mature in 100 to 150 days should perform well. In Davao, Philippines (fig. 2), where the rainfall pattern is bimodal, early maturing varieties, if planted in April, might suffer from moisture stress at flowering time. Perhaps planting 130- to 150-day varieties in June would insure sufficient water at panicle initiation and development. This would give the plants time to recover from early stress. The rainfall pattern in Ibadan, Nigeria, is also bimodal, but monthly rainfall is lower than the minimum requirement (Brown 1969). If, as Brown reported, upland rice cannot be grown with less than 200 mm/mo.



2. Average monthly precipitation in Davao City, Philippines from 1964 to 1972.

of rainfall, then many areas of the world, including West Africa and northeastern Thailand, are not suited for upland rice production.

Tropical cyclones (typhoons and hurricanes) usually occur during the monsoon season, when upland rice is planted. The strong winds may cause lodging in upland rice areas of the northern Philippines, eastern South Vietnam, and western Burma.

SOLAR RADIATION

The fact that upland rice is grown during the cloudy monsoon season puts a ceiling on yield. At best, the potential of upland rice is no higher than that of rainfed lowland rice.

Little data is available on intensity of solar radiation in rice-growing areas. Most of the principles discussed, therefore, are based on information gathered in the Philippines.

Because the effects of solar radiation are closely associated with moisture supply, both will be examined together.

The simplest method of examining the effects of solar radia-

Table 1. Effects of date of planting on the grain yield of upland rice. IRRI, 1967 wet season.[a]

Planting time	Yield (t/ha)			
	IR8	IR400-28-45	Milfor-6(2)	Palawan
June	4.7	4.9	3.1	2.5
July	5.0	5.3	2.8	2.2
Aug.	1.7	2.0	1.5	0.6
Sep.	0.7	0.8	0.5	0.4
Mean	3.0	3.3	2.0	1.4

[a]Source: Jana and De Datta 1971.

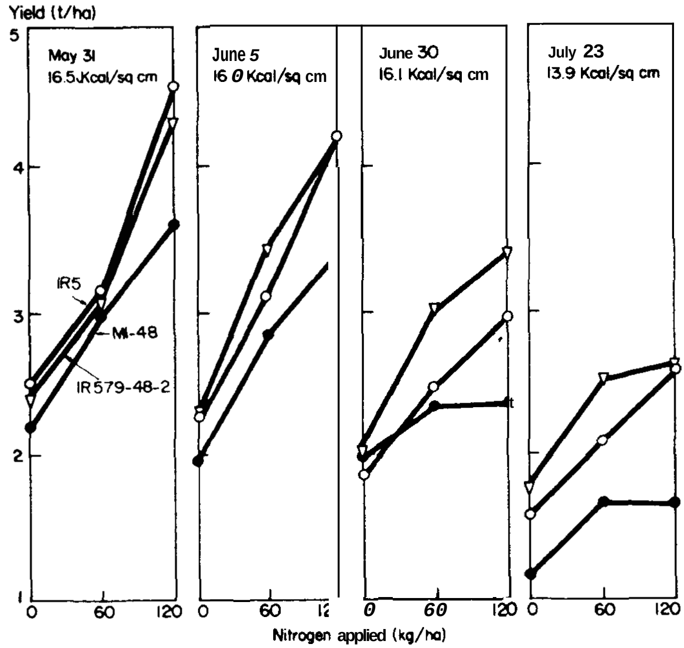
tion and rainfall on grain yields is to plant upland rice at several dates during the wet season, then critically examine crop performance. This was done in experiments at the IRRI farm and at several locations in the Philippines. The varieties and lines used in these trials varied from year to year. One recommended upland variety from the Philippines was included in each trial.

The yields of two semidwarfs, IR8 and the line IR400-28-4, responded postively to increased solar radiation during their reproductive periods in 1967 trials at IRRI.. The yields of Milfor 6(2) and of the upland variety Palawan did not respond to increased radiation (Table 1). The yield of the crop seeded in September was extremely low, primarily because of soil moisture stress during'the reproductive stage (Table 2), rather than because of the level of solar energy (the solar energy values were comparable to those of the June-seeded crop). To evaluate the earlier findings, additional

Table 2. Solar radiation, rainfall, and grain yield of upland rice. Average of four varieties and lines. IRRI. 1967 wet season.[a]

Planting time	Vegetative stage		Reproductive and ripening stage		
	Solar radiation (kcal/sq cm)	Rainfall (mm)	Solar radiation (kcal/sq cm)	Rainfall (mm)	Yield (t/ha)
June	29.3	401	19.0	466	3.8
July	24.7	435	20.2	341	3.8
Aug.	24.6	650	16.7	510	1.5
Sep.	24.5	783	16.8	84	0.6

[a]Source: Jana and De Datta 1971.



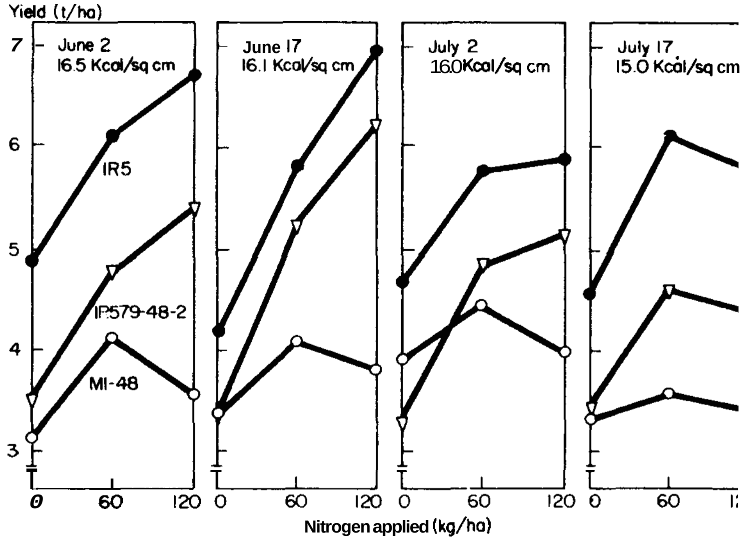
3. Nitrogen response of IR5, IR442-2-58, and M1-48 under upland conditions at four dates of seeding with solar radiation total for reproductive and ripening periods of the crop. IRRI, 1970 wet season (De Datta *et al.* 1974a)

field experiments were conducted at IRRI and Maligaya using four planting dates during the 1970 wet season (Jana and De Datta 1971). Despite low soil moisture stresses (fig. 3), the high-yielding lowland varieties consistently outyielded the upland variety M 1-48 at the IRRI farm.

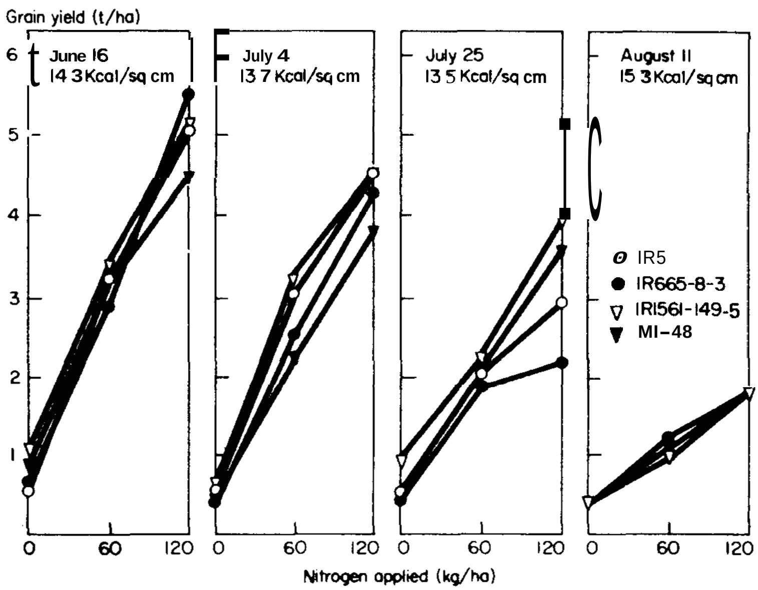
The crop that was seeded on May 31 received the most solar energy during the ripening period; the crop seeded on July 23 received the least (fig. 3). Grain yield was low for the July 23 crop, partly because solar energy was low during the ripening period.

IR5 consistently yielded higher under upland conditions than did the upland variety M1-48 or the early maturing line IR579-48-2 on a clay loam soil with flat topography at Maligaya (fig. 4).

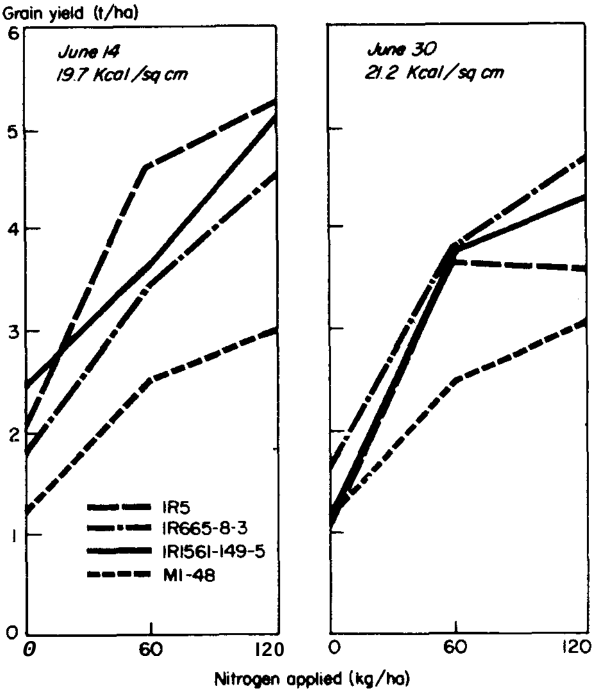
A crop of IR5 which was seeded on June 17, and which received a good level of moisture throughout the growing season, yielded 7 t/ha. This was the highest grain yield obtained in any of



4. Nitrogen response of IR5, IR579-48-2, and M1-48 under upland conditions at four dates of seeding plotted with solar radiation total for reproductive and ripening periods of the crop. IRRI-BPI Cooperative Soil Fertility Experiment, Maligaya, Philippines, 1970 wet season. (De Datta and Beachell, 1972).



5. Nitrogen response of four varieties grown under upland condition at four dates of seeding with solar radiation total for reproductive and ripening periods of the crop (IR5 seeded on August 11 was damaged by rats). San Pascual, Batangas, 1972 wet season (De Datta *et al.* 1974 *a.*).

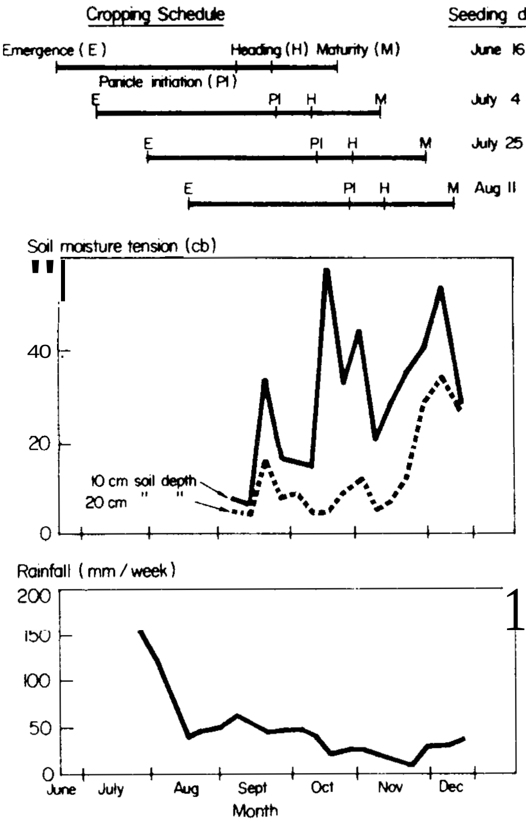


6. Nitrogen response of four **varieties grown under upland conditions at two dates** of **seeding with solar radiation total for reproductive and ripening stages. Maligaya, Philippines 1972 wet season.**

IRRI's upland experiments (and higher than the yields of any lowland experiments conducted at Maligaya) (IRRI 1971). The 7-ton yield probably approaches the upper limit for 1K5 during the wet season, when the total solar energy during the ripening period seldom exceeds **16.5** kcal/sq m (De Datta and Beachell 1972).

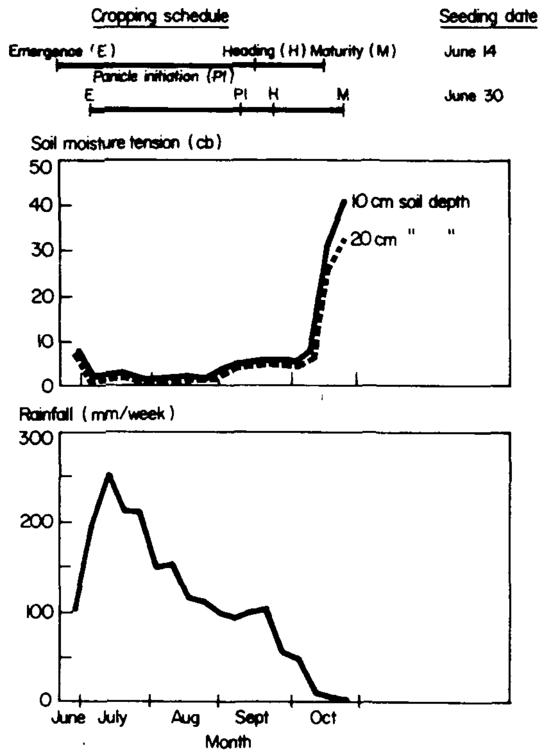
The highest grain yields came from fields seeded at the earlier dates at Maligaya and from a farmer's field in Batangas. Philippines, during the 1972 wet season. This was probably because of higher solar radiation and better rainfall distribution (Jana and De Datta 1970; **De** Datta and Beachell *1971).* **IR5** and the line **IR665-***8-3* yielded more than *5* t/ha in both locations. The upland variety **M1-48** yielded **4.5** t/ha in Batangas (fig. 5), and *3* t/ha in Maligaya (fig. 6).

In Batangas (Lipa clay loam. pH **5.1.** an alfisol), rainfall began to taper off in mid-August and soil moisture tension increased from September to December (fig. 7). Because of higher soil mois-



7. **Rainfall and** soil **moisture tension** in **the date of seeding experiment for upland rice. San Pascual, Batangas, Philippines, 1972 wet season.**

ture tension, the crop which matured in late November and early December was affected by severe moisture stress which substantially reduced grain yields. Unlike rainfall, solar radiation values were relatively constant during the ripening period for all four seeding dates (fig. 5). The reduced yields at later seeding dates, therefore, were due not to low solar energy but to high soil moisture tension. In Maligaya, the rainfall during the vegetative period was adequate. The crop that was seeded on June 30, however, matured in October when the rainfall had virtually ceased, increasing the soil moisture tension (fig. 8). Only IR5 matured during this drought period, however, because its growth duration was longer than that of the other varieties. Because of moisture stress, the



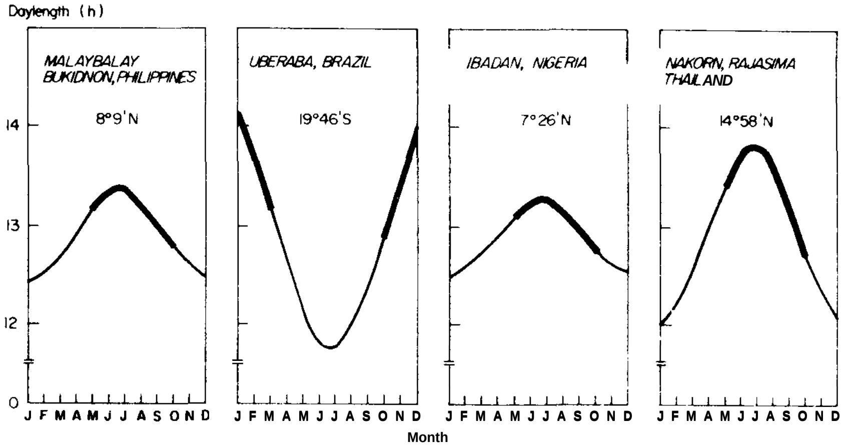
8. Rainfall and soil **moisture tension in an experiment on date** of **seeding** for **upland rice. Maligaya, Nueva Ecija, Philippines, 1972 wet season.**

crop seeded on June **30** yielded **less** than that seeded on June 14 (fig. 6).

These studies, conducted over **4** years, suggest that moisture supply during the crop's growth is far more important than is variation in solar energy during the reproductive and ripening stages. When the moisture supply is adequate, however, grain yields and nitrogen response are closely related to the amounts of solar energy during the reproductive and ripening stages.

DAYLENGTH

In the monsoon areas, upland rice fields are generally prepared and sown at the start of the monsoon season. Upland rice is planted as



9. Daylength of selected upland rice areas. Heavy lines indicate the cropping season.

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

Variety	Country	Time to flowering[b] (days) 10 h	14 h[c]	Basic vegetative phase (days)	Photoperiod sensitive phase (days)
		Photoperiod insensitive			
Pate Blanc MN3	Ivory Coast	113	113	78	0
Colombia 1	Colombia	98	101	63	3
IAC 1246	Brazil	85	91	50	6
Seratus Molam	Indonesia	93	99	58	6
E-425	W. Africa	93	100	58	7
Perola	Brazil	a2	89	47	7
Azmil	Philippines	90	98	55	8
Miltex	Philippines	9s	104	60	9
Moroberekan	Guinea	94	104	59	10
Yassi	Ivory coast	99	110	64	11
OS 4	Zaire	88	100	53	12
Palawan	Philippines	99	112	64	13
63-83	Ivory Coast	84	98	49	14
LAC 5	Liberia	96	111	61	15
Cartuna	Indohesia	72	89	37	17
LAC 23	Liberia	98	119	63	21
IR442-2-58	Philippines	84	108	49	24

(Table 3 *continued)*

Variety	Country	Time to flowering[b] (days) 10 h	14 h[c]	Basic vegetative phase (days)	Photoperiod sensitive phase (days)
		Weakly sensitive			
M1-48	Philippines	78	112	43	34
IR5	Philippines	93	128	58	35
Ku 70-1	Thailand	58	106	23	48
Khao Lo	Laos	54	130	19	76
Ku-104	Thailand	55	205	'20	150
		Strongly sensitive			
Khao Phe	Laos	59	–	24	
Ku-113-1	Thailand	64	–	29	
Moddai Karuppan	Sri Lanka	84	–	49	
TD-47	Thailand	75	–	40	
TD-48	Thailand	71	–	36	
TD-51	Thailand	70	–	35	
Thiorno	Senegal	77	–	42	
Vanam Villai	Sri Lanka	84	–	49	

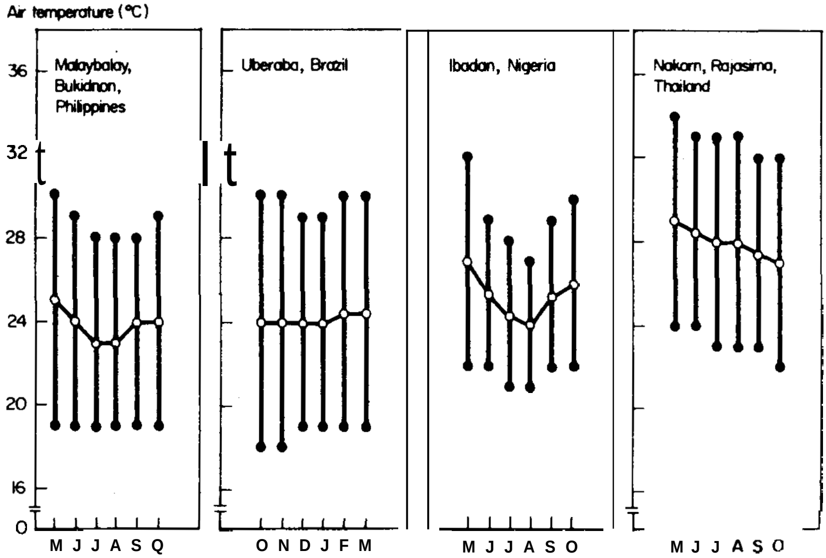
[a]Unpublished data of K. Alluri, IRRI. [b]At different photoperiods. [c] – means no panicle primordia after 200 days of growth.

early as April in Vietnam, and as early as May in the Philippines and Thailand (fig. 9).

Upland rice is generally planted during the periods when the daylength is increasing, as in Brazil, the Asian countries, and most African countries.

Varieties which are insensitive to photoperiod are needed in the areas where upland rice is planted when the days are becoming longer and flowering occurs at relatively long days Most of the upland varieties tested are insensitive to photoperiod (Table 3). Mdst of the upland varieties tested flowered at long daylengths and most have long basic vegetative phases. All varieties tested, except Curtuna and Perola, generally have longer growth durations than does IR8.

In the regions of India where upland rice is drilled during the



10. Temperature variation during the cropping seasons of selected upland rice areas.

last week of June, sensitivity to photoperiod probably makes no difference.

Almost all of the improved lowland varieties are insensitiue to photoperiod; they should present no flowering problems if used for upland culture.

TEMPERATURE

Most upland rice is grown in plains, with high temperatures which range from 24 to 26°C (fig. 10). Low temperatures can be a problem, however, in the high-altitude areas of India, Indonesia, Burma, Vietnam, and several South American countries. Upland rice is often planted on rolling hills; levees are often difficult to construct and water percolation and runoff are problems.

Japanese workers reported an association between drought tolerance and cold tolerance (Hasegawa 1963). 4 graduate sudent reported similar findings using tropical upland varieties (A.B.M. Salahuddin, M.S. thesis, University of the Philippines at Los BaAos, 1972, *unpublished).* If these findings are substantiated, then the problem of low temperature in upland rice should be of minor importance.

Soils on which upland rice is grown

Surajit K. De Datta and Reeshon Feuer

The characteristics of soils on which rice is grown are as diverse as are the climatic conditions to which rice is exposed; soil texture varies from sand to clay; pH varies from 3 to 10; organic matter content varies from 1 to 50 percent; salt content, from almost 0 to 1 percent; and nutrient availability, from acute deficiency to surplus. Rice is also exposed to dynamic changes in moisture regimes, which vary from dry land to various depths of flooding (Ponnamperuma 1972).

The following sections deal with the physiography, texture, and structural properties of upland rice soils and with the major soil groups on which upland rice is grown in Asia, Africa. and Latin America.

SOIL TEXTURE

Texture may be the most important property of rice soils. when moisture regimes are equal and mineral compositions are comparable (Moorman and Dudal 1965). Soil texture affects the moisture status of a soil more than any other property except topography. Texture is particularly important in upland rice fields which have no bunds to hold moisture.

The textural profile includes not only the surface layers but also the layers below. If the sub-soil has sufficient clay content. the importance of the surface soil texture diminishes. In a clayey profile, a surface horizon that is of medium texture may be the most favorable rice soil, possibly because of greater pore space (Grant 1960). A surface soil of medium texture can also be easily worked. Less water is necessary for initial rice growth because less water is lost through cracks than from a soil with a clayey surface.

The soil textures of upland rice vary greatly. For.example, loamy and sandy soils are typical of the slightly elevated areas of Thailand's foothills and flat lands, but most upland rice in the hills is cultivated on clayey and clay loam soils. In Batangas. Philip

Table 4. Soil orders; comprehensive classification system (USDA).[a]

Order	Key profile characteristics
entisols	recent soils; little or no change from parent material
inceptisols	light colored subsoils; weak soil development
mollisols	soft, deep, dark soils; high base status of surface horizon
alfisols	subsoil horizon of accumulated clay; high base saturation; high in weatherable minerals
ultisols	subsoil horizon of accumulated clay; low base saturation; few or no weatherable minerals
oxisols	uniform textured; friable profile high in oxides of iron and aluminum with kaolin clay; no weatherable minerals; low cation exchange capacity
vertisols	dark soils; high in montmorillonitic clay, prone to shrink and swell; high cation-exchange capacity
aridisols	mineral soils of dry regions with either calcium carbonate or salt accumulation
spodosols	strong brown subsoil underlying a gray to brown surface horizon; strongly acid
histosols	soils with more than 30 percent organic matter to a depth of 40 cm

[a]Source: USDA 1960; revised 1967; supplement 1970.

pines, where upland rice is widely grown on alfisols, the soil texture varies from clay loam to loam.

The frequency and duration of moisture stress will be affected not only by rainfall distribution but also by the capacity of the soils to retain water.

Soil surface structures may develop under dry conditions, depending on the soil texture and the nature of clay minerals found in the soil. The surface structure of dry sandy soils is usually weak and crumbly, and that of medium-textured soils may be slightly more crumbly or granular. Polygonal cracks may form upon drying of soils which have sufficient clay of the shrinking-swelling type. The crumbly and granular structures are common in upland rice soils, although the highest yields are generally obtained on clayey soils.

Because upland'rice is grown on many kinds of soils, and because different countries and authors classify and describe soils by different systems, Tables 4 and 5 are presented to facilitate better understanding of terms used in this section (Buol *et al.* 1973; Aubert and Tavemier 1972; United States Department of Agriculture 1967; Mariano and Valmidiano 1972; Brady 1974).

SOIL GROUPS

In Southeast Asia, the major soils of the sloping unterraced land, where most upland rice is grown. are ultisols and alfisols, using the USDA system (Table 5) (working group on establishment of Southeast Asian cropping systems test sites, IRRI 1974, ***unpublished).***

Ultisols are much more common, particularly in Sumatra and Kalimantan, Indonesia, and in Thailand. These soils have a sandy surface texture, and a more clayey subsoil. The base saturation is low, and the clay type is 1:1. They are found in the older (but not in the oldest) geomorphic landscape surfaces in the tropics. Ultisols are easy to cultivate but because the clayey subsoil is commonly closer to the surface than the subsoil of alfisols, they are more subject to erosion during heavy rainfall; the surface soil becomes saturated, causing runoff of excess water from sloping areas.

Alfisols have more clay (including layer lattice clay) in the B than in the A horizons. The base saturation is high. Alfisols are more common in very dry zones and developed from basic materials, on geomorphically young landscapes. Alfisols are easy to till because of their typically granular surface soil structure. These soils have a high capacity to retain rainfall because the more clayey B horizon retards percolation losses.

Oxisols cover minor upland rice areas in Southeast Asia. They are found in the lower areas in Sarawak, Malaysia (United States Department of Agriculture 1966) and in the mountainous Ban Me Thuot area of South Vietnam (Tung 1973). Oxisols are the most important rice soils in Java; they are locally classified. however, as latosols.

Oxisols in Southeast Asia are found on materials derived from volcanic rock. These are highly weathered soils with few textural changes throughout the profile. Oxisols are high in clay content. mostly kaolin with oxides of iron and aluminum. However. they have only small proportions of water-dispersable clay, and. usually, high water infiltration rates.

The soil is acidic in many upland rice areas of Southeast Asia.

Table 5. Comparison of terms (approximate) used in current classification systems, with representative Philippine soil series. 1973.

Great soil group[a]	Soil units[b] (FAO)	Comprehensive classification system (USDA) Great soil group[c] order	sub-order	Representative Philippine soil series
alluvial	eutric fluvisols	entisol	tropofluvent	San Manuel Mandawe
ando soil[d]	humic andosol	inceptisol	eutrandepts	Tupi Mayon Taal
rendzina and brunizems	rendzina and phaeozems	inceptisol and mollisols	eutropepts xerochrepts and lithic sub-groups and rendolls	Faraon Lugo Cataingan Sevilla Sibul
		inceptisol	tropepts of many kinds	Lithic, Vertic, Rendollic, Dystric, Andic, Oxic, Eutric sub-groups of soils developed from basic igneous rocks, mostly hilly to mountainous
either latosolic brown forest or	eutric cambisol	mollisol or alfisol	typic rendoll; haplustic	Lipa Maahas

(**Table 5** *continued*)

Great soil group[a]	Soil units[b] (FAO)	Comprehensive classification system (USDA) Great soil group[c] order	sub-order	Representative Philippine soil series
gray brown, podzolic	or luvisol		rendoll or udalfs tropudalfs	Ibaan Tigaon Magallanes
either gray brown podzolic or non-calcic brown	luvisol[e]	alfisol	tropudalfs	Quinqua Umingan
red-yellow podzolic and reudish brown lateritic	acrisols and dystric nitosols	ultisols	tropudult ustult xerult	Castilla Annam Aliminos Barotac San Rafael Bolinao Alimodian Carig Ilagan Sara Kidapawan
latosol, red latosol,	rhodic ferralsols	oxisol	orthox acrorthox	Luisiana Antipolo

(Continued on next page)

(Table 5 *continued*)

Great soil group[a]	Soil units[b] (FAO)	Comprehensive classification system (USDA) Great soil group[c]		Representative Philippine soil series
		order	sub-order	
earthy latosol laterite			ustox acrustox	Sigcay Adtuyon (also Andic phase) Gimbalaon Tugbok
grumosol	chromic vertisols	vertisol	chromusterts	Prenza Rugao
grumosol	pellic vertisols	vertisol	pellusterts	Bantog Buenavista Maligaya Bigaa San Fernando Toran Sta. Rita
grumosol	pellic vertisols	vertisol	pelluderts	Pili Palo

[a]Source: USDA 1938; 1949. [b]Source: Official system of FAO, data taken from 1970 World Soils Map. [c]Official system of USDA (USDA 1967). [d]Kanno 1967. [e]FAO 1972; Harradine 1967.

The pH, for example, in Ban Me Thuot, Vietnam, and in Batangas, Philippines is from 4.5 to 5.8.

In West Africa, both the capacity of the soil to retain water and the pattern of rainfall distribution particularly help determine the success or failure of upland rice. Most upland soils in West Africa have low capacities to hold available water, so even dry spells of short duration significantly reduce grain yields (Moorman 1973). In flat areas, on the other hand, percolating rainwater often saturates the soil profile, providing a buffer against dry spells, such as on soils classified as gleyic luvisols by the FAO system (Table 5) in the Laina Kara region of Togo or in the Abeo-Kuta region of Nigeria. Some rice varieties can withstand recurrent dry spells on these soils, although prolonged drought would kill the plants or cause low yields.

In areas of lower slopes, the land forms offer better edaphic conditions for growing rice. In the dryer parts of West Africa. these may be the only areas suitable for rainfed rice culture (Moorman 1973). The small quantities of water from runoff, however, can seldom avert moisture stress damage to the rice crop during prolonged drought.

Hydromorphic soils (soils in which groundwater is shallow or at the surface during part of the growth cycle) are considered suitable for upland rice. Research at the International Institute of Tropical Agriculture (Moorman 1973) shows a marked correlation between the depth of groundwater and the growth and production of upland rice. OS 6, an upland variety from West Africa, was more tolerant of drought than was IR20 when the depth of groundwater was about 80 cm.

Moorman and Dudal (1965) and Higgins (1964) also found satisfactory correlations between yield levels and textures of the soils in northern Nigeria; coarse-textured soils produced the lowest yields.

At IITA, scientists found that the negative effects of a sandy soil structure can be largely overcome by applying fertilizers, provided that moisture is not limiting.

Surface soils with medium to sandy texture overlying a subsoil of finer texture are often considered best for upland rice because they are easy to cultivate (Moorman 1973).

Soil structure helps determine a soil's capacity to hold moisture, as well as the plant's capacity to develop roots. Soils which are prepared dry do not lose their original structure. For upland rice culture, subsoils with open structure favor good root develop ment. However, they also retain water poorly, thus increasing the chance of moisture stress.

The inherent fertility levels and chemical composition of soils often explain yield differences and even cultural practices. Shifting cultivation is common in West Africa, for example, largely because most upland rice is grown on highly weathered oxisols which have high rates of leaching. A review of fertility levels of West African rice soils by Kang (1973) indicates that these infertile oxisols cannot sustain continuous rice culture without added fertilizer (Moorman 1973).

No data are available on the relationship between the organic matter content of the soil and the productivity of upland rice. Field observations indicate, however, that low organic matter negatively affects the yield of upland rice. Although the pH of rice land in West Africa varies from **4.5** to *6.5*, most upland rice is grown on acid soils.

MOISTURE GROUPS

The rice-growing soils of West Africa can be divided into two main groups: freely drained soils, and hydromorphic soils (which have high water tables and receive supplemental water through surface runoff).

Rice depends entirely on rainfall for water in the freely drained soils. It is limited to high rainfall areas with good rainfall distribution. These soils, classified by the FAO system (Table 5), include: nitosols, acrisols, luvisols, ferralsols, and cambisols.

Because 'areas with hydromorphic soils receive supplemental water through surface runoff, rice production is not limited to rainfall distribution patterns. The main soils of this type are entisols, ultisols, and vertisols.

In West Africa, a number of level, fine-textured soils have been classified as particularly suitable for rice culthre. Gleyic cambisols, humic gleysols, and eutric fluvisols (FAO classification) have been planted to rice where climatic factors are favorable (Riquier 1971). Orthic ferralsols are considered marginally suited for rainfed rice. Riquier (1971) also suggested that fine-textured soils are preferable for rainfed rice because the hydromorphy and even the bedrock at a given depth were considered favorable.

Accordingly, the potential of the soils in West Africa has been outlined in maps. These subunits (gleyic cambisols, humic gleysols, and eutric fluvisols) represent a large proportion of actual and potential rice areas in humid parts of West Africa (Moorman 1973).

Riquier (1971) made these generalized comments on the suitability of upland rice in various countries in West Africa,:

- 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 Portuguese Guinea, upland rice is grown on mangrove soil as well as on low fertility ferralsols.
- In Guinea, despite steep slopes and intensive erosion, upland rice can be grown on humic ferralsols.
- Numerous poorly-drained areas in Sierra Leone are suitable for upland rice.
- In Liberia, upland rice productivity is low because the soils, mostly oxisols (USDA classification system), degrade rapidly.
- The soils of the region north of Upper Volta are dry and fine textured, similar to sodic soils (aridisols, Table 4) and are difficult to cultivate. The valleys of northern Niger are often too sandy for upland rice.
- Good areas for upland rice are found in the central and northern Ivory Coast. Nigeria has large areas suitable for rice production, including upland rice.

Scientists at IITA (1972) studied and compared soils which originated from the same parent materials but which developed under different climatic conditions. Table 6 shows the relationships between rainfall and certain chemical characteristics of such soils. As annual rainfall increased, the soil pH dropped from 6 to 4; the cation exchange capacity (CEC).increased from 2.2 to 4.4 me/100 g soil; and the base saturation decreased 'from 77 to 16 percent. For these modal, well-drained soils, each having the same or similar parent material, the break between high and low base saturation and high and low pH appears between 1,750 and 1,850 mm of rainfall (Table 6). Thus, the soils in eastern Nigeria's high rainfall zone may be classified as ultisols (USDA classification system), while the western soils are classified as alfisols.

Table 6. Rainfall and certain chemical characteristics of West African soils which originated from the same parent materials (pleistocene-oligocene soils) but which developed under different climatic conditions[a].

Location	Annual rainfall (mm)	Surface soil			Subsoil (75-125 cm)		
		pH/H_2O	CEC[b] (me/100g)	Base saturation (%)	pH/H_2O	CEC (me/100g)	Base saturation (%)
Accra Plains, Ghana	890	6.1	2.15	77	5.6	4.91	72
Iperu, Dahomey	1610	6.2	5.68	93	6.3	3.12	95
Benin, Nigeria	1780	6.3	2.29	94	6.1	1.35	37
Onitsha, Nigeria	1880	4.6	2.57	31	4.8	2.06	19
P. Harcourt Nigeria	2300	5.2	2.59	36	4.6	2.49	16
Warri, Nigeria	2780	4.0	4.43	16	4.7	2.43	24

[a]Source: IITA 1972. [b]Cation exchange capacity.

UPLAND RICE REGIONS OF LATIN AMERICA

In the tropics of Central and South America. the following regions either produce, or have the potential to produce. upland rice (Buol 1972).

Savannas of infertile soils. Oxisols (USDA classification system) of extremely low fertility with high iron and aluminum contents are prevalent in the vast areas of first peneplain[1] and second peneplain[2] erosion surfaces in the Cerrado of Brazil (Feuer 1956: Cline and Buol 1973), and the upland Llanos of eastern Colombia. The dystrophic clayey, dark-red latosols on the gently sloping first and second surfaces are very old, devoid of weatherable minerals, and very low in bases. These soils are not suitable for upland rice except for localized areas of high base status. Such eutrophic, dusky-red latosols from diabase sills are found in the eutrustox areas of the Brazilian Cerrado.

Upland rice is commonly grown. however. on the eutrophic reddish-brown latosols of the sloping third peneplain erosion surfaces. The soils have some weatherable minerals and are able to support semi-deciduous forests. Upland rice is also grown on some second erosion surface soils, derived from basic rocks. which still have weatherable minerals and can support semi-deciduous forests (Feuer 1956).

Tropical rain forest soils. Tropical rain forests cover large underpopulated areas of Latin America. In Peru. ultisol and alfisol soils predominate both well-drained and poorly drained areas (Oficina Nacional de Evaluacion de Recursos Naturales 1967). A few young alluvial soils are found along the river margins (Zamora 1966). A low proportion of true oxisols are found in the Selva Baja. Upland rice is grown on both acid and fertile alluvial soils which are not subjected to permanent flooding (Sanchez and Nureña 1972).

Mountainous areas with soils of volcanic ash origin. Because of the dominance of amorphous clay mineral, phosphorus deficiency is acute in these soils, and phosphorus fertilizers are difficult to manage (Buol 1972).

Seasonally flooded plains and desert areas. In Central and South America, these areas have no potential for upland rice cul-

[1]Highest and oldest landscape.
[2]Next landscape, lower and younger than the first peneplain.

ture. In Brazil, upland rice is grown on rolling topography and on soils which can be worked easily (de Souza **1973).** Soils in these areas range from heavy clay to sandy. Farmers prefer coarse-textured soil for upland rice cultivation because they are easier to till.

DRAINAGE CONDITIONS OF UPLAND SOILS IN LATIN AMERICA

Upland rice areas in Latin America can be grouped into well-drained areas and poorly drained areas. The grain yields are closely related to the moisture regimes in the subsoils.

Well-drained soils. Most of Latin America's upland rice is planted on well-drained soils, principally highly weathered oxisols, particularly in the Campo Cerrado of Brazil, the Llanos Orientales of Colombia. and parts of the Amazon jungle.

Some alfisols and ultisols are found in Sao Paulo, Minas Gerais, and Goias states, Brazil. All these soils are deep and well drained. Most are clayey, with low levels of available moisture because of their excellent structures and high levels of iron and aluminum oxides. The oxisols generally have pH levels between **4** and 5; aluminum saturation of more than 60 percent; low levels of available phosphorus; and an effective cation exchange capacity of **2** to **8** meq/100 **g** of soil. The ultisols have either kaolinitic or oxidic type clays. On these soils, rice responds to N, **P, K,** Ca, and, in some cases, Zn and Fe. Lime is necessary for some varieties, but it **is** generally applied as calcium and magnesium fertilizer. The eutrustox (latosol roxo) soils of central Brazil, which have all the above properties, but are 100 percent base saturated when the forests are cleared, are an important exception (Feuer 1956). They become acidic after 5 to 10 years of cultivation. The ultisols, which are important in Sao Paulo state, Brazil, are coarser in the surface, but have somewhat similar fertility problems. The alfisols are often found in the third erosion surfaces of the Cerrado, interspersed with oxisols at higher erosion surfaces. Farmers prefer to rotate rice and pasture in the alfisols because these soils have a higher base saturation. The oxisols are particularly important in southern Goias, around Goiania and Anapolis, Brazil. Upland rice yields in the Cerrado and the Llanos are low, about 1 t/ha. The principal factors that limit yields seem to be moisture stress, low fertility, and the lack of high-yielding varieties suited to these conditions. N, P, **K,** and **S** (sulfur) fertilizers are normally applied.

Rice is also grown on well-drained soils, principally highly acid ultisols, throughout the Amazon jungle. Cassava, corn, and other crops are intercropped with rice in a shifting cultivation system which covers the Amazon region from Yurimaguas in Peru, to Belem in Brazil. Yields are extremely low because of moisture stress and low soil fertility. These soils generally have a higher range of available water than do the oxisols of the Campo Cerrado, although their topsoils are coarser. The soil pH levels are low, aluminum saturation is high, and P content is low. Ashes left after the vegetation is burned are the main sources of P and bases; no fertilizer is applied.

Poorly drained **soils.** Upland rice can be found on poorly drained soils throughout the region. They may range from vertisols in Cuba, to andosols (volcanic ash soils) on the Pacific coast of Guatemala, to excellent alluvial soils on the Pacific coast of Costa Rica, to poorly drained ultisols, oxisols, inceptisols, and alfisols in Peru and Brazil. The fertility status and physical and chemical properties vary, but rice generally suffers less from moisture stress in poorly drained than in well-drained areas. Yields are also usually higher in the poorly drained areas. All the high upland rice yields (7 t/ha and higher) reported in Costa Rica and Peru were obtained on these soils with high water tables.

SUMMARY

Based on data from Asia, West Africa, and Latin America, the soil pH is low (4.5 to 5.8) in most upland rice areas. Wherever yields are low, both moisture stress and soil problems induced by moisture stress are common.

Varieties for upland cultivation should have high tolerance to soil acidity and to manganese and aluminum toxicity. Although iron deficiency is important in most neutral to alkaline soils, it has also been' observed in many varieties grown on acid soils (pH 5.5 to 5.8).

Tolerance of drought and tolerance of soil problems are important characters for upland rices which must be incorporated into high-yielding varieties of appropriate growth duration with resistance to diseases and insects and to lodging.

Growth-limiting factors of aerobic soils

Felix N. Ponnamperuma

Upland rice is grown over a wide variety of soil conditions. The soils range from highly weathered oxisols and groundwater podsols to inceptisols and entisols; the slopes range from steep to concave; and the drainage ranges from free to restricted. But one overriding difference distinguishes upland from lowland soils: the water regime. Upland rice soils are neither submerged nor saturated with water for any appreciable part of the growing season. The rice plant is physiologically, morphologically, and anatomically adapted to water-logged, anaerobic soils. But under upland conditions, it must adjust itself to a diametrically opposite environment – dry, aerobic soils. This adjustment is not easy; thus, we find that retarded plant growth, nutritional disorders, and low yield characterize upland rice (Ponnamperuma 1955; Senewiratne and Mikkelsen 1961; IRRI [Undated] *a,b,c;* 1967 *a;* 1970; 1970; 1972; 1973). By comparing the physical, chemical, and biological properties of submerged or anaerobic soils with those of upland or aerobic soils, we can identify the adverse factors of aerobic soils and counter them by proper soil management.

The most obvious difference between aerobic (nonflooded, upland) rice soils and anaerobic (flooded, lowland) rice soils is the presence of a layer of standing water. Standing water benefits rice by eliminating water stress, by controlling weeds, by regulating the microclimate, and, perhaps most important, by providing a favorable chemical and microbiological environment for the rice roots.

CHEMICAL REGIMES OF AEROBIC AND ANAEROBIC SOILS

Flooding a soil cuts off its oxygen supply. Within a few hours, soil organisms use up the trapped oxygen and render the soil anaerobic. Rice roots, like the roots of wheat, barley, or tomato, need oxygen for respiration and nutrient uptake (Vlamis and Davis 1943). To grow and ward off toxins which are present in anaerobic soils, rice has evolved a genetically fixed system of transporting oxygen from shoot to roots (Van Raalte 1940; 1944; Armstrong

1970). The system is only lightly less efficient in upland than in lowland rice (Arikado 1959). This remarkable characteristic of rice operates to its disadvantage when it is grown in aerobic soils, as we shall see later.

Oxygen is depleted soon after flooding. Soil microorganisms then use oxidized soil components as electron acceptors in their respiration. They are reduced in the following order: nitrate, manganese dioxide, ferric hydroxide, sulfate, and carbon dioxide (Ponnamperuma 1972). **As** nitrate disappears, large amounts of manganese and iron enter the soil solution, and sulfate is converted to insoluble sulfides. Thus, soil reduction eliminates nitrate, increases the concentration .of water-soluble manganese and iron, inverts the iron-to-manganese ratio in the soil solution, and lower? the availability of sulfate. The secondary effects of soil reduction include an increase in pH of acid soils and an increase in the solubility and availability to rice of phosphate and silica (Ponnamperuma 1965). Another important consequence is that organic matter decomposes anaerobically. This process is slower than aerobic decomposition; it produces a variety of substances of which carbon dioxide, organic acids, methane, ammonia, and hydrogen sulfide are the most important, The carbon dioxide accumulates in the submerged soils. It depresses the pH of calcareous and sodic soils, and prevents the pH of reduced acid soils from rising above 6.5 to 7.0 (Ponnamperuma *et al.* 1966). Thus the pH values of both acid and alkaline soils converge at 7 after submergence. The organic acids act like carbon dioxide, but their influence is transitory.

To summarize: an upland soil has much less interstitial water than has a submerged soil; iron, phosphate, and silica are less soluble; available nitrogen is present as highly mobile nitrate; and soil acidity and alkalinity may be problems.

IMPLICATIONS OF UPLAND SOIL CHARACTERISTICS

Nutrients are delivered to roots primarily by mass flow and diffusion. The delivery rate of nutrients by both of these mechanisms decreases as the moisture content of the soil decreases (Parish 1971). Thus the lower soil moisture content in upland soils reduces the supply of nutrients to the roots.

The content of water-soluble iron in most aerobic soils is so small that it is almost chemically undetectable. Plant roots extract iron by first reducing insoluble ferric iron to the more soluble ferrous form (Ambler *et al.* 1971). Because the flux of oxygen from the bulk of the soil to the root surface decreases. the rhizospheres of the mesophyte roots tend to be reducing. This facilitates the uptake of iron. The rhizosphere of rice, however, is oxidizing because oxygen flows from the shoots to the roots (Armstrong 1970) and the greater the oxygen flux, the smaller is the uptake of iron (Armstrong 1971). So, the iron requirement of rice is a p parently higher than that of other plants (Gericke 1930; Lin 1946), and rice suffers from iron deficiency in well-drained upland soils. The severity of iron deficiency increases with the pH of the soil (IRRI [Undated] *c*) so that iron deficiency is the major limiting factor of aerobic neutral and alkaline soils. But if the redox potential of an upland soil falls below 0.2 V at pH 7 as a result of temporary waterlogging, or if the subsoil is saturated and anaerobic, iron deficiency may not occur, even in alkaline soils.

During soil reduction the availability of phosphate increases, whether judged by chemical tests or by plant uptake (Ponnamperuma 1965). Thus phosphate deficiency can be a limiting factor in upland soils, especially strongly acid oxisols. Soil reduction also increases the availability of silica, which may also be a limiting factor in upland soils.

The nitrogen regime in aerobic soils is quite different from that in submerged soils. Organic nitrogen mineralizes faster in aerobic soils but no nitrogen is released unless the nitrogen content of the substrate exceeds 1 to 2 percent. Thus, less total nitrogen is mineralized in aerobic than in anaerobic soils (Borthakur and Mazumder 1968). Besides, the A values, or the availability of N supply, are only half as high as those for anaerobic soils (Broadbent and Reyes 1971). Additional disadvantages include the lower rate of nitrogen fixation in aerobic soils (Yoshida and Ancajas, 1973), the loss of nitrate by leaching and denitrification in anaerobic pockets, and the lower rate of plant uptake.

Upland soils, unlike submerged soils, are not able to adjust their pH levels to the favorable range of 6.5 to 7.0. This means that manganese and aluminum toxicities can occur in strongly acid soils, and iron deficiency in alkaline soils.

The solubility of manganese increases steeply in aerobic soils as the pH falls below 4.5, while that of iron does not change measurably until a pH of 2.7 to **3.0** is reached. This decrease in pH of an acid soil dramatically increases the ratio of manganese to iron in the soil solution, leading to manganese toxicity and iron deficiency (IRRI 1971). Nitrate aggravates the problem (Tanaka and Navasero 1966*b*). Manganese toxicity is another hazard on acid upland soils. If the soil pH is depressed to about 4.0 (by the use of large amounts of ammonium sulfate, for example), aluminum toxicity becomes a serious retarding factor.

The following observations on upland rice soils reported by Nagai (1958) support some of the above findings:

> (1) productive soils are rich in organic matter, and have higher pH values and lower redox potentials than non-productive soils; and (2) the straw of the rice on productive soils has a higher content of iron and a much lower content of manganese than does the straw from non-productive soils.

SUMMARY AND CONCLUSIONS

Rice yields less on aerobic soils than on the same soil rendered anaerobic by flooding. The chemical components of the unfavorable environment of aerobic soils for rice include: iron deficiency and low availability of nitrogen, phosphate, and silica on all soils; and the toxicity of manganese and aluminum in acid soils. Upland rice will do best on the lower members of the toposequence of slightly acid soils. Sodic, calcareous, and saline soils, acid sulfate soil, and soils low in organic matter are contraindicated for upland rice.

chapter three

CHARACTERISTICS OF UPLAND RICE

Factors that limit the growth and yields of upland rice
Shouichi Yoshida'
Varietal diversity and morpho-agronomic characteristics of upland rice
Te-Tzu Chang[2] *and Benito S. Vergara*[3]

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Factors that limit the growth and yields of upland rice

Shouichi Yoshida

Anything that affects the growth of rice can also limit its grain yield under certain conditions. We would like to know which factors limit the growth and yield of rice under common upland conditions. In this section, we will describe and compare the growth characteristics of upland and lowland rices, and then examine several theories of why upland rice yields are low.

Growth characteristics. The rice plant grown under upland conditions and hence subjected to different degrees of moisture stress is generally shorter, and has fewer tillers and less leaf area. Sterility is higher; the effective tiller percentage, or the ratio of panicle number to maximum tiller number, is lower. It flowers later than lowland rice, produces less dry matter, and has a lower harvest index or grain-to-straw ratio. These factors, or combinations of them, contribute to another characteristic common to upland rice – lower grain yields (Chaudhry and McLean 1963; Senewiratne and Mikkelsen 1961; Wu 1966).

The most striking characteristics of the rice plant under moisture stress are reduced plant height, delayed flowering, and extremely high sterility. The high sterility results in a low ratio of panicles to straw. The total dry matter and panicle-to-straw ratio was reduced to a similar degree in one experiment, suggesting that low yields are caused not only by suppressed growth but also by higher sterility (Table 1).

Any theory that explains the poor growth of upland rice should also explain most or all of these characteristics associated with upland rice.

Effects of weeds. Upland fields almost always have more weeds, which compete for nutrients and light, than lowland fields. Flooding has been recognized as an effective weed control method for many years (Chambliss and Jenkins 1925; Cralley and Adair 1937; Jenkins and Jones 1944). Later research, however, shows that weeds are not the ultimate factor limiting the growth of upland rice (Vlamis and Davis 1944; Miura and Kanaki 1950; Yoshino and Kawasaki 1953; Clark *et al.* 1957; Chaudhry and McLean

Table 1. Growth patterns of PI 215936 grown under upland and lowland conditions. IRRI, 1964 rainy season.[a]

Wks after water treatment began	Culture	Dry wt (kg/sq m)	Dry matter (% of fresh straw)	Plant ht (cm)	Tillers (no./sq m)	Panicles (no./sq m)	Effective tillers (%)	Panicle: straw ratio	Grain yield (t/ha)
0	Upland Lowland	0.01	17.9	18	238	–	–	–	–
3	Upland	0.06	17.3	32	371	–	–	–	–
	Lowland	0.15	15.3	50	502	–	–	–	–
6	Upland	0.30	26.1	75	282	–	–	–	–
	Lowland	0.89	21.3	103	573	–	–	–	–
9	Upland	0.54	32.8	107	273	–	–	–	–
	Lowland	1.00	25.1	115	[illegible]	–	–	–	–
12	Upland	0.85	21.4	128	253	227	61.2	0.65	2.9
	Lowland	1.26	19.1	131	380	378	72.6	0.84	4.6

[a]Source: Wu 1966.

1963). Even in weed-free conditions, rice grows better under flooded than under upland conditions.

Decreased or excessive supply of nutrients. Many scientists have claimed that lowland rice grows better because submerged soil conditions increase the availability of several elements including silica (Subramanyan 1937, cited by Grist 1959; Ponnamperuma 1965), iron (Lin 1946; Ponnamperuma 1955; Clark and Kesnicky 1956), phosphorus (Aoki 1941, 1942; Shapiro 1958; Ponnamperuma 1965; Patrick and Mahapatra 1968), and manganese (Clark and Resnicky 1956; Clark *et al.* 1957; Ponnamperuma 1965).

There is little doubt that the increased availability of certain nutrients such as iron, phosphorus, and manganese has a beneficial effect on rice growth under flooded conditions. But if the lack of nutrients is the ultimate cause of poor growth of upland rice, then correcting the nutrient deficiencies should improve its growth and its yield to a level comparable to those of lowland rice. This is not the case (Chaudhry and McLean 1963; IRRI [Undated]*b*, c). Even when a neutral soil that is deficient in phosphorus, iron, and silica receives these nutrients at field capacity of soil moisture, upland growth and yield are still lower.

Neither phosphorus deficiency (Ishizuka and Tanaka 1960) nor low silica (Yoshida 1965) seems to cause high sterility. Superphosphate applied at the rate of 1,000 pounds of P_2O_5 per acre (1.12 t/ha) to unflooded muck soil brought the phosphorus content in plant tissue to the same level as that in rice grown on flooded soils, but did not advance the flowering date (Chaudhry and McLean 1963).

Senewiratne and Mikkelsen (1961) claimed that the higher manganese content of rice plants grown in an upland treatment (789 ppm for unflooded and 102 ppm for flooded) affects the indoleacetic acid oxidase mechanism, retarding growth and depressing grain yields. But rice is tolerant to a high manganese content in tissues (Clark *et al.* 1957; Tanaka and Navasero 1966*a*). A manganese content of less than 1,000 ppm would not likely retard growth. Also, the better growth of lowland rice is often associated with a higher level of manganese content in the plant tissues, contrary to the conclusion of Senewiratne and Mikkelsen (1961).

Moisture stress. Internal moisture stress in plant tissues seems to cause poor growth in many upland crops (Kramer 1969; Slatyer 1967, 1969). Little research of this nature has been done, however, on rice.

Early work in Japan clearly indicated that the rice plant is most sensitive to drought from the cell division stage to the flowering stage (Togawa and Nakagawa 1937; Kawahara 1944; Wada *et al.* 1945; Nagato 1949). This was confirmed by Matsushima (1968) who studied an indica variety in Malaysia (Table 2). Three days of drought around the critical time (from 11 days to 3 days before heading) reduced yield by causing high percentages of sterility.

Agronomically, a great deal of evidence indicates that growth and yield of upland rice are highly correlated with the amount and duration of irrigation (Uyeda 1933, 1935; Takahashi and Takahashi 1952; Yoshino and Kawasaki 1953; Nakamura *et al.* 1960; Urano *et al.* 1960).

Table 3 shows how different water conditions affect the nitrogen response and yield of rice. In the dry season, with adequate water, grain yield increased as nitrogen level increased. But under rainfed conditions, yields were extremely low and the rice did not

Table 2. Effects of 3 days of drought on yield and yield components of an indica rice variety.

Drought treatment	Yield (g/hill)	Panicles (no./hill)	Sterility (%)	Filled grains (%)	1,000-grain wt (g)
			Days before heading		
55	18.0	11	11	70	21.8
51	16.8	11	9	66	22.0
43	19.5	11	14	65	21.5
35	20.0	12	11	60	20.5
27	17.0	11	12	54	20.2
19	15.7	11	34	52	20.8
11	6.5	10	62	29	21.6
3	8.3	10	59	38	20.9
			Days after heading		
5	16.5	11	10	59	21.9
13	20.5	10	7	66	22.5
No stress	22.7	10	15	65	21.9

[a]Source: Matsushima 1968.

Table 3. Yield of PI 215936 (t/ha) grown under different water regimes and nitrogen levels. IRRI, 1965, dry and rainy seasons[a].

Water regime	N level			
	Split application			Basal application
	0 kg/ha	60 kg/ha	120 kg/ha	90 kg/ha
			Dry season	
Flooded	3.0	4.8	1.2	–
Saturated	3.0	4.1	6.8	–
Irrigated upland	1.3	4.1	6.0	–
Rainfed upland	0.7	1.0	0.6	–
			Rainy season	
Flooded	2.6	4.9	4.2	3.4
Saturated	2.8	4.6	4.0	3.2
Irrigated upland	0.6	3.0	3.9	1.7
Rainfed upland	0.4	2.8	2.9	2.0

[a]Source: Wu 1966.

respond to increased nitrogen applications. Moisture stress was clearly the most limiting factor of growth. During the rainy season, even rainfed rice responded positively to nitrogen, because rainfall provided an adequate supply of water.

A shading experiment also indicated that moisture stress is the most limiting factor of upland rice growth and yield. Shading decreased grain yields when the water supply was adequate (Table 4). But under rainfed conditions, shading improved growth and increased grain yields.

The amount of water that the plant loses through evapotranspiration is directly related to the amount of solar radiation that falls on the plant. Thus, shading conserves water. Since shaded plants suffer less moisture stress, they can maintain their physiological activity longer under a lower light intensity. Also, efficiency of photosynthesis per unit of light is higher at lower light intensities. So, the shaded plants produced more dry matter and grain than did the unshaded plants.

In conclusion, moisture stress is the primary limiting factor of growth and yield under upland conditions. If adequate water is provided, then nitrogen tends to be the major limiting factor of yield.

Table 4. Effects of shading on PI 215936 grown under four water regimes. IRRI, 1965 dry season'.

Water regime	Unshaded	Shaded[a]
	Total dry wt (kg/sq m)	
Flooded	2.25	1.94
Saturated	2.22	1.97
Irrigated upland	2.10	2.02
Rainfed upland	0.87	1.02
	Grain yield (t/ha)	
Flooded	7.15	6.10
Saturated	6.81	6.07
Irrigated upland	6.01	6.20
Rainfed upland	0.74	1.37
	Grain: straw ratio	
Flooded	0.85	0.81
Saturated	0.84	0.82
Irrigated upland	0.80	0.81
Rainfed upland	0.31	0.35

'Source: Wu 1966. [b]70 to 75% of sunlight shaded with a sinamay screen

ABSORPTION AND LOSS OF WATER BY THE RICE PLANT

When the plant loses more water than it absorbs through its roots, it suffers internal moisture stress. So we must examine absorption as well as loss of water by the rice plant if we seek to really understand the effects of drought.

Root growth, available water, and water table. Root develop ment has long been recognized as an important factor in determining a given plant species' adaptability to dry conditions (Lundegardh 1957). Hasegawa (1963) demonstrated that some upland rice varieties have longer and better developed roots than do some lowland varieties.

At IRRI, Chang *et al.* (1972) have shown that some varieties normally used in upland culture, such as Palawan and OS **4,** develop deeper roots that are more branched.

Deeper roots are desirable for upland rices because soil moisture increases with depth of the soil profile (Michael *et al.* 1970). Under dry conditions, a variety with deep roots can reach. and use, soil moisture at a greater depth.

During dry periods. the major sources of water for the plants are moisture from rain that is retained by the soil. and ground water.

The water readily available to plants (in the range between the field capacity and permanent wilting point) is measured in millimeters of water per unit depth of soil. Soils differ greatly in the storage capacity of water that is readily available to the plants. For example, in one measurement, storage capacity ranges from 4.3 to 8.6 mm/30 cm in fine sand to 77.0 mm/30 cm in a clay. Obviously, plants growing in soils that have low storage capacities will exhaust the readily available water and suffer from drought much sooner than plants growing in soils with high storage capacities. The limitation of storage capacity becomes particularly important for plants such as rice, that have shallow roots. or that grow on shallow soils underlain by rock or hardpan layers that are almost impermeable to roots, such as lowland paddy fields (Kramer 1969).

The extent to which ground water can supply needed moisture to the root zones is primarily determined by the depth of the water table and the soil texture. A higher water table will supply more moisture to the root zones.

The soil texture determines the capillary ascent of water in soils (Siline-Beckchourine 1963). In a fine soil, water moves upward a long distance at a slow rate. A coarse soil permits rapid capillary action. but only for a short distance. Kramer (1969) states that. with a water table 00 cm deep. water moved upward at 5 mm/day in a coarse-textured soil but only at 2 mm/day in a fine-textured soil. With the water table at 90 cm, the flows were reduced to 1 mm/day in both soils.

Soil moisture content itself is also important. Decreased soil moisture makes the rate of flow of water extremely slow (Richards 1936).

Table 5 shows how the depth of the water table affects growth and yield of rice. When the water table was set at 25 cm below the soil surface, the rice plants produced only about 64 to 85 percent as much total dry matter as when sufficient soil moisture was supplied. Grain weight was only 50 percent. Rice plants on Maahas

Table 5. Efiects of water level depth on growth and yield of rice grown in Maahas clay in a greenhouse[a].

	Water level			
	Above soil surface	Below soil surface		
	5 cm	0 cm	25 cm	50 cm
Total dry wt (g/plant)	370	490	313	142
Grain wt (g/plant)	203	282	118	22
Dry matter (% of fresh straw)	24	27	35	42
Panicles (no./plant)	49	53	28	23
Effective tillers (%)	98	100	85	12
Plant ht (cm)	140	155	132	93
Panicle: straw ratio	1.2	1.4	0.7	0.2

[a]Source: Wu 1966.

clay soil suffered from severe moisture stress when the water table was 25 cm or more below the soil surface. Varieties with deeper roots would have performed better.

Transpiration ratio. Transpiration is the loss of water vapor from a plant. The transpiration ratio is the number of grams of water transpired per gram of dry matter produced. The transpiration ratio of the rice plant varies with soil moisture, climatic environment, variety, growth stage, and growth duration of the plant (Kato *et al.* 1962, 1965; Matsushima 1968). It ranges from 171 to 438 g/g (Kato *et al.* 1962, 1965), but it is generally around 250 to 350 g/g.

The transpiration ratio implies that dry matter production is proportional to the amount of water transpired by the plant, explaining why rice growth and yield under upland conditions are highly correlated with the amount and duration of irrigation.

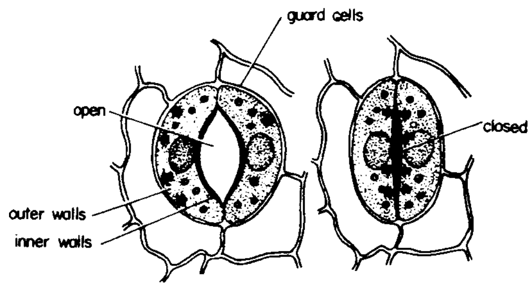
The transpiration ratio of rice is about twice that of sorghum (Table 6). In other words, rice uses water for dry matter production only about half as efficiently as does sorghum.

Stomatal transpiration. Transpiration is controlled primarily by the opening and closing of small openings on the leaves called stomata (fig. 1). Under soil moisture stress, the stomata partially or entirely close, conserving water and, hence, preventing loss of internal plant moisture. Stomatal resistance, or the resistance of the leaf to moisture loss through the, stomata, can be used as a

Table 6. Efficiency of water use in photosynthesis and dry matter production of rice and sorghum[a].

Water regime	Simultaneous measurement[b]: Transpiration (mg $H_2O \cdot leaf^{-1} \cdot hr^{-1}$)	Simultaneous measurement[b]: Photosynthesis (mg $CO_2 \cdot leaf^{-1} \cdot h^{-1}$)	Transpiration/ photosynthesis ratio	Pot experiment[c]: Dry wt (g/pot)	Pot experiment[c]: Transpiration (g/pot)	Pot experiment[c]: Transpiration ratio (g/g)
			Rice			
Flooded	–	–	–	10.75	2405	224 ± 10
Upland	162	4.1	40	7.55	1847	244 ± 23
			Sorghum			
Up [illegible]	[illegible]5[illegible]	12.8	20	8.45	913	114 ± 29

[a]Source: IRRI 1972. [b]3 weeks after sowing. [c]Measured 5 weeks after sowing.



1. Open (left) and closed (right) stomata The stomata is open when the guard cells are turgid; the inner cell walls of the guard cells are thicker than the outer cell walls. The stomata is closed when the guard cells lose their turgidity.

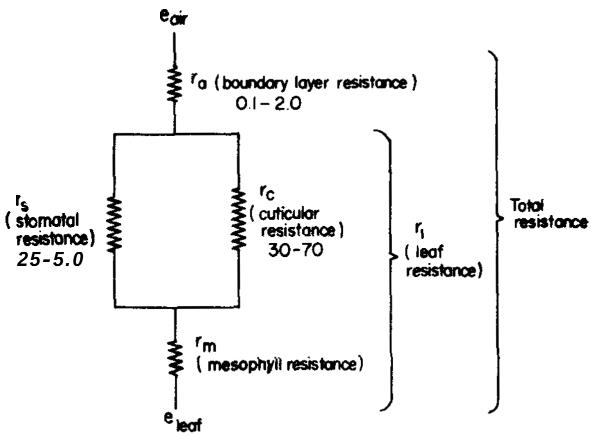
measure of internal moisture stress. As stomatal resistance lessens, the transpiration rate increases:

$$\text{transpiration rate} \propto \frac{\text{saturation deficit}}{\text{stomatal resistance.}}$$

The transpiration rate is also affected by boundary layer resistance, a function of leaf size and wind speed. Figure 2 illustrates various kinds of resistances to diffusion of water vapor from a rice leaf. With an adequate supply of water, one side of a leaf surface has about 2.5 to 5.0 s/cm of stomatal resistance. This magnitude of stomatal resistance of rice leaves is quite common among mesophytes.

Drought resistance of pearl millet and corn is partly caused by the rapid closing of the stomata in response to soil moisture stress (Sullivan *et al.* 1971). Rice varieties that are tolerant of drought, such as M1-48, OS 4, and IR5, show high stomatal resistance in response to soil moisture stress (Table 7). Susceptible varieties, such as IR20 and TN1, have low stomatal resistance.

Stomatal resistance is regulated not only by soil moisture, but also by the aerial environment (solar radiation. air temperature, air humidity). Thus, the stomatal resistance. even of identical varieties grown under the same moisture stress, might differ under different aerial environments. On cloudy days. we observed visual symptoms of moisture stress only on plants grown at 35 percent of field moisture capacity in an IRRI experiment, whereas on sunny days.



2. Resistance to diffusion of water vapor from a rice leaf. Transpiration is proportional to the steepness of the gradient in water vapor pressure, e_{leaf} to e_{air}, and inversely proportional to the size of the resistances, expressed in seconds per centimeter (adapted from Kramer 1969).

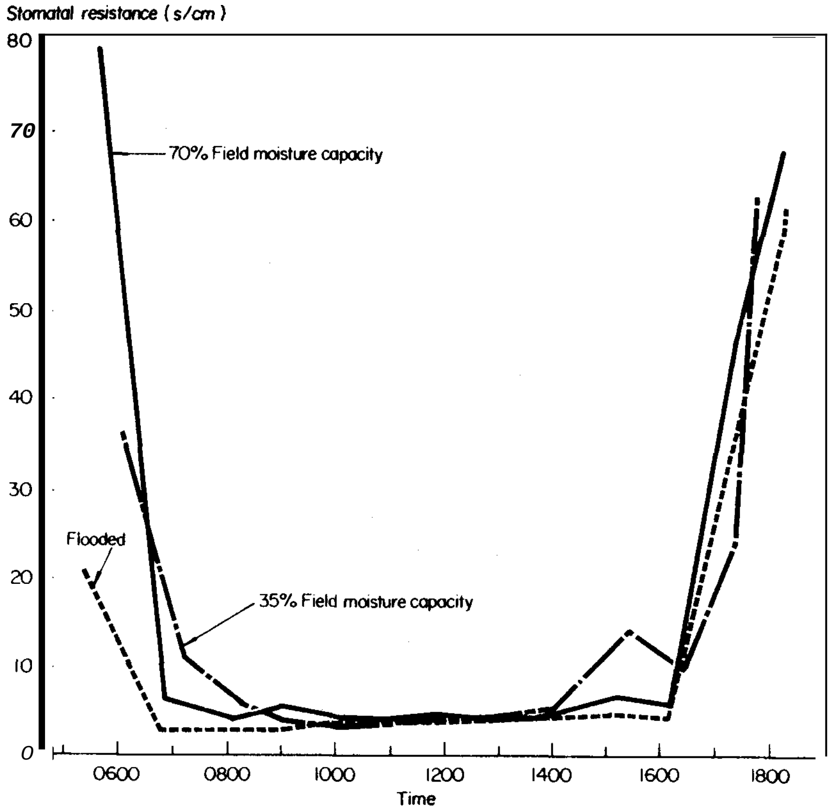
Table 7. Stomatal resistance to loss of water vapor of 12 varieties[a]

Variety	Stomatal resistance (s/cm)	
	Without moisture stress	With moisture stress
Jappeni Tunkungo	3.7	12.4
M 148	3.8	10.8
IR5	3.6	10.1
OS 4	3.7	10.0
Tainan 3	3.7	10.0
Palawan	3.5	9.6
Dular	3.9	9.4
PI 215936	3.8	9.1
E 425	3.5	8.5
TN 1	3.9	8.3
T 141	3.6	7.9
IR 20	3.6	6.9
LSD (5%)	0.3	2.5

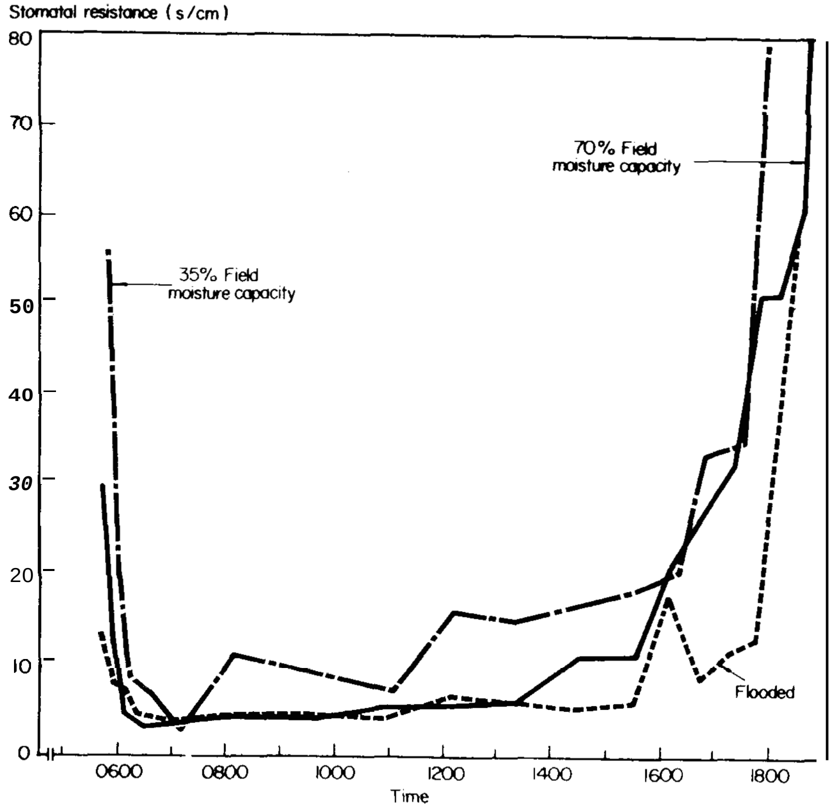
[a]Source: IRRI 1973.

all plants grown at 35 percent, 50 percent, and 70 percent of field moisture capacity showed signs of moisture stress.

Figures 3, 4, and 5 show that the patterns of hourly changes in stomatal resistance of plants grown in flooded soils are similar, regardless of weather conditions. The stomatal resistance values were high early in the morning and late in the afternoon. During the daytime, they remained low, around 2.5 to 5.0 s/cm, indicating that light intensity controls the stomatal resistance of rice plants grown in flooded soils and that stomata are kept open during the daytime. This implies that rice plants grown in flooded soils did not suffer enough internal moisture stress to cause the stomata to close during the daytime. Under such conditions. the plant may use solar radiation for photosynthesis at maximum efficiency.



3. Hourly **changes** in **stomatal resistance** on **Aug. 4,** 1973 **(cloudy day).**

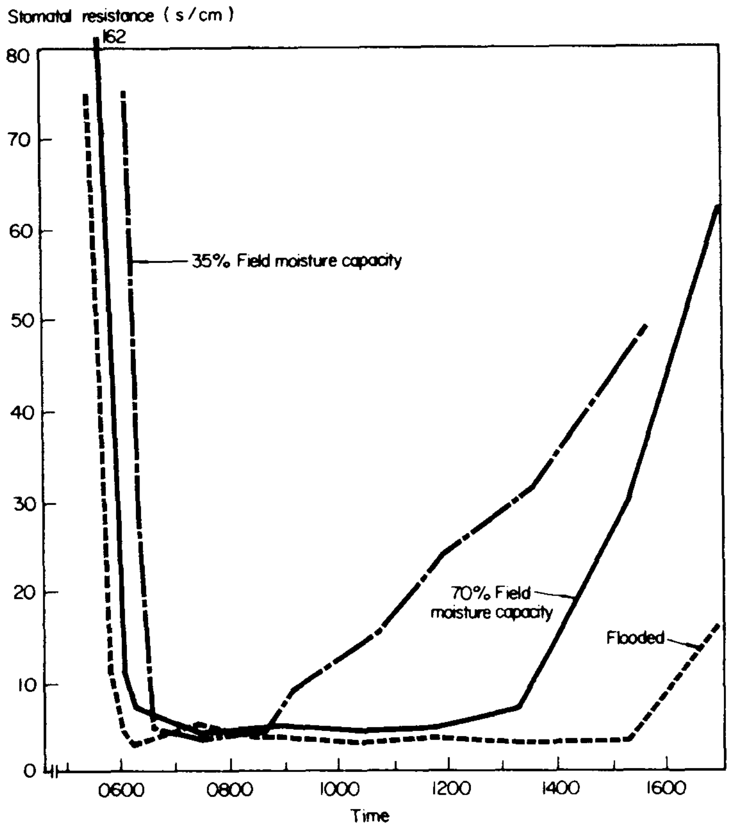


4. Hourly changes in stomatal resistance on Aug. 6. 1973 (partly cloudy day).

A few reports, however, describe partial closure of stomata during the daytime under flooded conditions (Mohsin 1970; Ishihara *et al.* 1971). Whether the apparent discrepancy is due to soil problems, to the aerial environments, or to the measuring technique remains to be studied.

The plants grown under upland conditions showed similar hourly changes in stomatal resistance on cloudy days. On sunny days, however, stomatal resistance increased rapidly in the afternoon, sometimes even in the morning. depending on weather conditions. This indicates clearly that even under the same soil-water regime, internal plant moisture stress is higher on sunny than on cloudy days.

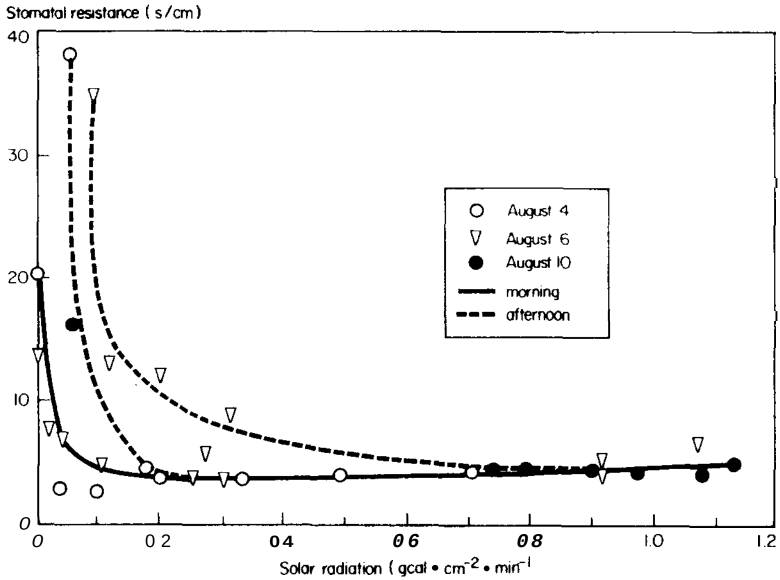
Figure 6 shows the relationship between stomatal resistance and solar radiation under flooded conditions. Stomatal resistance



5. Hourly change of leaf resistance on Aug. 10, 1973 (sunny day),

values of the plant decreased rapidly with increasing solar radiation, and reached the constant value of about 4 s/cm at about 0.1 $cal \cdot cm^{-2} \cdot min^{-1}$. Under moisture stress, the stomatal resistance values first increased proportionately with increasing solar radiation, then rose sharply, indicating moisture stress in the plant tissues. At the same levels of solar radiation, stomatal resistance values were higher in the afternoon than in the morning, simply because the plant had been under moisture stress longer. Thus, under high levels of solar radiation and moisture-stress conditions, the stomata of the plant will close during the day, and the plant will not use the solar radiation for photosynthesis.

The relationship between solar radiation and plant growth, therefore, is quite different under flooded and moisture-stress conditions. Under flooded conditions, increased solar radiation in-



6. Relationship between stomatal resistance and solar radiation under flooded conditions.

creases plant growth. Under moisture-stress conditions, however, high solar radiation does not necessarily increase plant growth; in fact, it may even adversely affect plant growth (Table 4).

Culticular transpiration. When stomata are completely closed, whether during the nighttime or because of moisture stress, most of the water lost by the plant is through cuticular transpiration.

Cuticular resistance differs significantly among different plant species. In general, aquatic species have low resistance values, whereas xerophytic species (adapted to dry climates) have high resistance values. Mesophytes (adapted to intermediate climates) are between the two. The study of varietal differences in cuticular resistance for a given species has largely been neglected. Most researchers doubt that there is much difference in varieties. But we recently found large varietal differences in rice: cuticular resistance values of 20 varieties ranged from 30 *to* 68 s/cm (Table 8).

Measuring cuticular resistance of rice is difficult because both sides of a rice plant's leaf have stomata. In the above experiment, we placed the rice plant in the dark, then took measurements. Differences in cuticular resistance seem to partially explain varietal differences in drought resistance. Azmil, Rikuto Norin 21, Azucena, and MI-48 are recommended for upland culture, and IR442-

Table 8. Cuticular resistance of 20 rice varieties[a].

Variety	Cuticular resistance (s/cm)
Azmil	68.3
Rikuto Norin 21	66.4
Azucena	60.2
NARB	57.8
M1-48	56.0
IR442-2-58	53.8
IR5	47.6
IR841-67-1-1-1	46.5
Jappeni Tunkungo	42.4
IR1529-680-3-2	41.4
IR8	37.0
81B-25	36.5
PI-215936	35.2
Palawan	33.1
IR127-80-1	32.8
E425	32.5
IR20	32.2
Dular	30.0
Miltex	29.5
OS 4	29.5

[a]Source: IRRI 1973.

258 and IR5 perform well under upland conditions (De Datta and Beachell 1972). All have high cuticular resistance values. Some varieties normally used for upland planting. such as Palawan and OS 4, have rather low cuticular resistance values. but they have long roots (Chang *et al.* 1972). Sorghum, which has higher cuticular resistance and a longer root system than corn, is also more resistant to drought (Sullivan *et al.* 1971).

Transpiration at night. although much lower than during the day. accounts for from 10 to 17 percent of the total transpiration loss under upland conditions (Table 9). At night. transpiration is largely through the cuticles: hence. control of cuticular transpiration should prevent unnecessary water loss. Higher transpiration **loss** at night under upland conditions may be related to lower air humidity.

Table *9.*. Transpiration **loss** during the day and night under upland and lowland conditions.[a]

	Transpiration (g/4 hills)			Night/Total x 100
	Day	Night	Total	
		Sept. 11 - 12		
Upland	878	96	974	9.8
Lowland	714	11	724	1.5
		Sept. 19-20		
Upland	898	189	1087	17.4
Lowland	710	104	814	12.7

[a]Source: **Kato** ***et** al.* 1965.

PHYSIOLOGICAL ASPECTS OF DROUGHT RESISTANCE

Avoidance and tolerance. The drought resistance of rice is a total expression of its ability to stay alive, grow, and ultimately produce grain, under moisture stress for at least part of its life cycle.

The rice plant resists drought by either avoiding or tolerating it. Drought avoidance (or escape) is the plant’s ability to absorb sufficient water, or to suppress its loss of water early enough to prevent moisture stress in the cells or the tissues. Drought tolerance, or desiccation tolerance, is the ability of the cells to survive and metabolically function even when the tissues are desiccated (Levitt **1963).**

Little **work** has been done on drought’ resistance of rice in terms of avoidance and tolerance.

After reviewing drought resistance of pearl millet, sorghum, and corn (Sullivan ***et*** *al.* 1971), we propose that the following characters be examined to explain the principal mechanisms of drought resistance in rice:

Mechanism	*Plant characters to be examined*
Avoidance	o Closure of stomata in response to moisture stress
	o Cuticular resistance
	o Root systems
Tolerance	o Desiccation tolerance
	o Heat tolerance

We have some research results on each of these characters. Researchers are now collecting more data on a larger number of varieties, simplifying a technique for examining root development, and identifying the characteristics most responsible for drought resistance of the rice plant.

Physical consideration of leaf size and leaf angle. The size and angle of plant leaves significantly affect the water loss and leaf temperature.

Besides stomatal and cuticular resistance, as discussed earlier, other factors limit water movement in the plant (see fig. 2). Boundary layer resistance is closely related to the size and shape of the leaf. We can estimate boundary layer resistance for narrow leaves, such as those of rice, by the following formula (Cowan and Milthorpe 1968):

$$\text{boundary layer resistance} = 1.3 \times \sqrt{\frac{\text{leaf width, cm}}{\text{wind speed, cm/s}}}$$

Assuming that leaf width ranges from 0.5 to 2.0 cm, the boundary layer resistance will range from 0.92 to 1.83 s/cm at a wind speed of 1 cm/s, to 0.09 to 0.18 s/cm at a wind speed of 100 cm/s. Because the stomatal resistance of rice leaves without stress is about 3 to 5 s/cm, the leaf width will affect the transpiration rate only at low wind speeds.

The leaf angle will influence the leaf temperature and, hence, the rate of transpiration. By cosine law, leaves which are at right angles to the sun's rays are warmer than those which are parallel to the radiation. Because solar radiation is more intense when the sun is high, droopy leaves will be hotter than erect leaves, and will have higher transpiration rates. When the leaf temperature exceeds a critical value, leaf tissue cells are destroyed, resulting in "leaf scorching" on a droopy leaf. *So,* wide and erect leaves tend to minimize water loss by transpiration when leaf area index is relatively small.

Leaf angle has another implication, Under moisture stress, stomata open in the morning, and close during the rest of the day. In the morning, when the sun is low, erect leaves may be less efficient for photosynthesis, while droopy leaves might allow deeper sunlight penetration.

So, the merits and demerits of erect and droopy leaves depend on the water regime being considered and on a given variety's degree of heat tolerance.

MINERAL NUTRITION OF UPLAND RICE

Response to **N, P,** and **K.** Upland rice needs fertilization more than does lowland rice (Table 10). Both nitrogen and phosphorus play important roles in its growth and yield. Phosphorus is more vital in upland rice culture than in lowland rice culture partly because applied phosphorus is less easily available under aerobic and acidic conditions, and partly because of high phosphorus fixation of upland soils.

Mineral composition of upland- and Iowland-grown rice plants. The percentage of all essential nutrients has been found lower in rice plants grown under upland conditions than in those grown under lowland conditions (Table 11). The higher percentage of dry matter in upland-grown plants indicates a lower moisture content.

Although still within the normal ranges, the iron and manganese contents of upland-grown plants were markedly lower than those of lowland-grown plants. The deficiency and toxicity content levels of various elements in lowland rice. compiled in a previ-

Table 10. Effect of optimum levels of N, P, and K fertilizers on crop yields in Japan[a].

Fertilizer treatment	Response (% yield)				
	Lowland rice	Upland rice	Wheat	Sweet potato	White potato
NPK	100	100	100	100	100
PK	75	46	46	93	47
NK	97	66	69	84	68
NP	94	90	72	63	70
None	69	39	33	67	37

[a]Source: **Mitsui 1964.**

Table 11. Dry weight and element contents of variety PI 215936 grown under upland and lowland conditions. IRRI, 1964 wet season[a]

Wks after flooding	Culture	Dry wt (kg/sq m)	Dry matter (% of straw)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	SiO_2 (%)	Fe (ppm)	Mn (ppm)
3	Upland	0.1	17.3	3.0	0.2	3.4	0.4	0.6	11.1	150	63
	Lowland	0.2	15.3	2.9	0.2	4.0	0.4	0.5	11.8	259	1044
6	Upland	0.3	26.1	1.5	0.2	2.7	0.4	0.4	11.9	210	150
	Lowland	0.9	21.3	1.6	0.2	2.9	0.5	0.5	12.9	343	1469
9	Upland	0.5	–	1.1	0.1	2.3	0.5	0.3	12.7	147	282
	Lowland	1.0	25.1	1.5	0.2	2.3	0.5	0.3	14.3	294	1575
12	Upland	0.8	21.4	0.9	0.0	2.2	0.4	0.2	14.8	84	469
	Lowland	1.3	19.1	1.1	0.1	2.4	0.5	0.3	15.8	291	1419

[a]Source: IRRI 1964.

ous publication (Tanaka and Yoshida 1970). can be used as a guide only at initial stages of diagnosis. Clements (1964) pointed out that the moisture level of the plant may affect the critical level for nutrients. The manganese content of upland plants is also greatly influenced by soil type.

Nitrate versus ammonia. Nitrogen, usually found as ammonium in lowland soils, is found as nitrate in upland soil. At optimum pH, nitrate is as good as ammonia as a source of nitrogen for rice (Pirschle 1931; Kasugai 1939; Tanaka *et al.* 1959; IRRI [Undated] c). The optimum pH is lower for nitrate than for ammonia (Table 12). When ammonium nitrate is applied, the plant absorbs the ammonium faster than the nitrate. As a result, the pH of the soil surrounding the root zone goes down earlier.

Because nitrate absorption increases the pH of the root zone, the plant may suffer from iron deficiency.

Nitrate facilitates absorption of most nutrients, particularly manganese (Table 12) (Kasugai 1939: Tanaka *et al.* 1959).

Nitrate leaches from a field faster than does ammonia, so splitting the nitrogen application is more important in upland than in

Table 12. Effects of pH and of two nitrogen sources on the plant weight and the iron and manganese content of the rice plant.[a]

pH	Dry wt (g/plant)	Nutrient content (ppm) Fe	Mn
		NH_4-N	
3.5	13	273	35
4	36	216	40
5	41	198	230
6	44	158	305
7	19	81	340
		NO_3-N	
3.5	24	174	45
4	39	172	145
5	39	162	415
6	24	90	500
7	9	82	690

[a]Source: IRRI [Undated] c.

Table 13. Effects of water regimes on iron and manganese contents of rice plants grown on five types of soils.

	Luisiana clay[a] pH 4.8	Maahas clay[a] pH 6.6	Calcareous clay[a] pH 7.5	Stockton clay[b] pH 4.1	Brookston silt loam[c] pH 6.5
			Fe (ppm)		
Submerged	282	200	77	52	57
Upland	91	133	75	47	63
			Mn (ppm)		
Submerged	783	690	364	102	232
Upland	1870	141	41	789	18

[a]Source: IRRI [Undated]. [b]Senewiratne and Mikkelsen 1961. [c]Clark et *al.* 1957.

lowland culture.

Phosphorus. The availability of phosphorus is lower in upland soils than in submerged soils (Aoki 1941, 1942; Shapiro 1958; Ponnamperuma 1965; Patrick and Mahapatra 1968) because upland soils are aerobic and tend to be acidic. Furthermore. some upland soils (such as Ando soils) fix phosphate more readily than do alluvial lowland soils. so they require more phosphate fertilizer (Egawa *et al.* 1957).

Iron and manganese. Iron and manganese are usually less available in upland than in submerged soils. In the plants. however. mineral content is not so straightforward. Table 13 shows that the iron content of rice plants grown under upland conditions is lower than or equal to that of rice plants grown under submerged conditions. On the other hand, submergence decreased the manganese content of plants on acid soils but increased it on neutral or alkaline soils.

Iron deficiency is often a problem on neutral or alkaline soils (Kobayashi, M. 1958; IRRI [Undated]*a*). It can be identified easily by an abnormal yellowing, or chlorosis, between the leaf veins. Symptoms are more pronounced in the newer leaves. Iron deficiency can be corrected by applying a foliar spray of 0.1 to 0.2% ferrous sulfate or ferrous citrate solution, or by applying sulfur flour to the soil (Kobayashi, M. 1958). Sodium nitrate. calcium cyanamide, and ammonium nitrate should not be applied because they aggravate iron deficiency by raising the soil pH, making iron in the soil less available. Ammonium sulfate and ammonium chloride seem to be better nitrogen sources (Kobayashi, M. 1958). Several theories have been proposed to explain iron deficiency, including: 1) iron chlorosis induced by lime; 2) iron chlorosis induced by copper; 3) a higher ratio of phosphorus to iron and 4) a lower ratio of iron to manganese. M. Kobayashi (1958) observed that iron chlorosis of upland rice tends to appear when rains are frequent. This chlorotic condition is sometimes called "rain-induced scorching." This type of temporary iron chlorosis may not be serious, however, because such weather conditions eventually mean higher yields.

Silica. Some beneficial effects attributed to silica are: 1) maintenance of erect leaves (Iwata and Baba 1962; Cock and Yoshida 1970); 2) reduction of water loss, perhaps through cuticular transpiration (Yoshida 1965); 3) increased oxidizing power of roots (Okuda and Takahashi 1965); and 4) protection against diseases and insects (Yoshida 1959).

The availability of silica is lower in upland than in flooded soils. The silica content of plants grown in upland and lowland soils is about the same, however, because the reduced growth tends to increase silica content (Table 11). Lowland rice has 1 to 2 percent higher silica content, but such a small difference probably has no significant effects on plant growth.

Erect leaves will increase photosynthesis only when the leaf area index is higher than 5. Droopy leaves are better when the leaf area index is less than 3 (Montieth 1965).

Because the leaf area index of upland rice is generally less than 5, it seems unlikely that less erect leaves due to decreased plant silica content would seriously affect the photosynthetic activity. A further examination of the effects of silica on plant water loss and on susceptibility to such diseases as blast and Helminthosporium may be necessary. It seems doubtful, however, that a 1- to 2-percent difference out of a 10- to 15-percent silica content would markedly affect the transpiration rate and disease incidence.

Silica may increase the oxidizing power of rice roots and thereby help the rice plant perform better under highly reductive conditions. Decreased oxidizing power of rice roots under upland conditions, on the other hand, should help in the absorption of iron.

Sulfur. Sulfur is reduced to sulfide under lowland conditions but under upland conditions it remains as sulfate, which is more readily available to the rice plant (Nearpass and Clark 1960). Irri-

Table **14.** Effects of fertilizer and mineral content of water on dry matter yield and sulfur uptake of rice plants grown on Lipa clay loam under lowland and upland conditions **(IRRI** 1972).

		Treatment			
		$(NH_4)_2SO_4$ + TW	$(NH_4)_2SO_4$ + DW	Urea + DW	Urea + TW
		Dry wt (g/pot)			
Panicle:	lowland	96	94	25	88
	upland	34	33	20	31
Straw:	lowland	84	87	49	75
	upland	54	53	38	52
		S content (%)			
Panicle:	lowland	0.09	0.09	0.03	0.07
	upland	0.09	0.09	0.05	0.07
Straw:	lowland	0.18	0.14	0.04	0.04
	upland	0.22	0.19	0.04	0.11
		Total S uptake (mg/pot)			
	lowland	262	221	26	86
	upland	154	134	25	78

gation water supplies considerable sulfate to the rice plant in lowland fields (Kobayashi, J. 1958; Livingstone 1963). Some fertilizers, such as ammonium sulfate, superphosphate, and potassium sulfate, contain sulfur. The recent trend to use more non-sulfur fertilizers, such as urea and concentrated superphosphate, may induce sulfur deficiency as better agronomic management improves crop performance.

Table 14 shows that ammonium sulfate supplied sufficient sulfur to plants, regardless of water sources (tap water at 2.3 mg S/1, or demineralized water at 0 mg S/1). When urea was applied with demineralized water, sulfur deficiency symptoms developed under both lowland and upland conditions. The yield under lowland condition was only 26 percent of that obtained with ammonium sulfate plus tap water; it was 60 percent under upland conditions. Urea combined with tap water raised the yield to 94 to 95 percent of that obtained with ammonium sulfate plus tap water under both upland and lowland conditions. The plants absorbed twice as

Table 15. Availability of sulfur supplied by irrigation water under lowland and upland conditions (IRRI 1971).

S (mg) supplied by			Tap water consumed[b] (liter)	Total S in tap water[c] (mg)	S recovery (%)
Soil plus tap water	Soil[a]	Tap water			
			Lowland		
86	26	60	48.9	112	54
			Upland		
78	25	53	24.9	57	93

[a]Amount supplied by soil plus demineralized water. [b]Water requirement assumed to be 300 g H_2O/g dry matter for both lowland and upland rice. [c]Total water consumption x 2.3 mg/liter S.

much sulfur from urea added to tap water as from the soil under both water regimes.

To estimate the availability of sulfur applied by irrigation water, we compared the total amount of sulfur supplied by water with the amount recovered, taking into consideration the transpiration ratio of the rice plant and the sulfur content of irrigation water (Table 15). Sulfur applied by water was more available in soils under upland than under lowland conditions. This should hold true regardless of sulfur source.

Zinc. Zinc deficiency, although common in lowland rice (Yoshida *et al.* 1973), has only been recorded a few times for upland rice, in Brazil and Japan (de Souza and Hiroce 1969, *personal communication;* Uchida *et al.* 1970). Unlike other nutrients, such as phosphorus, iron, and manganese, zinc is more readily available in upland than in submerged soils (IRRI 1970). The zinc concentration in a soil solution decreases sharply when the soil is flooded, and tends to level at around 0.01 ppm.

The zinc content of the plant is much higher under upland than under flooded conditions (Table 16). The zinc uptake and the zinc content of the plant were higher on Luisiana soil under upland conditions, indicating that the high zinc content was caused not by poor growth but by high availability of zinc in the soil.

In Iwate, Japan, zinc deficiency of upland rice occurs widely on a variety of soils, particularly on highly acid volcanic ash soils (Uchida *et al.* 1970, 1971). Zinc content was higher in upper than

Table 16. Growth and zinc uptake of the rice plant under upland and flooded conditions (IRRI 1970).

Water regime	Dry wt (g/pot)	Nutrient content of shoot (ppm)			Total zinc uptake (mg/pot)
		Zn	Mn	Fe	
		Luisiana (pH 5.8)			
Upland	30	578	1162	515	17
Flooded	51	83	725	385	4
		Eagle Lake (pH 8.7)			
Upland	2	41	225	203	0.07
Flooded	14	15	337	166	0.21

in lower soil horizons, and zinc deficiency was mort' common where the upper soil horizons had eroded. Zinc applications corrected zinc deficiency symptoms on acid soils (pH 4.9) but improved plant growth only slightly. When lime was added to raise the soil pH to 5.5, however, zinc applications markedly improved growth and yield. Because soil zinc is so available under upland conditions, relatively low application of zinc (10 kg/ha) can effectively correct zinc deficiency (Uchida *et al.* 1971).

Varietal diversity and morpho-agronomic characteristics of upland rice

Te-Tzu Chang and Benito S. Vergara

UPLAND VERSUS LOWLAND VARIETIES.

The term ''upland rice variety" has been loosely used to designate any rice strain of *Oryza sativa* or *O. glaberrima*[1] that is suited for upland culture (Chang and Bardenas 1965). Upland rice culture encompasses a range of practices from rice that is seeded in dry soil in non-bunded fields dependent only on rainfall for moisture, to cultures in which a dry-seeded crop matures in a flooded field,[2] or where direct-seeded rice is transplanted into a puddled field when soil and water conditions are favorable. Years of selection under different climatic, soil, and cultural conditions have produced marked variability in the so-called upland varieties.

No clear-cut morphological differences could separate tropical rice varieties into distinct upland and lowland types; instead, the plant characteristics and growth features vary continuously. Any rice variety can be grown in either upland or flooded culture, but its growth and yield performance may differ markedly.

Most traditional varieties adapted to upland culture are medium-tall to tall, with relatively long and pale-green leaves, low to medium tillering ability, and long, well-exserted panicles. The maturity generally ranges from 105 to 135 days. But these characteristics are also found in many accessions designated as "lowland varieties'' in the IRRI germ plasm bank.

A study of 11 upiand and 14 lowland varieties from 1970 to 1972 showed that a low tillering potential and a nearly constant leaf area under different soil moisture regimes are distinctive features of many traditional upland varieties (Chang *et al.* 1972). Most are highly resistant to blast disease.

'Although *O. glaberrima* is extensively grown as an upland crop in West Africa, this species is not discussed in this chapter because of insufficient scientific information about African rices

'Such as *beasi* culture in India, or *gogo rantjah* in Indonesia.

VARIABILITY AMONG UPLAND VARIETIES

The traditional upland varieties vary less than do the lowland varieties in morpho-agronomic characteristics, Still, their inherent variability is undoubtedly great enough to be useful in improving varieties intended for upland culture. Further, some improved upland varieties already have certain desired agronomic features that are found in many lowland varieties.

Prior to 1970, only 200 accessions in the IRRI varietal collection were of the upland category, indicating that few serious efforts had been made to collect, evaluate, and preserve the upland varieties. So. few upland varieties were evaluated for resistance to diseases and insects in IRRI's systematic screening program during the 1960s. In recent years, IRRI has made special efforts to gather the upland types from the remote areas of tropical Asia and West Africa. The number of upland varieties in the IRRI germ plasm bank had grown to about 2,400 by 1974.

About 1,000 upland varieties in the IRRI germ plasm bank have been studied for field resistance to drought. Most tropical rices that have been designated as "upland" are of the traditionally tall type, moderately early maturing, low tillering, bold grained, and generally tolerant to drought. A few have high tillering ability and slender grains. They have apparently been subjected to varying degrees of mass or pedigree selection.

A dual-purpose type of early maturing varieties, adapted to both upland and lowland culture, includes Dular (from Bangladesh and India) and Bluebonnet 50 (bred as a lowland type in the U.S. but also grown as an upland variety in South America). A few modern hybrids, such as C 22 of the Philippines, are high tillering and moderately tall. Other varieties, adapted to combinations of both upland and rainfed-lowland cultures (such as *gogo rantjah* and *beasi* cultures), have many lowland features.

The upland varieties of Japan, on the other hand, differ distinctly from the lowland types: they are taller, and have fewer tillers, thicker culms, longer and broader leaves, and deeper roots. Their panicles, as well as their grains, are longer. They are generally more resistant to drought and the blast disease, but are less responsive to nitrogen (Ono 1971).

Because these varieties have been subjected to centuries of selection under upland culture, we can expect barriers to genetic recombination when they are hybridized with lowland varieties from the same geographic region. Yamaguchi (1963) observed up to 50 percent spikelet sterility in F_1 hybrids of several Japanese upland **x** lowland crosses. Crosses among several Japanese upland varieties also produced partially sterile F_1 hybrids. But the upland rices of Japan are quite diverse; some were fertile when crossed with a *tjereh*[3] variety from Indonesia or with an *aus*[4] variety from Bangladesh. Ono (1971) briefly mentioned difficulty in recombining desirable traits from upland x lowland crosses. At IRRI , experiments have shown that the F, s and later progenies (even to F_5 generations) of cross-combinations, such as semidwarf **x** African upland, and semidwarf x Japanese upland, are often partially sterile.

Most upland plantings in West Africa involve one of three types: varieties of common rice *(O. sativa,);* varieties of African rice *(O. glaberrima);* or a mixture of the two species (Jordan 1964; Oka and Chang 1964).

SEEDLING CHARACTERISTICS

Hasegawa (1963) summarized data from different sources to show that during germination both grain and brown rice of upland varieties tend to absorb water faster than lowland varieties. The upland varieties of Japan have slightly higher rates of germination and of radicle' development at a lower temperature (15°C) than at a higher temperature (30°C). Among the Japanese varieties the upland types generally produced shorter coleoptiles[6] and longer mesocotyls[7] than the lowland types. In the indica varieties, however, the lowland types produced longer mesocotyls and coleoptiles even though the upland types produced longer primary leaves (Hamada 1937).

An earlier literature survey indicates that tropical upland varieties generally emerge from the soil early after direct seeding and that the vigorous growth of the seedlings enables them to effectively compete with weeds (Chang and Bardenas 1965). Nagai (1958) also described a faster rate of germination in Japanese

[3] *Tjereh* varieties are long-grained indica types grown in lowland fields of Indonesia.
[4] *Aus* types are summer season varieties of Bangladesh and India, including both rainfed lowland and upland types. Some Japanese geneticists consider *aus* varieties as intermediate between the two major variety groups, indica and japonica (Chang **1964).**
'Embryonic root.
[6] First seedling leaf, or sheathing leaf.
[7] The internode between the coleoptile node and the point of union of the culm and root in a seedling.

upland varieties. When some 60 varieties were observed at IRRI, however, several lowland rices, such as IR747B2-6-3 and IR5, emerged from the soil as early as, or even earlier than, some fast-emerging upland varieties, such as Palawan and Sintiane Diofor. The lowland varieties also produced the first tillers, 3 to 4 days earlier than did the upland varieties. All lowland varieties produced more leaves per plant than did the upland group at 20 days after seeding (Chang *et al.* 1972). Under favorable conditions, the upland varieties seem to grow no more vigorously than do the lowland varieties under upland culture.

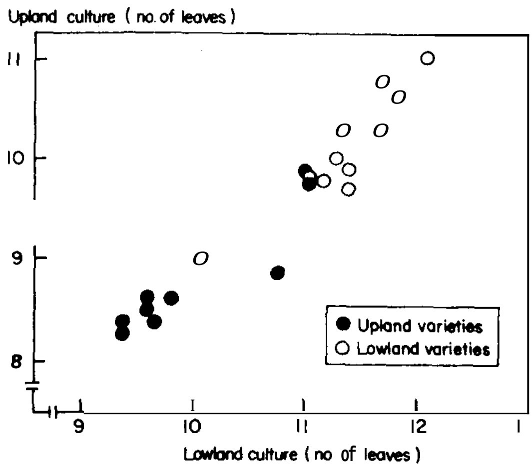
LEAF CHARACTERISTICS

Most tropical upland varieties have pale-green leaves that are relatively long and droopy. The leaf angles of most African and Philippine upland varieties are large -- often double those of the semidwarfs. A few traditional varieties, such as Jappeni Tunkungo, have long, erect, and dark-green leaves.

Because their leaves are generally longer and wider, the traditional upland varieties usually have larger leaf areas than the semidwarfs (Chang *et al.* 1972). But rate of growth and the number of leaves were slightly lower for the upland varieties as a group (fig. 7) than for several lowland varieties (Chang *et al.* 1972). A number of upland rices from the hills of Laos, the Philippines, and Thailand have glabrous, or hairless, leaves.

In Japan, the upland varieties generally have a longer and wider second leaf and a high leafsheath-length-to-blade-length ratio (Hasegawa 1963). The mechanical tissues of their leaf blades are better developed than those of the lowland varieties (Onodera 1931).

Despite their longer and more droopy leaves, the light transmission values of tropical upland varieties, measured at ground level 60 days after seeding, are equal to or slightly lower than those of semidwarfs. The difference increases, however, as the plants approach flowering. Without water stress, the semidwarfs. which had a higher number of both tillers and photosynthetically active leaves, produced fairly good ground cover (Chang *et al.* 1972). In pot experiments, IRRI plant physiologists also found that the lowland varieties had twice as many ieaves per hill as did the upland varieties. Under water stress, the traditional upland varieties had greater stomatal resistance to the escape of water vapor and were



7. Leaf number of nine upland and 11 lowland varieties grown under upland and lowland cultures 60 days after seeding.

injured less by high temperature (53°C) than several lowland varieties. Without moisture stress, only slight differences were observed between the two groups (IRRI 1973).

The Japanese upland varieties have heavier leaf blades than the lowland varieties (Hasegawa 1963). In tropical rices, though, the leaf thickness, or specific leaf weights of fresh leaf blades, does not consistently distinguish upland from lowland varieties. In some experiments, upland varieties produced higher specific leaf weights than did lowland varieties (Alluri *et al.* 1973). But these differences were not consistent in several field plantings.

When several traditional upland varieties and several short-statured lowland varieties were grown on the same date under both upland and transplant-flooded conditions, the upland types consistently varied less in length, width, and total area of leaf. Using a ratio (in percentages) to compare the leaf measurements of transplant-flooded with those of upland treatments, the ratios were lowest for leaf width, intermediate for leaf length, and highest for leaf area.

The ratios for the three leaf dimensions varied from 93 to 189 percent in four upland varieties; they ranged from 107 to 385 percent in four short-statured IRRI strains (Table 17). The less vari-

Table 17. Comparison of leaf dimensions of upland and lowland varieties grown under both transplant-flooded (lowland) treatments and upland treatments expressed in percentages. IRRI, 1971 dry season.

Variety	60 days after seeding			At heading		
	Length	Width	Area	Length	Width	Area
			Upland varieties			
M 1-48	129	100	116	146	127	183
Palawan	160	100	189	135	113	146
OS 4	147	117	140	93	106	93
Rikuto Norin 21	111	93	114	–	–	–
			Lowland varieties			
IR5	178	171	268	133	107	149
IR8	209	138	283	121	116	137
IR747B2-6	167	113	181	158	128	221
Taichung Native 1	252	143	385	125	120	201

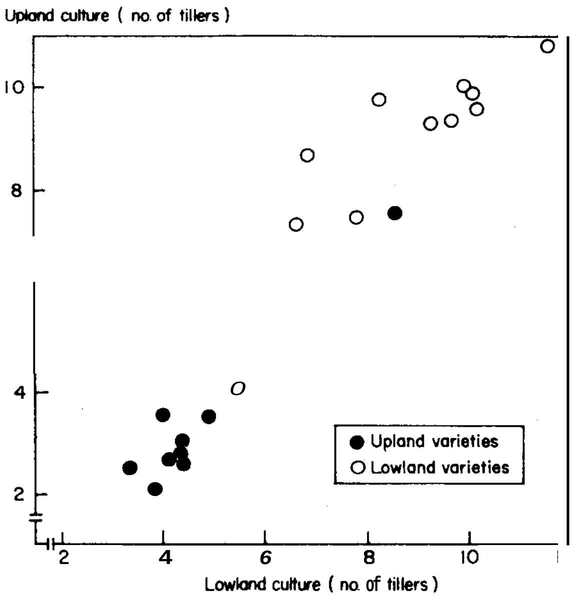
able leaf dimensions in the traditional upland varieties appear associated with their higher levels of drought resistance (Chang *et al.* 1972).

TILLERING CAPACITY

Traditional upland varieties generally produce fewer tillers than lowland varieties (IRRI [Undated] *b*; Chang and Bardenas 1965; Ono 1971; Chang *et al.* 1972; De Datta and Beachell 1972; Kawano *et al.* 1972; Krupp *et al.* 1972; In experiments, a group of upland varieties tillered about 3 days later than a lowland group and produced fewer tillers at 60 days after seeding **(fig. 8).** The difference in tillering rate was more marked in a drill-flood planting (Chang *et al.* 1972).

On the other hand, several upland varieties, such as C 22, Iguape Cateto, and Sintiane Diofor, produced nearly as many tillers as did moderately tillering lowland varieties. Dual-purpose varieties, such as Dular and Bluebonnet 50, are intermediate in tillering capacity (Chang *et al.* 1972).

When tiller number per unit area was compared for transplant-flood and upland cultures, the lowland varieties generally pro-



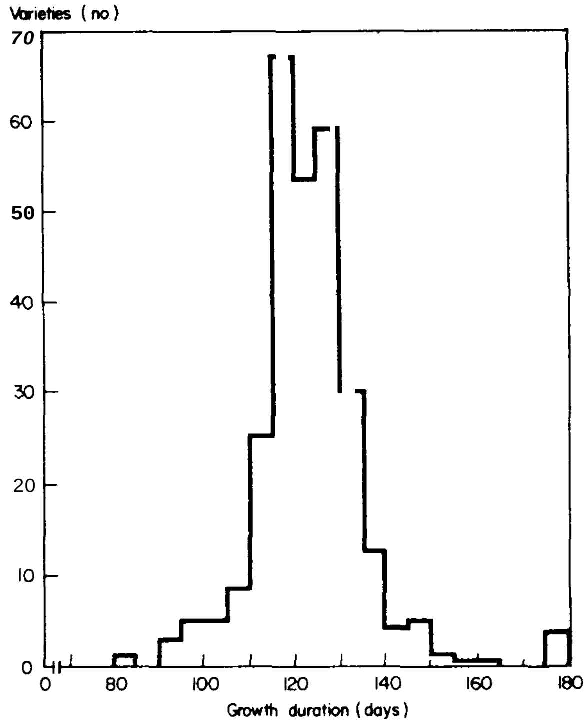
8. Tiller number of nine upland and 11 lowland varieties grown under upland and lowland cultures 60 days after seeding.

duced higher ratios (**0.79** in the wet season) than did the upland varieties (0.37 in the wet season). The ratios varied widely within each group, however, and overlapped between groups. Among the upland varieties, Sintiane Diofor had consistently high ratios, while Rikuto Norin **21** and Hirayama had consistently low ratios. Within the lowland group, the ratios were high for Peta, intermediate for IR5, and fairly low for IR8. Ratios for Dular were intermediate between upland and lowland groups. The low tillering capacity and plasticity of traditional upland varieties limit their yield potentials under the most favorable cultural conditions (Chang *et al.* **1972).**

In Japan, the primary tillers of upland varieties tended to emerge from the axil of the first true leaf, while they began from the axil of the second leaf in lowland varieties (Hasegawa **1963).**

GROWTH DURATION

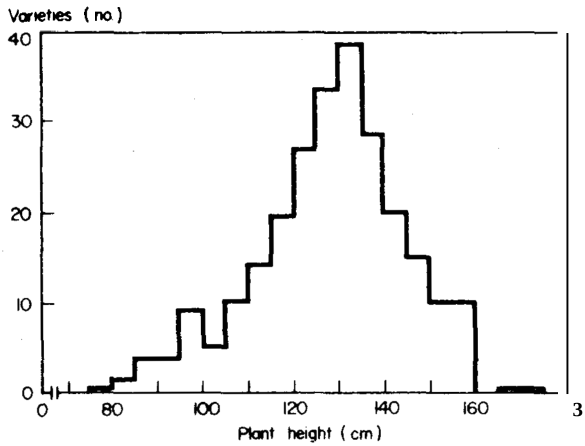
The growth duration of **284** drought-resistant upland varieties studied at IRRI ranged from 80 to more than 170 days in the wet season (fig. **9).** The growth duration of six commercially important



9. Frequency distribution of 284 traditional upland rice varieties by growth duration. IRRI, 1970-73 wet seasons.

upland varieties ranged from 95 days (for Rikuto Norin 21) to 125 days (for C 22) in the wet season; that of photoperiod-insensitive types ranged from 90 to 145 days in the dry season. A comparison of the data for two seasons shows that the popular upland varieties did not respond strongly to seasonal differences in photoperiod. In another JRRI experiment, eight traditional upland varieties tested under controlled photoperiods were all insensitive to daylength. Several late-maturing varieties, however, such as Basol, Thiorno, and Ourigho Cas 159, were strongly photoperiod sensitive.

When we compared upland and transplant-flooded plantings. we found that most upland varieties flowered from 1 to 15 days later under upland conditions. IR8, IR5, and Peta matured 17 to 23 days later when planted as upland crops. Of the three treatments, the .drill-flooded plantings generally flowered earliest. IR5, when planted as an upland crop, matured 37 days later than when



10. Frequency distribution of 252 traditional upland varieties by plant height. IRRI, 1970-73 wet seasons.

planted as a drill-flooded crop. This was the greatest difference of the experiment (Chang *et al.* 1972).

PLANT HEIGHT AND CULM CHARACTERISTICS

The adult plant height of 252 upland varieties studied in the wet seasons ranged from 80 cm for the Japanese varieties to 175 cm for several hill rices of Thailand (fig. 10). The African and Philippine upland varieties were generally taller than 150 cm in upland plantings. But the lowland varieties were generally much shorter than normal when grown in upland plots. The semidwarfs seldom exceeded 80 cm, although some taller strains reached 100 cm. IR5 often ranged from 98 to 110 cm tall (Chang *et al.* 1972).

Although the traditional upland varieties frequently have large and thick culms, their leaves and culms reach senescence quickly at maturity. In this aspect, they differ from the thick-culmed bulu[8] varieties of Indonesia. Because of their tall stature and quick senescence, most upland varieties are susceptible to lodging at maturity and, therefore, respond poorly to nitrogen.

[8]**Bulu varieties are tall, thick-stemmed, long-panicled, long-awned varieties with large and bold grains which are grown in the lowland fields of Indonesia. Some Japanese geneticists consider the bulu varieties as the thud variety group of O.** ***sativa,*** **the javanica group (Chang 1964).**

ROOT SYSTEMS

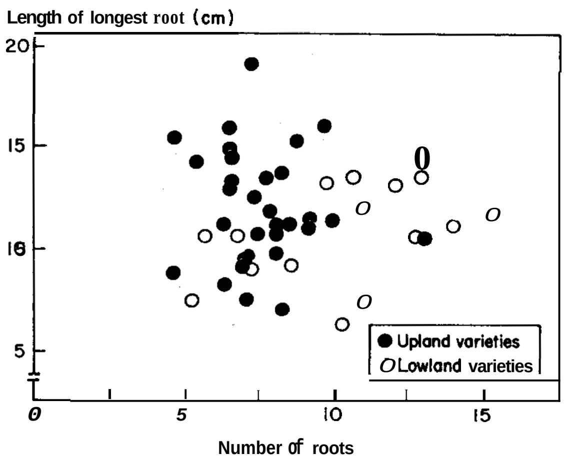
Hasegawa (1963) reported that the roots of two Japanese upland varieties extended more than 20 cm below the ground level. while only a few roots of two lowland varieties reached that depth. The ratio of root weight to shoot weight was higher tor the upland than for the lowland varieties. Nicou *et al.* (1970) found that the root systems of four varieties differed considerably in root weight. length of the longest main root. diameter of the main root. extent of branching, and the total length of roots. The African upland variety 63-83 had the highest root weight. the longest main root. and the largest total root length. Iguape Cateto. an upland variety from South America. was last in weight and length of roots. IR8 was superior to TN1 in diameter of the main root and extent of branching. But both semidwarfs were inferior to the African variety 63-83 in total length and weight of roots even though the fine root system of IR8 was most extensive.

Krupp *et al.* (1972) compared the root growth of the upland variety Palawan with that of IR5 under flooded and upland conditions at IRRI. IR5 produced heavier roots than did Palawan in flooded culture, but under moisture stress, the root development of Palawan was more extensive. Another IRRI researcher found that the upland variety M1-48 had thicker roots than had IR5 under both rainfed and flooded conditions.

IRRI studies on mature plants grown under upland culture showed that the roots of some drought-resistant upland varieties. such as OS 4 and Palawan, are mostly long and thick. while those of semidwarfs. such as IR8 and IR20, are generally thin and fibrous (Table 18). Even at 14 days after seeding, the upland rices had fewer, but longer, roots (fig. 11). By tracing root development by radioactive phosphorus at three stages of plant growth, the roots of African upland varieties were found to be generally longer (Chang *et al.* 1972).

Varietal differences in root characteristics became obvious at 60 days after seeding in recent IRRI studies. Striking differences were found in the depth of the longest roots, in the proportion of thick roots, and in the proportion of long roots to short roots (IRRI 1974).

The roots of some traditional upland rices will grow longer and thicker under moisture stress (IRRI 1971). In a puddled and flooded soil at 60 days after seeding, little difference was found in



11. Number and maximum length of roots of **14-day-old seedlings grown under upland culture.**

the root lengths of certain upland varieties, such as ***OS*** 4, and of semidwarfs, such as TN1 and IR841-67-1. But in a simulated upland culture, the ***OS*** 4 roots grew longer and thicker than the semidwarf roots at the same growth stage. TN1 and IR841-67 roots were generally thin and varied in length (fig. 12). The root systems of ***OS*** **4** and Palawan were considerably denser and deeper after a drought period than when they did not suffer from water stress. Likewise, the **OS 4** and Palawan roots were much thicker and denser than those of IR8 following moisture stress, but only slightly more so when moisture stress was light (fig. 13). This differential root response to water stress indicates a type of interaction between genotype and environment that could be used in a breeding program (Chang *et al.* 1972).

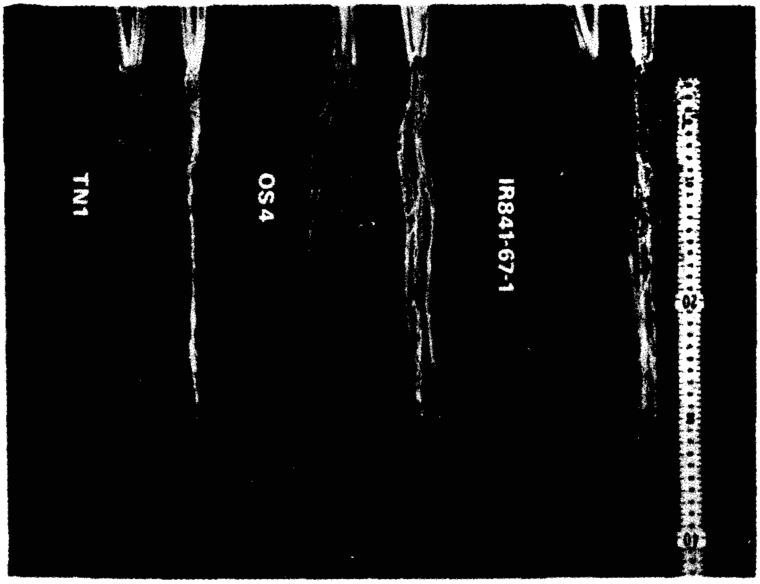
Harashima (1936) reported that more primary xylem' elements were found in the embryonic roots of Japanese upland varieties than in those of Japanese lowland vhrieties. Lowland varieties, however, such as Peta, have been found to have the same number (eight) of primary xylem in the seminal roots as did ***OS*** **4.** Among the lowland varieties examined, IR5 had five primary xylem elements in the central core; Palawan also had five.

[9]The vascular tissue which conducts water and mineral nutrients throughout the plant and provides mechanical support.

Table 18 Root development of upland and lowland varieties in an upland planting made on June 11, 1970. IRRI, 1970 wet season.

Variety	Predominant type[a]	Density[b]	Rootlets[c]	Length (mm)		Diameter (mm)	
				Mode	Max.	Avg	Thickest
Upland varieties							
Jappeni Tunkungo	2	2	4	15	24	0.88	1.0
M1-48	6	5	2	18	25	1.22	1.4
NARB	1	2	2	16	19	0.88	1.0
Palawan	6	4	1	18	34	1.38	1.6
OS 4	6	4	3	17	36	1.16	1.3
Rikuto Norin 21	6	2	2	19	22	1.04	1.2
Lowland varieties							
Dular	5	2	2	16	22	1.14	1.4
IR5	4	3	4	13	24	1.18	1.4
IR8	3	1	2	12	24	0.94	1.3
IR20	1	1	1	10	15	0.66	0.8
IR747B2-6-3	1	2	2	12	19	0.48	0.6
Peta	5	4	4	17	26	1.14	1.3
Taichung Native 1	2	1	2	14	21	0.88	1.0

[a]1 = very fine, to 6 = very thick. [b]1 = very few, to 5 = very dense. [c]1 = very few, 2 = from lower portion of root only, 3 = midportion to root tip, 4 = uniformly branched from base to tip.



12. Comparison of the root systems of an upland (OS 4) and two semidwarf (IR841-67-1 and TN1) varieties grown in two water regimes (upper: aerobic soil; lower: flooded soil) at 60 days after seeding. IRRI, 1972 dry season.

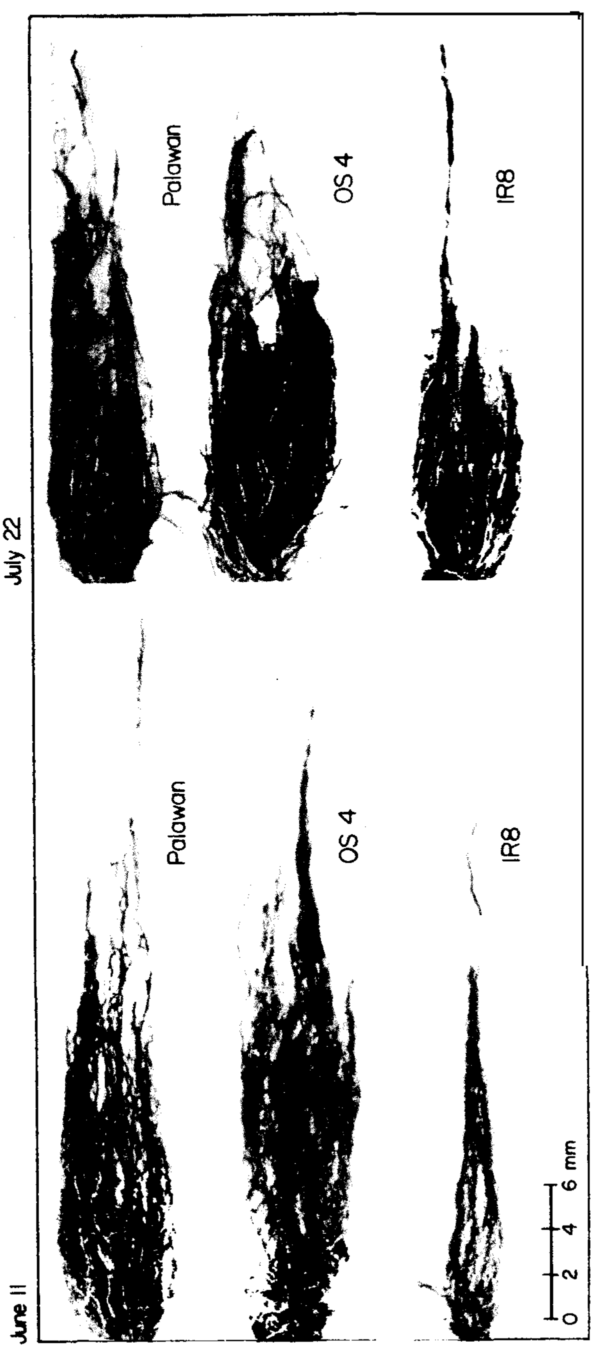
In conclusion, combinations of two or more of the following root characteristics are generally found in drought-resistant upland varieties: a high proportion of thick roots; several very thick and long roots; a dense root system; a uniform branching of fine root from the main roots (Loresto and Chang 1971).

PANICLE AND GRAIN FEATURES

Most traditional upland varieties have long, well-exserted panicles which make them well suited for panicle harvesting.[10] The panicles are generally resistant to shattering, a desired feature for any rice grown under upland culture.

Upland varieties usually have bold-shaped and thick grains that are high in 100-grain weight (Table 19), although some have slender grains.

[10] See Chap. 5, "Cultural Practices for Upland Rice."



13. Mature roots of two upland varieties (Palawan and OS 4) and one semidwarf (IR8) planted at different dates in an upland field, IRRI, 1970 wet season. Note the more extensive root development of the upland varieties planted on June 11, when drought prevailed during the crop season. The root development was similar for both upland and lowland varieties planted on July 22, when water stress was relatively light.

Table 19. Grain yield, panicle number per square meter, and 100-grain weight **of** five upland and three lowland varienes in an upland yield trial. IRRI, 1972 wet season.

Vanety	Grain yield (t/ha)	Panicles (no.)	100-grain wt (g)
		Upland varieties	
C 22	3.4	33	2.4
M148	2.4	18	2.5
OS 4	2.1	24	3.5
Palawan	2.3	14	3.0
		Lowland varieties	
Bluebonnet 50	2.2	18	2.6
IR5	3.9	31	2.6
IR8	2.7	29	3.1
IR442-2-58	4.1	34	2.5

A remarkable feature of upland rices is their ability to consistently produce completely fertile panicles of well-filled grains, even after mild drought (Jana and De Datta 1971; Chang *et al.* 1974). This certainly contributes to the stable, though relatively low, grain yields of drought-resistant upland varieties.

The amylose content of most Southeast Asian and African u p land rice is moderately high, from 22 to 26 percent, averaging about 25 percent. The gelatinization temperatures of these varieties range from low to high; most are intermediate. A few of these varieties, such as Azucena, are aromatic. Many upland varieties from Laos and Thailand are glutinous. Japanese upland varieties have low amylose content, about 15 percent. Some are glutinous (IRRI 1974).

DISTRIBUTION OF DRY MATTER IN PLANT PARTS

We found that the dry root weights of groups of upland and lowland varieties were similar at 40 days after seeding, even though the lowland group had heavier shoots. The group of upland varieties has significantly higher (about 10 percent) root-to-shoot ratios under both upland and drill-flooded cultures. At 60 days after seeding, however, the differences were smaller and non-significant.

The grain-to-straw ratios for all varieties were lower when grown as upland crops than when grown as transplant-flooded or as drill-flooded crops.

Under upland.culture, the grain-to-straw ratios of upland varic ties were generally higher than those of lowland varieties, probably because of their full panicle fertility and heavier grains (Chang *et al.* 1972).

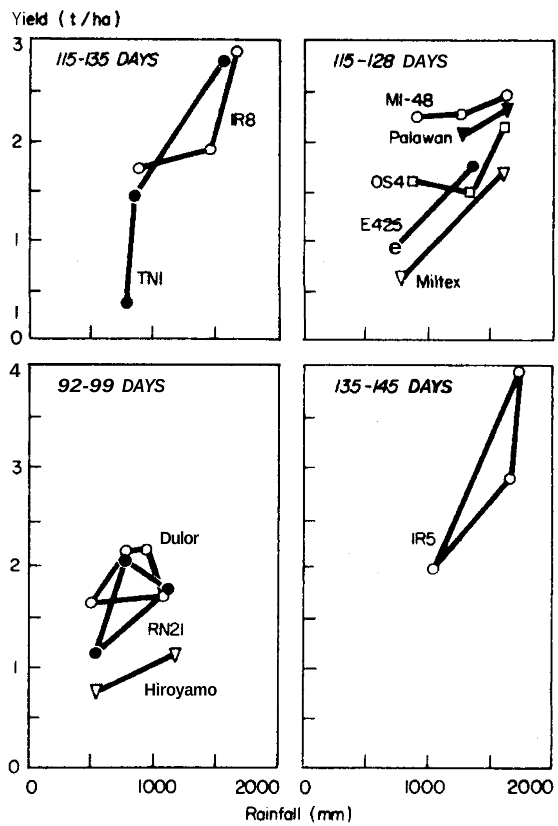
YIELD POTENTIAL AND STABILITY

Several seasons of testing on well-drained upland fields at IRRI have shown that the average yields of traditional upland varieties,. such as Palawan, MI-48, and *OS* 4, are limited to about 3 t/ha, while short-statured lowland varieties, such as IR8, IR5, and IR442-2-58, can often produce yields slightly more than 4 t/ha (Chang *et al.* 1972; IRRI 1972, 1973). Under the most favorable climatic and soil conditions in the Philippines, about 4 t/ha seems to be the upper limit for most traditional upland varieties, while the IRRI varieties may yield nearly 7 t/ha with high rates of nitrogen -- (Jana and De Datta 1971; De Datta and Beachell 1972; IRRI 1973, 1974). Similarly, semidwarfs grown under upland conditions in the Peruvian jungle have produced up to 6 t/ha in seasons of heavy rainfall with high fertilization (Kawano *et al.* 1972). C 22, a recent release from the College of Agriculture. University of the Philippines at Los BaAos, is the only upland variety which frequently yields from 3 to 4 t/ha (IRRI 1973, 1974).

Under severe water stress, however, all rice varieties yield poorly despite heavy fertilization and effective weed control (Jana and De Datta 1971; IRRI 1971, 1972, 1973). *So,* absolute grain yields reflect degrees of drought avoidance more than drought tolerance. particularly if the crop is harvested before water stress ends (Levitt 1972). But when drought ends before harvest, grain yield depends more on ability to recover.

We recognize that the low tillering capacity of most upland varieties is the main restraint to higher yields (Table 19) (IRRI 1971; Ono 1971; Jana and De Datta 1971; Abifarin *et al.* 1972; Chang *et al.* 1972; De Datta and Beachell 1972; Kawano *et al.* 1972). But the upland varieties generally produce heavy panicles of well-filled grain in spite of drought (Jana and De Datta 1971; IRRI 1973; Chang *et al.* 1974).

[1] 'See fig. 4, "Crop Environment of Upland Rice," page 20.



14. **Relationship among** growth **duration, total rainfall during growth period, and** grain **yield** in **seven upland varieties, one dual-purpose variety, and three lowland varieties. IRRI, wet seasons** of 1970-72.

The tall plant stature, quick senescence, and rather brittle culms of upland varieties increase lodging at high fertility levels and limit nitrogen response (Abifarin *et al.* 1972: Kaweno *et al.* 1972; De Datta and Beachell 1972). Yields of Japanese upland varieties are also low because of their tall stature and susceptibility to lodging (Ono 1971). The yield potential of many upland varieties, when grown at Los Baños, was further restricted by susceptibility to the bacterial leaf blight. sheath blight, and virus diseases, although they are generally resistant to blast. Ono (1971) also mentioned that many Japanese upland varieties are susceptible to sheath blight. Helminthosporium leaf spot, and stem maggots.

Although the yield potential of most traditional upland varieties is low, it is also stable during the wet season (barring major pest or typhoon damage) (fig. 14). Four types of varietal performance have been observed on a well-drained soil at IRRI (1) Semidwarfs such as IR8 and TN1 that produce high yields when rain is plentiful. The yields fluctuate markedly, however, primarily because they have low levels of drought resistance. (2) Early maturing varieties (92 to 99 days), such as Dular and Rikuto Norin 21, that often escape moisture stress, and that usually yield from 0.7 to 2.2 t/ha. They also have adequate levels of drought resistance. (3) Traditional upland varieties, such as M1-48 and OS 4, with stable yield levels, from 1.5 to 2.4 t/ha, even when rainfall fluctuates from 800 to 1,700 mm. (4) Weakly photoperiod-sensitive types, such as IR5, that mature in 135 to 145 days. IR5 has moderate drought resistance and strong vegetative vigor, as well as a flexible vegetative growth period, that enable it to survive prolonged drought and to use late rains. IR5 yields from 2 to 4 t/ha even during seasons of erratic rainfall distribution. However, IR5 would not produce such yields at locations where the rainy season is shorter than that of Los BaAos.

While high tillering contributes to high yields, thehigh-tillering C 22 in three seasons of testing lacked yield stability because it only has an intermediate level of drought resistance (IRRI 1972, 1973, 1974; Chang *et al.* 1974).

Subsistence upland rice farmers continue to plant the low-yielding traditional varieties year after year primarily because of their drought tolerance and yield stability, particularly in areas of low or erratic rainfall. Such varieties were probably developed by many years of selecting for genotypes adapted to low or unevenly distributed rainfall.

TOLERANCE TO ADVERSE ENVIRONMENTS

Upland rice is exposed to many adverse factors that may not be found under lowland conditions, such as water stress, hot and dry climatic conditions, and adverse aerobic soils that have excesses of toxic elements, such as aluminum or manganese, or deficiencies of vital elements, such as iron and phosphorus. Some rices have adapted to these adverse conditions through years of natural and human selection; they differ appreciably, however, in degrees of tolerance.

Traditional upland varieties from areas with relatively short rainy seasons generally have adequate drought resistance in the field (for example, early maturing varieties from West Africa, and hill rices from Laos, Thailand, and the Philippines). A few traditional lowland varieties, such as Peta and Lal Nakanda, also have relatively high field tolerance to drought, which may have resulted from years of selection under rainfed lowland conditions with frequent droughts.

Upland varieties grown at high elevations should be tolerant of cool temperatures. Drought resistance and cold tolerance have been reported to be associated in seedlings of Japanese upland rices (Togawa and Ando 1939: Hasegawa 1963).

Upland varieties also differ appreciably in tolerance to adverse factors in aerobic soils. IRRI soil chemists found both M 1-48 and E425 tolerant of iron deficiency, and MI-48 tolerant of manganese and aluminum toxicity. But a number of lowland varieties, such as IR24, were equally tolerant to such adverse soil factors, and many also better tolerate phosphorus deficiency. On the other hand, upland varieties are generally susceptible to adverse soil factors found in flooded soils (Ponnamperuma and Castro 1972; IRRI 1973, 1974). These findings point out the advantage of using diverse germ plasm to cope with adverse soil environments.

chapter four

VARIETAL IMPROVEMENT OF UPLAND RICE

Agronomic traits needed in upland rice varieties
Te-Tzu Chang[1] *and Surajit K. De Datta*[2]
Drought tolerance in upland rice
Surajit K. De Datta, Te-Tzu Chang, and Shouichi Yoshida[3]
Control of upland rice insects by varietal resistance
Mano D. Pathak[4] *and Gurdev S. Khush*[5]
Diseases of upland rice and thei- control through varietal resistance
Shu-Huang Ou[6]*, Keh-Chi Ling*[7]*, Harold E. Kauffman*[8]*, and Gurdev S. Khush*
Varietal resistance to adverse chemical environments of upland rice soils
Felix N. Ponnamperuma[9]
Breeding methods for upland rice
Te-Tzu Chang, Surajit K. De Dutta, and W. Ronnie Coffman[10]

[1] Geneticist, International Rice Research Institute. 'Agronomist, IRRI. 'Plant physiologist, IRRI. [3] Entomologist, IRRI. [5] Plant breeder, IRRI. [6] Plant pathologist, IRRI. 'Plant pathologist, IRRI. 'Plant pathologist, IRRI. 'Soil chemist, IRRL '' Associate plant breeder, IRRI.

Rice researchers should consider the following objectives in the development of upland rice varieties: efficient plant type (or types); wide adaptation; moderate levels of nitrogen responsiveness; early maturity; preferred panicle features and grain quality; adequate resistance or tolerance to and quick recovery from drought; resistance to major insect and disease pests; tolerance to toxic soils or nutritional deficiencies; and stability of yields under adverse conditions.

Although the above desired features will be discussed separately, many traits are interrelated. Breeding objectives should be considered as integral sets, suited to the specific environmental conditions under which the improved varieties will be grown. Breeders and their associates should thoroughly know the climatic, edaphic, biotic, and cultural conditions of the production areas; the breeding objectives must focus on production restrictions imposed by the environmental and cultural conditions.

Agronomic traits needed in upland rice varieties

Te-Tzu Chang and Surajit K. De Datta

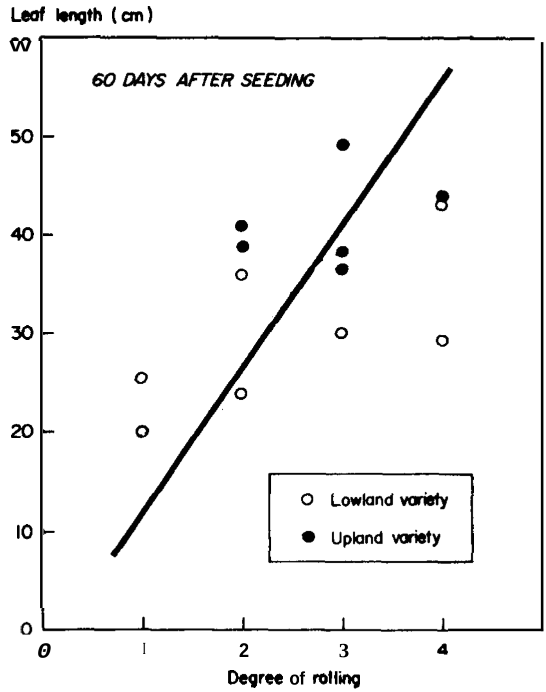
Although the semidwarf plant type – stiff-strawed, erect-leaved, and high-tillering – has greatly increased the yielding ability of tropical lowland rices, researchers differ in opinion concerning the ideal plant type for upland rice.

Several breeders and agronomists indicate a preference for a relatively short-statured type such as IR5 or the line IR442-2-58 (which range in height from 90 to 100 cm under upland conditions), because of their improved plant types, their high tillering abilities, and their resistance to lodging (Abifarin *et al.* 1972; Kawano *et al.* 1972; De Datta and Beachell 1972).

Others think that a moderately tall plant type (120-140 cm) with moderately long and droopy leaves might be better adapted to strict upland culture, and might also compete better with weeds (Chang *et al.* 1972; Krupp *et al.* 1972). This plant type would be slightly shorter than the traditional upland varieties but taller than the semidwarfs.

Varieties with moderately long leaves have shown more plasticity in leaf rolling and unfolding than have the semidwarfs (Chang *et al.* 1974). Such elastic behavior (fig. 1) might help conserve water in the plant tissues (Levitt 1972). In field tests for drought resistance, moderately long and droopy leaves were found in most drought-resistant tropical varieties (Chang *et al.* 1974). Moreover, plant height is positively associated with the length of leaves and of panicles in F_2 populations of diallel crosses involving lowland varieties (Chang *et al.* 1973). Onodera (1931) and Rajagopalon (1967) found a positive association between plant height and grain yield in upland plantings.

Seedling vigor is generally considered essential in upland rice for good stand establishment and ability to compete with weed growth (De Datta and Beachell 1972). Quick seedling emergence is found in both upland and lowland varieties. The rate of leaf and tiller production is generally higher, however, among the semidwarfs than among the traditional upland varieties (Chang *et al.* 1972).



1. Association between leaf length and leaf rolling in 13 varieties, 1971 wet season (y = 0.220 + 0.068x, R^2 = 0.3235*).

Better tillering capacity is a desirable feature to upgrade the yield potential of upland varieties. Trials in Nigeria (IITA 1973), Peru (Kawano *et al.* 1972), and the Philippines (Jana and De Datta 1971; De Datta and Beachell 1972; IRRI 1974) generally indicate that when rainfall is plentiful and the soil has good water-retention capacity. the high-tillering and short-statured varieties definitely respond better to nitrogen and yield higher than do the taller types. The high yields that IRRI researchers obtained with IR5 are close or equal to those of rainfed lowland culture (IRRI 1967*a*; De Datta 1970). High tiller number was a major factor contributing to high **yields** of IR5 at IRRI and at Maligaya during the 1970 wet season (Table 1) (De Datta and Beachell 1972). Even at continuously low soil moisture tension of 70 centibars during vegetative and reproductive stages. IR5 and many semidwarf breeding lines produced more tillers than did several upland Varieties under continuous saturation (Table 2). The most drought-tolerant

Table 1. Plant characters and yields (average of three nitrogen levels) of IR5 and M148 grown under upland conditions at IRRI **farm** and at the Maligaya Rice Research and Training Center, 1970 wet season.'

Planting date	Plant ht (cm)		Tillers (no./sq m)		Yield (t/ha)			
					Dry matter		Grain	
	IR5	M1-48	IR5	M1-48	IR5	M148	IR5	M1-48
					IRRI			
May 31	92	96	339	177	**7.5**	***6.5***	3.4	3.0
June 15	88	102	317	191	7.1	***6.6***	3.2	2.8
June 30	82	83	276	143	5.2	4.9	2.5	2.3
July 23	79	87	196	156	4.5	**3.8**	2.0	1.5
					.Maligaya			
June 2	107	130	352	222	11.9	8.1	5.9	3.6
June 17	116	132	355	242	11.9	9.i	*5.6*	3.8
July 2	118	134	339	193	13.5	10.1	5.5	4.1
July 17	114	133	337	247	12.6	10.2	5.4	3.4

'Source: De Datta and Beachell 1972.

semidwarf line in this experiment, IR1646-623-2, has medium tillering capability (De Datta ***et** al.* **1974*c*).**

Late tillering should be avoided in upland rice, however, because plants that tiller late and produce small panicles (or none at all) waste soil moisture (De Datta and Beachell **1972).**

When soil moisture is adequate, the semidwarfs tiller well, providing sufficient foliage and ground cover to efficiently compete with weeds (Chang *et al.* 1972). But when severe droughtoccurred, the semidwarfs tested so far suffered more than did the traditional types. Leaf **size** was greatly reduced: heading was delayed; plant height was reduced; panicle exsertion. poor: panicle length, reduced; panicle sterility, high: and gains. poorly filled. Severe water stress in the field generally reduced plant growth of the tall and intermediate varieties proportionately less than that of the semidwarfs (Chang *et al.* 1972, 1974; IRRI 1973).

Tiller number and panicle number are positively and closely correlated. A high panicle number, such as **is** found among the semidwarfs, is desirable for high yields. **On** the other hand, the moderate panicle number of the traditional upland varieties may

Table 2. Plant height, tiller number, and dry weight at harvest of some selected rice varieties and lines under continual saturation and percent reduction of the same growth characters due to soil moisture stress (75 cb) during the vegetative or reproductive stage. IRRI, 1973 dry season.

Variety or line	Plant ht			Tillers			Dry wt		
	Continual saturation (cm)	Reduction (%)		Continual saturation (no./1-m row)	Reduction (%)		Continual saturation (g/1-m row)	Reduction (%)	
		Early stress	Late stress		Early stress	Late stress		Early stress	Late stress
M1-48	105	18**	2	77	21	4	156	33**	11
Dinalaga	124	6	15**	90	26	7	205	34**	16
E-425	108	4	2	95	14	1	155	16	–5
OS6	110	22**	15*	119	17	1	242	50**	38**
Moroberekan	109	4	4	75	32	3	145	28	10
C-22	123	4	18**	131	2	–2	236	38**	17
IR5	113	5	13**	224	3	17	486	36**	48**
IR661-1-170	66	0	0	197	10	13	162	21	11
IR938-35-2	69	6	1	232	11	2	199	24*	9
IR1487-372-4	77	17*	14	208	2	10	177	24	11
IR1529-430-3	76	5	9	215	22*	–3	180	2	0
IR1529-677-2	77	1	10*	215	6	14	211	14	16

(Continued on the next page)

Variety or line	Plant ht			Tillers			Dry wt		
	Continual saturation (cm)	Reduction (%)		Continual saturation (no/1-m row)	Reduction (%)		Continual saturation (g/1-m row)	Reduction (%)	
		Early stress	Late stress		Early stress	Late stress		Early stress	Late stress
IR1529-680-3	82	20	17	209	44**	1	203	45**	−1
IR1531-86-2	100	−3	7	156	17	−4	196	31	9
IR1544-238-2	64	0	2	218	17	9	136	32	16
IR1561-149-5	67	10	3	247	10	4	140	21	3
IR1646-623-2	71	1	0	180	14	−12	146	21	−18
IR1721-11-6	76	−1	5	238	12	5	165	20	7

*, **Significant at 5% and 1%, respectively.

be partially compensated by the higher number of heavier grains on each panicle.

Yield levels of between 3 and 4.5 t/ha were obtained at IRRI from IR5 and IR442-2-58 (Tables 3 and 4) under good to sub-optimal soil moisture and heavy fertilization (120 kg/ha N). These strains have consistently outyielded the traditional upland varieties such as M1-48 and OS 4, provided that diseases such as blast, bacterial blight, and sheath blight did not seriously affect the grain yields (De Datta *et al.* 1974*a*). In such experiments, IR5 and IR442-2-58 produced from 200 to 320 tillers/sq m while the traditional varieties produced from 110 to 180 tillers. IR5 and IR442-2-58 have most of the essential yielding ability attributes, but higher levels of resistance to the major pests and to drought are needed to stabilize their yield perfomance.

Although high tillering capacity is the principal means to higher yield potential, a balance between shoot growth and root develop ment is essential for tolerance to prolonged drought. Studies in Japan suggest that the "panicle weight" types, which have long and heavy panicles but rather few of them, have deeper and thicker roots and higher rates of root activity than do the heavy tillering "panicle number" types (Lee and Ota 1973). For the dry regions or for soils of light texture with low water tables, low-tillering varieties with good drought resistance would insure more stable although low yield levels. Thus, a high ratio of root develop ment to shoot growth is essential to total drought resistance under field conditions (Levitt 1972). Such a high ratio of roots to shoots was found in the drought-resistant traditional upland varieties (Chang *et al.* 1972).

This difference in concept of an ideal plant type for upland

Table 3. Grain yield and some plant characters and yield components of five varieties grown under upland condition. IRRI, 1972 wet season.

	IR5	IR442-2-58	M1-48	OS 6	C-22
Grain yield[a] (t/ha)	3.2	4.5	2.4	2.7	3.0
Plant ht (cm)	96.0	98.0	121.0	129.0	115.0
Panicles (no./sq m)	216.0	204.0	110.0	140.0	198.0
100-grain wt[a] (g)	2.54	2.44	2.40	3.31	2.28
Growth duration (days)	140.00	123.00	118.00	113.00	122.00

[a]At 14% moisture.

Table 4. Plant characters, grain yield, and yield components of three varieties grown under upland conditions. IRRI, 1971 wet season.

	Variety or line		
	IR5	IR442-2-58	M1-48
Grain yield (t/ha)	4.0	3.4	1.6
Plant ht (cm)	95	83	110
Tillers (no./sq m)	310	322	182
Panicles (no./sq m)	269	305	167
Filled grains (%)	80	84	83
100-grain wt (g)	2.79	2.39	2.39
Growth duration (days)	138	120	116

rice revolves around a basic question: what are the climatic and edaphic environments under which upland rice will be grown? If the rainy season is short and distribution of rainfall is uniform within the season, a short-duration variety with low to moderate levels of drought avoidance may likely escape drought and produce satisfactory yields. If soils are heavy and fertile and rainfall distribution is abundant and uniform, any high-yielding semidwarf with a low level of drought resistance might produce high yields when properly fertilized and weeded. But when the total rainfall is low and the distribution rather erratic, an intermediate-statured variety that tillers low or moderately, with deep and thick roots and other drought-resistance properties, will provide reasonably good and stable yields under modest levels of management over the years. Therefore, the choice of an efficient plant type is more location specific for upland culture than for lowland culture. In all cases, however, the variety should have a high grain-to-straw ratio (harvest index) and a relatively high root-to-shoot ratio in order to yield efficiently.

While wide adaptiveness to planting dates is desirable, the breeder need not seek the extremely wide adaptive ranges found in the semidwarfs because the length of the rainy season in any locality restricts the growth duration of an upland variety. Photoperiod insensitive genotypes are generally more adaptable over a wide geographic range. Insensitivity to photoperiod is essential because upland rice is generally planted when the days are long, and the plants flower when the days are still relatively long.

In areas of bimodal rainfall and relatively low monthly distribution, early maturing genotypes of about 100 days have been suggested as appropriate for drought avoidance (Abifarin *et al.* 1972). However, a medium-duration (130-150 days) variety that has a high level of drought resistance might produce higher yields.

For areas where the rainfall abruptly cuts off at a given date, weakly photoperiod-sensitive lines that are selected in such areas to suit the rainy season would be more desirable.

PANICLE AND GRAIN FEATURES PREFERRED BY UPLAND RICE FARMERS

Most upland rice is grown for home consumption in areas where rice from outside sources is too expensive for the subsistence farmers. The farmers generally prefer rices with long. well-exserted and non-shattering panicles that can be harvested by cutting below the panicle axis. Most traditional upland varieties have medium to bold grains that are well filled (over 3 g/100 grains) and adapted to primitive milling such as by pounding. More slender grains are desired, if the improvement in grain shape does not affect the grain weight. A high recovery of milled rice is also desired.

The popular range in amylose content for tropical Asia and Africa is from 22 to 26 percent; the mode is 25 percent. The popular gelatinization temperature is from low to intermediately high. Glutinous rice is preferred in some areas of Laos and Thailand. Aromatic grains are preferred in some areas of the Philippines and Laos.

Drought tolerance in upland rice

Surajit K. De Datta, Te-Tzu Chang, and Shouichi Yoshida

Of the various factors that affect upland rice production, low soil moisture supply is generally the most serious. A low supply of moisture to the upland rice crop, or high moisture stress in plants, is due to uneven or inadequate rainfall, to rapid drainage because of coarse soil texture, or to rolling topography (De Datta *et al.* 1974). In IRRI experiments, crops totally failed in some years but yielded up to 7 t/ha in others (De Datta and Beachell 1972). Crop failures or low yields have primarily been due to prolonged moisture stress caused by lack of rain for 3 to 4 weeks. Yield fluctuations in four groups of rice varieties during three wet seasons at IRRI are largely related to the levels of drought resistance of the individual varieties. (See fig. 14, Chap. 3, page 88.)

There is a great deal of controversy on how much water the rice plant needs to produce normal yields. Briggs and Shantz (1914) in the United States remarked that rice needs about the same amount of water as do other cereals. Chandra Mohan (1965) in India stated, however, that rice requires more water than does any other crop of similar field duration and that requirements vary with soil texture, climate, cultural practices, and varietal growth duration. Researchers in California noted that plants subjected to low moisture treatments showed chlorosis, reduced leaf area, slow leaf development and delayed internode elongation (Senewiratne and Mikkelsen 1961; Gunawardena 1966). According to Halm (1967), rice performs better in submerged and in saturated soils than in soils at field capacity. Satyanarayana and Ghildyal (1970*a*, 1970*b*) observed that rice produced better shoot growth and higher grain yields when grown under flooded conditions than when grown under 60 cb moisture tension or under saturation.

Even in humid upland rice areas of the tropics, dry periods often occur during the growing season of the crop, at least in the upper soil surface. Drought tolerance is far more important in regions of extensive upland rice cultivation in West Africa and South America than in monsoon Asia. Drought occurs regularly in Brazil, where upland rice is grown on about 4.7 million ha with annual rainfall varying from 1,200 to **1,500** mm. This would be sufficient rainfall if it were uniformly distributed and if the soil were able to hold most of it. But rainfall is poorly distributed and the soil is highly porous, so drought tolerance becomes critical. Heavy-tillering varieties yield poorly because of moisture stress; so do crops spaced closely (20 to **30** cm). To conserve limited moisture, therefore, low tillering varieties of upland rice are grown at wide row spacings **(50** to 60 cm).

Drought tolerance appears to be the most important single factor to increase and stabilize production of upland rice. The questions raised then are: for what types of varieties should we search and breed, and how should they be screened for drought tolerance?

PLANT CHARACTERS ASSOCIATED WITH WATER STRESS RESPONSE

Upland varieties are generally tall and low tillering. They are "panicle-weight" types (rather than "panicle-number" types, which are used for lowland rice culture). Being tall, most upland varieties have weak straws and are susceptible to lodging. True, lodging susceptibility is less critical for upland than for lowland rice culture (Krupp *et al.* 1972). But most tall varieties lodge severely under normal monsoon conditions, adversely affecting grain yields (De Datta *et al.* 1974*a*). For spring wheat. Hurd (1971) stated that high tillering is a luxury that cannot be afforded in dry areas because the many tillers use up moisture rapidly and cause the plant to suffer from moisture stress later in the season.

In agronomy experiments, medium- to heavy-tillering varieties such as **IR5** or the experimental line **IR442-2-58** outyielded the upland variety **MI-48,** which is low tillering at every level of nitrogen. Under poor soil fertility, a medium- or heavy-tillering variety may have advantage over a low-tillering variety. The **IR5** crop that produced 7 t/ha at Maligaya was 130 cm tall under upland rice culture and averaged **380** tillers/sq m (De Datta and Beachell 1972). Under droughty upland rice culture, the same variety will be less than 100 cm in height and will produce about 300 tillers/sq m. Experiments conducted by IRRI breeders show that the plants grown under droughty upland conditions were generally more than **50** percent shorter than those grown in transplanted plots (Chang *et al.* 1972). With few exceptions, Chang *et al.* (1972) showed that plant height of lowland varieties was reduced more than that of upland varieties grown under upland conditions. Similarly, the leaves of lowland varieties are reduced more than leaves of upland types, particularly at the tillering stage, when grown in an upland soil.

Field experiments conducted during the 1973 dry season under moisture stress conditions (75 cb soil moisture tension) demonstrated that varieties and lines subjected to early and late stress treatments differ greatly in the reduction of plant. characters such as height, tiller number, and dry matter production. Among the Philippine and African upland varieties treated for stress, only two African varieties, E-425 and Moroberekan, showed no significant reduction in plant characters (De Datta ***et al.*** 1974*c*). **Among** the experimental lines that did not show significant reduction in plant characters, IR1646-623-2 was the most tolerant of drought at both vegetative and reproductive stages (Table 5). Other lines selected as promising for drought tolerance were IR661-1-170, IR1531-86-7, IR1544-238-2, IR1561-149-6, and IR1721-11-6. Plant height and dry matter production of IR5 were significantly reduced by stress during the reproductive stage, confirming our earlier findings.

Plants subjected to moisture stress at the reproductive and ripening stages showed various stress symptoms. Older leaves died prematurely and the younger leaves and flag leaves wilted. Although the two tall and low-tillering upland varieties, E-425 and Moroberekan, were tolerant of moderate drought, they are of low yield potential (De Datta ***et al.*** 1974*c*). On the other hand, improved lines that looked promising for drought tolerance. such as IR1646-623-2, are shorter than what we want for upland rice culture. Among the promising drought-tolerant lines, only IR1531-86-2 has the plant height under upland rice culture (about 100 cm) that IRRI agronomists believe is desirable for low moisture and fertility conditions that prevail in most farmers' fields during dry periods (De Datta *et al.* 1974*c*).

Plant physiologists at IRRI grew 20 varieties in the field at three water regimes (Table 6). Plant height at different moisture regimes relative to plant height at saturation was used as an indicator of drought resistance. Traditional upland varieties such as E-425, MI-48, or OS 4 were considered more resistant to drought than the lowland varieties such as IR20 and selections such as IR841-67-1 tested (Yoshida ***et*** *al.* 1974). These results seem to agree with the those reported earlier by plant breeders (Chang *et*

Table 5. Plant height, tiller number, and dry weight at harvest of some selected rice varieties and lines under continual saturation, and percent reduction of the same growth characters due to soil moisture stress (75 cb) during the vegetative or reproductive stage. IRRI, 1973 dry season.[a]

Variety or line	Plant ht			Tillers			Dry wt		
	Continual saturation (cm)	Reduction (%)		Continual saturation (no./1-m row)	Reduction (%)		Continual saturation (g/1-m row)	Reduction (%)	
		Early stress	Late stress		Early stress	Late stress		Early stress	Late stress
M1-48	105	18**	2	77	21	4	156	33**	11
Dinalaga	124	6	15**	90	26	7	205	34**	16
E-425	108	4	2	95	14	1	155	16	–5
0S6	ITO	22**	15**	IT9	17	I	242	SO**	38**
Moroberekan	109	4	4	7S	ƎZ	Ǝ	145	Z8	10
Ɛ-TZ	IZƎ	4	18**	131	Z	–2	236	38**	17
IR5	113	S	IƎ**	224	I Ǝ	17	ƚ86	36**	48**
IR661-1-170	66	0	0	197	10	IƎ	T6Z	21	11
IR938-35-2	69	6	I	ZƎZ	11	Z	•199	Zd*	9
IR1487-372-4	77	17*	14	208	Z	10	177	Zd	11
IR1529-430-3	76	S	9	215	ZZ*	–3	180	Z	0

(Continued on next page)

(Table 5 *continued*)

Great soil group[a]	Soil units[b] (FAO)			Comprehensive classification system (USDA) Great soil group[c] order		sub-order	Representative Philippine soil series		
IR1529-677-2	77	1	10*	215	6	1d	211	1d	16
IR1519-680-3	82	20	17	209	44*	1	203	45**	–1
IR1531-86-2	100	–3	7	156	17	–4	196	31	9
IR1544-238-2	6d	0	2	218	17	9	136	32	16
IR1561-149-5	61	10	3	247	10	4	1d0	21	3
IR1646-623-2	71	1	0	180	1d	–12	1d6	21	–18
IR1721-11-6	16	–1	5	238	12	5	165	20	1

[a]Source: DeDatta *et al.* 1974 *c*. *, **Significant at 5% and 1%, respectively.

al. 1972). Among the lowland varieties, IR5 was regarded as relatively resistant to drought and IR20 as the most susceptible (Yoshida *et al.* 1974) confirming the data obtained by both agronomists (IRRI 1967b; De Datta *et al.* 1974*a*) and breeders (Chang *et al.* 1972). Some physiological characters. such as heat tolerance and rapid closure of stomata in response to moisture stress, also support that E-425, M1-48, OS 4, and Palawan are resistant to drought and that IR20 is susceptible (IRRI 1973). Deeper penetra-

Table 6. Drought resistance of 20 varieties assessed by plant height reduction under moisture stress in field. IRRI, 1973 dry season.[a]

Variety	Plant ht (cm)[b]	Relative plant ht[c]		
	No stress	Moderate stress	Severe stress	Mean
E425	75	79	77	78
Miltex	86	77	68	73
M1-48	107	72	69	71
Jappeni Tungkungo	92	68	73	71
OS4	89	68	67	68
Palawan	97	69	66	68
Dular	96	70	61	66
Rikuto Norin 21	85	74	57	66
PI215936	55	74	58	66
Azucena	105	67	61	64
Azmil	88	73	54	64
IR5	62	70	56	63
IR127-80-1	84	69	52	61
81B25	88	65	54	60
IR442-2-58	66	60	57	59
NARB	96	61	52	57
IR8	62	61	47	54
IR1529-680-3	65	60	47	54
IR841-67-1	62	57	48	53
IR20	64	57	44	51

[a]Source: Yoshida *et al.* 1974. [b]Measured 41 days after sowing. [c]Taking plant height at no moisture stress as 100.

tion of roots into soil is generally believed to be one of the most effective means of avoiding drought because more water is available at deeper soil horizons. Most rice roots, however, are confined to the surface soil; root distribution is negligible beyond 20 cm below the soil surface (Krupp *et al.* 1972).

Chang *et al. (1972)* compared root features of several upland and lowland varieties, and determined the relationships of rooting patterns to field reactions to drought. The drought resistant varieties generally had predominantly thick roots, densely formed at the crown, and many deep roots (see fig. 13, Chap. 3, page 85). Moreover, the drought-resistant upland varieties responded to water stress by producing proportionally more thick and long roots.

Among the upland varieties, *OS* 4 had the longest roots. Rikuto Norin 21, M1-48, and RT 1095 produced the thickest roots. Among the lowland varieties, Dular and IR841-67-1 produced the thickest roots. Maximum root length and maximum diameter of thick roots were not always found in the same variety. Dry weight of roots per unit length of row obtained in the wet season did not appear to be associated with drought resistance (Chang *et al.* 1972).

Studies in Japan indicate that drought resistance in Japanese lowland varieties is also associated with root number, total root length, root depth, and length of the longest root (Minabe 1951). Tests of root strength by Miyasaka (1969) indicate some degree of correlation between pulling strength and the cross-sectional area of the root.

TERMINOLOGY BASED ON PLANT METABOLISM

Because the drought problem is complex, various terms have been used, sometimes interchangeably, to describe the response of the plant to moisture stress. In many instances, the terms "drought tolerance" and "drought resistance" are used interchangeably, depending on the authors' preferences. But other authors use the terms to describe specific response of crops to moisture stress. Terminology based on plant metabolism has been adequately discussed by Sullivan (1971) and summarized by Yoshida *et al.* (1974).

Drought resistance: A total expression of a plant's ability to stay alive, grow, and ultimately produce grain with at least part of its life cycle under water stress (Sullivan *et al.* 1971).

Drought avoidance: The ability of the plant to keep the water potential high by either absorbing water and conducting it to the shoot, or reducing water losses by closing the stomata and by a highly impermeable cuticle (Sullivan 1972; Levitt 1969).

Drought tolerance (or ***desiccation tolerance):*** The ability of cells to survive and metabolically function although the tissues are desiccated or are at reduced water potentials. Drought tolerance can be defined as the'equilibrium relative humidity (or water potential) which causes 50 percent killing of the cells (Sullivan *et al.* 1971; Sullivan 1972). For convenience, it is also expressed as percent injury of cells at a specified humidity.

TERMINOLOGY BASED ON PLANT RESPONSE TO SOIL MOISTURE STRESS

Such precise terminology based on moisture status of the plants and metabolic functions may be difficult to ascertain if varietal differences are to be established by screening a large number of breeding lines.

For plant response to soil moisture stress in rice, IRRI agronomists offer the following terminology:

Drought tolerance in rice: The ability of the plants to withstand relatively mild moisture stress for relatively long periods, or to withstand severe stress for relatively short periods at specific growth stages.

Drought resistance in rice: The ability of the plants to adjust growth characteristics by avoidance mechanisms to minimize drought damage, and the capability to recover rapidly when the stress is relieved. A drought-resistant crop has drought tolerance at all growth stages.

IRRI agronomists do not suggest that these descriptions of the term “drought tolerance” and resistance” replace the descriptions offered based on the plant metabolism. Instead, these terms describe the plant’s response to moisture stress in a simpler manner, without losing the opportunity of quantification.

APPROACHES TO SCREENING VARIETIES FOR DROUGHT TOLERANCE

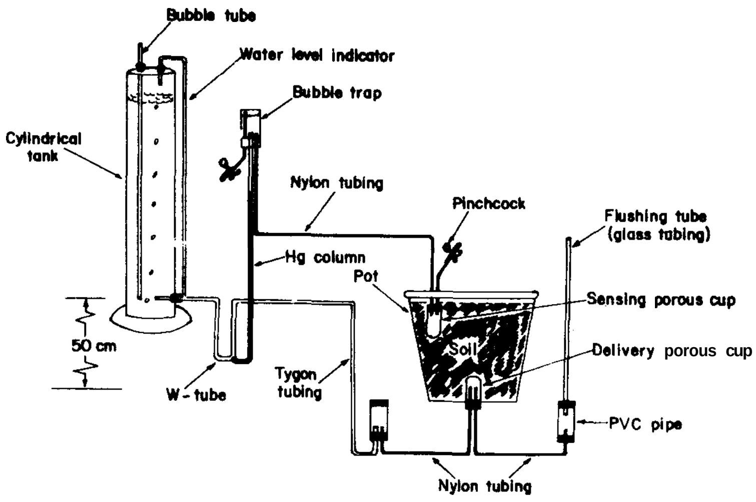
The ability to withstand severe moisture stress is desirable in any crop grown under non-irrigated conditions. Most cereal crops are grown in semi-arid climates where the available moisture supply is often severely limiting (Hurd 1971). Upland rice also faces frequent water stress periods.

Many techniques have been developed or modified in the past decade for measuring water stress in plants. No method or combination of methods, however, can be considered as most desirable for measuring drought stress because all methods have advantages and disadvantages (Sullivan 1971). Merits of some methods to measure plant stress, such as relative water content (RWC) or relative turgidity (RT), have been discussed by Sullivan (1971).

The most difficult problem is to develop a suitable technique for screening a large number of varieties and breeding lines for drought resistance or tolerance during vegetative or reproductive stages or both. One approach is to plant rice at short intervals from the beginning of the wet season, assuming that the crop in each date of seeding will receive different amounts of rainfall and that sunlight is relatively constant throughout the wet season (Jana and De Datta 1971; De Datta and Beachell 1972). True, by planting rice in the wet season, the rainfall distribution cannot be predicted. Fortunately, droughty periods occurred frequently during the wet seasons at Los Baiios so that significant varietal differences in drought tolerance were observed at different dates of planting.

On the other hand, soil moisture can be controlled in the dry season by applying known increments of water. Results may not be directly applicable to a wet-season crop because the sunlight intensity in the dry season is about 50 percent greater than in the wet season (De Datta and Beachell 1972) but they do provide first approximations of large varietal differences in drought tolerance.

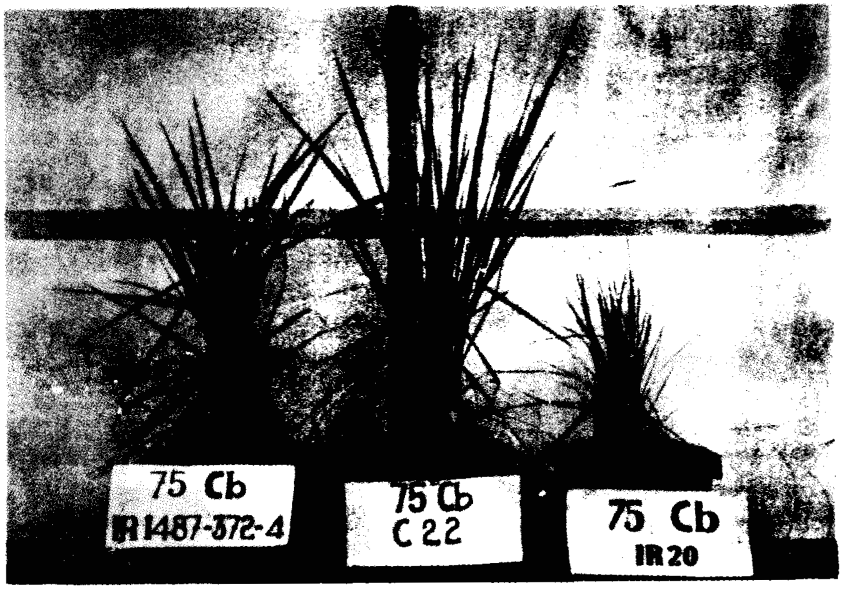
IRRI agronomists have recently designed two methods for maintaining various soil moisture tensions (IRRI 1973). The system to supply water at relatively constant soil moisture tension in pots is composed of five major parts – water tank, W-tube, water distribution system, soil moisture tension sensors, and pots (fig.2). Using this technique, four varieties and eight experimental lines were screened for drought tolerance by growing them in pots at three



2. A technique to maintain a predetermined level of soil moisture tension for studying drought tolerance in rice. IRRI, 1973. (Source: E. I. Alvarez and S. K. De Datta 1974, *unpublished*).

relatively constant soil moisture tensions, 0, 33, and 75 cb. Figure 3 shows the growth differences between the Philippine upland variety C-22, the experimental line IR1487-372-4, and the lowland variety IR20 at 75 cb soil moisture tension, demonstrating that IR1487-372-4 and C-22 have better drought tolerance than does IR20, and confirming the results of 2 years of field experiments. In a greenhouse experiment, IR442-2-58, IR1487-372-4, and IR1529-430-3 gave the highest grain yields at 33 cb (about 13 g/pot), indicating their moderate levels of drought tolerance. At 33 cb, the African variety OS 6 gave the lowest yield (2.8 g/pot).

To meet the need for evaluating large numbers of varieties and selections for breeding programs, Chang *et al.* (1974) have developed a mass screening test for evaluating field resistance to drought in the dry season under alternate cycles of intermittent watering and severe water stress. The stress periods are applied at three growth stages – tillering, panicle initiation, and grain development – for varieties that mature in from 115 to 135 days. The plant responses used to indicate drought resistance are: (1) plasticity in leaf rolling and unfolding during stress; (2) death of lower leaves; (3) injury to upper leaves; (4) degree of stunted growth; (5) delay in panicle emergence; (6) degree of panicle exsertion; and (7) panicle fertility. More than 1,400 varieties and



3. The experimental line IR1487-372-4 and the Philippine upland variety C-22 both grew better than IR20 when subjected to continual soil moisture tension of 75 cb, using a testing system devised at IRRI. Greenhouse, IRRI, 1973.

lines were screened during the 1973 dry season, and 2,600 more entries during the 1974 dry season. Table 7 shows the relative levels of drought resistance of selected entries that have been tested for at least two seasons. We not only found that the varietal reactions obtained in the dry seasons agreed with those observed during the droughty periods in the wet seasons, but we also noted a good association between our ratings for drought resistance and the relative reductions in grain yield when drought occurred during the 1972 wet season (IRRI 1974; Chang *et al.* 1974). Difference in drought resistance between the moderately susceptible IR20 and the intermediate IR1529-680-3 selection was also reflected in the marked difference in grain yield of the two strains in rainfed lowland trials when prolonged drought prevailed in Central Luzon during October and November of 1972 (IRRI 1974).

Recently, constant water table boxes were designed to test the effects of water table on rice growth. In these boxes, water was provided by capillary movement from a predetermined groundwater level (Yoshida *et al.* 1974). Different moisture regime treatments can be imposed in each of the tanks. Moisture status at different soil depths was monitored. By using this technique, most upland varieties were found to have lower percentages of survival than lowland varieties including the susceptible variety IR20 (Yoshida *et al.* **1974).** Similarly, IR20 survived even at soil **mois-**

Table 7. Relative ranking **of** rice varieties and selections according to the level **of** resistance to drought in field tests, IRRI.[a]

Class	Upland	Lowland
Susceptible	NARB Sintianne Diofor	IR747B2-6-3 TN1 IR532-1-218 IR790-281-1 IR1514A-E666
Moderately susceptible	Jappeni Tunkungo Iguape Cateto	IR20, IR22 IR577-24-1 IR1541-76-3 MTU-17 C4-63 Mala
Intermediate	BPI 9-33 C22-51 DB1, DB4 Miltex Tapol	IR8, IR24 IR305-4-20 IR442-2-58 IR841-67-1-1 IR1529-680-3 C12, Pelita I/1 81B-25
Moderately resistant	OS6, E425 Agbede Azmil Rikuto Norin 21 Bala Hirayama Palawan Kinandang Puti Khao Lo Moroberekan	Peta Carreon IR5 Bluebonnet 50
Resistant	OS4, M1-48 63-83 Sankok KU-70-1 N22 Cartuna Padi Pupurong	Dular

[a]Source: Chang *et al.* 1974.

Table 8. Porometer readings of rice varieties grown under upland conditions. IRRI. 1971 dry season.[a]

Variety	Porometer reading (s) — Leaf stage of rice			
	7th	10th	13th	Mean
IR8	8	8	7	8
IR5	10	19	15	15
IR20	11	11	10	10
IR1561-69-5	11	8	9	9
Palawan	13	10	13	12
M1-48	8	15	10	11
OS4	12	13	12	12
E425	9	20	17	15
81 B-25	9	11	9	10
Rikuto Norin 21	11	8	8	9

[a]Source: De Datta *et al.* 1974*a*.

ture tension of more than 10 bars during the vegetative period in experiments conducted by the IRRI agronomy department. Among lowland varieties, IR5 was regarded as moderately resistant to moisture stress (Yoshida et *al.* 1974), confirming earlier results obtained at IRRI (IRRI 1967*b*; De Datta 1970; Chang *et al.* 1972; Wickham 1973; De Datta *et al.* 1974*a*; De Datta *et al.* 1974*c*).

Recently, IRRI has tried to develop a way to monitor the degree of resistance to stomatal opening of the rice leaves as a criterion for drought tolerance (De Datta *et al.* 1974*a*). The assumption is that at lower stomatal openings, water loss through transpiration is low. The time taken to register the changes in mercury column from 120 mm to 110 mm in a porometer was considered an indication of the degree of resistance to stomatal opening in rice leaves. Higher porometer readings (in seconds) indicate higher drought tolerance. Several upland and lowland varieties have been screened by this technique for drought tolerance under upland condition. IR5 and an African variety, E-425 had the highest parameter readings (Table 8).

Little attention has been paid to varietal differences in cuticular resistance for given crops. Cuticular resistance in rice plants is difficult- to measure because rice leaves have stomata on both

Table 9. Cuticular resistance **of 35** rice varieties, one sorghum, and one corn **variety.**[a]

Variety	Cuticular resistance (s/cm)	Variety	Cuticular resistance (s/cm)
Sorghum (Cosor 3)	116	IR841-67-1	47
Corn (Early Thai composite)	112	RP-7-2	44
Azmil	68	IR1529-680-3	43
Rikuto Norin 21	66	IR1561-228-3	43
RP-79-19	66	Jappeni Tungkungo	42
RP-79-14	63	IR26	41
RP-79-13	60	IR8	37
RP-79-16	60	81B25	37
Azucena	60	IR1541-76-3	36
NARB	58	IR24	35
RP-79-23	57	PI215936	35
M1-48	56	Palawan	33
IR442-2-58	54	IR127-80-1	33
Bala	51	E425	33
Sigadis	49	IR20	32
TN1	49	Dular	30
IR5	48	Miltex	30
N-22	41	OS4	30
RP-8-8	47		

[a]Source: Yoshida *et al.* 1974.

sides.

In an experiment conducted by IRRI plant physiologists, **35** rice varieties or lines were compared with sorghum and corn for cuticular resistance (Table 9). The cuticular resistance of sorghum was at least one-and-a-half times greater than the highest values **ob-**tained with any rice varieties tested. Some rice varieties that perform well under upland conditions, such as **Azmil,** Rikuto Norin 21, RP-79, Azucena, M 1-48, IR442-2-58, Bala, and IR5, showed higher cuticular resistance in leaves (Yoshida *et al.* 1974). On the other hand, some upland varieties **such** as E-425, Miltex, and OS4 showed lower cuticular resistance. The upland varieties E-425 and *OS* 4 have longer roots (Chang *et al.* 1972) which would permit them to extract water from greater soil depths, explaining their lower cuticular resistance (Yoshida *et al.* 1974).

Other indirect approaches have been attempted to compare rice varieties for drought resistance. For example, Tsai and Tang (1969) have used the resistance to potassium chlorate toxicity, the water absorption power of germinating seeds in 0.6 M manitol solution, the water-retaining capacity of excised plants, and the changes in sugar content of seedlings after drought treatment. Their conclusion that indicas have poorer drought resistance than do japonicas cannot be substantiated with current IRRI results (De Datta end Beachell 1972). Most of the world's upland varieties are indicas, many of which have good drought tolerance (Chang *et al.* 1972). Garg and Singh (1971) associated higher ascorbic acid content of Taichung Native 1 with higher drought tolerance than IR8. Field studies at IRRI and elsewhere did not bear this out (De Datta and Beachell 1972; Chang *et al.* 1972).

Several aspects of plant metabolism have been shown to be affected by water deficit, including inhibition of protein synthesis and changes in amino acid metabolism (Bamett and Naylor 1966). Although the concentration of some amino acids decreases with moisture stress, the concentration of soluble nitrogenous compounds increases (Chen *et al.* 1964). The most pronounced increase in concentration of soluble nitrogenous compounds is of the amino acid proline which may accumulate up to 1,200 μg/g dry weight in leaf tissues (Barnett and Naylor 1966). The mechanisms of proline accumulation, however, are not clear. In a recent study, Singh *et al.* (1973*a*) reported a marked increase in the free proline content of all the plant organs in barley grown in perlite with rooting medium of the plant flooded with polythelene glycol solution (mol wt 4,000) of -10 to -20 bars osmotic potential. Subsequent studies by the same group of researchers (Singh et *al.* 1973*b*) showed that in barley, there were substantial varietal differences in proline accumulation, which they related to leaf survival during stress and to plant growth rate following stress.

Plant physiologists at IRRI subjected 20 rice varieties to water stress by polythelene glycol. They showed considerable varietal difference in proline accumulation under water stress (Yoshida *et al.* 1974). The relevance of proline accumulation to drought tolerance in rice or recovery following drought period is being studied both by physiologists and by agronomists at IRRI.

These indirect methods of screening for drought tolerance should be correlated with findings from field and greenhouse experiments to determine their importance and relevance to drought tolerance in upland rice.

Finally, recent results from the IRRI agronomy department clearly demonstrate that the reduction in grain yield due to increased soil moisture tension may be due to the direct effect of moisture stress or to soil problems induced by moisture stress, such as iron deficiency, or to a combination of both. Therefore, moisture stress and soil problems should both be considered in evaluating the suitability of rices for upland rice (De Datta *et al.* 1974c).

RECOVERY FROM WATER STRESS

While drought resistance and tolerance are essential to the survival of upland rice under severe water stress, the ability of a variety to recover and resume rapid growth following the stress period is even more important to grain production. Earlier, we found little or no correlation between field resistance to drought and recovery from desiccation (IRRI [Undated]c; IRRI 1971; Chang *et al.* 1972). Most traditional upland varieties are rather poor in recovery, while many lowland varieties or selections, particularly IR5 or IR442-2-58, and the semidwarfs, have excellent recovery capability. Recently, we found that several traditional upland varieties such as BPI-9-33, 63-83, and Kinandang Puti have moderately good recovery ability. We recognize the need to combine both drought resistance and recovery ability in an upland variety when yield performance is of major concern.

Control of upland rice insects through varietal resistance

Mano D. Pathak and Gurdev S. Khush

VARIETAL RESISTANCE TO INSECT PESTS

Several thousand rice varieties have been evaluated for resistance to the major insect pests that infest and damage upland rice. These include: the striped rice borer, ***Chilo suppressalis*** (Walker); the green leafhopper, *Nephotettix virescens* (Distant); the brown planthopper, ***Nilaparvata lugens*** (Stal); the white-backed planthopper, ***Sogatella furcifera*** (Horvath); and the zigzag leafhopper, ***Recilia dorsalis*** (Motschulsky). Many are being used in breeding programs to combine insect resistance with other good plant characteristics (Table 10) (Pathak *et al.* **1971**; Pathak **1971, 1972;** Athwal and Pathak **1972;** Khush and Beachell **1972).** Selected resistant varieties are being tested to determine the causes and the genetic nature of insect resistance.

Rice stem borer. About 10,000 varieties were screened for resistance to the stem borer in field experiments. Selected varieties were further evaluated by infesting them with a uniform number of striped borer lavae in greenhouse experiments. About 30 varieties are resistant to the striped borer. Types of resistance differ. Some are resistant because the insects consistently lay fewer eggs on them. Other resistant varieties seem to contain material which affects insect growth. Borer larvae placed on these varieties suffered higher mortality, grew slower, were smaller, and had lower percentages of pupation than the larvae caged on susceptible varieties.

Figures **4** and **5** show the differences in the survival and weight of larvae reared on resistant and on susceptible varieties. Some plant characters were correlated with stem borer susceptibility (Table 11). Other plant characters that were positively correlated with resistance to the striped borer included heavily sclerotized stem tissues, closely spaced vascular bundle sheaths, ridged stem surfaces, and high silica content.

Most insect resistance, however, seems to be due to differences in the chemical constituents **of** the plant. Some varieties were re-

Table 10 Rice varieties resistant to insect pests at IRRI

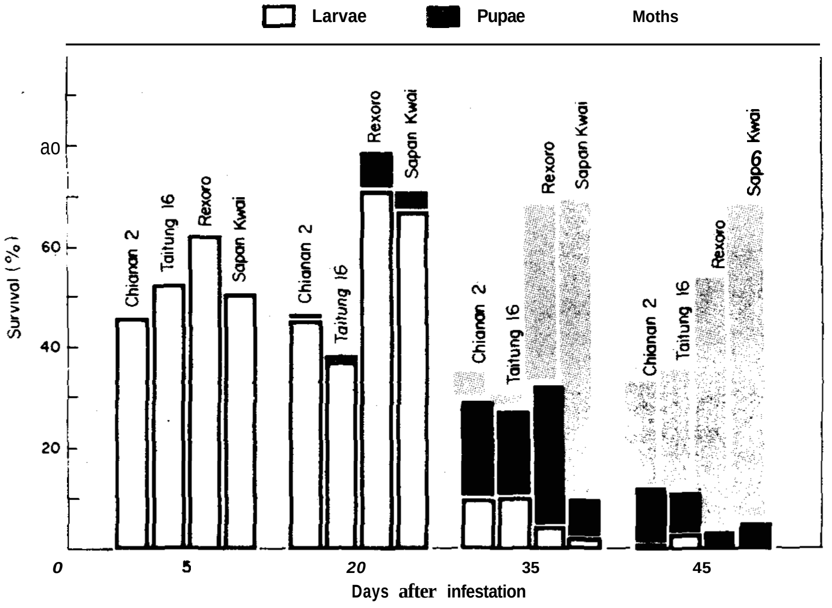
Chilo suppressalis[a]	*Nephotettix virescens*[b]	*Nilaparvata lugens*[c]	*Sogatella furcifera*[d]	*Recilia dorsalis*[e]
Bir-co 884	ADT-14	ASD 7	ARC 5752	Haji Haroon
C-409	ASD-7	Babawee	ARC 6248	H5
Chiang-an-Tsao-Pai Ku	ASD-8	Balamawee	ARC 6563	H105
Choh-chang-san-hao	ARC 5752	CO 3	ARC 6624	MTU 15
CO 13	ARC 7059	CO 22	ARC 6650	RDR 2
CO21	ARC 7302	Dikwee	ARC 7251	CI 5662-2
DD 48	ARC 10229	Gangala	ARC 7331	Intan 2400
DNJ 97	Baguamon 14	Hathiel	ARC 10595	Peta 2802
DZ 41	CO 9	H 105	ARC 10600	Suwan 158
DV 88	D-204-1	Kuruhondarala	Balamawee	Ziongzo
Ginmasari	DK 1	MTU 15	C 5-17	Saguon Thang P204
HBJ Boro II	DM 77	Mudgo	CI 5662-2	DA 19
Kipusa	DNJ 9	Murunga 307	Colombo	DA 5
Lu-wan-hsien	DNJ 97	Murungakayan 3	Dahanala 2014	Duc Phung R37
Patnai 6	DV 29	Murungakayan 101	HR 106	Emata Pindogale A28-6
PI 160, 638	DV 139	Murungakayan 104	JBS 34	Pankhari 203

(Continued on next page)

(**Table 10** *continued*)

Chilo suppressalis[a]	*Nephotettix virescens*[b]	*Nilaparvata lugens*[c]	*Sogatella furcifera*[d]	*Recilia dorsalis*[e]
Rusty Late	Hashikalmi	Murungakayan 302	Kaluheenati	Ptb 27
Su-yai 20	Jingasail	Murungakayan 303	Miao-Tien-I-Li-Chan	Ptb 21
Szu-miao	Kalimekri 391	Murungakayan 304	MTU 18	ASD 7
Taitung 16	Khama 49/8	Ptb 19	Mudgo	D-204-1
Ta-mao-shan	Palasithari 601	Seruvellai	Muthumanikam	Baguamon 14
Ta-poo-cho 2	Pankhari 203	SLO 12	Pankhari 203	Mudgo
Ti-Ho-Hung	Ptb 18	Sudurvi 305	Pu San 1	Ta-yang-tsin
TKM-6	Ptb 21	Thirissa	Sudurvi 306	Pal Kweng 48
Yabami Montakhab 55	Su-yai 20	Vellailangayan	Tien-lie	Rathu Heenati

[a]Striped rice borer. [b]Rice green leafhopper. [c]Brown planthopper. [d]White-backed planthopper. [e]Zigzag leafhopper.

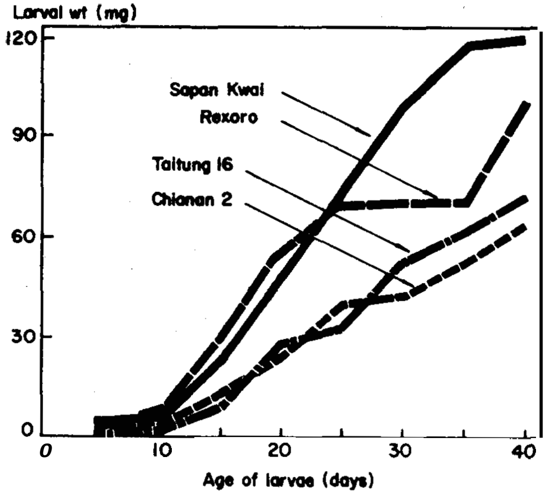


4. Survival and development of 600 *C. suppressalis* larvae caged on each of four rice varieties (Because of their small size not all Living larvae in the plant tissues could be recovered on the fifth day after infestation).

sistant from the seedling stage to maturity while others were resistant only during the vegetative stage of plant growth.

In field studies, stem borer populations and damage were consistently lower among the resistant varieties. Identical numbers of striped borer larvae were caged on a resistant and a susceptible variety for 120 days (about four stem borer generations). The insect population that developed on the susceptible variety was 15 times larger than that on the resistant variety. The susceptible variety had 56.3 percent dead hearts while the resistant variety had only 1 percent.

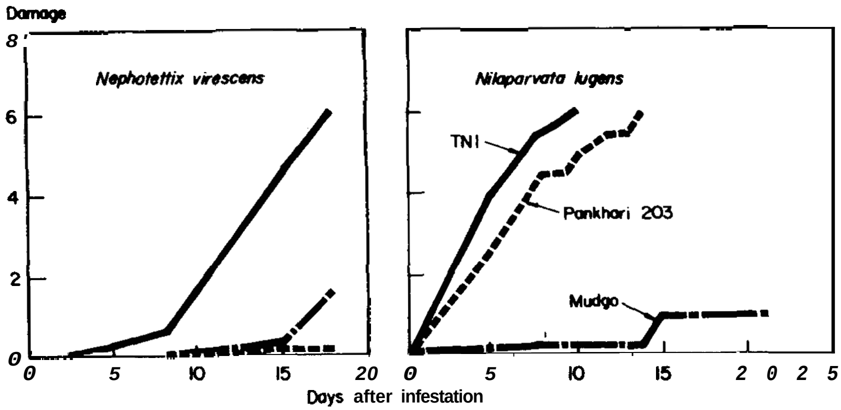
Selected varieties resistant to the striped borer were also evaluated for their resistance to the yellow borer, *Tryporyza incertulas* (Walker), the white borer, *Tryporyza innotata* (Walker), and the pink borer, *Sesamia inferens* (Walker). We found that striped borer resistance does not necessarily imply resistance to other types of borer. Different factors may govern resistance to different insect types.



5. Average weight of individual *Chilo suppressalis* larvae reared on resistant and susceptible varieties of rice.

Table 11. Correlations between rice plant characters and percentages of tillers infested with striped rice borer.

Plant character	Correlation coefficient
Elongated internodes. number	0.632**
Third elongated internode, length	0.71S**
Flag leaf, length	0.798**
Flag leaf, width	0.836**
Culm height	0.796**
Culm, external diameter,	
at half its length	0.672**
at one-fourth its length from the base	0.785**
Culm, internal diameter at half	
its culm	0.67I**
at one-fourth its length from the base	0.790**
Tillers per plant, number	–0.756**
Stem area occupied by vascular bundle sheaths (percentage)	–0.756**



6. Damage caused by caging 100 fit-instar nymphs on resistant and susceptible varieties.

Leafhoppers and planthoppers. From 5,000 to 10,000 varieties have been evaluated for resistance to the green leafhopper, the brown planthopper, and the white-backed planthopper. Several thousand varieties have been evaluated for resistance to one species of the green leafhopper, ***Nephotettix nigropictus*** (Stal), and the zigzag leafhopper. The leafhopper and planthopper studies have progressed faster than the stem borer studies because we have much simpler methods for mass rearing and screening varieties for resistance to these insects (Pathak 1972).

Many varieties have been found highly resistant to different species of leafhoppers and planthoppers. Resistance is generally quite specific; varieties which are resistant to one species of the insects may be highly susceptible to others. For example, Pankhari 203 is highly resistant to the green leafhopper but susceptible to the brown planthopper, while Mudgo is highly resistant to the brown planthopper but susceptible to the green leafhopper, Populations of insects caged on resistant varieties are low because the insects suffer high mortality, grow at a slow rate, have small bodies, and lay few eggs. Some plants are so resistant that even large insect populations caged on them cause negligible plant damage (fig. 6). Such resistant varieties seldom need protection from these insects even when field infestations reach epidemic levels.

Insects generally feed on both resistant and susceptible varieties at first. They do not remain on resistant plants for sustained feeding, however, even though they can puncture the plant tissues and their probosces can reach the feeding sites. Brown planthoppers die off, apparently of starvation, when caged on resistant plants. This has been attributed to either the presence of a feeding repellent or the absence of a feeding stimulus in resistant plants. When the green leafhopper and the whitebacked planthopper are caged on resistant plants, they feed sparingly on the resistant plants, then die off in a few days. This indicates that the plants either lack nutrients vital to these insects' health or that the plants contain substances that are toxic to them.

BREEDING FOR INSECT RESISTANCE

Varietal resistance to various insect pests is usually first found in plants of poor agronomic character, but can be transferred to plants of improved type. IR20, which is resistant to the striped borer and the green leafhopper, was obtained from the cross TKM 6 x (Peta/3 x Taichung Native 1). TKM 6 and a few other resistant varieties have been used extensively in IRRI's crossing program; several advanced breeding lines now have varying degrees of borer resistance (Table 12).

Stem borer resistance, howevtr, unlike leafhopper and planthopper resistance, is generally found at moderate levels. While the resistance of some varieties to the striped borer protects them from dead heart damage, it is not high enough to protect them from white heads. To improve the existing levels of resistance, we are using a diallel selective mating scheme (Jensen 1970) to cross moderately resistant varieties listed in Table 6. These lines were crossed in every possible combination; the resulting F_1's were also crossed

Table 12. Promising breeding lines that are moderately resistant to stem borers.

Designation	Cross
IR1514A-E597	IR20/TKM 6
IR1561-228-3	IR8/Tadukan//TKM 6^2/TN1
IR1365-83-2	$Peta^3$/TN1//BJ 1
IR1416-131-3	$Peta^4$/TN1//Tetep
IR1721-1 1-33	$IR24^3$/*O. nivara*
CR94-13	IR8//Ptb 18/Ptb 21
RP6-590-17-1	IR8/TKM 6

Table 13. Lines of improved plant type hat have resistance to different green leafhopper and planthopper species.

Designation	Cross	Reaction[a] to			
		Nephotettix virescens	*Nephotettix nigropictus*	*Nilaparvata lugens*	*Sogatella furcifera*
IR20	Peta^3/TN1/TKM 6	R	S	S	S
IR26	IR24/TKM 6	R	S	R	S
IR833-6-2	Peta^3/TN1//Gam Pai 15	R	R	S	S
IR944-102-2	TN1/M. Sungsong//IR8	R	S	S	R
IR1514A-E597-2	IR20/TKM 6		≤		S
IR1539-823-14	IR24//Mudgo/IR8	R	S	R	S
IR1614-389-2	IR22//Mudgo/IR8	R	S	R	S
IR1702-158-4	IR24/Ptb 18	R	S	R	S

[a] R = resistant; MR = moderately resistant; S = susceptible; MS = moderately susceptible.

with each other in every possible combination. Progenies of these double crosses were screened for stem borer resistance. The progenies of several cross combinations were more resistant than either parent. The better plants selected from these crosses were mated with each other; we will screen these F_1's for stem borer resistance. By repeating this process, we hope to accumulate quantitative genes for stem borer resistance from different sources and to develop breeding lines that are highly resistant to the stem borers.

Crosses of Mudgo have given us breeding lines of improved plant type that are resistant to the brown planthopper. Resistance to both the brown planthopper and the green leafhopper has been combined in numerous crosses (Table 13). We have also obtained lines resistant to brown planthopper from crosses of two susceptible varieties (TKM 6 and IR8, or IR20, or IR22, or IR24). Genetic studies have revealed that TKM 6 is homozygous for the *Bph 1* gene, which carries brown planthopper resistance. It is also homozygous for a linked inhibitor gene, *I-Bph 1*, which inhibits *Bph 1*. When crossed with other susceptible varieties, segregates which are resistant to the brown planthopper are produced (Martinez and Khush 1974). IR26, which IRRI released in late 1973, is resistant to the brown planthopper. It is a progeny of a cross of IR24 and TKM 6. Several other selections from an IR20 x TKM 6 cross, including IR1514A-E666 and IR1514A-597, have resistance to the brown planthopper.

The recessive gene for brown planthopper resistance, *Bph 2*, from Ptb 18 has been incorporated into the improved plant type lines of IR1702 (Table 13).

A small proportion of the progenies of TKM 6 crosses are also resistant to the brown planthopper. Many advanced breeding lines that were developed from TKM 6 and other sources are resistant to the borers, the green leafhopper, the brown planthopper, and the whitebacked planthopper.

Most IRRI breeding lines are resistant to green leafhopper, conditioned by either of the two dominant genes for resistance, *Glh1* and *Glh3*. A few breeding lines are resistant to the whitebacked planthopper and the *Nephotettix nigropictus* species of the green leafhopper. We have crossed many improved plant type lines in an attempt to combine, in a single line, resistance to the four leafhopper and planthopper species.

Diseases of upland rice and their control through varietal resistance

Shu-Huang Ou, Keh-Chi Ling, Harold E. Kauffman, and Gurdev S. Khush

DISEASES OF UPLAND RICE

The basic diseases of upland rice are similar to those of flooded lowland rice. The absence of flood water, however, creates around the plants a different type of microclimate, one that favors the development of certain diseases. Soil-borne pathogens, for example, are more active, and cause more severe problems, in upland than in lowland rice.

Rice blast, caused by ***Pyricularia oryzae,*** is the most serious disease found in the extensive upland rice areas of Latin America, Africa, and Southeast Asia. The microlimate around upland plants appears to directly favor blast disease, although some early experiments indicate that high blast susceptibility might be caused by the reduced uptake of silica.

Sheath blight disease, caused by the soil-inhabiting fungus ***Rhizoctonia solani (Thanatephorus cucumeris,*** commonly known as ***Corticium sasakii),*** may become increasingly serious as more fertilizers and other improved cultural practices are used on upland rice. The fungus is not active in flooded soil, but it will grow and multiply throughout the year in upland soil. It has a wide host range.

Seedling diseases, seldom a problem in lowland transplanted rice, may be important in direct-seeded upland rice. Soil-borne fungi and bacteria may cause seed decay or may attack the young seedlings.

Bacterial leaf streak ***(Xanthomonas translucens*** f. sp. ***oryzicola)*** is frequently found in upland rice, but seldom causes much damage.

Little information is available on bacterial blight ***(X. oryzae)*** in upland rice. We don't know if the disease can be transmitted through rice seeds. Under upland conditions, however, bacterial blight cannot be spread by irrigation water, so it may not be as destructive as in lowland rice.

Incidences of tungro and grassy stunt diseases seem to be similar for both upland and lowland rice. We don't know, however, the effect of the upland microclimate on the populations of the insect vectors.

Many more species of nematodes attack upland rice than lowland rice. In Japan, the cyst nematode was reported to have caused continuous cropping to fail in upland rice. In Liberia, cyst nematode severely damaged a small experimental plot of upland rice after continuous cropping. The International Institute of Tropical Agriculture, Ibadan, Nigeria, has stated, "Rice grown at IITA under upland conditions was generally infected by plant parasitic nematodes. The spiral nematode was distributed in all plantings in large numbers. The root-knot nematode, the root-lesion nematode, and the pin nematode occurred in less than 10 percent of the samples. One planting of five rice varieties in soil infested with the root-lesion nematode (55%) and the spiral nematode (45%) had 31,000 nematodes per plant 6 weeks after planting. All five varieties were more or less equally infected. IR20 rice grown on soil fumigated with D-D mixture to control the spiral nematode gave a 25.4-percent increase in yield over non-fumigated plots. IR665-79-2 showed no increase in the same trial."

Because microclimate in upland and lowland rice differ, the severity of other diseases may also differ.

VARIETAL RESISTANCE

Rice varieties that are resistant to various major diseases of lowland rice should also be useful for breeding resistance to upland rice.

Good sources of resistance to blast have been identified by the international blast nurseries (Table 14). Many have been crossed with semidwarf varieties or lines. Among the commonly used donor varieties are Tetep, Tadukan, C46-15, Carreon, Mamoriaka, Dawn, Kataktara DA2, and others. Some hybrid lines combine several sources of resistance to blast. A few such lines tested in upland trials in the Philippines were also good yielders. An example is a line from the complex cross IR8/Dawn//IR8/Kataktara DA2.

Table 15 lists varieties resistant to bacterial blight. From these sources, many new varieties or lines that are resistant to bacterial blight – among them IR20, IR22, IR26, and several unnamed

Table 14. Resistant varieties selected from international blast nurseries.[a]

Variety	Origin	Total tests 1964–1973	Susceptibility index	Resistant frequency (%)
		Group I		
Tetep	Vietnam	ƎOZ	1.24	98.0
Nang Chet Cuc	Vietnam	Z9Z	1.6d	88.3
C46-15	Burma	307	1.56	93.8
Tadukan	Philippines	Ǝ09	1.S0	94.5
Trang Cut L. 11	Vietnam	263	1.70	94.3
Pah Leuad 111	Thailand	258	1.57	94.3
H-5	Sri Lanka	ƎId	1.71	92.7
R-67	Senegal	291	1.85	92.4
CI 7787	U.S.A.	278	1.83	91.7
Mekeo White	New Guinea	276	1.9d	92.8
Ram Tulasi (Sel)	India	297	1.70	91.9
D25-4	Burma	292	1.7Ǝ	93.6
M-302	Sri Lanka	310	1.86	90.3
Padang Trengganu 22	Malaysia	2Ǝ9	1.93	87.4
Ta-poo-cho-z	China	277	1.61	91.3
<u>Susceptible varieties:</u>				
Kung-shan-wu-shen-ken	China	246	4.30	24.4
Fanny	France	252	4.39	19.d

(Continued on next page)

(Table 14 *continued*)

Variety	Origin	Total tests 1964–1973	Susceptibility index	Resistant varieties (%)
		Group II		
C46-15	Burma	229	1.51	97.3
Mamoriaka	Malagasy	227	1.48	97.8
Carreon	Philippines	227	1.38	97.4
Huan-sen-goo	China	216	1.35	96.3
Dissi Hatif	Senegal	223	1.51	91.3
Ram Tulasi	India	211	1.41	97.2
Ram Tulasi (Sel)	India	194	1.42	97.3
Thava Lakkanan PTB 9	India	222	1.52	96.9
Macan Tago	Philippines	155	1.75	95.5
Ahmee Puthe	Burma	136	1.49	97.1
Ca 435/b/5/1	Indonesia	205	1.56	97.1
DNJ-60	Bangladesh	224	1.93	93.8
Ca 902/b/2/2	India	219	1.60	94.5
R-67[b]	Senegal	202	1.64	94.6
N-12[b]	Japan	225	1.80	93.9
Pah Leuad 29-8-111	Thailand	220	1.65	95.5
T 23	India	220	1.74	94.4
DZ-193	Bangladesh	231	1.19	94.4
Pi-4	Japan	166	1.54	93.9
Ca 902/b/3/3/1	Chad	226	1.60	94.7

[a]Group I consists of 258 varieties selected at random and tested in IBN since 1963; Group II consists of 321 varieties selected from more than 8,200 varieties after repeated tests at IRRI and was entered in IBN since 1965. [b]Upland varieties.

Table 15. Sources of resistance to bacterial blight (BB): tall donor parents and their semidwarf progenies (1972 and 1973 International Bacterial Blight Nursery).

Tall resistant donor	Semidwarf progeny	Cross[a]	BB disease rating[b]			Resistance or tolerance to other diseases and insects[c]
			NE Asia	SE Asia	South Asia	
			Single recessive gene[d]			
BJ1	–	–	R	MR	R-MS	BLS, B, T, SB
BJ1	RP291-18-60	IR8/BJ1	R	R	MR-S	BLS, GLH
BJ1	RP633-150-6-5	IR22//IR8/BJ1	R	R	X	
DZ 192		–	R	MR	MS-S	ST8
DZ 192	IR1545-339	IR24/DZ 192	R	MR	MX-S	ST8, HT3
			Single dominant gene			
Sigadis		–	MR	MR	MS	B, T
Sigadis	IR1529-680-3	IR305/IR24	MR	MR	MR-MS	B, ST8, GLH
TKM 6	–	–	–	R	MX-MS	B, GLH, T
TKM 6	IR20	IR262/TKM6	MR	MR	∀X-MS	B, GLH, T, SB
TKM 6	IR26	IR24/TKM6	R	MR	MR-MS	B, BPH, GLH, T, SB
TKM 6	IR2061-464	IR833//IR1561/1737				B, T, GSV, BPH, GLH, SB
W1263		–	MR	MR-MS	MR-S	T, BPH, GLH, SB, GM
W1263	IR2031	–	–	MR	–	T, GSV, BPH, GLH, GM
Wase Aikoku		–	–	MR	MX-S	
Wase Aikoku	IR1697-42-2-2	IR8^2/Wase Aikoku	MR	MR	MS	

(Continued on next page)

(**Table 15** *continued*)

Tall resistant donor	Semidwarf progenies	Cross[a]	BB disease rating[b] NE Asia	SE Asia	South Asia	Resistance or tolerance to other diseases and insects[c]
		Other tall varieties with no advanced dwarf progenies – Inheritance of resistance				
Lacrosse x Zenith-Nira	–	–	–	MR	MR-S	
Malagkit Sungsong	–	–	MR	MR	MR-MS	
Nagkayat	–	–	R	MR	MR-MS	
Remadja	–	–	MR	MR	MR-MS	GLH, T
Semora Mangga	–	–	–	R	MR	

[a]/ = first cross; // = second cross. [b]R = resistant; MR = moderately resistant; S = susceptible; MS = moderately susceptible. [c]BLS = bacterial leaf streak; B = blast; T = tungro; BPH = brown planthopper; GLH = green leafhopper; SB = stem borer; GM = gall midge. [d]Inheritance to typical Philippine strain of *X. oryzae* (Pxo 61).

Table 16. Sources of resistance to bacterial leaf streak from tall indica varieties and their semidwarf progenies.[a]

Variety or cross	Resistance		Comments
	India	Philippines	
		Talls	
BJ1	MR	R	R-MR to BB
DZ 192	–	MR	R-MR to BB
Zenith	MR-MS	MR	R-MR to B and BB
Perurutong (NB)	–	MR	MR to BB
TKM 6	MR	MR	R to BB
		Semidwarfs	
Vijaya	MR	R	High yield potential
RP 291	MR	MR	
IR 1545	–	R	R to BB
IR883	–	MR	Pure line
IR127-80-1	–	R	R to BB, T; pure line
IR26	–	MR	R to BB, T, BPH, GLH

[a]Source: Ou *et al.* 1971; Row *et al.* 1968 Rao *et al.* 1972.

hybrid lines – have been developed. Progenies from some crosses between resistant varieties have broader spectrum and higher levels of resistance than the individual parents.

Good sources of resistance to bacterial leaf streak and resistant hybrid lines are shown in Table 16. The following tall local varieties and hybrid lines are resistant to tungro virus.

Adday local (Sel)
Adday (Sel)
Andi from N. Pokhara
T412
Basmati 37
Basmati 370
Bengawan
Chunta 313 Hao x
Binastian
Dee-geo-mean-don

Pehkahok-kimkan
Prine Chan Ying Tao
PI 160677-2
PI 184675-2
PI 184675-4
PI 184676
Podiwi, A8
Rajamandal Baran .
Ram Tulasi
Red Rice

Table 17. Sources of resistance to tungro virus: tall donor parents and their semidwarf progenies.

Tall resistant donor	Semidwarf progenies	Cross[a]	Resistance to other diseases and insects
Gam Pai	IR2061-464	IR833//IR1561/IR1737	BB, GSV, BPH, GLH
	XB-2	Gam Pai 15^2/TN1	
H8	BG11-11	Engkatek/H8//H8	BPH, GLH
HR21	IR1364-37	IR262/HR21	GLH
Pankhari 203	IR825-11-2	(IR8/P203//Peta^6/TN1)	–
Peta	C4-63	BPI 76/Peta	GLH
PTB 18	CR94-13	PTB 18/PTB 21//IR8	BPH, GLH, GM
	IR2070 selections	IR20^2/*O. nivara*//CR94-13	BB, GSV, BPH, GLH
	IR2071 selection	IR1561/IR1737///CR94-13	BB, GSV, BPH, GLH
Sigadis	Mala	CP-SLO^2/Sigadis	BB, GLH
TKM 6	IR20	IR262/TKM 6	BB, GLH, SB
	IR26	IR24/TKM 6	BB, BPH, GLH, SB
W1263	IR2039 selections	IR1330-5/IR1737	BB, GSV, BPH, GLH, GM

[a] / = first cross; // = second cross; /// = third cross.

DV 29
Fadjar
FB 24
Habigonj DW # 8
H4
Indrasail
JC 170
Kai Lianh Hsung Tieng
Ladang
Lang Chung Yi Lung Ju
Latisail (Dacca 17)
Latisail (T. Aman)
Malagkit Sungsong
Padi Kasalle
Salak 2885
Seratus Hari T/36
Seri-Raja
Tjahaja
Tjeremas
TP x Rexoro SB
Tsou-yuen
Urang-urangan 89
59-334 (B-11 x Mass)
6517

We also find sources of resistance to tungro among tall varieties and their semidwarf progenies (Table 17).

The only source of high-level resistance to grassy stunt is a strain of wild rice, ***Oryza nivara.*** Fortunately, the resistant gene of this strain is easily transferred to many semidwarf varieties. Several sources of field resistance to grassy stunt without ***Oryza nivara*** heritage appear promising, particularly **CR94-13** from India. Many hybrid lines that are resistant to both the viruses and their vectors are now being tested.

Distinct genetic differences in resistance to sheath blight have been observed, although highly resistant **or** immune varieties have not been found. The upland variety Hashikalmi and the dual-purpose variety Dular are both moderately resistant. Most of the following varieties and hybrid selections are lowland rices that appear to be at least moderately resistant to sheath blight:

Tall	Dwarfs
CTG 1206	Bahagia
DD 24	Mehran
DD 63	Pankaj
Dular	Pelita 1/1
DZ 192	
Hashikalmi	
Kunrari DA-15	
K.P.F. 6	
Laka	
TKM 6	
46 Palman	

Because several diseases often occur simultaneously in the same field, new upland varieties should have combined resistance to all major diseases. Several promising hybrid lines developed for lowland culture have such resistance. Although IR26 is resistant or tolerant to most rice diseases, neither it nor other promising hybrids have been tested for suitability for upland culture.

Varietal resistance to adverse chemical environments of upland rice soils

Felix N. Ponnamperuma

Upland rice is grown on soils that are aerobic or oxidized for the greater part of the growing season. Even without water stress and weed competition, the oxidized state of the soil is unfavorable to the growth of rice because of two adverse conditions: iron deficiency in all oxidized soils, and manganese and aluminum toxicities in strongly acid soils (IRRI 1971). If resistance to these adverse conditions can be combined with other desirable traits, scientists may be able to develop rice varieties that are better suited to upland conditions than are the old upland types.

Preliminary pot experiments revealed that varieties differ markedly in resistance to iron deficiency and to manganese and aluminum toxicities. Because the severity of iron deficiency increases as pH increases, while the degrees of manganese and aluminum toxicities increase as pH decreases, we used three soils with three different pH levels to screen varieties for resistance to adverse chemical environments: an acid soil (Luisiana clay: pH, **4.6;** organic matter, ***3.2%);*** a neutral soil (Maahas clay: pH, 6.6; organic matter, 2.0%); and a calcareous soil (Maahas clay, limed to a pH of 7.6).

Experiments with upland rice are limited by the absence of quantitative data on two important parameters: redox potential, which reveals whether a soil is aerobic or anaerobic, and soil moisture tension, which indicates the degree of moisture stress. **We** controlled and measured both in this experiment (Ponnamperuma and Castro 1972). To ensure aerobic conditions, we provided drainage at the bottom of the three concrete receptacles or tanks (each tank measured 10.8 **x** 8.3 x 0.3 m). We placed each of the three soils in the tanks, avoiding soil compaction. To prevent soil moisture stress, we installed sprinklers above the soils. Eight platinum electrodes and eight tensiometers were placed 10 cm below the soil surface in each receptacle. We measured redox potential weekly and soil moisture tension daily at 1400 h. The soil moisture tension was maintained at 0.1 to 0.2 atm. In this moisture range the redox potential was above 0.5 V at pH 7.

We prepared the seedbed, then broadcast fertilizers at rates equivalent to 100 kg N/ha as ammonium sulfate, 50 kg P/ha as concentrated superphosphate, and 50 kg K/ha as muriate of potash. Presoaked seeds of the varieties to be tested were then sown in furrows 20 cm apart with three rows for each variety. The tall varieties were grouped together and, at later growth stages,

Table 18. **Mean yields (per linear meter) on three aerobic soils. IRRI, 1971 dry season.**

Variety or selection	Yield (g/m)	
	Grain	Straw
M1-48	151	247
E425	120	228
IR661-1-170	119	133
PI 215936	105	163
IR577-11-2	102	123
IR127-80-1	102	147
Taichung Native 1	101	156
CI 5094-1	99	257
IR12-178-2	99	143
IR24	94	126
IR305-3-17	92	122
IR140-136	90	133
IR159B3-1-1	89	195
IR424-21-PK2	89	161
IR305	88	109
IR759-53-5	88	137
IR773-112-1	88	113
CP231 x SLO17	85	133
IR20	81	130
IR262-43-8	81	113
IR789-8-3	81	146
IR22	72	106

(Continued on next page)

were supported to prevent lodging. We observed the plants weekly and noted the weights of straw and of filled grains of the middle rows. The resistance ratings were based on plant observations and the grain yield. Promising varieties were tested in replicated field trials.

We observed not only marked differences in foliar symptoms, growth, and yield among the varieties but also some interactions between soils and varieties (Tables 18 and 19).

(Table 18 *continued*)

Variety or selection	Yield (g/m)	
	Grain	Straw
Azmil 26	70	170
IR790-5-1	70	135
IR648-2-8	69	124
Nira	69	171
Dickwee 328	68	243
IR8	68	151
Azucena	65	163
C4-63G	61	174
Palawan	60	165
Texas Patna	56	263
Milfor	55	182
IR5	53	284
Agbede	51	132
Dima	50	293
Pinulot 330	50	155
IR159B2-3-1	49	111
IR878B4-220-3	48	168
Dinalaga	47	165
M1-139	36	232
Original Century Patna	32	97
Century Patna 231	32	96
IR332-2-10	32	210
Peta	14	462

Table 19. Grain yields of 15 varieties on three aerobic soils at field capacity. IRRI, 1971 dry season.

Variety	Luisiana clay		Maahas clay		Limed Maahas clay	
	(g/m)	Rank	(g/m)	Rank	(g/m)	Rank
M1-48	138	1	154	1	161	1
IR661-1-170	129	2	116	4	115	5
IR577-11-2	104	4	111	7	91	11
IR127-80-1	109	3	104	11	92	9
CP231 x SLO 17	82	15	91	20	83	17
IR22	69	25	77	28	71	26
C4-63G	52	33	74	30	58	30
MI-329	21	45	50	42	36	42
Original Century Patna	18	46	45	44	34	43
Peta	6	48	28	46	9	46
Taichung Native 1	82	16	118	3	104	6
E425	83	15	150	2	124	2
IR24	76	21	112	5	94	8
IR20	87	12	108	8	48	34
IR5	42	35	113	5	3	47

The top yielders were M1-48 and E425, both upland varieties; the lowest yielder was Peta, a typical lowland rice (Table 18). IR5, which has been reported to yield well under upland conditions (De Datta and Beachell 1972), was 34th in rank among the 45 varieties tested because it suffered severely both from iron deficiency on the calcareous soil, and from manganese toxicity on the acid soil. It was the fifth highest yielder on the nearly neutral soil.

Most varieties maintained their relative yield ranks on all three soils, but some interactions between varieties and soils were evident (Table 19). On all three soils, M1-48 (in spite of its poor tillering capacity) was the top yielder; IR22 was a moderate yielder; and Peta was the lowest yielder. But Taichung Native 1 and E425 fared poorly on the acid soil compared with their performances on the neutral soil. IR5 did much better on the nearly neutral soil than on the other soils.

M1-48, E425, IR661-1-170, and IR424-21-PK2 were greener than others and showed no signs of iron deficiency nor of manga-

Table 20. Visual rating of the severity of aluminum toxicity in 14 varieties on aerobic Luisiana clay, 7 weeks after sowing. IRRI, 1971 wet season.

Variety	Score[a]
Monolaya	0
Peta	3
M1-48	0
C22-51	0
IR1721-11-6	0
IR442-2-58	3
IR712-23-2	3
IR665-8-3	1
IR1561-228-3	3
IR1008-14-1	0
IR24	0
IR20	5
IR1514A-E666	3
IR1514A-E597	5

[a]0: no symptoms; 5: severe symptoms.

nese toxicity. A healthy green color may indicate adaptability to aerobic soils that are not under moisture stress.

This experiment shows that some varieties fare much better than others on aerobic soils, regardless of pH, and that some varieties do well on neutral soils but not on acid soils and calcareous soils.

Four of the five top yielders on the nearly neutral soil (Table 19) were grown in a replicated field experiment on Maahas clay at the IRRI farm in the 1972 wet season. E425 yielded 3.8 t/ha; M1-48, 4.1 t/ha; IR661-1-170, 5.7 t/ha; and IR5, 6.2 t/ha. In a similar experiment with six varieties on an acid oxisol at Luisiana, Laguna, Philippines, three varieties and lines confirmed their adaptability to acid aerobic soils: M 1-48 yielded 4.8 t/ha; IR661-1-170, 5.0 t/ha; and IR 127-80-1, 6.6 t/ha.

Aluminum is a major cause of soil acidity injury to crops (Hoyt and Nyborg 1971). Rice is no exception. We have evidence that the yellowish white interveinal mottling and the drying of the older leaves of plants raised on aerobic Luisiana clay fertilized with ammonium sulfate in the greenhouse are symptoms of aluminum toxicity (IRRI 1971, 1973). When the symptoms were observed the pH was 3.7 (compared with 4.7 at the start) and the concentration of water-soluble aluminum was 4 ppm. But we saw no signs of aluminum toxicity on the acid soil in the outdoor tanks. Tests showed that the pH of the soil in outside tanks had risen from 4.6 to 5.3 as a result of irrigation with alkaline water from a deep well. So we applied flowers of sulfur to bring the pH down to 4.0 [the pH value of this soil about 8 weeks after the application of 100 kg/ha N as $(NH_4)_2SO_4$]. Two weeks later, the presoaked seeds of 14 varieties were sown in furrows as described earlier. Four weeks after sowing, symptoms of aluminum toxicity were visible but the severity differed with the variety. The rices were scored 7 weeks after sowing; IR20 and IR1514A-E597 were the most susceptible, while Monolaya and M1-48 were among the least susceptible (Table 20).

Field tests on a strongly acid oxisol at Luisiana, Laguna, Philippines, revealed that M1-48, IR24, and IR127-80-1 were resistant to aluminum toxicity while IR5 and IR20 were susceptible.

At Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, more than 1,000 varieties have been screened for aluminum toxicity. The varieties were grown in culture solutions containing 3 and 30 ppm aluminum. The ratio of the root lengths of the 3-week-old plants at these two levels of aluminum was taken as a measure of resistance to aluminum. Field tests on a strongly acid oxisol of the Colombia Llanos Orientales confirmed the validity of the screening technique. Monolaya and Colombia 1, both native varieties, were highly resistant while CICA 4 was highly susceptible to aluminum toxicity.

The fairly consistent behavior of the 290 varieties tested in greenhouses, in outdoor receptacles. and (in some cases) in fields. permits the following grouping:

iron deficiency		manganese and aluminum toxicities	
resistant	susceptible	resistant	susceptible
IR20	IR441-20-3	IR24	IRS
IR442-2-58	Bahagia	IR127-80-1	IR20
IR661-1-170	ICA 10	IR661-1-170	IR1514A-E666
IR665-8-3	Peta	IR1008-14-1	IR1514A-E597

IR1008-14-1	**CAS 209**	**Peta**
IR1561-228-3	**M1-48**	
CAS 209	**Monolaya**	
E425	**Colombia 1**	
M1-48		

The best sources of resistance to iron deficiency are IR1561-228-3 and CAS 209, while the best sources of resistance to manganese and aluminum toxicities are M1-48 and Monolaya.

Because IR24, IR661-1-170, IR1008-14-1, CAS 209, and M1-48 resist both iron deficiency and manganese and aluminum toxicities; they are suited to acid, neutral, and even calcareous aerobic, soils.

SUMMARY

Differences in the growth, appearance, and yield of rice grown on an acid, a neutral, and a calcareous soil maintained at a redox potential of > 0.5 V and at a soil moisture tension of 0.1 to 0.2 atm were used to screen 290 varieties for resistance to the major chemical hazards in aerobic soils, iron deficiency, and manganese and aluminum toxicities. Varieties differed markedly in their resistance to these adverse soil conditions. IR24, IR661-1-170, IR1008-14-1, CAS 209, and M1-48 resisted both iron deficiency and manganese and aluminum toxicities, while Peta succumbed to both sets of adverse soil conditions. IR5 resisted iron deficiency but suffered from manganese and aluminum toxicities; Colombia 1 strongly resisted manganese and aluminum toxicities but suffered from iron deficiency. The best sources of resistance to iron deficiency are IR1561-228-3 and CAS 209; the best sources of resistance to manganese and aluminum toxicities are M1-48 and Monolaya.

Breeding methods for upland rice

Te-Tzu Chang, Surajit K. De Datta, and W. Ronnie Coffman

BREEDING METHODS

Because improved upland rice varieties are intended for cultivation under a cultural system that involves dry land preparation and direct seeding, selection among hybrid progenies should be carried out under such conditions. In this respect, the techniques for planting and field evaluating improved lines are similar to those for small grains such as wheat. But upland rice breeding can be accelerated by planting F_1 hybrids, selected early-generation lines, and promising selections under lowland culture for maximum seed production. In tropical areas where irrigation water is available during the dry season, it is possible to grow and select two generations of hybrid progenies in a year.

Because the climatic, edaphic, and cultural conditions of each major upland rice production area differ, scientists should direct initial attention to the broad needs of major production areas, rather than to the development of a cosmopolitan genotype, such as IR8, for all areas of the tropics. The breeders in a major production area should know the ecological conditions and have well-defined breeding objectives, and judicially assess the germ plasm to be used as parents. Breeders of several areas with similar objectives can share early-generation (F, or F_3) breeding populations, but they should begin selecting in the area concerned from the earliest possible generation. Breeding lines should also be exchanged among areas at an early stage. This approach departs somewhat from that most commonly used in lowland rice where water supply, the largest variable in crop production, is kept more or less constant. In upland rice production, the diverse differences in precipitation patterns and and in soil types require intense local selection within breeding populations in the early hybrid generations. Moreover, the variable rainfall patterns at any location require longer testing periods to identify the most adaptable genotypes. Although irrigation makes the planting of a second crop each year possible, selection and testing for yield performance should be in the wet season (IRRI 1973). Consequently, progress will be slower in breeding upland than lowland rices. Moreover, the variable and restricted rainfall in most upland rice areas results in less dramatic increases in grain yields than those in fully irrigated areas. Field tests replicated over a number of sites and extended for several seasons are the most practical means of identifying promising genotypes for upland areas.

The choice of parents can be challenging; the breeder must consider a wide array of both traditional upland and lowland cultivars. Specific parents should be selected according to well-defined breeding objectives.

As mentioned earlier, the traditional upland group contains useful genes for moderately early maturity, insensitivity to photoperiod, resistance to drought, desirable panicle and grain features, resistance to blast, tolerance to problem soils, and stable but low yields.

They generally lack, however, resistance to bacterial blight, virus diseases, leafhoppers and planthoppers, and stem borers. So improved as well as traditional lowland varieties should be used to provide genes for extreme earliness, tillering ability, resistance to the major diseases and insects, superior grain characteristics, and above all, a higher yielding potential because of a nitrogen-responsive and lodging resistant plant type. Some lowland varieties also have tolerance to problem soils.

The guiding principle in breeding, therefore, is to accumulate favorable genes, such as for drought resistance and yield, from both variety groups, and to eliminate unfavorable genes, such as for low tillering and pest susceptibility.

To accumulate genes that transmit favorable attributes for areas of unreliable rainfall and other adverse environmental conditions, the greatest possible number of such favorable genes should be assembled by every conceivable breeding method, whether it calls for composite crosses, backcrosses, or recurrent selections. Initially, three-way or composite crosses may bring together a large number of gene combinations within a relatively short time. Other approaches should be adopted, however, when applicable.

So little has been published about the varietal development of upland rices that the breeder must mobilize his own resources and imagination to organize hybridization and selection programs. Parental sources of desired traits are available from IRRI (Table 21). The list will be expanded and revised as further progress is made in breeding and testing. Drought-resistant strains of *O. glaber-*

rima and of the wild relatives of *O. sativa* (Morishima *et al.* 1962) are also potential parents. The underlying principle is to use the best genetic sources available regardless of variety designation.

Field resistance to drought is so important in most upland rice areas that breeding population and lines should be screened for this trait as early as the F_2, and not later than, the F_3 generation. Before a breeding line becomes reasonably homozygous, tests for drought resistance should continue for several generations. An effective method is to select F_2 plants in the wet season in an upland field, test the F_3 lines in the dry season, further select among the F_4 lines in the wet season, and so on. Since drought resistance and yield are related traits, estimates of yield performance in the wet season, when feasible, will increase the reliability of dry season findings. This approach is, of course, subject to the unpredictable occurrence of drought in the wet season. Planting on different or several dates in the wet season improves the chances of subjecting plants to drought periods.

Refined screening techniques for drought resistance that offer greater precision than mass screening should be developed and adapted to use on parental varieties and breeding lines in more advanced generations. With such techniques, the avoidance and tolerance mechanisms that operate at different growth stages could be thoroughly assessed.

Because extremely high levels of drought resistance and of yielding ability do not appear to be biologically compatible, the breeder may compromise between a reasonably high level of drought resistance for the specific area concerned and an improved yield level through increased use of locally available inputs.

As with breeding for drought resistance, breeding populations intended for use in areas with problem soils should be grown and selected during the early generations on such problem soils for maximum efficiency. But large-scale testing of breeding lines from other sources should also be included in breeding for tolerant genotypes.

To combine desired traits in improved genotypes, large numbers of crosses should be made and enough F_1 seeds of each should be produced. The more promising cross combinations may be identified through visual selection among F_1 populations.

Thousands of F_2 plants per cross should be space-planted, or drilled into a row and later thinned to single-plant hills, along with rows of the parent plants in an upland field for selection. The dif-

Table 21. Parental source of desirable traits in the IRRI breeding program for upland rice.

Trait	Variety group	Parents
Early maturity	Upland	E425, M1-48, OS 4, OS 6, Rikuto Norin 21
	Lowland	IR1561-149-1, IR1561-228-3, Dular
Intermediate height and vegetative vigor	Lowland	IR5, IR442-2-58, C4-63, C12, Pelita I/1 and I/2, Mala
	Upland	C22, LAC 23
Tillering ability	Lowland	Semidwarfs, C4-63, C12
	Upland	C22
Drought resistance	Lowland	Bluebonnet 50, Dular, IR841-67-1
	Upland	Agbede, E425, Khao Lo, KU-10, KU-70-1, M1-48, Moroberekan, Rikuto Norin 21, 63-83
Recovery from drought	Lowland	IR5 and many semidwarfs
	Upland	OS 4, 63-83, BPI-9-33
Blast resistance	Lowland	Carreon, IR8/4 x Dawn, IR790-28-1, IR1544-340-6
	Upland	M1-48, OS 6, E 425
Bacterial blight resistance	Lowland	Sigadis, IR1529-680-3, IR1541-76-3
	Upland	Khao Lo, KU-70-1, M1-48, 63-83
Tungro resistance	Lowland	IR833-6-2, IR841-67-1, IR1364-37-3, PTB 18, BG11-11
Grassy stunt resistance	Lowland	IR1721-11-13, IR1721-11-8, IR2061-464-2

(Continued on next page)

(**Table 21** *continued*)

Trait	Variety group	Parents
Green leafhopper resistance	Lowland	PTB 18, IR833-6-2, IR1529-680-3, IR1541-76-3, BG11-11
Brown planthopper resistance	Lowland	BG38-4, PTB 18, IR1561-228-3, IR1541-76-3
Stem borers resistance	Lowland	IR1711-11-13
Toxicity factors in aerobic soils	Lowland	IR24
	Upland	E425, M1-48
Non-shattering panicles	Upland	OS 4, E425, KU-10

ference in vegetative vigor of F_2 plants under fairly dry soil conditions could indicate the drought resistance **of** different segregants. Visual selection for yield potential would be rather inefficient at this stage. On the other hand, selection for reaction to blast and to bacterial blight could begin at the F_2 generation. Leaf and neck blast occurs frequently in upland plantings. F_2 plants can be inoculated with bacterial blight by the “leaf clipping” method, and their reactions rated.

Selected F_2 plants should be grown as lines in single rows under both upland and lowland cultures. The upland planting could also be designed as a test for drought resistance when the lines are grown in the dry season. The lowland planting would furnish sufficient seed for further testing under upland conditions at one or more sites and for various disease and insect resistance tests and for quality analysis. F_3 or F_4 lines can be tested for reaction to several diseases and insects in the same manner as they are evaluated in lowland rice breeding programs.

The planting of F_4 and lines of later generations in single or two-row plots under upland conditions in the wet season would give information on their potential yielding ability and reactions to blast, sheath blight, bacterial blight, and other prevalent pests. Testing of such lines at several locations would increase chances of finding more widely adaptable genotypes. Several plants from each line could be selected on the basis of morphological similarity and desired agronomic features to provide seed stock for planting in the next generation. Agronomic data taken from a concurrent planting of the breeding lines in lowland culture could indicate each line’s potential tillering and yielding ability.

As soon as sufficient seed are obtained, the selected lines should be extended to more locations by cooperating agronomists and experiment station staffs. Refined drought resistance studies could begin as early as the F_5 or F_6 generation. Meanwhile, the lines should be continuously tested, preferably under controlled conditions, for their reactions to various diseases and insects. Detailed evaluation for grain quality should begin at this stage. Fertilizer and cultural management experiments could begin in the F, or F_8 generation. Seed increases can be accelerated by lowland planting of purified seed stocks.

Breeders and agronomists should choose representative sites for testing during selection. Repeated testing and selection under one specific set of environmental conditions would quickly lead to the fixation of genes adapted to that set. In our selection process we have noted that the intermediate type of progenies from upland-lowland crosses tended to be tall, low tillering, and resistant to drought in upland plantings if the plants were selected in the preceding generation from an upland planting. On the other hand, progenies selected from a lowland planting with the same objectives tended to be short, high tillering. and less resistant to drought when grown under upland conditions. These results point to the importance of relating test conditions to the kind of progenies to be identified.

When we used wide crosses, such as African upland x semidwarf and Japanese upland x semidwarf, appreciable sterility appeared in many hybrid progenies. Some fertile progenies also showed sterility when we grew a seed increase plot of F_5 lines during the cool months. Moreover, in the crosses involving a semidwarf and a traditional upland variety, we often found an excess of the tall, low-tillering parental type. fewer semidwarfs than expected, and a few intermediate types. These observations suggest barriers to full genetic recombination in wide crosses. While few intermediate types were found in the initial batch of single crosses (IRRI 1973, 1974), we expect a wider range of recombinants when we use double crosses and intercrosses among hybrid progenies. Although progress has been slow in isolating the desired progenies, repeated rigorous selection among large populations would yield promising lines. As Hurd (1971) pointed out. breeding for high yield in semi-arid climates would largely require many genes to be assembled, each having a small effect. Recurrent selection may therefore prove an efficient way of obtaining the desired genotypes.

As upland culture encompasses a wide range of climatic and cultural conditions, breeding populations should be tested and selected in diverse environments to provide arrays of genetic lines adapted to different ecologic niches. The important consideration is the choice of the most suitable parents and of the test sites in relation to the environmental conditions of the production areas for which the genetic lines are intended. When the breeders use diverse parents. large breeding populations, and multi-site testing at an early stage, a wide array of genotypes may be developed that can fit into environments ranging from rainfed lowland culture to dry upland culture. The breeder should therefore fully use the genetic potential of the hybrid populations by exploring different environments during selection and testing.

Because the soil types in and around the IRRI farm at Los Baños are mostly heavy and retain soil moisture well, yields are generally higher than those of the major upland rice areas. Moreover, the rainy season also lasts longer in Los Baños than i– most major upland rice areas. Repeated selection at Los Baños among segregating generations might lead to the fixation of genotypes that are adapted to the local climatic and edaphic environment. Therefore, we have been supplying breeders in Brazil, Indonesia, Ivory Coast, and Nigeria with lines which have not been rigorously selected and purified at IRRI so that the likelihood of finding locally adaptable progenies can be enhanced. Some breeders in national programs have indicated that they preferred to receive from IRRI seeds of F_2 bulks, rather than selections from advanced generations.

Since 1967 (prior to crossing especially for upland culture at IRRI) agronomists have been testing improved varieties bred for either upland or lowland culture under upland conditions at IRRI and at other Philippine experiment stations. In most agronomy trials, the superior performance of IR5 and the line IR442-2-58 over upland varieties indicate that suitable lines for upland rice culture can be identified from lines bred for lowland rice culture (Tables 3 and 4).

IR5 and IR442-2-58, however, lack resistance to many diseases and insects; both have shallow root systems; and IR5 has poor grain quality and a rather long growth duration.

Since 1974, IRRI agronomists have tested about 500 breeding lines from the lowland nurseries under upland culture at the IRRI farm and in farmers' field at Batangas, Philippines. In the 1972 wet season, the lines were planted in two replicates, one with insect protection and the other without. The agronomic characteristics and disease reactions of 12 promising lines from such trials are summarized in Table 22. When we compare similar data obtained from the improved upland varieties of the Philippines and of Africa (Table 23), many IRRI breeding lines obviously have a greater yield potential and higher resistance to some of the diseases. From 427 breeding lines tested in the 1973 wet season, 26 promising lines were identified on the basis of growth characteristics, field reactions to blast and sheath blight, and plant reaction to iron deficiency. Several lines yielded significantly higher than

Table 22. Grain yield, growth duration, some agronomic characters and field reactions to major diseases of 12 promising lines grown with and without insecticides under upland conditions. IRRI, 1972 wet season.[a]

Experimental lines	Treatment[b]	Grain yield (g/sq m)	Growth duration (days)	Plant ht (cm)	Tillers (no./sq m)	Dry wt (g/sq m)	Lodging	Reaction to BLS	BB	GS	B
IR1721 11-6	[illegible]	259	[illegible]	84	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	R
	[illegible]	680	121	87	[illegible]	[illegible]					
IR1480-14-147-3	w/o	158	127	69	451	300		S	S	S	R
	w	629	122	72	344	291					
IR1537-347-3	[illegible]	191	128	76	323	279		[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	597	122	93	298	304	×				
IR788-21-3	w/o	203	120	71	302	303		MS	MS	R	MS
	w	581	117	82	336	352					
IR1529-219-3	w/o	134	123	78	323	308		MR	MS	MR	MR
	w	581	117	85	317	363	x				
IR1531-24-3	w/o	136	117	95	306	282		MS	MR	MR	MR
	w	568	117	101	289	407	x				
IR790-28-1	w/o	161	161	63	319	230		MR	S	MR	MR
	w	548	548	84	289	392					
IR1529-394-1	w/o	117	130	78	489	341		MS	MS	S	R
	w	534	124	84	306	321					

(Continued on next page)

(Table 22 *continued*)

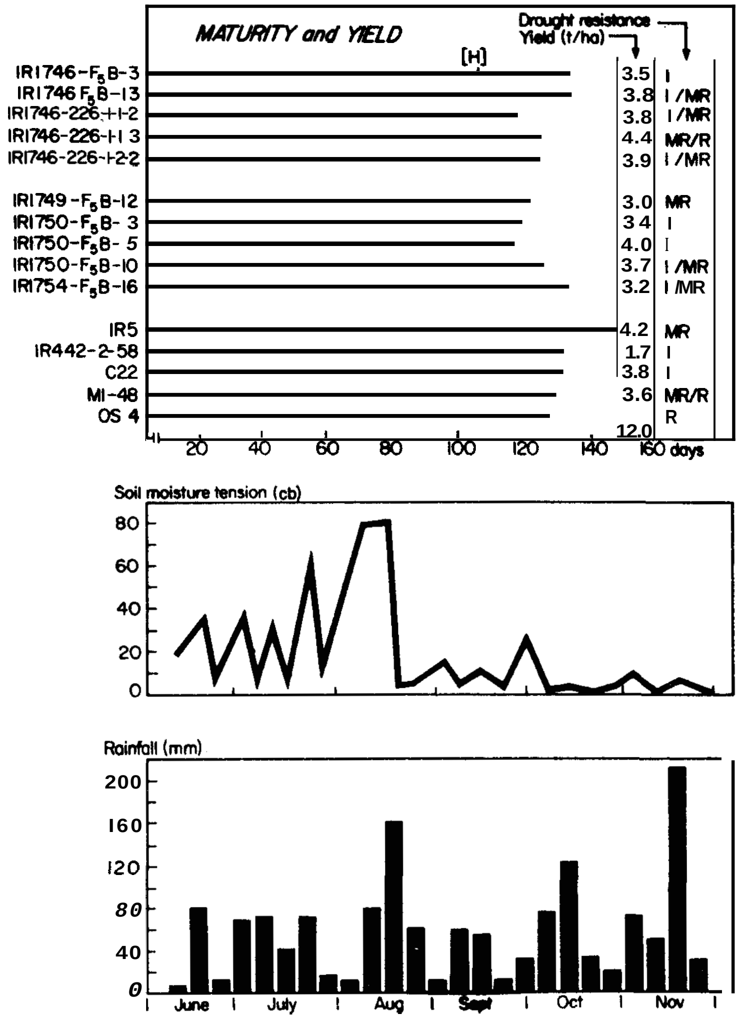
Experiment[a] lines	Treatment[b]	Grain yield (g/sq m)	Growth duration (days)	Plant ht (cm)	Tillers (no./sq m)	Dry wt (g/sq m)	Lodging	Reaction to			
								BLS	BB	GS	B
IR1480-116-3	w/o	70	134	76	417	356		MS	–	S	MR
	w	520	520	84	242	256					
IR1721-11-13	w/o	228	122	78	268	255		S	S	R	R
	w	515	122	83	289	302	x				
IR1537-190-3	w/o	70	130	72	400	274		MR	–	S	MR
	w	515	122	85	349	380	x				
IR1355-3-2	w/o	54	139	82	293	242		MR	MR	MR	MR
	w	512	124	87	304	336					

[a]Source: Unpublished M.S. thesis, F. G. Faye. [b]w/o = without insecticide; w = with insecticide.

Table 23. Grain yield, growth duration, some agronomic characters and field reactions to major diseases of some recommended upland varieties from the Philippines and one variety from Africa, grown with and without insecticides under upland conditions. IRRI, 1972 wet season.[a]

Variety	Treatment[b]	Grain yield[c] (g/sq m)	Growth duration (days)	Plant ht (cm)	Tillers (no./sq m)	Dry wt (g/sq m)	Lodging	Reaction to BLS	BB	GS	B
OS 6[c]	w/o	163	117	105	183	275	x	MS	S	S	MR
	w	458[d]	112	114	157	445	x				
Dinalaga	w/o	76	120	122	315	305	x	MS	HS	HS	R
	w	440	117	131	204	404	x				
M1-48	w/o	95	120	125	176	206	x	MR	S	S	R
	w	397	117	138	130	363	x				
Azucena	w/o	116	117	125	119	123	x	S	S	MR	MR
	w	386	117	130	159	303	x				
C-22	w/o	110	134	114	240	322	x	S	S	MR	MS
	w	368	136	115	261	386	x				
E425[c]	w/o	174	117	113	259	208	x	MS	S	S	R
	w	349	115	125	149	404	x				
OS 4[c]	w/o	121	117	110	230	184	x	S	HS	HS	MR
	w	334	115	117	247	285	x				
Palawan	w/o	125	120	121	174	157	x	S	HS	HS	MR
	w	312	117	126	140	322	x				
Azmil 26	w/o	83	120	114	110	118	x	S	S	S	MS
	w	265	117	120	87	277	x				

[a]Source: Unpublished M.S. thesis, F.G. Faye. [b]w/o = without insecticide; w = with insecticide. [c]Upland varieties from Africa, the others are from the Philippines. [d]Grain yield of one replication.



7. Several F_7 lines selected in upland fields have yielded well. Santo Tomas, Batangas, Philippines, 1973 wet season.

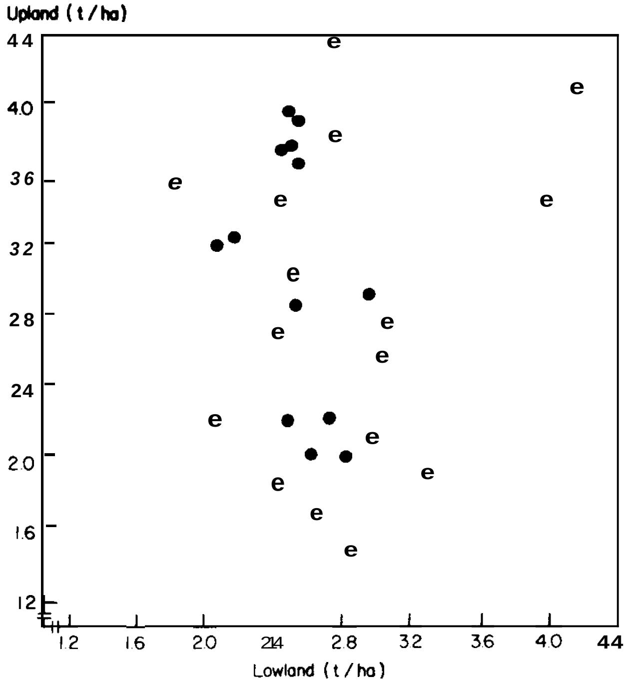
IK5 (IRRI 1974). These 26 lines, along with eight promising lines bred from upland x lowland crosses, will be entered in yield trials to be conducted in the Philippines, Bangladesh, Brazil, Indonesia, Liberia, and Nigeria during 1974. The testing of such lines which already have adequate levels of insect and disease resistance would save time in identifying strains having promise under upland culture over a wide range of environments.

Yield levels for the above IRRI semidwarf lines in experiment stations outside Los Baños were quite exciting (IRRI 1973, 1974). The performance of such lines on one seeding date at a given location, however, needs to be closely examined in relation to prevailing rainfall distribution, disease and insect incidence, soil type of the test site, and the soil fertility level involved, so that rice researchers may gain some insight into the ecological system at the test site. In choosing more appropriate crosses or lines for the site and in interpreting long-range yield data from the site or from neighboring farms, varietal performance should be analyzed on the basis of prevailing ecological conditions. The inclusion of a constant check variety or varieties over a number of sites and years would provide a useful reference point in interpreting varietal performance at the site and over a number of sites.

In our field screening, resistant or moderately resistant progenies were only found in those crosses that involved at least one resistant parent, usually a traditional upland variety.

So far, much of the varietal improvement phase of upland rice follows an empirical approach of identifying and evaluating desirable genotypes by rigorous testing and selection under upland conditions. Progress in breeding for improved upland rice could be greatly accelerated by concurrent physiological and genetic research on the mechanisms of drought resistance and other related subjects. Maximum progress in breeding often results from exploring genotype-environment interactions.

To increase seed production per plant for concurrent tests to various diseases and insects, the selection of F_2 plants in lowland fields has been suggested as an alternate approach to continuous selection in upland fields. While this scheme has its merit in accelerating the multi-pest testing program, we have found that distinct segregation for adaptation in an upland culture showed up more clearly when the F_2 populations of upland x lowland crosses were planted in aerobic soils. Through repeated cycles of selection in upland fields, we have identified several F_7 lines which yielded about 4 t/ha at Santo Tomas, Batangas, Philippines, during the 1973 wet season. For these lines the panicle development took place during a 2-week period of low rainfall when the soil moisture tension stayed at around 80 cb at a soil depth of 20 cm (fig. 7). Their yield levels were similar to those of the two higher tillering



8. Relationship between grain yields (kg/ha) of 29 varieties and lines obtained from an upland experiment in Santo Tomas, Batangas, Philippines, and a lowland experiment at IRRI, **1973** wet season. The simple correlation coefficients was non-significant.

and later maturing varieties, C22 and IR5, and exceeded those of the traditional varieties OS4 and M 1-48. The panicle development of C22 and IK5 largely took place after the drought period. On the other hand. the grain yields of the same group of 26 F, lines, along with those of three check varieties obtained from lowland and upland yield trials. failed to show a positive association (fig. 8). This points out the need to evaluate genetic materials intended for upland culture in upland fields. But if drought resistance or tolerance to adverse soil factors were not the primary breeding objective, or when drought resistance is already present in the genetic background of the parents, the alternate scheme of selecting F_2 plants in a lowland field. followed by testing in upland fields, may have advantages.

While much remains to be learned about refined breeding techniques and attainable potentials in improving upland rice through large-scale hybridization and testing. one prospect appears certain:

that upland rice breeding will call for a broader and greater scope of interdisciplinary and international cooperation than the usual level required in other plant breeding programs. The need for intensified collaboration across the disciplinary, institutional, and national levels at the initial stage is prescribed by the diverse climatic, edaphic, and cultural conditions under which upland rice is grown.

chapter **five**

CULTURAL PRACTICES FOR UPLAND RICE

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Cultural practices for upland rice

Surajit K. De Datta and Vernon E. Ross

The yields of upland rice are generally lower than those of flooded rice (De Datta and Beachell 1972) because of many factors: scarcity of suitable varieties; irregular rainfall distribution; difficulty of weed control; scant knowledge of proper fertilizer application; and poor control of insects. Cultural practices for upland rice have been studied far less than have cultural practices for lowland rice. In this chapter, we have summarized the cultural practices for upland rice and available research data on each of these practices.

LAND PREPARATION

Current practices. In most of Asia, little mechanization is used to prepare land for planting. As soon as enough rain has fallen to permit initial land preparation, the field is plowed with an animal-drawn implement, then harrowed with a comb harrow[1] to prepare a good seedbed and to firm up the soil Sometimes the weed seeds are allowed to germinate for a week, and then the field is harrowed for the final time, destroying all germinated seeds.

In Thailand, slightly elevated areas are plowed by water buffalo and cattle, and then hoed. On hills, the soil is hardly cultivated.

Indonesian farmers generally prepare the land with animal-drawn plows during June thru August. Indian farmers simply turn the soil over with country plows and pulverize it no more than 10 cm deep.

About 98 percent of the rice land in Africa is prepared manually because draft cattle are scarce, most being susceptible to the trypanosome disease (Food and Agriculture Organization Inventory Mission 1970).

Land preparation methods vary greatly from country to coun-

[1] Known as *suyod* in the Philippines.

try in Latin America. In the shifting cultivation areas of Peru, for example, mature secondary forests are cut and burned during the drier months from July to September. Upland rice is then seeded by dibbling without further land preparation (Sanchez 1972). Shifting cultivation in Peru is quite similar to the slashand-burn methods that precede planting in Malaysia, Burma, or Thailand.

On the other hand, upland rice fields are prepared with tractor-driven equipment in some parts of Sao Paulo district, Brazil.

Research data. Researchers and workers have speculated on the possible effectiveness of minimum tillage, using herbicides for weed control, in upland rice production (Evans 1964; Hood *et al.* 1964; Shear 1965). Woodford and Evans (1963) reported that contact pre-emergence weed killers, such as pentachlorophenol at 3.3 to 4.4 kg a.i./ha may be used for a variety of crops. To be successful, however, the cultivator should use the "delayed seed-bed" techique, where the seedbed is prepared from 7 to 10 days before seeding, and the soil is disturbed as little as possible during seeding. This techique encourages the weeds to germinate before the crops are planted. The herbicide may be sprayed within 2 days before or after sowing (pre-sowing application is preferable if enough weeds have germinated by that time).

The stale seedbed technique with non-selective herbicides was studied at IRRI as early as 1964 (IRRI [Undated] *c*). In one experiment, the land was rotovated in the dry season to clean and pulverize the seedbed. After the rains began and grassy weeds reached 3 to 4 inches tall, 7.5 kg PCP (pentachlorophenol)/ha was sprayed as an oil emulsion, completely killing the weeds.

During the 1965 wet season, rice was drilled in a weedy field at IRRI on the 18th day after rotovation. Then 4 kg each of PCP in diesel oil, and PCP as an oil-water emulsion, were sprayed per hectare in upland rice fields. Yields were satisfactory with both sprays (IRRI 1966).

Akhanda (1966) reported that increasing the volume of a spray of PCP-oil-water emulsion reduced weed weights and, thereby, increased grain yields.

These research data indicate that the stale seedbed technique and non-selective herbicides will reduce both weed growth and conventional land preparation. But wide-scale adoption cannot be recommended until either the productivity of upland rice is significantly raised. or a need arises to save labor or animal power.

SOWING METHODS, SEED RATE, AND ROW SPACING

Current practice. In most of the Philippines, an animal-drawn wooden plow[2] is used to open furrows. Dry seeds are then broadcast. An implement[3] is then used to divert the seeds into rows and to cover them.

In most of India, seeds are broadcast on either dry or moist soil in roughly prepared fields. In Indonesia, seeds are broadcast on dry soils soon after the rainy season begins.

In the shifting cultivation areas of Asia, the land is cleared by the "slash and burn" method, then seeds are dibbled into the soil.

In West Africa, rice is sown by broadcasting or dibbling. On the 40 percent of the upland area with annual rainfall of less than 1,500 mm, seeds are dibbled into rows made with a pointed stick or a narrow bladed hoe. On the 60 percent that has more than 1,500 mm annual rainfall, seeds are broadcast in dry soil (Food and Agriculture Organization Inventory Mission 1970).

Seeding methods vary greatly among Latin American countries. In Peru, eight to 10 rice seeds are normally planted in holes dug with a pointed stick[4] at irregularly wide spacings, about 50 x 50 cm. The seeds are not covered with soil. Sanchez (1972) considers this system of seeding inefficient because the rice competes poorly with weeds and ripens unevenly.

In parts of Brazil, seeds are drilled with a tractor-driven seed drill, at spacing as wide as 60 cm.

Upland rice in Latin America, whether grown under shifting or under semi-mechanized cultivation, is generally spaced widely to discourage the spread of blast disease and to help the crops tolerate drought.

Research data. Methods of planting, row spacing, and seeding rates of upland rice have seldom been studied, although these important factors affect plant competition for light, water, nutrients, and space.

At IRRI in a factorial experiment, IR8 was tested at two seeding rates, three methods of seeding, and three row spacings (IRRI 1967*b*; De Datta *et al.* 1974*a*). The mean yield of the broadcast-

[2]Called a *lithao.*
[3]Called a *kalmut.*
[4]Called a *tacarpo.*

Table 1. Effect of seeding rate, row spacing, and planting method on the grain yield of IR8 under upland conditions. IRRI, 1967 wet season.[a]

Spacing (cm)	Grain yield (t/ha)[b] Seeding rate (kg/ha) 80	160	Mean
15, single row	5.8	5.4	5.6
30, single row	5.6	5.2	5.4
45, single row	4.2	4.4	4.3
Avg	5.2	5.0	5.1
30-15, double row[c]	5.0	5.1	5.0
45-15, double row	4.4	4.4	4.4
60-15, double row	4.0	4.1	4.0
Avg	4.5	4.5	4.5
20-10, band[d]	5.7	5.0	5.3
35-10, band	4.9	4.0	4.4
50-10, band	3.4	4.0	3.7
Avg	4.7	4.3	4.5
Broadcast (control)			
	5.5	5.5	5.5
Mean (seeding rate)			
	4.8	4.7	4.8

[a]Source: De Datta *et al.* 1974*a*. (LSD = 0.23 t/ha; CV = 10%). [b]Avg of four replications. [c]Paired row, with 15-cm distance between a pair of sows. [d]Width of band was maintained at 10 cm.

seeded plots was significantly higher than the mean of all other methods of planting. The highest grain yield, 5.8 t/ha, was obtained at a seeding rate of 80 kg/ha in single rows spaced 15 cm apart. This did not differ significantly, however, from the yield of the 30-cm row spacing (Table 1).

In another IRRI experiment, IR8 seeds were drilled at 15-cm row spacings with a linkage seeder mounted on a tractor. Seeding

Table 2. Effect of seeding rate on the grain yield of IR8 grown under upland conditions. IRRI. 1967 wet season.[a]

Seeding rate[b] (kg/ha)	Grain yield[c] (t/ha)
25	5.1 a
50	5.1 a
75	5.3 a
100	4.8 ab
125	4.7 bc
150	4.7 bc

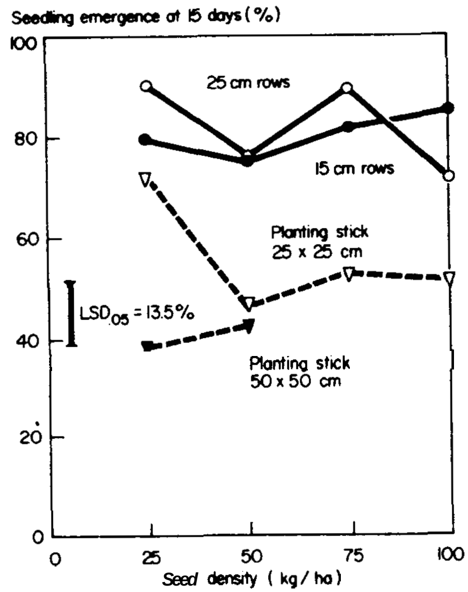
[a]Source: De Datta *et al.* 1974*a*. [b]Drilled at 15-cm row spacing. [c]Avg of four replications. Any two means followed by the same letter are not significantly different at the 5% level.

rates varied from 25 to 150 kg/ha at 25-kg increments. A total of 90 kg N/ha was applied in three equal doses: during planting, at the maximum tillering stage, and at panicle initiation. The highest grain yield, 5.3 t/ha, was obtained at a seeding rate of 75 kg/ha. Grain yields were significantly lower at seeding rates of 125 and 150 kg/ha than at lower rates of from 25 to 75 kg/ha (Table 2) (IRRI 1967*b*; De Datta *et al.* 1974*a*).

Experiments in Sarawak, Malaysia, and in Peru indicate that closer spacing is highly desirable for upland rice production under shifting cultivation. In Sarawak, spacings of 31 and 38 cm were compared in 18 experiments. Closer row spacing increased grain yields highly significantly in four experiments, and significantly in two experiments. Yields were increased (but not significantly) in four experiments. In other treatments, wider spacing increased the yields significantly. Row spacing did not affect grain yields in seven experiments (Dunsmore 1970).

Rows are usually spaced wider than the 38-cm maximum in these experiments. Closer spacings were recommended in Sarawak because tiller and panicle numbers and panicle weights were lower when rows were spaced widely (Dunsmore 1970).

In Peruvian studies, seeds were closely planted at 25- x 25-cm row spacings, at seeding densities of 17.5, 35, and 70 kg/ha (Sanchez 1972). The grain yields were significantly higher than those obtained by conventional practices (*tacarpo* system). The highest



1. Percent seedling emergence of IR8 planted under upland conditions by the drilled-row and the open–hole ("tacarpo") systems (Sanchez 1972).

grain yields were obtained with the modified *tacarpo*[5] system (5.7 t/ha) and with row seeding (5.9 t/ha). Closer spacing increased yields by an average of 1.7 t/ha – 40 percent over the check plot.

In another Peruvian experiment, scientists compared two spacings of drilled rows 15 and 25 cm apart. They also compared *tacarpo* plantings at 25 x 25 cm and at seed densities of 25, 50, 75, and 100 kg/ha with the conventional *tacarpo* spacing and seed densities used by Amazon Basin farmers. 50- x 50-cm spacings at 25 and 50 kg/ha seeding rates (20 and 40 seeds/hole).

Germination rates and percentages of seedlings established were significantly higher in the drilled row system than in the *tacarpo* holes (fig. 1). In the drilled rows. the lowest seed density produced lower yields than did the higher seed density.

The modified *facarpo* system (25- x 25-cm spacings) produced yields similar to those from row-seeded crops. The conventional

’Pointed stick.

tacarpo system with rows spaced 50 x 50 cm produced 1 t/ha less than did the same system planted with rows spaced 25 x 25 cm. Despite the higher incidence of blast, the closely spaced plots produced higher yields than did the widely spaced plots.

From these experiments, Sanchez (1972) suggested that planting upland rice at closer spacings would raise production in areas under shifting cultivation where land cannot be adequately prepared.

DATE OF PLANTING

Current practice. Upland rice farmers have learned through experience to plant early in areas where rainfall distribution is modal and the rainy season lasts about 4 months. Rice farmers in Batangas, Philippines, plant early maturing varieties in late April and harvest the crop by the end of September, which leaves 3 months to grow cash crops such as onion, garlic, vegetables, and sweet corn.

Research results. Several experiments have shown that upland rice gives the highest grain yields and the best nitrogen response when planted shortly after the first monsoon shower (Jana and De Datta 1971; De Datta and Beachell 1972; De Datta *et al.* 1974*a*).

Results from current experiments in farmers' fields in Batangas, Philippines, again confirmed that early seeding of upland rice helps the crop avoid drought (fig. 2).

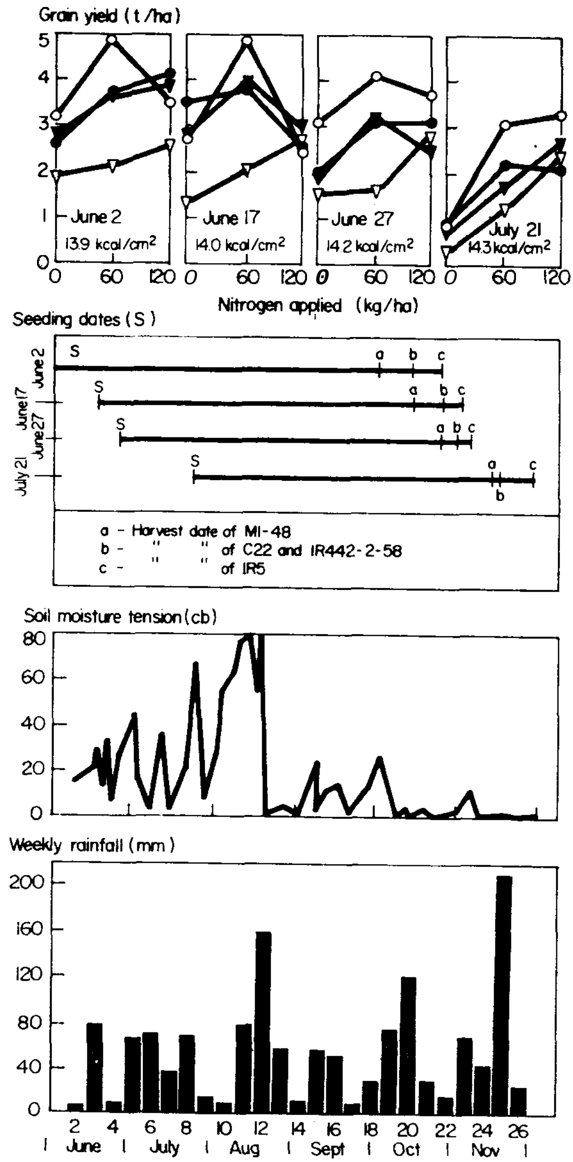
We found that IR5, MI-48, and C22 lodged when more than 60 kg N/ha was applied. The line IR442-2-58 suffered from severe blast injury and yielded lower than did the other rices (fig. 2).

Early maturing rices with high disease and insect resistance and high yield potential could, if developed, raise the potential of upland rice production.

FERTILIZATION

Current practices. Many subsistence farmers who grow upland rice do not generally apply fertilizer, even though most upland rice areas are seriously deficient in nitrogen. Most upland rices do not respond well to nitrogen, and nitrogen fertilization increases susceptibility to blast and lodging. However, many farmers in Batangas, Philippines, apply between 60 and 90 kg N/ha to traditional upland rice varieties and get about 3 tons of rice.

The response of an upland rice to phosphorus generally depends on the soil. Many acid soils are deficient in phosphorus. Iron



2. Nitrogen response of four varieties grown under upland conditions at four dates of seeding with solar radiation total for reproductive and ripening period and rainfall **and** soil moisture tension in the experimental site in relation to stage of crop growth. **Farmer's field,** Santo Tomas, Batangas, 1973 wet season. (Source: **S.K.** De Datta and **J.A.** Malabuyoc 1974, ***unpublished).***

deficiency, or iron chlorosis, is common in many reclaimed soils and calcareous soils. Spraying with iron or iron chelate may correct iron deficiency, but it is expensive and the yield increase may not justify its use. Varieties grown in those areas should be tolerant of iron deficiency.

Although upland rice is not commonly fertilized in many tropical Asian countries, we know that fertilizer application can increase grain yields. Recommendations are available to farmers who wish to apply fertilizer in some countries, such as Thailand, where the use of 60 to 80 kg of compound fertilizer (16-20-0) per hectare has been suggested to obtain grain yields of 2 to 3 t/ha.

The fertilizer rate recommended for upland rice in India is 40 kg each of P_2O_5 and K_2O per hectare applied as a basal dressing. Nitrogen application is delayed until the seeds have fully germinated. The first two applications (20 kg each of P_2O_5 and K_2O/ha) are made at 20 to 25 and at 40 to 45 days after seeding. A final topdressing of **40** kg N/ha at 70 to **75** days after seeding has been suggested.

Similarly, in the Philippines, the suggested treatment is 90 kg N/ha applied in equal split doses at 10, 35, and 65 days after seeding and 60 kg each of phosphorus and potassium per hectare incorporated during the last harrowing.

In Japan, upland rice farms are fertilized with compost, barnyard manure, ammonium sulfate, “night soil,” grass ashes, etc. Compost and barnyard manure are usually applied at 5.6 to 7.5 t/ha as a basal fertilizer (De Datta 1970).

Fertilizer use on upland rice is limited in West Africa and Latin America.

In northern Brazil, including Maranhao and Para states, rice is grown with corn, beans, squash, banana, and cassava as a part of the shifting cultivation. The best yields have been obtained at Siete Lagoas with 91-50-25 kg/ha of NPK. In Goiania, however, only **30** kg N/ha and 24 kg P_2O_5/ha were adequate; potassium depressed the yields (de Souza 1973).

Research results. Much has been published about the fertilization of upland rice. Many of the experiments concern two factors which contribute to the varietal differences in grain yield under upland conditions: the rate and time of nitrogen application.

In a 1967 wet-season experiment at IRRI on the time of nitrogen application, Palawan, a tall “standard” upland variety from the Philippines, and IR8 and IR5, both fertilizer-responsive semidwarfs, were subjected to 19 treatments. Nitrogen was applied in various splits at 0, 60, and 120 kg/ha. IR5, treated with 60 kg N/ha applied in two equal split doses (during panicle initiation and booting stages) gave the highest yield reported to that date in any replicated upland rice experiment in the world, 6.2 t/ha (Table **3)** (De Datta 1970). The highest yield for the lodging-susceptible Palawan was **4.6** t/ha, grown with 60 kg N/ha applied in three equal split doses at maximum tillering, panicle initiation, and booting stages (Table **3).** These high yields were obtained in fertile Maahas clay soil (mean yield for the three varieties with 0 N was **3.3** t/ha). On infertile soils, high yields may require more than 60 kg/ha N (De Datta 1970). In farmers' fields in Bulacan and Nueva Ecija, Philippines, the yield response to nitrogen for IR5 was greatest at 90 kg/ha (Table **4).**

In Peru, local lodging-susceptible varieties did not respond to nitrogen. The improved line IR4-2 responded positively to nitre gen with higher yields up to 60 kg N/ha; the economic optimum, however, was about **30** kg/ha (Sanchez 1972). Other varieties, such as IR8 and IR5, responded erratically. Grain yields ranging from 5 to 7.5 t/ha have been reported for some semidwarf varieties, such as IR8, at high rates of 90 to 180 kg N/ha in upland conditions in Costa Rica and Peru (Cordero 1970; Kawano *et **al.*** 1972; Cordero and Romero 1972). The high upland yields were attributed to the use of varieties that have high tillering capacities, short stature, and high resistance to lodging (Sanchez 1971).

Research on the sources of nitrogen for upland rice has been limited. Scientists at IRRI and in Brazil compared sulfur-coated urea (slow-release), standard urea, and ammonium sulfate fertilizers for upland rice. Slow-release fertilizer showed no clear advantage over standard fertilizer.

Research data on the response of upland rice to phosphorus or potassium have not been reported as frequently as data on its response to nitrogen. In two out of four upland experiments conducted in farmers' fields in Bulacan and Nueva Ecija, Philippines, IR5 yields were more than 1 t/ha higher with 30 to 60 kg P_2O_5/ha (Table *5).* Dunsmore (1970) found that all replications of experiments over four seasons in Sarawak, Malaysia responded positively to 62 kg P_2O_5/ha. Interestingly, while nitrogen alone did not increase yields significantly, nitrogen combined with phosphorus did increase grain yields. Potassium increased grain yield significantly on three of 18 sites.

On the other hand, some reports indicate that potassium fer-

Table 3. Effect of varietal type and time of nitrogen application on the grain yield of upland rice. IRRI, 1967 wet season.[a]

Nitrogen applied (kg/ha)					Grain yield (t/ha)			Mean (treatment)
Planting	Maximum tillering	Panicle initiation	Booting	Heading	IR8	Palawan	IR5	
0	0	0	0	0	3.4	2.6	3.9	3.3
60	0	0	0	0	4.2	2.9	5.3	4.2
0	30	30	0	0	5.1	3.6	5.5	4.7
0	0	30	30	0	4.8	3.6	6.2	4.9
0	0	0	30	30	3.9	3.0	4.4	3.8
0	20	20	20	0	4.8	4.6	5.1	4.8
0	0	20	20	20	4.8	4.0	5.8	4.8
0	20	20	0	20	5.0	3.0	5.8	4.9
0	15	15	15	15	4.6	3.4	5.6	4.5
12	12	12	12	12	4.9	3.8	5.1	4.6
120	0	0	0	0	4.0	2.5	4.2	3.6
0	60	60	0	0	5.2	2.1	3.8	3.7
0	0	60	60	0	4.5	4.5	5.9	5.0
0	0	0	60	60	3.4	2.9	4.7	3.7
0	40	40	40	0	4.6	3.0	5.1	4.2
0	0	40	40	40	4.7	3.9	5.7	4.8

(Continued on next page)

(Table 3 *continued*)

Nitrogen applied (kg/ha)					Grain yield (t/ha)			Mean (treatment)
Planting	Maximum tillering	Panicle initiation	Booting	Heading	IR8	Palawan	IR5	
0	40	40	0	40	4.7	3.1	5.3	4.4
0	30	30	30	30	5.7	3.2	6.1	5.0
24	24	24	24	24	4.9	3.2	5.2	4.4
						Mean		
					4.6	3.3	5.2	

[a]Source: De Datta 1970. LSD = 0.84 t/ha. CV = 12%. LSD = 0.84 t/ha. CV = 12%..

Table 4. Nitrogen response of two varieties under upland conditions in four locations, Bulacan and Nueva Ecija, Philippines, 1971 wet season.[a]

Nitrogen applied (kg/ha)	Grain yield (t/ha)				
	Experiment no.				Mean
	1	2	3	4	
			IR8		
0	1.2	1.4	0.8	[b]	1.1
30[c]	1.7	2.1	1.2	0.7	1.4
60[d]	2.7	2.8	2.5	1.6	2.4
90[e]	3.3	3.4	2.6	2.2	2.9
120[f]	3.6	3.4	2.7	2.0	2.9
			IR5		
0	0.7	1.1	0.9	1.4	0.8
30	1.6	2.2	2.0	0.6	1.6
60	2.4	2.2	2.5	1.4	2.1
90	2.5	2.6	3.4	2.2	2.7
120	2.6	3.0	3.9	2.4	3.0

[a]Source: IRRI 1972. [b]Less than 0.1 t/ha. [c]Applied 10 days after seeding (DAS). [d]30 kg/ha N applied 10 DAS, 15 kg/ha N applied 35 DAS and 65 DAS. [e]30 kg/ha N applied 10, 35, and 65 DAS. [f]40 kg/ha N applied 10, 35, and 65 DAS.

tilization negatively affects upland rice. Grain yields were significantly lower when potassium was applied in experiments in Nsukka, Nigeria (Enyi 1964). Nitrogen response was substantial, however, in the same trial. De Souza (1973) reported a positive response to nitrogen and to nitrogen and phosphorus combined in the acid latosols of Goias, Brazil. But nitrogen and potassium combined responded negatively. Phosphorus response was highly significant.

Response to zinc is not common in upland rice. De Souza (1973) in Brazil, however, corrected zinc deficiency on soils with a pH slightly below 7.0 by placing 5 kg zinc sulfate/ha in the rows at planting. Zinc deficiency symptoms were visible when the zinc content in plants was less than 15 ppm (dry weight basis).

Table 5. Phosphorus response of direct-seeded IR5 with 90 kg/ha N and 60 kg/ha K_2O under upland conditions. Bulacan and Nueva Ecija, Philippines, 1972 wet season.[a]

Phosphorus applied (kg/ha)	Grain yield (t/ha)				
	Location				Mean
	1	2	3	4	
0	2.2	1.6	3.9	1.9	2.4
30	3.2	1.1	4.1	3.7	3.0
60	3.6	2.5	4.4	2.6	3.3

[a]Source: IRRI 1973.

Iron is the most important minor element needed by upland rice grown on neutral or alkaline soils. Iron deficiency occurs wherever upland rice is grown. It is difficult to ascertain how much iron deficiency reduces yields.

We recently observed rice varieties grown under upland conditions in the greenhouses, in IRRI fields, and in farmers' fields in Batangas, Philippines. We found iron deficiency symptoms to be common even in some acid soils, particularly when heavy rains were followed by periods of drought. Varieties differ distinctly. however, in susceptibility to iron deficiency.[6]

Compost is commonly used in upland rice in Japan. In a compilation of more than 1,000 experiments. compost increased yields of upland rice by 20 percent; compost increased yields of lowland rice only 1 or 2 percent (Nagai 1958). This may be partly because compost increases the availability of phosphorus, iron, and silicon.

WEED CONTROL

Current practice. Poor weed control is second only to inadequate supplies of water as major barriers to higher upland rice production (De Datta and Beachell 1972; De Datta 1972). The most common weed control method, hand weeding, is very time consuming. A single hand weeding requires about 300 man-hours labor/ha;

[6]See "Varietal Resistance To Adverse Chemical Environments," p. 136.

often, several such hand weedings are necessary to keep upland rice fields free of weeds.

In regions where upland. rice is grown in West Africa, weeding is an important operation. African farmers often build heaps and ridges of soil in upland fields. The ridges are later levelled and destroyed, not only killing the weeds on the ridges, but also burying the weeds growing at the bases of the ridges. Intercropping is another indirect method of weed control.

The most common and, perhaps, the most effective way to control weeds in Africa, however, **is** pulling them by hand or destroying them with a short-handled hoe (the same hoe used for land preparation) (Food and Agriculture Organization Inventory Mission 1970).

On a commercial upland rice farm in Sao Paulo district, Brazil, rice was planted in rows spaced 40 to 50 cm apart; weeds grew vigorously between the rows. About 1,200 man-hours of labor/ha were required to weed once by hand (De Datta ***et al.*** 1974*a*).

The number of hand weedings necessary for weed control indicates that chemical control will probably be an essential operation for successful production of upland rice (De Datta 1972).

In slash-and-burn areas of Peru, manual weeding is sometimes supplemented with sprays of the herbicide 2,4-D, both to control broadleaved weeds and to prevent the regrowth of fallen tress (Sanchez 1972). The herbicide propanil (3', 4'-dichloropropionanilide) is used extensively in Latin America (Smith and Shaw 1966).

Research **results.** Experiments were conducted at IRRI during the 1970 wet season to identify herbicides that would control weeds in IR8 grown as upland rice under monsoon conditions.

The major weed species in the experimental area were: grasses such as ***Echinochloa colona, Digitaria sanguinalis,*** and ***Eleusine indica;*** sedges such as ***Cyperus iria;*** and broadleaved weeds such as ***Ipomea triloba.*** The natural weed population was so heavy that no grain was produced in the untreated control (Table 6). The chemicals butachlor, benthiocarb, and fluorodifen were most effective when sprayed, before the weeds and rice germinated.

IRRI's Office of Rice Production Training, and Research compared four of the promising herbicides from this trial with hand weeding under upland field conditions in Bulacan, Philippines, during the 1971 wet season. Large populations of grasses, broad-

Table 6. Promising liquid herbicides for weed control in upland rice (variety IR8). IRRI. 1970 wet season.[a]

Treatment	Application		Visual rating[b]		Grain yield[c] (t/ha)
	Rate (kg a.i./ha)	Time (days after rice emergence)	Weed control	Crop toxicity	
Butachlor	2	0	5	1	3.2 a
Benthiocarb	2	0	3	1	2.4 ab
NTN 5006	2	0	5	1	2.3 ab
Fluorodifen	4	0	2.5	1.5	1.3 b
Propanil[d]	3	15	1	1.5	0 c
Propanil[e]	3	15	1	1	0 c
Hand weeding twice[f]	–	–	5	1	2.6 ab
Untreated control	–	–	1	1	0 c

[a]Source: Adapted from IRRI 1971. [b]At 52 days after emergence of rice. Control rated on a scale of: 1 = no control, 5 = complete control. Toxicity rated on a scale of: 1 = no toxicity, 5 = complete kill. [c]Avg of two replications. Any two means followed by the same letter are not significantly different at the 5% level. [d]From Monsanto Chemical. [e]From Rohm and Haas. [f]At 15 and 30 days after emergence of rice.

Table 7. Effects of different weed control treatments on grain yield of IR8 under upland conditions in farmers' field trials. Average of six locations, Bulacan and Nueva Ecija, Philippines. 1971 wet season.[a]

Treatment	Rate (kg a.i./ha)	Grain yield (t/ha)
NTN 5006	2	2.2
Butachlor	2	2.3
Benthiocarb	2	2.2
Fluorodifen	2	2.4
Hand weeding (twice)	–	2.4
Untreated control	–	1.4

[a]Source: V. E. Ross and I. C. Bolo 1971 *unpublished.* LSD = 0.3.

leaved weeds, and sedges were present in the six farmers' fields selected for the trials. All four herbicides were as effective as hand weeding in farmers' fields; all of the treated plots yielded significantly higher than did the untreated control (Table 7).

Under simulated upland conditions at IRRI during the 1972 dry season, several new chemicals, such as USB 3153 and dinitramine, and U-27,267[8] seemed highly promising (Table 8).

During the 1972 wet season seven chemicals were compared with hand weeding in a farmer's upland rice field in Batangas, Philippines. The treatments were replicated four times, with IR5 as the test variety. The major weed species present in the experimental site were grasses such as *Echinochloa colona. Eleusine indica, Digitaria sanguinalis,* and *Dactyloctenium aegyptium;* broadleaved weeds such as *Ipomea triloba, Portulaca oleracea, Commelina benghalensis, Eclipta alba,* and *Vernonia cinerea;* and sedges such as *Cyperus rotundus* and *Cyperus iria.* The weed infestation was so heavy that the untreated control yielded only 1 t/ha (Table 9).

All treated plots yielded significantly higher than did the untreated control. The highest grain yields, 4.9 t/ha, were from the plots weeded twice by hand and from those treated with a com-

[7]A product of U.S. Borax Co., U.S.A.
[8]A product of Upjohn Pharmaceutical Co., U.S.A.

binafion herbicide, C-288 [(S-(2-methyl-1-piperidylcarbonylmethyl)-0, 0-di-n-propyl dithiophosphate (C-19490) and 2-(1',2'-

Table 8. Promising liquid herbicides for rice (rice line: IR442-2-58) grown under simulated upland conditions. IRRI, 1972 dry season.[a]

Treatment	Application		Grain yield[c] (t/ha)
	Rate (kg a.i./ha)	Time[b]	
Fluorodifen	3	3 DAS	2.7[d]
Butachlor	2	3 DAS	4.1
USB 3153	1	3 DAS	4.8
Dinitramine	1	3 DAS	4.5[d]
U-27, 267	2	3 DAS	3.8
Propanil	3	15 DARE	4.5[d]
Hand weeding (twice)	–	15 & 30 DARE	3.8
Untreated control	–	–	0.4

[a]Source: IRRI 1973. [b]DAS = days after seeding, DARE = days after rice emergence. [c]Avg of two replications. [d]Yields from one replication only.

Table 9. Promising liquid herbicides for upland rice (variety IR5), farmers' field, Batangas, Philippines. 1972 wet Season.[a]

Herbicide	Rate (kg a.i./ha)	Time	Grain yield[b] (t/ha)
Benthiocarb	2.0	6 DAS	4.4 abc
Butachlor	2.0	6 DAS	3.5 abc
C-288	2.0	6 DAS	4.9 a
Fluorodifen	2.0	6 DAS	3.1 bc
Fluorodifen	3.0	6 DAS	4.7 ab
A-820	2.0	6 DAS	4.6 ab
U-27, 267	2.0	6 DAS	2.8 c
USB 3153	2.0	6 DAS	4.2 abc
Hand weeding (twice)	–	20 & 40 DARE	4.9 a
Untreated control	–	–	1.0 d

[a]Source: S. K. De Datta and P. C. Bernasor 1974, *unpublished*. [b]Any two means followed by at least one common letter are not significantly different at the 5% level.

Table 10. Promising liquid herbicides for upland rice (rice line: IR442-2-58). IRRI, 1973 wet season.[a]

Treatment	Application Rate (kg a.i./ha)	Application Time (DS)	Grain yield[b] (t/ha)
Benthiocarb	2.0	4	2.7 b
Butachlor	2.0	4	2.1 b
C-19490/C-18898 (C-288)	1.6/0.4	4	2.6 b
Fluorodifen	2.0	4	3.0 ab
Butralin	2.0	4	2.8 ab
USB 3153	2.0	4	3.0 ab
Dinitramine	2.0	4	3.3 ab
MC 4379	2.0	4	3.1 ab
AC 92390	2.0	4	2.6 b
AC 92553	2.0	4	2.9 ab
Oxadiazon	0.5	4	3.0 ab
Oxadiazon	1.0	4	3.0 ab
Oxadiazon	2.0	4	3.3 ab
Oxadiazon	3.0	4	3.0 ab
Butachlor fb MBR 8251	2.0 fb 2.0	4 fb 15 DARE	2.1 b
Propanil	3.0	15 DARE	0.7 c
Hand weeding (twice)	–	20 & 40 DARE	3.6 a
Untreated control	–	–	o c

[a]Source: S. K. De Datta and P. C. Bernasor 1974, *unpublished.* [b]Any two means followed by the same letter are not significantly different at the 5% level.

dimethyl-propyl-amino)-4 ethylamino-6-methylmercapto-s-triazine) (C-18898)]. Butachlor adequately controlled weeds except once. when *Mimosa invisa* severely infested the plot and substantially reduced the grain yield. Nevertheless, the yield with butachlor was not significantly different from that of the best treatment (Table 9). Fluorodifen at 3.0 kg a.i./ha continued to look promising. Yields with U-27,267 (3,4,5-tribromo-N,N,α-trimethylpyrazole-1-acetamide) were low because the herbicide was severely toxic throughout the cropping period. Most of these chemicals performed well in farmers' field trials in Bulacan and Nueva Ecija, Philippines (IRRI 1973).

Table 11. Effects of herbicides (applied at 2 kg/ha a.i.) and hand weeding on grain yield of IR5 grown under upland conditions, Bulacan and Nueva Ecija, Philippines. 1973 wet season.[a]

Treatment	Grain yield (t/ha)					
	Location					Mean
	1	2	3	4	5	
Benthiocarb	2.6	1.2	1.1	3.1	1.3	1.9
Butachlor	2.0	2.7	1.7	3.2	1.9	2.3
C-288	2.4	3.4	2.3	4.0	3.1	3.0
Preforan	2.8	1.9	1.7	1.8	0.7[b]	1.8
Butralin	2.7	1.6	2.1	4.3	2.2	2.6
USB 3153	2.1	1.6	2.3	3.8	1.5	2.3
Hand weeding (twice)	2.6	2.5	1.6	3.7	1.8	2.4
Control	2.3	1.3	1.4	0.8	0.7	1.3

[a]Source: V. E. Ross 1973, *unpublished.* [b]The chemical clogged on the nozzles of the sprayer and formed precipitates due to hard water.

Liquid butachlor. the only herbicide presently available in the Philippines, is expensive – U.S. $25/ha, at our recommended rate of application. An increase in grain yield of about 0.6 t/ha, however, would pay for the butachlor. The use of butachlor or fluorodifen increased grain yields by at least 2 t/ha in our experiments. So, chemical weed control, even at $25/ha. may be worth considering if farmers are not willing to invest at least 400 to 500 man-hours/ha, including at least two hand weedings. Improved varieties must be grown. however. under optimum cultural practices to get maximum yields (De Datta *et al.* 1974*a*).

We tested several new chemicals for the first time, along with promising ones earlier identified, during the 1973 wet season at the IRRI farm. The experimental line IR442-2-58, an intermediate-statured rice that appeared promising for upland conditions, was used as the test selection. The natural weed population was so heavy that the untreated, plots produced no grain yield (Table 10). Butachlor, fluorodifen, benthiocarb, butralin, C-288, USB 3153, and dinitramine provided good control of annual weeds. Among the new chemicals, oxadiazon (2-tert-butyl-4-(2,4-dichloro-5-isopropylphenyl) Δ^2-1,3,4-oxadiazoline-5-1) gave excellent weed control at the low rate of **0.5** kg/ha a.i. Two other new herbicides, MC 4379 (methyl '5-(2',4'-dichlorophenoxy)-2- nitrobenzoate) and **AC** 92553 (N-(l-ethylpropyl)-2,6-dinitro-3,4-xylidine), also looked promising for upland rice.

During the 1973 wet season, rice treated with the herbicide C-288 produced twice as much grain as did the untreated control in five experiments in farmers' fields **in** Bulacan and Nueva Ecija, Philippines (Table 11).

We reported earlier that suitable control measures should be developed for persistent weeds such as ***Cyperus rotundus*** (purple nutsedge) before upland rice culture becomes commercially attractive (De Datta 1972; De Datta ***et al.*** 1974*a*). We conducted experiments under simulated upland conditions during the 1972 and 1973 dry seasons to identify herbicides that would control perennial nutsedges and annual weeds in upland rice.

All treated plots gave significantly higher grain yields than did the untreated control in the 1972 dry season (Table 12). The highest grain yield, **4.8** t/ha, was from plots treated with a combination of USB 3153 (coded compound) at 1 **kg** a.i./ha **3** days after seeding, followed by MCPP [2-(2-methyl-4-chlorophenoxy) propionic acid] at 1 **kg** a.i./ha 20 days after crop emergence. USB **3**153 completely controlled annual weeds, while MCPP controlled the perennial nutsedge. The highest yield did not differ significantly from that obtained in the plots that were hand weeded twice. Butachlor, dinitramine, A-820, U-27,267, Propanil, and **MON 843** controlled annual weeds adequately. When combined with MCPP for nutsedge control, these plots yielded about the same as did the best treatment. In similar plots which were not treated with MCPP, grain yields were reduced by **0.3** to 1.5 t/ha (7 to 40 percent) as a result of nutsedge competition. MCPP appeared promising for the control of *C.* ***rotundus*** in upland rice. Its control of nutsedge differed, depending on which pre-emergence herbicides were applied before it.

All treated plots yielded significantly higher than did the untreated control during the 1973 dry season (Table 13). The highest grain yield, 4.1 t/ha, was obtained with the combination of K-223 [N-(α,α-Dimethylbenzyl)-N'-p-tolyl urea] at '10 **kg** a.i./ha incorporated before planting. followed by butachlor applied at 2 **kg** a.i./ha 3 days after seeding, and by bentazon at 2 **kg** a.i./ha 7 days after crop emergence. The yield was not significantly higher, how-

Table 12. Control of perennial nutsedge *(Cyperus rotundus)* and annual weeds by various herbicides and their effects on grain yield of upland rice (rice line: IR442-2-58). IRRI, 1972 dry season.[a]

Treatment	Rate (kg a.i./ha)	Perennial nutsedge control[b] (%)	Grain yield[c] (t/ha)
USB 3153 fb MCPP	1.0 fb 1.0	41	4.8 a
Dinitramine fb MCPP	2.0 fb 1.0	27	4.5[d]
Butralin fb MCPP	2.0 fb 1.0	50	4.5[d]
Propanil fb MCPP	1.0 fb 1.0	28	4.5[d]
Butachlor fb MCPP	2.0 fb 1.0	41	4.1 ab
Butachlor fb MCPP	4.0 fb 1.0	28	3.8 ab
U-27,267 fb MCPP	2.0 fb 1.0	54	3.8 ab
MON 843 fb MCPP	3.0 fb 1.0	71	3.3 ab
Hand weeding (twice)	–	100	3.8 ab
Untreated control	–	0	0.4 d
		CV (%)	
		9	12

[a]Source: L. I. Okafor and S. K. De Datta 1974 *unpublished.* [b]Count taken 30 days after crop emergence. [c]At 14% moisture content. Statistical significance at the 5% level. Means followed by the same letter are not significantly different at the 5% level. [d]From one replication, not included in the statistical analysis.

ever, than that of the plots which were weeded twice by hand, nor than yields obtained with K-223 applied at 10 kg a.i./ha before planting followed by butachlor at 2 kg a.i./ha 3 days after seeding without the bentazon treatment (Table 13).

K-223 at 8 and 10 kg a.i. controlled nutsedge excellently with no visible crop injury. Following K-223 with butachlor gave good annual weed control. Following K-223 with bentazon at 2 kg a.i./ha for nutsedge control, however, did not significantly increase yields. Although bentazon was very selective, it controlled nutsedge less effectively than did K-223.

We have not yet identified a suitable herbicide to control *Mimosa invisa.* another weed problem in upland rice, although experiments have been conducted in farmers' fields in Batangas, Philippines, and at the Ban Me Thuot rice station, South Vietnam. An experimental herbicide, USB 3153, controlled initial infestation of

Table 13. Effects of the substituted urea herbicide K-223 on the control of perennial nutsedge under simulated upland conditions (rice line: IR442-2-58). IRRI, 1973 late dry season.[a]

Treatment[b]	Rate (kg a.i./ha)	Total weed wt ıt (g/sq m)	Dry wt of nutsedge (g/sq m)	Grain yield (t/ha)
K-223 fb butachlor fb bentazon	10 fb 2 fb 2	98 ab	2 a	4.1 a
K-223 fb butachlor fb bentazon	8 fb 2 fb 2	92 ab	5 ab	4.0 ab
K-223 fb butachlor	10 fb 2	77 ab	3 a	4.0 ab
K-223 fb butachlor	8 fb 2	54 a	6 ab	3.8 bc
K-223 fb butachlor fb bentazon	[illegible] fb 2 fb 2	73 ab	12 abc	3.5 [illegible]
Butachlor fb bentazon	2 fb 2	62 a	18 abcd	3.5 cd
K-223 fb butachlor	[illegible] fb 2	64 a	14 [illegible]cd	3.4 d
Hand weeding (twice)	–	27 a	2 a	4.0 a
Untreated control	–	666 c	58 e	0.4 e

[a]Source: L. I. Okafor and S. K. De Datta 1973, *unpublished*. [b]K-223, applied before planting, fb butachlor 3 days after seeding, fb bentazon 7 days after crop emergence.

M. invisa in both locations, but regrowth was heavy.

We also plan to investigate "integrated weed control," such as the shifting of weed populations to easily controllable species. Bantilan and Harwood (1973) called this a "desired" weed community. Weed management by the use of intermediate-statured varieties, crop rotation, cultural practices, and herbicide applications may be more desirable and feasible under upland than under lowland conditions. Our future challenge will be to provide upland rice farmers with several alternate ways to control difficult weeds.

HARVESTING AND THRESHING

Current practice. Rice is harvested and threshed by hand in most Asian countries. For harvesting, farmers in Batangas province, Philippines, and in Indonesia clip the panicles from the rest of the straw with a sharp knife. So, varieties with exserted panicles are preferred for upland planting in these two countries. Indian farmers use hand sickles to cut both straw and grain about 20-25 cm above the soil surface. The hand-threshed rice is sundried, then stored for home consumption.

Upland rice in West Africa is harvested by hand. Individual panicles are often cut, as in some countries in Asia.

A tremendous amount of rice grains are lost during harvesting, particularly from shattering-susceptible varieties derived from ***Oryza glaberrima.*** Bird damage is excessive in **all** of West Africa (Food and Agriculture Organization Inventory Mission 1970).

In Peru, because varieties are mixed and plants are spaced widely (40 to 50 cm apart), the crop does not mature uniformly. Farmers harvest rice panicle by panicle (Sanchez 1972).

Research results. We do not know **of** any research conducted on the harvesting and threshing of upland rice.

chapter six

STUDIES ON INSECT PESTS OF UPLAND RICE

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Studies on insect pests of upland rice

Mano D. Pathak and Arnold Dyck

COMMON INSECT PESTS

Most of the insects found on lowland rice are also found on upland rice. Important upland rice pests found on the IRRI farm include: the stem borer (*Chilo suppressalis, Tryporyza incertulas, Sesamia inferens,* and *Chilotraea polychrysa);* the green leafhopper *(Nephotettix nigropictus* and *N. virescens);* the brown planthopper, *Nilaparvata lugens;* the rice leaf folder, *Cnaphalocrosis medinalis* (Guenee); the rice seedling fly, *Atherigona* spp.; and the mole cricket, *Gryllotalpa africana* (P. de Beauv.). Soil insects which can not survive in flooded fields, such as the mole cricket, termites, the rice root aphid, *Tetraneura nigriabdominalis* (Sasaki), and root worms, are mostly confined to upland rice.

In an extensive survey of upland rice fields in Batangas and Quezon provinces, and in Bicol, Philippines, we observed several species of grasshoppers and stem borers, leaf folders, white-backed planthoppers, green leafhoppers, zigzag leafhoppers, brown planthoppers, white rice leafhoppers, termites, and some root worms. We also found several insect predators that were present in the crop throughout the growing season, but that reached distinct peaks in density.

Much of the insect control technology developed for lowland rice, including varietal resistance and foliar insecticide sprays, may also be used for upland rice.

CONTROL MEASURES

Furrow placement **of** insecticides. We evaluated the effectiveness of several systemic insectides placed at the bottom of furrows before seeding upland rice. We expected the roots of the germinating rice to absorb the chemicals, controlling the insect pests by a systemic effect. The compounds carbofuran, chlordimeform, acephate, and gamma-BHC + MTMC, each used at 2 kg a. i./ha, provided significant brown planthopper control for up to 50 days after seeding (Table 1). Corbofuran, propoxur, **AC** 64,475,

Table 1. Effect of placing insecticides in the furrows before seeding for the control of upland rice pests. Line used: IR442-2-58. IRRI, 1973 wet season.[a]

Insecticide[b] (2 kg a.i./ha)	Brown planthoppers[c] (no./1-m row)				Hopperburned area (%) 66 days	Green leafhoppers (no./10 sweeps)			Leaves damaged by leaf folders (%) 52 days
	30 days	58 days	62 days			35 days	50 days	57 days	
	N	N	N	A					
Carbofuran	48	147	203	3	1	0	0	0	5
Propoxur	86	700	785	27	65	1	3	0	13
AC 64, 475	54	520	695	36	41	2	2	0	9
Phentriazophos	66	686	885	44	51	2	5	2	8
γ-BHC + MTMC	52	139	481	15	4	3	9	0	8
BPMC	52	462	644	38	36	5	12	1	9
JF 4089	60	780	721	18	87	5	10	3	13
Formetanate	32	562	1112	32	72	6	14	2	9
Chlordimeform	43	301	507	10	26	2	8	3	9
Thiadiazinthion	64	826	1005	18	84	1	2	0	12
Acephate	52	430	386	7	20	9	16	2	10
Untreated control	103	532	1484	36	93	4	12	9	14

[a]Because stem borer and virus incidence during the experiment was low, there was no difference among various treatments. There were large numbers of leaf folder (*C. medinalis*) adults (about 10-20/10 sweeps) but there was no consistent difference among various treatments. [b]Also applied as a side dressing at 55 days after seeding. [c]N = nymphs; A = adults.

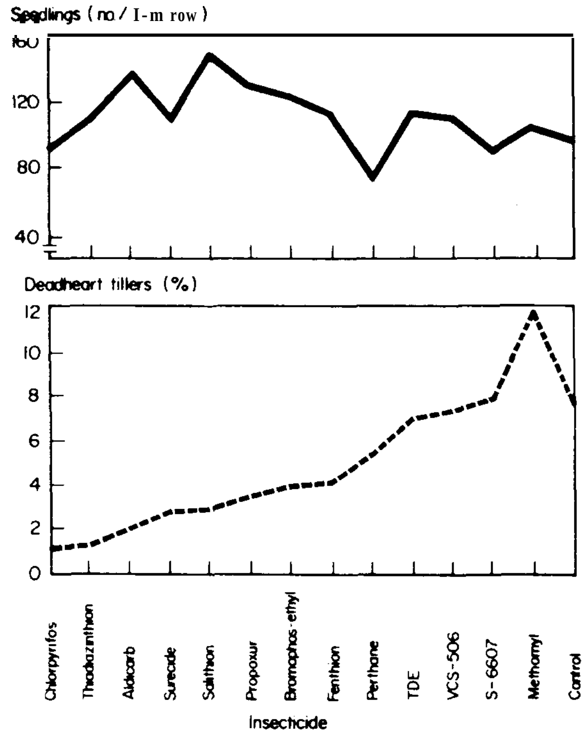
phentriazophos, and thiadiazinthion were all effective against the green leafhopper. Carbofuran also effectivelv controlled the rice leaf folder.

Seed treatment. Treating rice seeds with insecticide can be a practical method of controlling seedling pests of upland rice. We tested about 50 insecticides as seed treatments in laboratory and field experiments. Each test compound was thoroughly mixed with IR8 seed at the rate of 2 kg a.i./100 kg of seed. The wettable powder and emulsifiable concentrate formulations were first mixed with enough water to saturate the seeds. We added methyl cellulose to the mixture to make a sticker solution of 1 percent.

Table 2. Mortality of green leafhopper *(Nephotettix virescens)* adults 24 hours after they were caged on rice seedlings grown in test tubes from seeds treated with various insecticides. IRRI, 1967.[a]

Insecticide[b]	Seed germination (%)	Leafhopper mortality (%) 11 days after sowing	Leafhopper mortality (%) 20 days after sowing
Phenthoate 50 EC	50	78	28
Azinphosmethyl 5 G	60	100	100
Cyanox 5 G	60	73	38
Methomyl 5 G	60	10	0
Aldicarb 10 G	100	100	84
Bromophos-ethyl 80 EC	80	14	49
Methyl parathion 10 G	50	86	76
Metalkamate 10 G	20	100	100
Perthane 45 EC	90	42	37
TDE 50 WP	100	14	34
Salithion 5 G	80	4	6
Surecide 5 G	100	29	52
Propoxur 5 G	100	100	78
Chlorphyrifos 24 EC	40	92	91
VCS 506 36 EC	70	5	10
Thiadiazinthion 10 G	90	100	97

[a]Avg of 10 replications. Each replication contained 10 adult insects. [b]At 2 kg/100 kg of rice seeds. Seeds treated with mecarbam, A 3010, E 605, Cytrolane, No. 6538, and dimethoate did not germinate.



1. The effectiveness (29 days after seeding) of various insecticides when used as a seed treatment at the rate of 2 kg/100 kg of seed in protecting the crop from stem borers.

Using a fine droplet atomizer. we sprayed this solution on the seeds as they were rotated in a cement mixer. We preferred the wettable powder formulation rather than the emulsifiable concentrate or granules for the seed treatment.

The treated seeds were grown in 2.5- x 30-cm test tubes in laboratory experiments. At 11 and at 20 days after sowing, green leafhopper *(Nephotettix virescens)* adults were caged on the seedlings. Insect mortality was recorded at 24 hours after caging.

As seed treatments, azinphosmethyl, metalkamate, chlorpyrifos, and thiadiazinthion killed more than 00 percent of the leafhoppers that were caged on the seedlings in the test tubes at 20 days after sowing, while several other compounds killed more than

Table 3. Effect of seed treatment on insects caged on seedlings of direct-seeded rice 20 to 43 days after seeding. IRRI, 1971 wet season.

Insecticide	Mortality[a] (%)						
	Greenhouse					Upland field	
	Green leafhopper			Brown planthopper		Green leafhopper	Brown planthopper
	20 days	34 days	43 days	21 days	36 days	26 days	25 days
Carbofuran	100	38	93	95	45	32	100
TBPMC	100	58	34	55	5	0	4
XMC	93	0	–	8	0	0	6
C-17475	38	0	–	0	0	5	0
C-17018	38	0	–	3	0	3	0
Thiadiazinthion	98	70	95	0	3	7	26
Chlorpyrifos	43	3	–	8	3	4	6
C-10015	75	28	13	5	3	3	5
Dimethoate	35	8	–	0	0	21	4
Propoxur	42	8	5	13	5	4	63
Disulfoton	5	0	–	0	0	8	2
MIPC	3	0	–	8	8	8	0
Control	–	–	–	–	–	–	–

[a] 24 hours after the insects were caged; values adjusted using Abbott's formula.

Table 4. The effect (at 50 and at 90 days after transplanting) of insecticidal sprays containing 0.05% a.i. every 15 days. IRRI, 1966 dry season.

Insecticide	Dead hearts (%) 50 days	White heads (%) 90 days	Tungro-infected hills (%)	Grain yield (t/ha)
Monocrotophos	2	8	4	5.7
Phosphamidon	4	8	8	4.9
Chlorfenvinphos	1	9	2	5.2
R-5092	2	9	5	4.6
GS 13005	2	7	8	5.2
Endosulfan	2	10	6	4.8
S-6538	1	8	7	5.4
Azinphosmethyl	2	9	2	4.9
Methyl parathion	2	6	7	4.9
SD-8211	2	8	6	4.8
Fenthion	2	11	4	4.7
M-2840	2	11	7	5.2
Dicrotophos	3	12	3	5.1
Bromophos	3	13	9	3.9
Fenitrothion	2	9	5	4.6
Mecarbam	2	12	8	4.3
UC 8305	2	11	6	4.3
Fitios	4	13	10	4.0
Malathion	4	13	8	3.8
SD 8447	3	11	10	4.4
Fentin acetate	3	10	24	3.8
Naled	3	12	16	3.6
Control	5	14	33	2.8

50 percent (Table 2). Although we do not know whether the mortality was due to the systemic effect of the compounds or to the vapors emitted by the toxicants, the results indicate that seed treatment may be a practical way to protect seedbeds or direct-seeded rice from the green leafhopper.

For the upland field experiments, we air-dried the treated seeds for 48 hours and drilled them at the rate of 80 kg/ha in rows 30 cm apart in 4- x 8-m plots. Four replications were planted using a randomized complete block design: untreated seeds were planted as controls.

To determine the effect of different treatments on seed germination and on insect damage to seedlings, we counted the seedlings in a meter-long area in each of three randomly selected rows at 13, 29, and 40 days after sowing. We also graded the crop visually for percentage of germination and for green crop growth at 10 and at 29 days after seeding.

The seeds treated with dimethoate, Cytrolane, AC 47,031, and mecarbam did not germinate; fewer than 10 percent of those treated with metalkamate, **A-3010,** A-605, and S-6626 germinated. In all other test plots, germination was almost normal. At 13 days after seeding, we found 13 compounds that effectively protected the crop from dead heart damage by stem borers. At 29 days after seeding, we found that seeds treated with chlorpyrifos. thiadiazinthion, aldicarb, Surecide, Salithion, and propoxur produced plants with significantly lower percentages of dead hearts than seen in the control plants (fig. 1). The compounds chlorpyrifos, thiadiazinthion, and Surecide effectively controlled the green leafhopper as well (Table 2, fig. 1). These results suggest that a simple and practical method may be found to protect direct-seeded rice from ants, mole crickets, soil grubs, and other soil insects.

In another experiment, the same insecticides were used at 1 kg a.i./100 kg of rice seed. We first coated the seeds with a sticker solution of 2 percent methyl cellulose, then we applied the insecticides. Last, we coated the seeds with activated charcoal which absorbs surface moisture and prevents the seeds from lumping together. The seeds were treated by rolling them with the various chemicals in a plastic bucket. The untreated controls received the same treatment, but without insecticide.

We planted the treated seeds directly in 15-cm clay pots at 15 seeds per pot. We also directly seeded them with a seeder in an upland rice field in 2- x 4-m plots using three replications. We bioassayed both the potted seedlings and the upland plots by caging green leafhoppers and brown planthoppers on them.

In the pot experiment, carbofuran, **TBPMC,** and thiadiazinthion caused high mortality of the green leafhoppers caged on the

Table 5. Summary of the effects of selected insecticides applied as foliar sprays. IRRI, 1968 to 1972 wet and dry seasons.

Insecticide	Trials[a] (no.)	Whorl maggot damage[b] (grade)	Dead hearts (%)	Virus-infected hills[c] (%)	White heads (%)	Mean hopperburned area (%)	Mean yield (t/ha)
Metalkamate	2	2.0	1.8	9	0.7	2	4.72
Carbofuran	3	1.0	0.5	14	0.2	4	4.53
Monocrotophos	7	1.0	1.5	14	0.3	6	4.41
Carbaryl	2	2.0	0.5	15	0.5	5	4.20
Promecarb	2	2.0	2.1	3	1.1	8	4.12
MIPC	4	1.5	2.4	15	1.2	4	4.07
C-10015	2	2.0	2.7	38	1.4	6	3.61
Vamidothion	2	1.0	2.8	49	1.6	14	2.28
Control	7	4.0	5.8	20	1.3	17	3.20

[a]Each trial consisted of four replications. Insecticide concentration ranged from 0.04 to 0.05% applied every 10 to 14 days. [b]On a scale of 0 to 5. Larger number means greater damage. [c]Mostly grassy stunt.

Table 6. Effectiveness of foliar sprays containing 0.05% a.i. insecticide applied at 15-day intervals in preventing hopperbum and leaf folder damage in upland rice (line IR442-2-58). IRRI, 1973 wet season.

Insecticide	Hopperbumed area[a] (%) 70 days	Leaf folder damage[b] 57 days
Chlordimeform	Oa	0.9 a
Metalkamate	Oa	3.4 bc
Acephate	Oa	0.5 a
Monocrotophos	1 a	0.5 a
BPMC	8 ab	4.6 de
Chlorpyrifos	17 abc	0.5 a
Fenthion	28 abc	3.6 bcde
Fenitrothion	39 bcd	3.5 bcd
Endosulfan	51 cde	4.5 cde
Azinphos ethyl	76 de	2.8 b
Surecide	90 e	0.6 a
Untreated control	42 bcde	4.8 e

[a]Any two numbers followed by the same letter are not significantly different at 5% level. [b]On a scale of 0 to 5. Larger number means greater damage.

seedlings up to 43 days after seeding. Carbofuran and TBPMC also effectively controlled the brown planthopper, but for shorter durations (Table 3).

The insecticides were much less effective in the upland field tests. Although the plots treated with several of these insecticides grew more luxuriantly than did the untreated controls, the differences subsided within 40 to 50 days after seeding.

Foliar sprays. **Most** available insecticides have been tested as foliar sprays on lowland rice and are expected to perform similarly under upland conditions (Tables 4 and 5).

Using 0.05 percent solutions, we sprayed selected compounds on upland rice fields every 15 days in an experiment at IRRI and found several, including chlordimeform, metalkamate, acephate, and monocrotophos. that effectively controlled both the brown planthopper and the leaf folder (Table 6). But the foliar sprays have short residual periods and are easily washed off by rain. Be-

Table 7. Effectiveness of foliar sprays (0.05% solution at 250 gal/ha) in controlling the brown planthopper in upland rice. IRRI, Oct. 22 – Nov. 5, 1973.[a]

Insecticide	Brown planthoppers[b] (no./25-cm row)				
	Nymphs		Adults		Nymphs
	1 day before spraying	2 days after spraying	14 days after spraying	21 days after spraying	35 days after spraying
Perthane	184	1	4	5	13
Chlordimeform	160	1	2	6	16
Metalkamate	135	1	2	4	12
MIPC	88	2	4	7	24
Acephate	167	10	13	7	31
Monocrotophos	107	17	26	9	53
CPMC	189	20	16	6	32
Phentriazophos	180	21	28	8	96
Carbaryl	139	47	38	4	56
Dicrotophos	108	52	64	8	78
Methyl parathion	87	54	78	8	49
Untreated control	141	84	104	8	14

[a]Avg of four replications. [b]Visually counted.

Table 8. Effectiveness of foliar sprays (0.05% solution at 250 gal/ha) in controlling grasshoppers in upland rice. IRRI, Oct. 22 – Nov. 5, 1973.

Insecticide	Grasshoppers (no./10 sweeps)		
	1 day before spraying	2 days after spraying	21 days after spraying
Methyl parathion	1	1	6
Chlordimeform	1	2	5
MIPC	3	2	6
Carbaryl	3	3	3
Metalkamate	6	4	7
Acephate	2	2	5
Dicrotophos	5	0	4
Monocrotophos	4	0	2
Phentriazophos	3	2	2
CPMC	5	5	8
Perthane	4	6	4
Untreated control	2	5	7

Table 9. Effectiveness of foliar sprays (0.05% solution at 250 gal/ha) in controlling green leafhoppers in upland rice. IRRI, Oct. 22 – Nov. 5, 1973.

Insecticide	Green leafhoppers (no./10 sweeps)		
	1 day before spraying	2 days after spraying	21 days after spraying
Methyl parathion	3	0	6
MIPC	2	0	6
Acephate	3	0	6
Phentriazophos	4	0	2
Perthane	1	0	6
Monocrotophos	3	0	3
Dicrotophos	3	0	7
Metalkamate	2	0	6
Carbaryl	2	0	6
CPMC	2	0	8
Chlordimeform	1	1	10
Untreated control	1	2	11

cause they do not readily penetrate to the base of the rice plant where brown planthoppers feed, sprays generally give poor control of this insect. The brown planthopper seems to be increasing and the pest problem spreading; hopperburn damage **is** now a common sight in Asia.

In an experiment, we sprayed selected compounds into the brown planthopper's normal feeding area. The lower half of the rice plants were sprayed by keeping the spray nozzle at about the middle height of the plant. This method is quite effective for brown planthopper control (Table 7). The compounds Perthane, chlordimeform, metalkamate, and MIPC were most effective against the insects. Monocrotophos and dicrotophos were effective against grasshoppers for as long as 21 days after spraying (Table 8). Most of the insecticides tested effectively controlled the green leafhopper; phentriazophos and monocrotophos were effective even at 21 days after the spray (Table 9).

chapter seven

RELATED STUDIES

Pesticide residues in upland rice soil

Tomio Yoshida[1]

Mineral microbial transformations in upland soil

Hitoichi Shiga[2]

[1]Soil microbiologist, International Rice Research Institute. [2]Visiting soil microbiologist, IRRI

Pesticide residues in upland rice soils

Tomio ***Yoshida***

INTRODUCTION

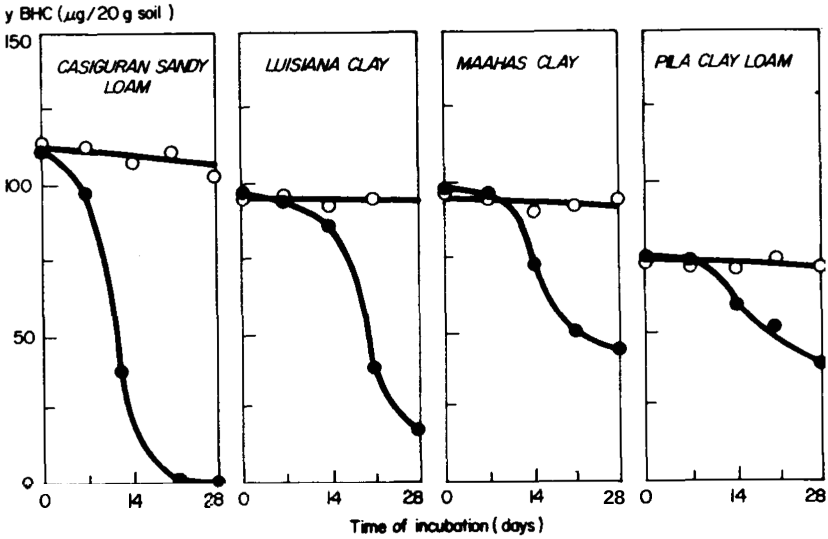
The rapid growth of the human population, particularly in Asia, is creating greater demands for food. The intensification of agriculture and the rapid improvement in agricultural chemical technology has resulted in greater use of insecticides, herbicides, fungicides, algicides, fumigants, nematocides, and rodenticides. The vast amounts of agricultural chemicals now being used, however, may pollute our soil, water, and air. Microorganisms in soil and water have the vital function of transforming these synthetic organic constituents.

Some pesticides break down easily while others are quite tolerant to biodegradation. Contamination of crops by pesticides can be reduced by leaching, absorption, volatilization, or nonbiological degradation. Organochlorine pesticides, particularly the chlorinated hydrocarbons, are considered persistent in our environment. Some of them can persist for several years in soils. The organophosphorus pesticides or carbonate pesticides, on the other hand, are considered relatively nonpersistent in the environment. The IRRI soil microbiology department has begun studying the residue problems of some insecticides and herbicides in rice soil in the Philippines.

ORGANOCHLORINE PESTICIDES

Lindane or the gamma isomers of benzene hexachloride (γ-BHC) and BHC (mixed isomers of alpha, beta, gamma, and delta benzene haxachloride) are most commonly used in the Philippines. Their persistence in soil may cause contamination of water supplies and of plants grown in the soil, and eventually of human tissues. The biodegradation of γ-BHC was evaluated in four Philippine rice soils and its activity in upland conditions was compared with its activity in submerged soil conditions (Yoshida and Castro 1970).

The soils used were Maahas clay (pH, 6.6; organic matter, 2.0%; total nitrogen, 0.14%), Luisiana clay (pH, 4.7; organic mat-



1. Degradation of γ-BHC in Philippine soils under upland and flooded conditions. Source: Yoshida and Castro 1970.

ter, 3.2%; total nitrogen, 0.21%), Pila clay loam (pH, 7.6; organic matter, 1.5%; total nitrogen, 0.09%), and Casiguran sandy loam (pH 4.8; organic matter, 4.4%; total nitrogen, 0.2%). In the upland condition, water was provided to give each soil 80 percent of its maximum water-holding capacity. In the submerged condition, the water level was kept at 5 cm, then the soils in both conditions were incubated at 30°C.

Very little γ-BHC, if any, was degraded during incubation in all four soils in the upland condition (fig. 1). On the other hand, much of the added γ-BHC was degraded within 1 month in the submerged soils. Thus it appears that γ-BHC may be degraded to a major extent under anaerobic soil conditions, but not under aerobic upland soil conditions. This was confirmed by an experiment in which Maahas clay soil was tested for the biodegradation of γ-BHC in aerobic, submerged, and anaerobic conditions. Aerobic conditions were obtained by incubating the soil samples in 250-ml Erlenmeyer flasks on a rotary shaker operated at 150 rpm; anaerobic conditions were produced by incubating the soil samples in an anaerobic desiccator under an atmosphere of He; the submerged conditions were obtained by allowing the soil to stand immobile during incubation. As shown in Table 1, no biode-

Table 1. Biodegradation of γ-BHC in Maahas clay loam soil under different conditions.

Soil condition	γ-BHC decomposed[a] (%)				
	Incubation period (days)				
	0	3	7	10	15
Aerated	0.0	0.0	0.0	0.0	0.0
Submerged	0.0	30.0	47.6	58.3	63.2
Anaerobic	0.0	28.9	51.5	54.9	61.8

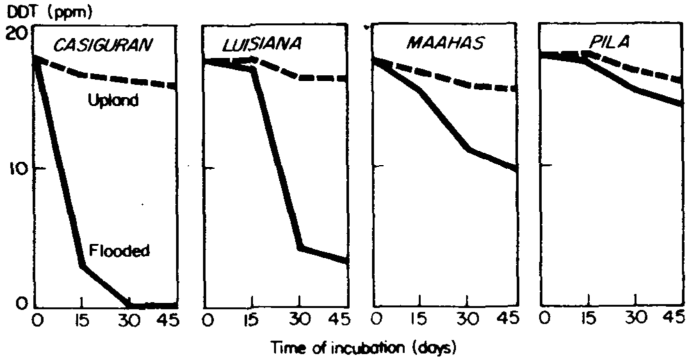
[a]Initial amount of γ-BHC added was 204 μg/20 g soil. Values were obtained by taking the difference between the amounts of γ-BHC remaining in the sterilized soil and in nonsterilized soil.

gradation of γ-BHC occurred under the aerobic conditions, while greater than 60 percent degradation occurred in 15 days under the submerged and anaerobic conditions. The major role of molecular oxygen for microorganisms is that of an electron acceptor of aerobic respiration. The molecular oxygen in aerobic upland soil might inhibit the microbial degradation of γ-BHC, since degradation occurs only in its absence.

However, besides molecular oxygen, combined oxygen, such as nitrate and manganic oxide, depressed the degradation of γ-BHC in submerged soil in which γ-BHC degrades rapidly (MacRae, Raghu, and Castro 1967; Raghu and MacRae 1966). The persistence of γ-BHC under upland soil conditions, therefore, can be explained by the presence not only of oxygen, but also of combined oxygen, such as nitrate or manganic oxides.

Gamma-BHC applied to aerobic upland soil starts to induce the amounts only after these oxidized compounds have disap peared in soil by keeping the soil submerged. Therefore a bacterium present in the upland soil which can degrade γ-BHC degrades γ-BHC only in the absence of oxides. Several bacteria that degrade γ-BHC were Isolated from rice soils (IRRI 1967*a*). One of them was identified as ***Clostridium*** sp.

A study of the microbial degradation of γ-BHC by the bacterium showed that the bacterium anaerobically converts ^{14}C-γ-BHC to a metabolite, which **is** further degraded (Sethunathan *et* al. 1969). Analysis by gas chromatography and thin layer chromatography indicated that the first degradation product of



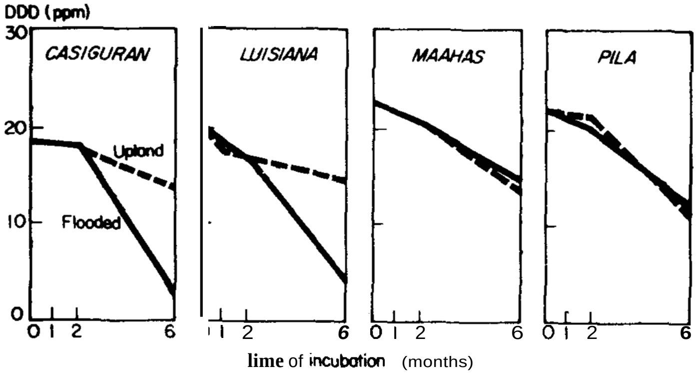
2. Degradation of DDT in four soils. Source: Castro and Yoshida 1971.

γ-BHC is probably γ-pentachlorocyclohexane (γ-PCCHane), a product of reductive dechlorination of γ-BHC. The bacterium also degraded DDT to DDD, apparently in the same manner.

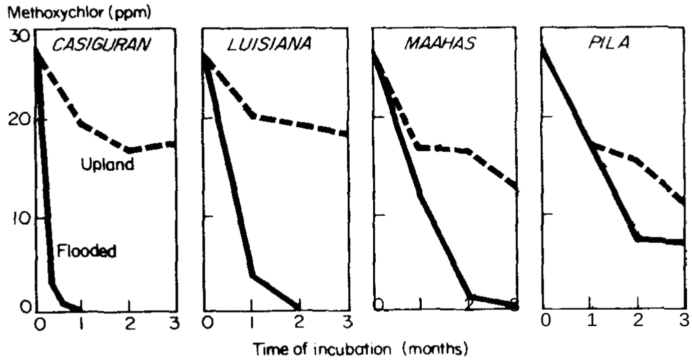
A retardation in the rate of γ-BHC degradation in aerobic upland soil and in anaerobic submerged soil in the presence of nitrate or manganic oxides would be due to the high oxidation-reduction potential (Eh) in these soils. The high Eh status of soil might influence the microbial function of reductive dechlorination.

Other organochlorine insecticides commonly used in agriculture – DDT, DDD, methoxychlor, heptachlor, chlordane, endrin, dieldrin, and aldrin – were studied for their microbial degradation in four Philippine rice soils (Castro and Yoshida 1971; IRRI 1970). The soils used and the methods of incubation were the same as those used in the γ-BHC experiment. The results are shown in figures 3, 4, 5, 6, 7, 8, 9, and 10.

Only small amounts of DDT were lost under upland conditions in all four soils (fig. 2). But DDT was degraded in submerged soil condition and much more rapidly in the soils with higher organic matter content. DDD, a possible first intermediate of DDT, was detected in the gas chromatograms only in the submerged soil conditions. Similarly, more DDD was produced in submerged soils with higher organic matter content. DDD, when added to the soils was more persistent than DDT, but the amount of its residues in submerged Casiguran and Luisiana soils was small after 6 months (fig. 3). The loss of methoxychlor and heptachlor in upland soils during 3 months of incubation was relatively high (fig. 4, 5). The



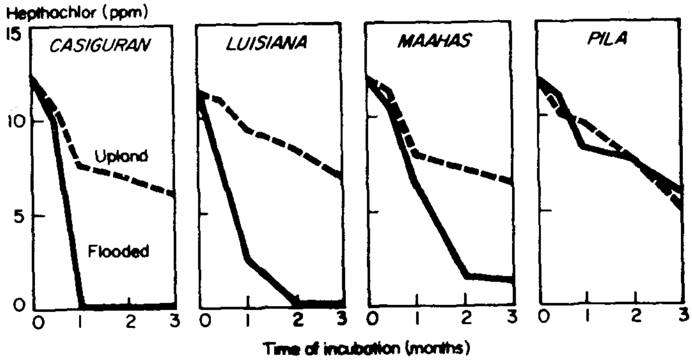
3. Degradation of DDD in four soils. Source: Castro and Yoshida 1971.



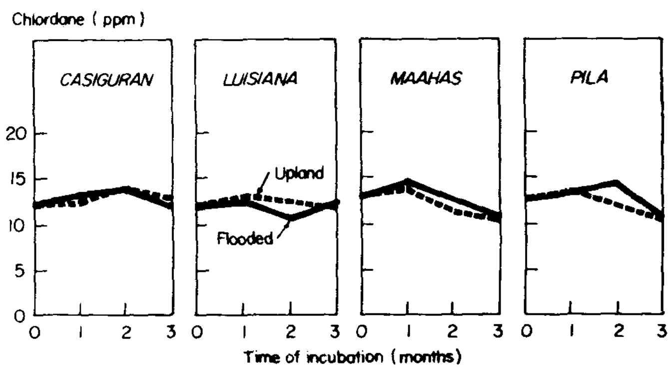
4. Degradation of methoxychlor in four soils. Source: Castro and Yoshida 1971.

two insecticides also had much less residue under submerged conditions than under upland conditions. The mechanism involved in the degradation of DDT, methoxychlor, and heptachlor under submerged soil conditions was considered similar to that involved in γ-BHC degradation; anaerobic reductive dechlorination by bacteria (Castro and Yoshida 1971).

There is considerable evidence that the organochlorine insecticides are volatilized in soil (Edwards 1966). Some losses of DDT, DDD, methoxychlor, and heptachlor under upland condition were probably caused by chemical volatilization and adsorption by soil colloids or organic matter.



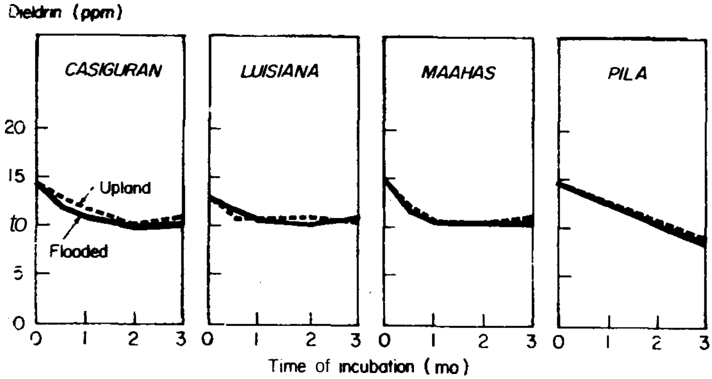
5. Degradation of heptachlor in four soils. Source: Castro and Yoshida 1971.



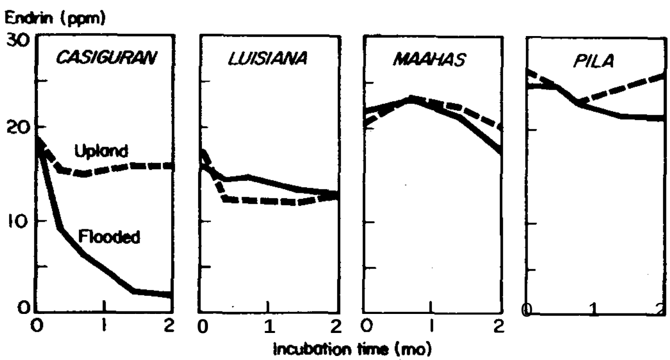
6. Degradation of chlordane in four soils. Sources: IRRI 1970; Castro and Yoshida 1971.

On the other hand, chlordane and dieldrin remained quite stable for *3* months in all soils (fig. 6, 7). Endrin was unstable only in the flooded Casiguran soil (fig. 8). Aldrin had more residue in submerged soil than in upland soil (fig. 9). The greater loss under upland conditions could be attributed to the greater volatilization rate of aldrin under aerobic conditions and could be explained by the oxygen requirement for its epoxidation.

The persistence of herbicides in soil is important for weed control but their degradation is as important in preventing damage to succeeding crops and pollution of soil and water. The degradation of 2,4-D, 2,4,5-T, and picloram was studied under upland and



7. Degradation of dieldrin in four soils. Sources: IRRI 1970; Castro and Yoshida *1970.*

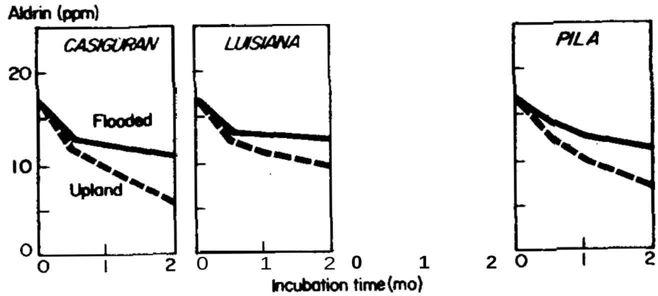


8. Degradation of endrin in four soils. Sources: IRRI 1970; Castro and Yoshida 1971.

submerged conditions in Maahas clay soil and Luisiana clay soil (IRRI 1973).

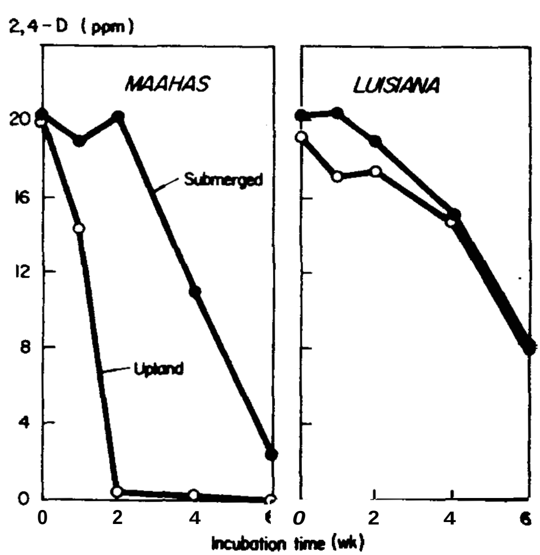
Each herbicide was applied to 20 g of each soil in a large test tube. One set of tubes was kept under upland conditions (80% of field capacity) and another set under submerged conditions with **3** cm of surface water. After the tubes were incubated at 30°C for a time, the soil was analyzed for herbicide residue by gas chromatography. The amount of 2,4-D in the soils was determined at 0, **2, 4,** and *6* weeks after incubation. The amount of picloram in the soil was determined at 0, **3,** and *6* months after incubation.

Little 2,4-D was found in Maahas clay under upland conditions after 2-weeks of incubation (fig. 10). Under submerged soil con-

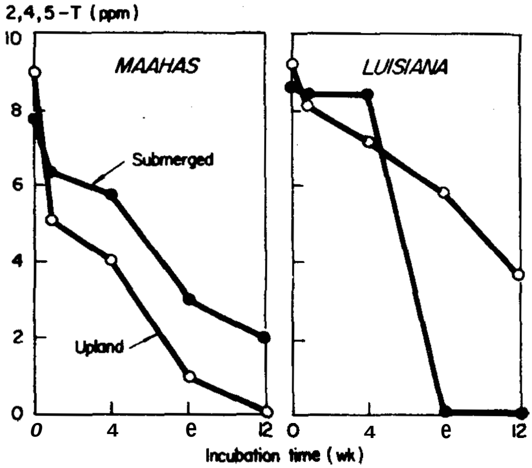


9. Degradation of aldrin in four soils. Sources: IRRI 1970; Castro and Yoshida 1971.

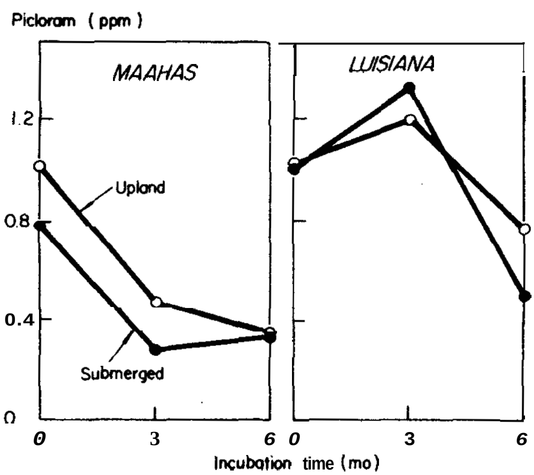
ditions a relatively large amount of 2,4-D remained during the **first** 2 weeks, but the chemical degraded fast until the sixth week of incubation. In Luisiana clay soil the amount of 2,4-D gradually decreased until 6 weeks of incubation, but there was not much difference in the degradation rates between the upland soil and the submerged **soil.** More than 60 percent of 2,4-D was not recovered from the Luisiana soil at the sixth week of incubation.



10. Degradation of 2,4-D in two Philippine soils under upland and submerged conditions. ***Source:*** **IRRI 1973.**

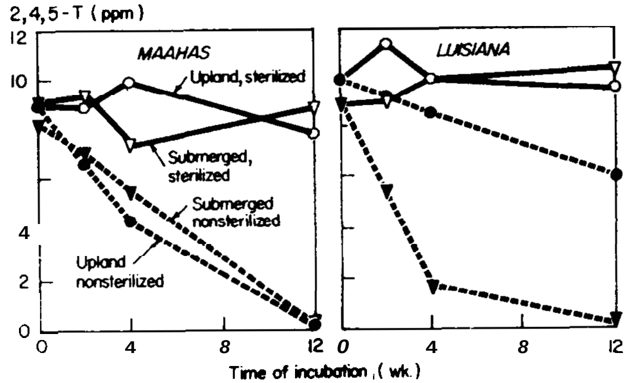


11. Degradation of 2,4,5-T in two Philippine soils under upland and submerged conditions Source: IRRI 1973.



12. Persistence of picloram in two Philippine soils under upland and submerged conditions Source: IRRI 1973.

The herbicide 2,4,5-T degraded fast in Maahas clay soil, both under upland and submerged conditions (fig. 11). A negligible amount remained in submerged Luisiana soil by 2 months after



13. Degradation of 2,4,5-T in sterilized and nonsterilized soils under upland and submerged conditions. Source: IRRI 1973.

submergence. Under upland conditions, however, the herbicide degraded more slowly.

Picloram was more persistent in soil than 2,4-D or 2,4,5-T. It degraded faster in Maahas soil than in Luisiana soil (fig. 12). Six months after incubation 74 percent remained in Luisiana soil under upland conditions, while 45 percent remained in it under submerged conditions.

The biodegradation of 2,4,5-T in sterilized and nonsterilized Luisiana and Maahas soils was studied in both upland and sub-' merged conditions. The amounts of 2,4,5-T remaining in the soils were determined after 0, 2, 4, and 12 weeks of incubation. In sterilized Maahas and Luisiana soil, 2,4,5-T remained stable during incubation, while in the control soils, it degraded under both upland and flooded conditions (fig. 13), suggesting that 2,4,5-T is degraded by microbes in soil.

To examine the persistence of PCP in rice soils, 20 g of Maahas clay soil was mixed with PCP and incubated in upland conditions, at 80 percent of the soil's water-holding capacity, and in submerged soil conditions. At 0, 3, 5, 10, and 15 days after incubation at 30°C, the soil was shaken for 2 hours with 0.1 M sodium hydroxide. A portion of the alkaline solutions was centrifuged at 2,100 rpm for 10 min to separate soil particles. Boric acid was added to adjust pH between 6.5 and 7.0. The solution was then extracted with toluene for 30 min. After methylation, the PCP remaining in the soil was analyzed by gas chromatography. Most

Table 2. Degradation of PCP in Maahas clay soil

Soil condition	PCP degraded (ppm)				
	Incubation time (days)				
	0	3	5	10	15
Upland	16.7	9.6	5.1	0.84	0.07
Submerged	15.2	12.4	10.7	4.48	0.04

of the PCP added to Maahas clay degraded within 15 days, both in upland and submerged soil conditions (Table 2).

ORGANOPHOSPHORUS PESTICIDES

Information on the fate of diazinon in upland soil indicates that the initial step in the degradation of the insecticide involves chemical hydrolysis which results in the formation of 2-isopropyl-4-methyl-6-hydroxy pyrimidine and the ethyl phosphothionate moiety. In studying the degradation of diazinon in rice soils we found a significant loss of diazinon attributable to volatilization and chemical hydrolysis (IRRI 1967*b*). When diazinon is applied to a nearly neutral soil, the soil microflora seem to play a significant role in the degradation of diazinon. A study to identify the degradation compound of diazinon in submerged Maahas clay soil showed that a hydrolysis product of diazinon (2-isopropyl-4-methyl-6-hydroxy pyrimidine) accumulated to a greater extent in nonsterilized soil than in sterilized soil (IRRI 1968), indicating that microorganisms are involved in diazinon degradation.

To compare the results obtained under submerged soil conditions with those obtained under upland soil conditions, 0.5 ml of C^{14}-labeled diazinon solution was added to 20-g samples of sterilized and nonsterilized Maahas clay. Each tube also received 5 ml of unlabeled diazinon solution (40 ppm), which had been previously sterilized by filtering, to provide 50 percent water-holding capacity. The soils were then incubated at room temperature and the levels of diazinon and the hydrolysis product on the 30th day were determined after extraction by thin-layer chromatography (TLC) and isotopic technique.

Under upland soil conditions, more hydrolysis product was recovered from sterilized soils than from submerged soils (Table 3) (Sethunathan and Yoshida 1969). In both upland and submerged soils, the first step in the degradation of diazinon is hydrolysis at the P-O-pyrimidine bond, but the rate of the hydrolysis is faster in submerged soil than in upland soil. Furthermore, the result suggested that metabolism of the pyrimidine ring in the hydrolysis product, 2-isopropyl-6-methyl-4-hydroxy pyrimidine, is more active in the aerobic upland soil than in the anaerobic submerged soil. The metabolism of the pyrimidine ring appeared rather negligible in submerged soil. We isolated from a rice soil a bacterium which metabolizes diazinon as a sole carbon source (IRRI 1972). The bacterium identified as a *Flavobacterium* sp. hydrolyzed diazinon under both aerobic and anaerobic conditions, but did so rapidly under aerobic conditions. .The pyrimidine ring of the hydrolysis product of diazinon was disrupted only under aerobic conditions (Table 4).

It appears that the major step in the degradation of diazinon in rice soil is hydrolysis, which results in the formation of 2-isopropyl-6-methyl-4-hydroxy pyrimidine as one of the degradation products. Under submerged soil conditions where the bulk of soil microflora is anaerobic, oxidation is negligible and the hydrolysis product tends to accumulate and to persist in large quantities without being oxidized. The hydrolysis product in soil should not, however, pose a serious residue problem because it is far less toxic than the parent molecule. In upland soil conditions, however. aerobic microflora decompose rapidly the hydrolysis product by oxidizing it to carbon dioxide as the end-product.

The persistence of parathion was also investigated in four Philippine soils (Sethunathan and Yoshida 1973*a*). The soils. the same as those used in the organochlorine experiments, were incubated

Table 3. Recovery of C^{14} diazinon and C^{14}-2-isopropyl-6-methyl-4-hydroxy pyrimidine 30 days after C^{14}-diazinon application to upland Maahas clay.

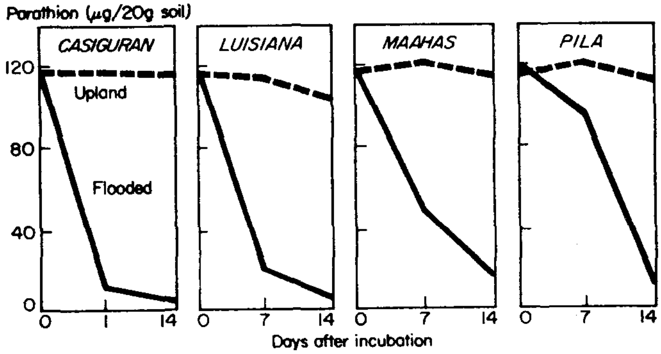
	Amt recovered (cpm/20 g soil)	
	Nonsterilized soil	Sterilized soil
Diazinon	14,000	24,000
2-isopropyl-6-methyl-4-hydroxy pyrimidine	19,000	29,000

Note: 0.5 ml. of aqueous C^{14}-diazinon solution (about 50,000 cpm) was added *to* each tube.

Table 4. Degradation of 2-isopropyl-6-methyl-4-hydroxy pyrimidine (IMHP) by diazinondegrading bacteria under aerobic and anaerobic conditions.

Incubation (days)	IMHP recovered (ppm)			
	Inoculated		Uninoculated	
	Aerobic	Anaerobic	Aerobic	Anaerobic
0	36	36	36	36
5	0	36	40	36

at 30°C. No appreciable degradation of parathion was observed in any of the four soils under upland condition (fig. 14). In contrast, most of the insecticide added to those soils under submerged conditions rapidly decomposed. During the first 7 days of incubation, the rate of degradation was greater in Casiguran soil, which had high organic matter content. By 14 days after incubation, however, most of the parent insecticide disappeared from all the four soils under submerged conditions. Gas chromatograms of hexane extracts revealed that amino parathion was formed during the degradation of parathion in submerged soils. The anaerobic condition of the submerged soils probably enhanced the formation of amino parathion by the reduction of the nitro group in parathion to the amino form. The organic matter content in soils seems to accelerate the rate of the nitro reduction.



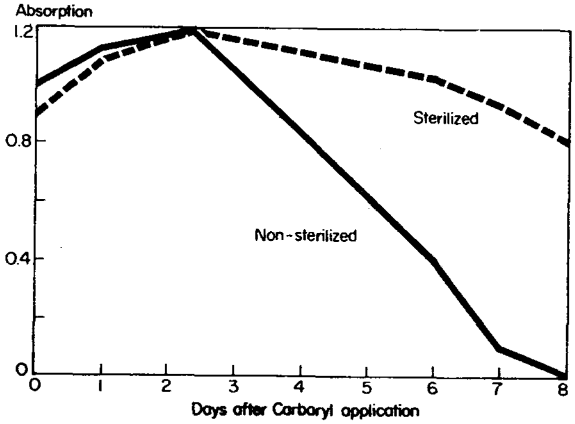
14. Degradation of parathion in four upland and submerged soils in the Philippines. Source: Sethunathan and Yoshida 1973b.

The diazinon-degrading ***Flavobacterium*** sp. showed an exceptionally high capacity to hydrolyze parathion to p-nitrophenol in pure culture (Sethunathan and Yoshida 1973*b*), which suggested that parathion was degraded to amino parathion anaerobically. but to p-nitrophenol aerobically by soil microorganisms, although the level of parathion in aerobic upland soi!s was much less significant than the degradation of parathion in anaerobic submerged soils (fig. **14).** Furthermore, the bacterium which degrades both diazinon and parathion also degraded dursban, but not malathion. Diazinon, parathion, and dursban have a P-0-C bond in their molecule while malathion is characterized by P-S-CH bond. Evidently the bacterium possesses an enzyme which attacks the P-0-C linkage of the organophosphorus insecticide's molecule.

CARBAMATE PESTICIDES

The pucleus of the carbaryl molecule is a naphthalene ring structure that strongly absorbs light **m** the ultra-violet region of the spectrum giving rise to two major absorption peaks at 270 nm and **280** nm. If the double-aromatic-ring structure of the naphthalene nucleus were ruptured as a result of microbial degradation, the absorption maxima in the ultra-violet region of the spectrum would be lost. This characteristic was used in determining the biodegradation of carbaryl.

Sterilized and nonsterilized suspensions of three Luzon soils (Maahas clay, Luisiana clay, and a fine sandy loam from Albay) were treated withcarbaryl (approximately 50 ppm) and incubated at 30°C. (**IRRI** 1967*a*). Periodically, samples were withdrawn and centrifuged to remove soil particles, and the absorption of the supernatants was determined at 270 nm and 280 nm against a soil suspension blank that had not received the insecticide. After an initial lag period of about *3* days, the absorption due to the naphthalene ring declined rapidly in the nonsterilized soil suspension of Maahas clay, whereas the absorption of the sterilized soil suspension remained relatively constant over the 8-day incubation period (fig. 15). No absorption was detected in the nonsterilized Maahas clay suspensions after 8 days, indicating that the naphthalene ring structure of carbaryl had been completely disrupted. The more rapid loss of ultraviolet absorption in nonsterilized suspensions of the same soil strongly suggests biological degradation.



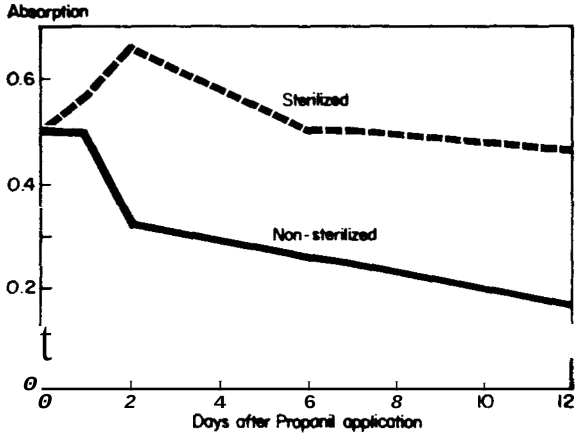
15. Absorption of 280 nm of supernatants from suspensions of Maahas clay treated with carbaryl. (IRRI 1967b).

No significant loss of absorption occurred during the same incubation period in nonsterilized suspensions of Luisiana clay or of the fine sandy loam from Albay. These results may indicate differences in the persistence of the insecticide among the three soils. But because loss of ultra-violet absorption requires a rather complete degradation of the insecticide molecule, the persistence of carbaryl in Luisiana clay, in Albay sandy loam, and in similar soils should be checked by a more specific chemical technique for the assay of carbaryl.

After enrichment culture procedures, a number of aerobic bacteria were isolated for their ability to degrade carbaryl. From these bacteria two very active cultures were selected that could grow in liquid medium with carbaryl as the sole carbon source. The aromatic nucleus of carbaryl was completely degraded in 1 week. When the cultures were supplied with yeast extract as a supplementary carbon source, their growth was accelerated and carbaryl was completely degraded in only 3 days.

There is unequivocal evidence that microbial degradation is one of the important factors governing the persistence of carbaryl in submerged soils.

The herbicide propanil possesses an aromatic nucleus and, like carbaryl, absorbs light strongly in the ultra-violet region of the spectrum (248 nm). Sterilized and nonsterilized soil suspensions of three Luzon soils (Maahas clay, Luisiana clay, and a fine sandy



16. Absorption of **242** nm **of supernatant liquids from suspension of Maahas clay treated with propanil.** (IRRI 1967b).

loam from Albay) were treated with propanil (approximately 10 ppm) and incubated at 30°C. Periodically, samples were withdrawn and their ultra-violet absorption was determined. The ultra-violet absorption of the sterilized suspensions changed slightly during the 14-day incubation period (fig. **16).** But the ultra-violet suspensions declined rapidly, indicating rupture of the aromatic nucleus by the soil microflora. Within the first 48 hours of incubation. the absorption maximum of the nonsterilized supernatant liquid shifted from 248 nm to 242 nm. No such change occurred in the sterilized soil suspensions. This slight shift of the absorption maximum may be attributed to cleavage of the propionic acid side chain from the aromatic nucleus, leaving 3,4-dichloroaniline, which is then degraded by the soil microflora, resulting in loss of absorption of 242 nm. The results obtained with the fine sandy loam soil were similar to those obtained with Maahas clay. Very little degradation was detected in suspensions of Luisiana clay.

Several bacterial cultures were isolated from the Maahas clay suspensions that were able to degrade propanil.

CONCLUSION

Scientists studied the microbial degradations of 16 organic synthetic pesticides that belong to the organochlorine, organophosphorus, and carbamate groups of chemicals in four Philippine rice soils, and found that microorganisms in soil have a significant role in the degradation of the synthetic pesticides. Among the pesticides studied, the organochlorine insecticides were found most persistent in the soils. But some of them, such as γ-BHC, DDT, DDD, heptachlor, and methoxychlor, degraded faster under anaerobic or submerged soil conditions. Microbial dechlorination was the first step in the chemical degradation in anaerobic rice soils. Some soil treatments which accelerated the activity of organochlorine insecticide-degrading bacteria in soil, such as soil submergence or organic matter application, helped eliminate the residue problem in the use of some Organochlorine insecticides. Among the organophosphorus insecticides tested, parathion was persistent in upland rice soils. But again it disappeared fast in submerged soils because of the microbial function of the nitro-group in the molecule. **A** bacterium that degrades some organophosphorus insecticiaes which have phosphorus ester linkage in molecule, such as diazinon or parathion, was isolated from rice soil. It might be useful as a tool in decontaminating the parathion-polluted environment. Organochlorine herbicides, 2,4-D, 2,4,5-T, and picloram were found degradable in the rice soils by our experiments.

Mineral microbial transformations in upland rice soil

Hitoichi Shiga

INTRODUCTION

Soil is a complex ecosystem which harbors a wide variety of microorganisms. These organisms bring about a large number of biochemical changes. Upland rice soil is considered an aerobic environment in which various aerobic biochemical functions occur in the presence of atmospheric oxygen. But the soil is a heterogenous medium that provides an anaerobic environment. In upland soil the anaerobic environment appears localized in a small microenvironment, such as in pores of soil particles or in soil aggregates. Yet aerobic 'bacteria, fungi, and actinomycetes make up the dominant group of microorganisms in upland rice soil.

The energy needs of soil microbes. like those of other living organisms. are met by respiration, oxidation of organic compounds, and liberation of free energy. In aerobic-biological oxidation, molecular oxygen is the ultimate electron acceptor. In its presence organic substrates are oxidized mainly to CO_2 , while it **is** itself reduced to water. Soil microorganisms actively oxidize elements essential for rice growth, such as nitrogen and sulfur.

But many upland rice-growing areas in the world largely depend on rainfall as a source of water. Occasional excess rainfall may change an aerobic soil environment to an anaerobic environment in which aerobic functions of microorganisms, such as reduction of minerals, become active in soil. In addition, inherent properties of the soil or of the environment affect the microbiological regimes in rice soils.

Microbial transformation of elements has key geochemical and agrochemical roles. Elements essential for plant growth, such as nitrogen, phosphorus, or sulfur, occur in organic form in soil. These elements do not become available to the plant unless soil microorganisms decompose them to inorganic forms. But some elements even in their organic forms may not become available to the plant until soil microorganisms act upon them through oxidation, reduction, and solubilization. Although modern agricultural techniques allow us to apply essential elements in the form of fertilizers, agricultural production in many developing countries still largely depends on natural soil fertility. The most important problem is how to make the crop use the limited fertilizers efficiently. A major cause of inefficient use of fertilizer is the loss of elements through direct or indirect microbial functions. Undesirable microbial functions should be prevented and useful ones stimulated in mineral transformations in soil and crops. IRRI soil microbiologists have studied the role of microbes in mineral transformation. Their aim is to control various microbial functions, thereby maximizing the efficient use of fertilizer and natural source of elements for rice production.

NITROGEN TRANSFORMATION

Nitrogen is one of the most essential elements for maintaining life. Some microbes are the key agents that maintain the nitrogen balance in nature. Plants take up nitrogen in its inorganic form and convert it to protein, nucleic acid, and the nitrogen constituents of plant tissues. The plant nitrogen returns to the soil after decay. Mircroorganisms mineralize the nitrogen from organic form to inorganic form. Some nitrogen is lost by leaching and some by volatilization to the atmosphere. Some bacteria in soil can fix the atmospheric nitrogen and convert it to ammonia.

In a greenhouse experiment on the nitrogen cycle in soil and plants, IRRI scientists attempted to trace the fate of fertilizer nitre gen under different soil water regimes by the isotope technique (IRRI 1972, 1973) and studied how adding rice straw to the soil after crop harvest affects nitrogen transformation. Table 1 shows the distribution of nitrogen in the Maahas clay soil (pH, 6.6; organic matter, 2.0%; total nitrogen, 0.14%; total sulfur, 0.044%) used in the experiment.

Ten kilograms of Maahas clay soil were placed in glaaed porcelain pots and subjected to different water management treatments. Nitrogen was added as ammonium sulfate (125 ppm N) and two pots of each treatment received ^{15}N-tagged fertilizer. Organic matter (rice straw) was added to half of the pots at the rate of 0.5 percent. The other pots were used as controls. All treatments were replicated three times. To determine the effect of nitrification on nitrogen transformation and growth of rice, another set of pots

Table 1. Distribution of nitrogen *within* inorganic and organic fractions of Maahas clay soil.[a]

Fraction	Total N (%)
Exchangeable NH_4^+– and NO_3^-–N	1.4
Hydrolyzable NH_4^+–N	12.6
Amino sugar N	11.6
Soluble alkali-stable N	50.0
Acid soluble humin N	10.00
Fixed NH_4^+–N	0.3
Insoluble humin N	14.1

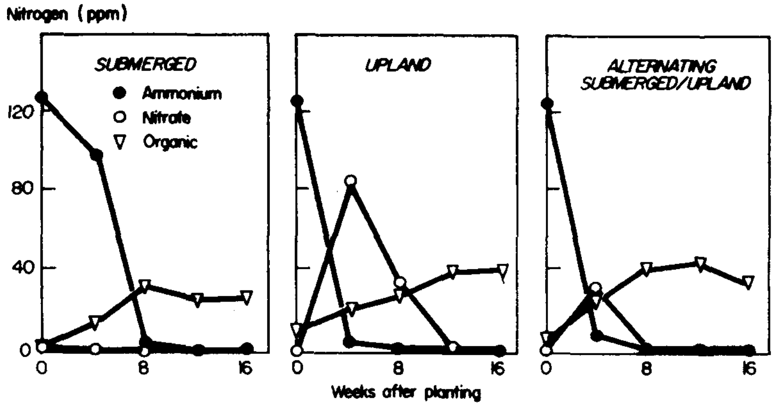
[a]Source: IRRI 1964.

was treated with the nitrogen fertilizer coated with N-Serve, a nitrification inhibitor.

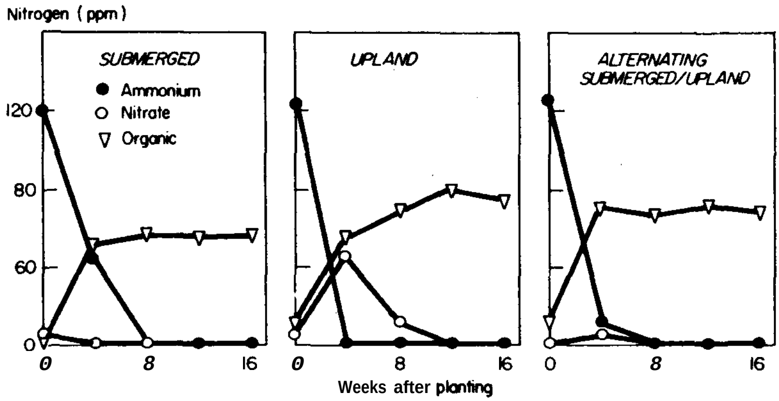
For upland conditions the fertilizer and rice straw were mixed thoroughly with dry soil; then water was added until the soil reached field capacity. Two germinated IR5 seeds were planted in each pot. The soil was maintained at field capacity throughout the growth of the rice crop. For submerged conditions, the soil was puddled with fertilizer and rice straw, then two 14-day-old IR5 seedlings were transplanted into each pot. The soil was kept submerged throughout the growth of the plants. The pots for the alternating conditions were prepared similarly except that the soil was flooded for 1 week, drained, and held at field capacity for 3 weeks. This pattern was repeated four times throughout the growth of the rice crop. Two 14-day-old IR5 seedlings were transplanted into each pot. Soil samples were taken every 4 weeks from all pots and analyzed for exchangeable ammonium, nitrate, and organic nitrogen.

By a month after planting, most of the fertilizer nitrogen had changed to nitrate in the upland soil, but remained as ammonia in the submerged soil (fig. 1). The loss of nitrogen was highest in the alternating conditions. The immobilization of nitrogen increased steadily during the season in upland soil, but in submerged soil, it reached a maximum 8 weeks after planting. Adding rice straw to the soils increased the microbial immobilization of nitrogen under all three soil conditions (fig. 2).

At harvest we found that in submerged soil the plants absorbed 51.7 percent of the tagged fertilizer nitrogen; 41.9 percent



1. Tagged fertilizer N recovered from soil planted to rice without addition of rice straw under different water regimes (IRRI 1971).



2. Tagged fertilizer N recovered from soils planted to rice and amended with rice straw under different water regimes (IRRI 1971).

went to the panicles and 9.8 percent remained in the straw. When rice straw was added the plants took up 37.0 percent of the fertilizer nitrogen, 27.9 percent of which went to the panicle and 9.1 percent of which remained in the straw. The plants took up much less fertilizer nitrogen under upland and alternating conditions; 26.1 percent was taken up under the upland soil condition and 28.3 percent under the alternating conditions. When rice straw was

Table 2. Balance sheet of tagged fertilizer nitrogen in rice plants and soils at harvest under different water regimes and with and without application of rice. straw in the greenhouse.[a]

Water regime	Tagged N recovered (mg/pot)						N recovery[b] (%)
	Plant		Soil			Total	
	Straw	Panicles	Ammonium	Nitrate	Organic		
			Control				
Submerged	117	500	3.3	0.9	233	854	71.6
Upland	158	167	1.8	6.9	439	773	62.2
Alternating[c]	109	226	4.6	1.2	318	659	55.8
			Rice straw added				
Submerged	105	321	9.3	0.0	502	937	81.6
Upland	82	119	2.8	24.4	651	879	70.5
Alternating[c]	51	116	4.9	5.2	596	773	62.6

[a]Source: IRRI 1971. [b]Based on the amount of tagged nitrogen measured in each pot at the start of the experiment. [c]1 week submerged, then drained and maintained at field capacity for 3 weeks.

added to the soil, the plants took up 16.1 percent of the fertilizer nitrogen under the upland condition and 13.5 percent under the alternating conditions. Much less fertilizer nitrogen was recovered in the rice panicles under both these conditions than under submerged conditions.

The largest amounts of fertilizer were recovered at harvest from the soil and from rice plants in submerged soil: 72 percent in the unamended soil, and 82 percent in the soil amended with rice straw (Table 2). Under upland condition, 62 percent of fertilizer nitrogen was recovered in the unamended soil and 68 percent in the soil amended with rice straw. Under the alternating conditions, 56 percent was recovered in the unamended soil and 63 percent in the soil amended with rice straw. A large amount of fertilizer nitrogen was immobilized in soils at harvest: 20 percent in the submerged conditions, 35 percent in the upland conditions. and 27 percent in the alternating conditions. When rice straw was added to the soil, more nitrogen was immobilized: 44 percent under the submerged conditions, 52 percent in the upland conditions, and 48 percent in the alternating soil conditions. The nitrogen usually

Table 3. Plant growth under different water regimes.

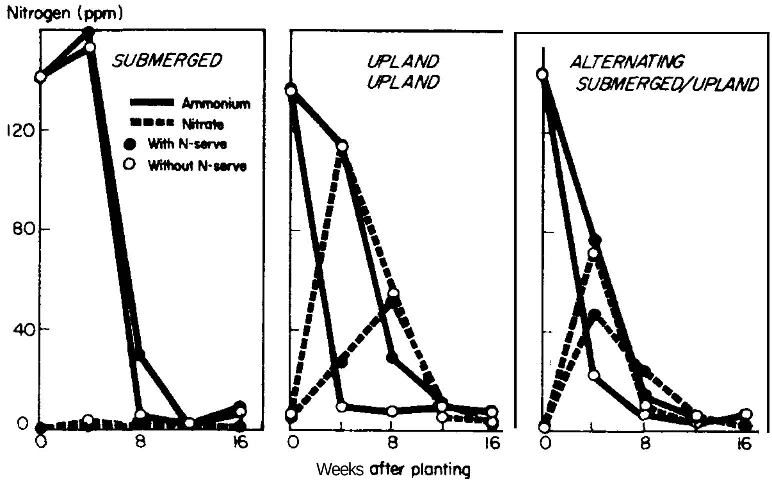
Water regime	Dry matter wt (g/pot)			
	Without added straw		With added straw	
	Straw	Panicle	Straw	Panicle
Submerged	64.0	89.8	76.5	89.2
Upland	54.0	26.3	48.8	29.4
Alternating	52.4	41.9	51.1	45.7

is immobilized within a month after transplanting and remains in the organic fraction until harvest.

The total dry matter of IR5 was highest under the submerged conditions (Table 3). When rice straw was added to the submerged soils the growth of rice was greatly retarded. The application of ammonium sulfate, however, largely prevented growth retardation. The grain of rice plants grown in the flooded soil had remarkably more fertilizer nitrogen than the grain of rice grown in upland or in alternating conditions. The ratio of fertilizer nitrogen to the soil nitrogen found in the rice plant was highest in the upland treatment and lowest in the submerged treatment (Table 4). It decreased when rice straw was added to the soil probably because fertilizer nitrogen was immobilized during the decomposition of rice straw. During the first 2 months after transplanting, N-Serve inhibited nitrification in upland conditions but had only a slight effect in the other two soil conditions (fig. 3). The effect on N-Serve and other nitrification inhibitors on nitrogen transformation in rice soil is also reported in other publications (Manguiat and Yoshida 1973; Yoshida and Padre 1974). The nitrogen content

Table 4. Plant uptake of fertilizer and soil nitrogen under different water regimes

Water regime	Plant uptake (mg/pot)					
	Without added straw			With added straw		
	Fertilizer N	Soil N	Total	Fertilizer N	Soil N	Total
Submerged	617	688	1305	426	686	1012
Upland	325	301	526	201	304	505
Alternating	335	343	678	167	362	529



3. Effect of N-serve on nitrogen transformations in soils planted to rice under different water regimes (IRRI 1971).

and dry matter weights of rice plants grown in upland soils with fertilzers coated with N-Serve were higher than those of plants grown in soils with ordinary fertilizers. N-Serve did not affect plant growth and yield in the other two soil conditions, however (Table 5, 6).

Most of the fertilizer nitrogen immobilized in the soil during the first crop remained in the soil as organic nitrogen through the second crop (Table 7). The nitrogen taken up by the second crop was 2.2 percent of the amount of fertilizer nitrogen applied in the previous crop under the submerged conditions, 3.1 percent under the upland conditions, and 1.5 percent in alternating wet and dry

Table 5. Nitrogen concentration in straw and panicles of IR5 grown under three water regimes and effect of the nitrification inhibitor.

N fertilizer	Nitrogen (%)					
	Flooded		Upland		Alternate	
	Straw	Panicles	Straw	Panicles	Straw	Panicles
			Control			
No nitrogen	0.34	0.92	0.30	0.92	0.38	0.79
Ammonium sulfate (AS)	0.40	1.20	0.53	1.16	0.43	1.08
AS coated with N-Serve	0.41	1.27	0.58	1.33	0.47	1.08

Table 6. Total dry matter of IR5 grown under different water regimes and effect of the nitrification inhibitor.

N fertilizer	Total dry matter[a] (g/pot)								
	Flooded			Upland			Alternate		
	S	P	T	S	P	T	S	P	T
					Control				
No nitrogen	40.7	42.2	82.8	29.8	20.2	50.0	24.4	15.7	39.1
Ammonium sulfate	64.0	89.8	153.8	54.8	26.3	81.1	52.4	41.9	94.3
AS coated with N-Serve	64.4	92.8	158.2	58.1	30.0	88.1	49.4	35.0	84.4

[a]S: straw; P: panicles; T: straw and panicles.

conditions. When rice straw was added to the soil, the nitrogen recovered by the second crop was 5.9 percent of the fertilizer nitrogen received by the first crop in the submerged conditions, 3.5 percent under upland conditions, and 2.0 percent under the alternating conditions.

After the second crop, the nitrogen that remained in the soil in the organic form was 14.8 percent under the the submerged conditions, 32.5 percent under upland conditions, and 21.7 percent under alternating conditions. When rice straw was added to the soil, the amounts of organic nitrogen increased to 32.0 percent under submerged conditions, 45.4 percent under upland conditions, and 38.7 percent under alternating conditions

In another experiment, we studied the effects of different soil moisture tensions on nitrogen transformation, on grain yield, and on nitrogen uptake by the rice crop. Ten kilograms of air-dried Maahas clay soil were placed in porcelain pots. To create different soil moisture tensions, water was allowed to continuously flow from a water reservoir into the pots through a column of mercury that corresponded to the soil moisture tension. The soil moisture tensions were 0, 5, 15, 25, and 35 cm Hg (corresponding to 0, 6, 20, 33, and 47 centibars, respectively). All treatments'were replicated three times. Ammonium sulfate was added at the rate of 100 ppm N. Tagged fertilizer was applied in two pots of each treatment.

Ammonium sulfate, as a solution, was mixed thoroughly with the soil. Two germinated IR5 rice seeds were planted in each pot. For comparison, the soil in three pots was puddled with the fertilizer,

Table 7. Balance sheet of tagged soil nitrogen in rice plants and soils at harvest of a second crop under different water regimes, with and without application of rice straw in the greenhouse.[a]

Water regime	Initial tagged soil N[b] (mg/pot)	Tagged N recovered (mg/pot)						N recovered (%)
		Plant		Soil			Total	
		Straw	Panicles	Ammonium	Nitrate	Organic		
				Control				
Submerged	240	7.6	18.8	2.7	1.2	177	207	86.4
Upland	488	13.0	25.6	5.2	7.9	405	457	93.7
Alternating	327	6.9	10.5	5.4	1.6	257	282	86.2
				Rice straw added				
Submerged	516	19.7	47.6	6.0	1.0	369	443	85.9
Upland	684	16.5	26.8	5.6	3.3	568	621	90.7
Alternating	611	10.1	14.0	4.5	11.5	479	519	84.9

[a]Source: IRRI 1972. [b]After harvest of the first crop.

Table 8. Amount of exchangeable NH_4–N in the soil at different stages of plant growth under different soil moisture tensions.

Soil moisture tension (cb)	NH_4–N (ppm)				
	0 week	4 weeks	8 weeks	12 weeks	16 weeks
Flooded	121	123.2	3.3	2.1	6.3
0	118	0.6	4.3	9.6	11.0
6	120	1.9	4.5	10.7	7.9
20	115	9.9	5.0	9.0	6.8
33	115	12.1	12.2	8.0	4.2
47	115	6.0	11.5	13.6	4.5

Table 9. Amount of NO_3–N in the soil at different stages of plant growth under different soil moisture tensions.

Soil moisture tension (cb)	NO_3–N (ppm)				
	0 week	4 weeks	8 weeks	12 weeks	16 weeks
Flooded	2.5	1.0	1.2	0.0	6.2
0	4.9	115.4	34.4	5.6	11.0
6	6.3	127.3	110.4	2.5	7.9
20	4.0	98.0	115.7	3.4	6.8
33	4.4	88.1	69.1	4.3	4.2
47	3.7	68.5	118.3	4.2	4.5

Table 10. Effect of different soil moisture tensions on dry matter production, plant height, and panicle number of IR5.

Soil moisture tension (cb)	Plant ht (cm)	Panicles (no./plant)	Grain wt (g/pot)	Straw wt (g/pot)	Total dry matter (g/pot)	Growth duration (days)
Flooded	132	19	105	138	243	146
0	115	19	66	103	168	146
6	113	19	56	88	144	160
20	112	17	47	91	138	168
33	109	17	37	95	132	168
47	97	16	22	89	111	190

Table 11. Plant uptake of fertilizer and soil nitrogen at different soil moisture tensions.[a]

Soil moisture tension (cb)	Plant uptake (mg/pot)					
	Straw		Grains		Total	
	Fertilizer N	Soil N	Fertilizer N	Soil N	Fertilizer N	Soil N
Submerged	167	356	310	698	471	1054
0	122	203	250	425	371	628
6	157	241	255	381	411	623
20	162	255	229	362	390	617
33	193	308	198	317	391	625
45	291	443	124	197	416	640

[a]Source: IRRI 1972.

then two 21-day-old IR5 seedlings were transplanted into each pot. The soil in these pots was kept submerged throughout the growth of the plants.

Soil samples were taken every 4 weeks and analyzed for exchangeable ammonium, nitrate, and organic nitrogen. The amount of exchangeable ammonium decreased rapidly within 4 weeks in the upland treatments (0 to 47 cb) (Table 8). The different soil moisture tensions did not greatly influence the decline in exchange ammonium. In the upland soil, a rapid decrease in exchangeable ammonium was followed by a rapid increase in nitrate which lasted up to 8 weeks after planting (Table 9). Almost no nitrate was found in the submerged soil.

At moisture tensions of 0, 6, 20, and 33 centibars, plants were almost the same height (Table 10). They were tallest under submerged conditions and shortest at a soil moisture tension of 47 centibars. The soil moisture tensions did not affect panicle number. Dry matter weight decreased as soil moisture tension increased, but growth duration increased with soil moisture tensibn.

At harvest, the nitrogen concentration in both straw and grain increased with soil moisture tension. But there was no difference in the total amount of nitrogen taken up by the rice plant at different soil moisture tensions. The amount of nitrogen in straw increased, while that in grains decreased, as soil moisture tension increased (Table 11). Soil moisture tension apparently affected the movement of nitrogen from leaves to panicles during the reproductive stage, but not the nitrogen uptake from thq soil.

The submerged rice plants took up more nitrogen, particularly soil nitrogen, than did upland plants. The amount of tagged fertilizer nitrogen recovered in the rice plant was higher (53.8%) in submerged plants than in upland plants (42.0 to 46.9% depending on soil moisture tension).

All treatments in this experiment had almost the same recovery of tagged nitrogen from soil and plant. The amount of immobilized nitrogen was lower and uptake by the rice plant was higher under submerged conditions than under upland conditions (Table 12).

From these results, we may conclude that microbial transformation of nitrogen in upland rice soil does not create conditions as favorable as those in submerged rice for the efficient use of nitrogen by the rice crop. Nitrogen becomes more inefficient in soil exposed to alternating wet and dry conditions during rice growth. Active nitrification and immobilization of fertilizer nitrogen appeared to be the main causes of the inefficient nitrogen **use** by rice in upland soil conditions. Applying fertilizers coated with nitrification inhibitors, such as N-Serve, can reduce the nitrification by nitrifying bacteria. Nitrification inhibitors increase the uptake of fertilizer nitrogen, although they do not seem effective in the alternating and the submerged soil conditions. More effective and more economically feasible nitrification inhibitors, if they become

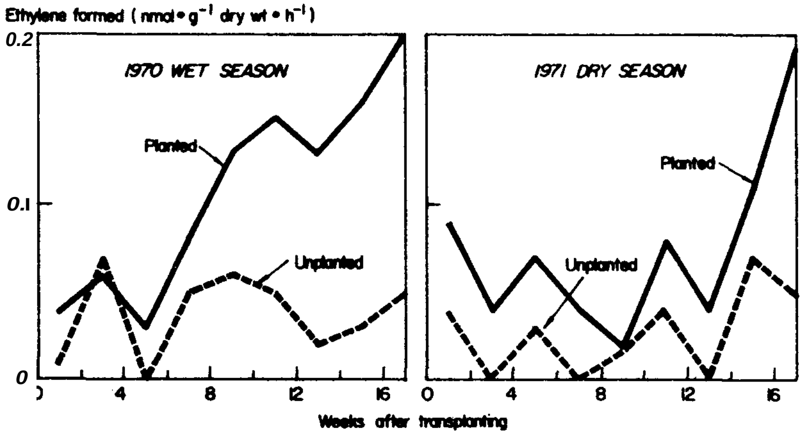
Table 12. Balance sheet of tagged fertilizer nitrogen in rice plants and soils at harvest under different soil moisture tensions in the greenhouse.

Soil moisture tension (cb)	Tagged N recovered (mg/pot)						N recovered (%)
	Plant		Soil			Total	
	Straw	Grain	Ammonium	Nitrate	Organic		
Fiooded	167	310	2.6	2.9	259	741	83.6
0	122	250	4.1	5.1	359	739	83.4
6	157	255	3.7	10.2	365	790	89.2
20	162	229	2.6	9.5	361	763	86.1
33	193	198	2.9	5.2	376	775	87.3
47	291	124	1.9	4.3	358	779	88.0

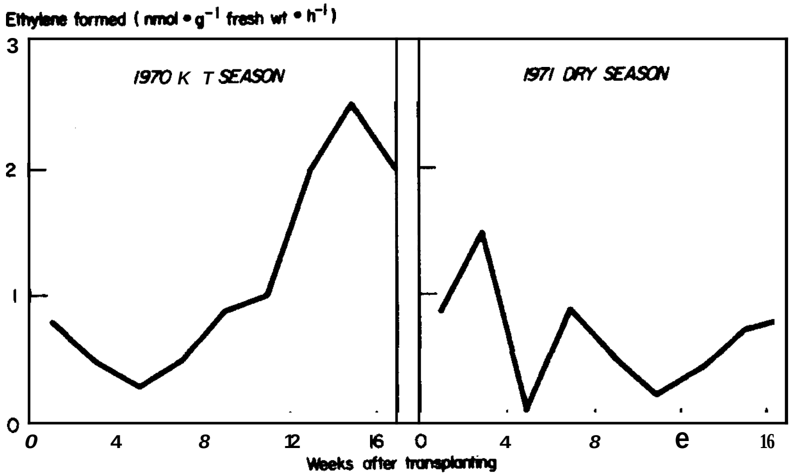
commercially available, would increase the efficient use of fertilizer by an upland rice crop. Nitrogen loss can also be prevented through the use of slow-release fertilizers, organic fertilizers, or split application of fertilizers. These methods are discussed in other sections. Among the upland soils subjected to various moisture tensions, there was no difference in total amount of nitrogen taken up by the rice plant. Even at a moisture level higher than the field capacity of the soil, the plants took up the same amounts of nitrogen in other upland soil conditions. But the amounts of nitrogen in the rice grain decreased greatly in the soils with higher moisture tensions. This decrease in grain nitrogen seems to be a physiological problem of nitrogen transformation in the rice plant, not of the nitrogen uptake from soil by the rice plant. Applying organic matter to soil improves the soil's physical properties and increases crop yields. But applying matured rice straw (which usually has a high carbon-nitrogen ratio) may cause soil microorganisms to immobilize available nitrogen because the microbial populations built up by the application of organic matter may compete with crops for available nitrogen. Rice should not be seeded when fresh rice straw has just been incorporated into the soil. Organic matter. such as compost or green manure. which has higher nitrogen content, would be desirable for upland rice production.

Various kinds of bacteria which can fix atmospheric nitrogen are isolated from Maahas clay soil in upland soil conditions. But their significance in atmospheric nitrogen fixation is not clear. In a field experiment to study the effect of the rice plant on the fixation of atmospheric nitrogen (IRRI 1971, 1972; Yoshida and Ancajas 1973), the rhizosphere samples in the field were examined for nitrogen-fixing activity. The acetylene reduction method was used every 2 weeks during the rice-growing period (Yoshida and Ancajas 1970, 1971). The results are shown in figures 4 and 5.

The nitrogen-fixing activity in upland soils was very low. There was a small rhizosphere effect in the activity at the later stage of rice growth. The washed roots also showed the acetylene-reducing activity but it was much smaller than that of roots of rice grown in submerged soil condition. The amount of nitrogen fixed in the upland soils was 3 kg/ha in unplanted soils. but 7 kg/ha in planted soil in the 1970 wet season and 5 kg/ha in the 1971 dry season. Although the amount of atmospheric nitrogen fixation was exceedingly small in the experiment, the rhizosphere effect was impor-



4. N_2-fixing activity in cropped and uncropped field soils under upland conditions by C_2H_2-C_2H_4 assay.



5. N_2-fixing activity in washed rice roots (rice variety IR20) grown in upland soils measured by C_2H_2-C_2H_4 assay.

tant. The rice plant's mechanism in fixing atmospheric nitrogen apparently is in some way associated with rhizosphere bacteria. The possibility of increasing nitrogen-fixing activity in the rice rhizosphere is an interesting future study problem.

SULFUR TRANSFORMATION

Living things need sulfur for growth. Both nitrogen and sulfur are constituents of cell materials, mostly as proteins. Some amino acids, cysteine, cystine, and methionine. contain sulfur in their molecules. **Living** organisms also need sulfur as an important element in various biochemical functions. In soil the concentration of inorganic sulfur is low; and a major portion of sulfur is organic, although very little is known about its chemical nature. The transformation of sulfur resembles that of nitrogen and its mineralization is well correlated with nitrogen release. Microorganisms need sulfur for their proliferation and they sometimes compete with the growing plants for available sulfur in soil. The major end-products of inorganic sulfur are sulfate in aerobic soil and sulfide in

Table 13. Rice plant growth on upland and submerged Maahas clay with and without application **of** rice straw.

Plant stage	Tillers (no.)	Plant ht (cm)	Dry matter wt (g/pot)	S content (%)	Grain wt (g/pot)
			Upland, control		
Tillering	11.4	52.7	2.9	0.290	–
Flowering	13.6	59.3	15.8	0.194	–
Harvest	14.0	58.0	26.5	0.144	10.5
			Upland, rice straw added		
Tillering	10.4	45.0	1.4	0.300	–
Flowering	12.0	52.7	8.9	0.194	–
Harvest	18.0	55.0	22.7	0.135	9.9
			Submerged, control		
Tillering	12.6	12.0	5.6	0.100	–
Flowering	12.1	78.0	19.6	0.040	–
Harvest	13.0	77.0	45.5	0.035	24.6
			Submerged, rice straw added		
Tillering	2.0	30.0	0.7	0.080	–
Flowering	2.6	57.0	2.3	0.029	–
Harvest	7.0	62.4	10.3	0.025	4.7

Table 14. Rice plant growth on upland and submerged Pila clay loam with and without application of rice straw.

Plant stage	Tillers (no.)	Plant ht (cm)	Dry matter wt (g/pot)	S content (%)	Grain wt (g/pot)
			Upland, control		
Tillering	7.0	50.0	2.5	0.300	–
Flowering	11.0	54.6	7.0	0.318	–
Harvest	16.6	63.0	21.5	0.130	3.3
			Upland, rice straw added		
Tillering	8.6	53.3	3.2	0.420	–
Flowering	13.0	54.0	6.8	0.330	–
Harvest	17.0	58.5	22.0	0.120	4.9
			Submerged, control		
Tillering	14.0	73.3	9.9	0.100	–
Flowering	15.6	73.0	21.5	0.060	–
Harvest	16.0	81.0	14.8	0.024	34.4
			Submerged, rice straw added		
Tillering	13.0	70.0	9.3	0.100	–
Flowering	12.6	74.0	26.5	0.060	–
Harvest	13.6	82.3	77.5	0.020	33.7

anaerobic soil. Sulfide is oxidized by sulfur-oxidizing bacteria and the sulfate is reduced by sulfur-reducing bacteria in soil. Sulfur often limits the growth of upland crops in some soils. Excessive sulfate in other soils, on the other hand. becomes injurious to crops.

The availability of sulfur to rice plants in upland soil conditions was studied and compared with its availability in submerged soil conditions, with and without organic matter radioisotope technique (Han 1973). Scientists weighed 3 kg each of Maahas clay soil and Pila clay loam (pH, 6.9; organic matter, 3.82%; total N. 0.215%; total S, 0.035%) and placed them in porcelain pots. Half of each soil was kept in upland soil conditions with moisture tension at field capacity and the other half in submerged soil conditions. Two weeks before planting, 100 ppm N as urea, 500 ppm P_2O_5 as KH_2PO_4, and 25 ppm K_2O as KCL were added to

Table 15. Sulfur uptake by rice plant in upland and submerged Maahas clay soil with and without application of rice straw.

Plant stage	Sulfur uptake (mg/pot)							
	Upland				Submerged			
	Soil S	Fertilizer S	Totals	Utilization of applied sulfur (%)	Soil S	Fertilizer S	Totals	Utilization of applied sulfur (%)
				Control				
Tillering	6.8	1.6	8.4	8.0	3.7	1.9	5.6	9.5
Flowering	21.7	.0	30.7	44.5	3.3	4.5	7.8	22.5
Harvest	26.7	1[illegible].5	38.2	57.5	9.5	6.4	15.9	32.0
				Rice straw added				
Tillering	3.3	0.8	4.1	4.0	0.5	0.1	0.6	0
Flowering	11.9	5.3	17.2	26.5	0.5	0.2	0.7	1
Harvest	21.0	9.6	30.6	48.0	1.9	0.5	2.6	

Table 16. Sulfur uptake by rice plant in upland and submerged Pila clay loam with and without application of rice straw.

Plant s[illegible]	Sulfur uptake (mg/pot)							
	Upland				Submerged			
	Soil S	Fertilizer S	Totals	Utilization of applied sulfur (%)	Soil S	Fertilizer S	Totals	Utilization of applied sulfur (%)
				Control				
Tillering	5.5	2.0	7.5	10.0	6.8	3.1	9.9	15.5
Flowering	21.8	4.6	26.4	23.0	10.2	6.3	16.5	1.5
Harvest	22.6	5.4	28.0	27.0	11.0	7.0	18.0	5.0
				Rice straw added				
Tillering	12.4	[illegible]	13.4	5.0	6.5	2.8	9.3	14.0
Flowering	20.2	2.4	22.6	12.0	11.3	4.7	16.0	23.5
Harvest	21.8	4.8	26.6	24.0	10.6	4.9	15.5	24.5

each pot. Radioisotope ^{35}S-labeled-K_2SO_4 with 20 mg of S as K_2SO_4 was used in this experiment, and rice straw was added as organic matter at the rate of 0.2 percent. The test rice variety was IR667-98. To prevent contamination from other sulfur sources, distilled and deionized water was used. Plants and soils were Sampled at tillering, at flowering, and at harvest. The samples were analyzed for total sulfur and for radioisotope sulfur 35. Soil samples were also analyzed for ammonium acetate soluble sulfur (AA-soluble) at the same time.

The growth of rice plants with and without added straw in upland soil conditions was poorer than in submerged soil conditions, except in submerged Maahas clay soil with added rice straw (Table 13, 14). But sulfur content of the rice plant was significantly higher in upland soil than in submerged soil throughout the growing stage of the rice plant. The addition of rice straw, which did not affect the plant's sulfur content under upland conditions, affected it under submerged condition in Maahas clay soil. The experiment using tagged sulfur indicated that much of the sulfur in the plant grown in upland soil came from the soil (Table 15, 16). The percentage of applied sulfur to sulfur used by rice plant was higher in Maahas clay soil than in Pila clay loam. The balance sheet of

Table 17. Balance sheet of tagged sulfur applied to Maahas clay soil under upland and submerged conditions with and without application of rice straw.

Plant stage	Sulfur in plant and soil (mg/pot)					
	Upland			Submerged		
	In plant	In soil		In plant	In soil	
		AA-soluble	Residual		AA-soluble	Residual
			Control			
Tillering	1.6	16.2	2.2	1.9	14.5	3.6
Flowering	9.0	7.9	3.1	4.5	10.7	4.8
Harvest	11.5	5.1	3.4	6.4	10.0	3.6
			Rice straw added			
Tillering	0.8	15.3	3.9	0.1	12.6	7.3
Flowering	5.3	10.1	4.6	0.2	12.1	7.7
Harvest	9.6	5.0	5.4	0.5	10.3	9.2

Table 18. Balance sheet of tagged sulfur applied to Pila clay loam under upland and submerged conditions. with and without application of rice straw.

Plant stage	Sulfur in plant and soil (mg/pot)					
	Upland			In soil		
	In plant	In soil		In plant	Submerged	
		AA-Soluble	Residual		AA-Soluble	Residual
				Control		
Tillering	2.0	15.5	2.5	3.1	14.6	2.3
Flowering	4.6	11.4	4.0	6.3	10.8	2.9
Harvest	5.4	10.0	4.6	7.0	7.8	5.2
				Rice straw added		
Tillering	1.0	13.9	3.1	2.8	14.2	3.0
Flowering	2.4	12.9	4.7	4.1	10.8	4.5
Harvest	4.8	9.4	5.8	4.9	7.6	7.5

tagged sulfur applied to the soils indicated that much of the sulfur remained in soil in ammonium acetate soluble form and in residual form, some of which may had been immobilized into soil organic fractions (Table 17, 18).

These results suggest that upland soil conditions favor sulfur uptake by rice plant much more than do submerged conditions. Nearpass and Clark (1960) reported similar results. The higher availability of sulfur in upland soil can be explained by the stability of the 'sulfate ion in the oxidized environment and by active microbial sulfur oxidation in soil.

Large areas in Southeast Asia have acid-sulfate soils that are largely unproductive because of severe acid soil conditions. To study microbial transformation of sulfur in an acid sulfate soil from South Vietnam (pH 3.5, organic matter 10%, sulfate 4,310 ppm), sterilized and nonsterilized soils were incubated under upland conditions at 35°C, at approximately field capacity. Each series consisted of four treatments: (1) soil + rice straw+ lime; (2) soil+rice straw; (3) soil + lime; **(4)** untreated soil.

In nonsterilized soil, the sulfate content of all four treatments increased and the soil pH decreased with time (Table 19). Sulfur-oxidizing bacteria were detected in the soil after **4** weeks of incubation and their numbers increased, reaching maximum populations after 12 weeks incubation.

Table 19. Changes in concentration of sulfate, pH, and number of sulfur oxidizing bacteria in acid-sulfate soil under upland condition.

Treatment	Weeks of incubation						
	0	2	4	6	8	10	12
				Concentration of sulfate (ppm)			
Soil + straw + lime	–	4860	4410	4940	5330	5480	5550
Soil + straw	–	4880	4230	4970	5360	5420	5540
Soil + lime	–	4220	4390	4630	4970	5160	5230
Soil	–	4310	4420	4510	4790	4950	5030
				pH			
Soil + straw + lime	4.10	4.23	4.01	3.88	3.83	3.85	3.75
Soil + straw	3.68	3.66	3.62	3.53	3.50	3.50	3.45
Soil + lime	3.93	4.01	3.87	4.00	4.10	4.10	4.10
Soil + straw	3.68	3.60	3.56	3.55	3.55	3.48	3.50
				Sulfur-oxidizing bacteria (no.)			
			x 10′			x 10^6	
Soil + straw + lime	0	0	0.83	1.8	7.2	9.0	9.3
Soil + straw	0	0	0.82	1.8	7.3	7.4	8.1
Soil + lime	0	0	0.81	1.9	5.4	6.4	6.7
Soil	0	0	0.93	2.9	4.9	5.9	6.3

In sterilized soil. sulfur content and pH remained constant. The organism isolated from acid sulfate soil was identified as *Thiobacillus neapolitanus* on the basis of its morphological and physiological characteristics.

The results suggested that the oxidation of soil sulfur may be attributed to microbial activities.

chapter eight

FUTURE EMPHASIS ON UPLAND RICE

Nyle C. Brady[1] *and Dilbagh S. Athwal*[2]

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Future emphasis on upland rice

Nyle C. Brady and Dilbagh S. Athwal

During its early years, the International Rice Research Institute placed primary emphasis on improving rice production under favorable soil, climatic, and cultural conditions. In the first production technology, the availability of water and nutrients was not a seriously limiting factor. This emphasis was appropriate; it was necessary to determine the potential of the rice plant under favorable as well as under limiting conditions.

But from the beginning of the Institute's programs, scientists were investigating ways to overcome several limiting factors. including moisture stress.

The short-statured, stiff-strawed varieties developed at IRRI and by national programs tillered profusely and responded remarkably to fertilizers and pesticides. Along with the production technologies, which were simultaneously developed to fit these newly engineered varieties, they triggered a significant productivity cycle in tropical rice. Where environmental conditions were favorable, this variety-technology combination revolutionized rice production, and similarly influenced the goals and perspectives of scientists and research agencies.

Despite the success of the new varieties and their custom-made technology, IRRI soon realized that these rices could express their full productive potential on no more than 25 or **30** percent of the world's rice land. IRRI scientists began to increase their emphasis on the development of rices and technologies for less-than-ideal conditions. This trend evolved into an institute-wide Genetic Evaluation and Utilization **(GEU)** program to help develop and share with national rice improvement programs large numbers of rices suited to a range of ecological and cultural conditions. **A** basic tenet of the **GEU** program is that genetic materials exist that can be exploited to develop improved rices that can resist, tolerate. or escape most of the factors which limit rice yields. Through the GEU program, scientists are incorporating into modern varieties as many as possible of these genetic traits. Our ultimate goal is to help national rice improvement programs develop and place seeds of these genetically tailored rices into the hands of all farmers, rich or poor, large or small.

Upland rice accounts for from 15 to 20 percent of the world's rice area. In many countries, such as Brazil or Nigeria, most of the rice is grown under upland conditions.

The problems faced by the upland farmer are many. Drought is a constant threat to upland rice, dictating a need for varieties with much higher drought tolerance than in lowland rice. Certain diseases, such as blast, are more severe under upland than under lowland conditions. Techniques by which large numbers of cultivars can be screened to determine sources of genetic resistance to these diseases are essentials in any effective research program. Insect control may sometimes be easier under .upland than under lowland conditions, but the upland farmer is less likely to have the money to purchase and apply the chemicals. Weed control is also a serious problem in upland rice fields because there is no standing water to flood out these unwanted competitors. Likewise, the fertilizer requirements for upland conditions may differ from those for paddy rice. Nutrients such as phosphorus, iron, and manganese are generally less available in upland than 'in submerged lowland soils. Nitrogen may have to be applied in a manner that will minimize denitrification losses.

Not only must scientists concerned with upland rice overcome serious biological constraints, but they must also focus on social and cultural problems. The upland farmer is usually poorer than his lowland neighbors, for example. His farming practices may not have changed for years – or even centuries – because neither the technology nor the financial resources have been available.

IRRI scientists are working cooperatively with scientists in national rice improvement programs around the world to help upland rice farmers. Through the intensified GFU approach, research can be concentrated on a number of plant characters needed for the improvement of upland rice. For example, IRRI is expanding its collection of drought-tolerant cultivars from around the world. These materials, along with thousands of accessions already in IRRI's germ plasm bank, and with IRRI breeding lines, will be screened for resistance, tolerance, and avoidance of drought. New and improved screening techniques are being developed for both greenhouse and field conditions. The relationships of drought resistance and morphological characteristics, such as rooting habits, are being studied.

Rices that are identified through the GEU program as resistant or tolerant of moisture stress will be shared with scientists in other countries. Upland rice nurseries will be included in an intensified International Rice Testing Program that will provide a large number of genetic materials from the national program and from IRRI, under a range of agro-climatic conditions. For each rice tested, information will be generated and shared on yield, fertilizer response, disease and insect resistance, eating quality, and agronomic characteristics.

Appropriate technology must be developed for upland rice farmers. More effective weed control through chemical, mechanical, and cultural methods will be investigated. Scientists will study the relationship among growth habits, plant height, and ability to compete with weeds. Response to various levels and methods of fertilizer applications under different soil and climatic conditions will be determined, along with improved methods of stand establishment.

Through research in controlled environments, scientists will study how upland rice plants respond to environmental stress. Physiological factors to be investigated include: hormonal control of the mechanisms by which rice plants escape and tolerate drought; factors that affect the opening and closing of leaf stomates; the effects of high temperature, wind, and humidity on plant performance; and the epidemiology of major upland rice diseases, such as blast.

Morphological characteristics, such as rooting habits, leaf angle, tillering potential, and length and size of panicles, will be studied in relation to actual field performance, under different cultural and soil conditions.

Research on the cropping system in which upland rice is grown will continue to receive high priority. We hope to determine if upland rice has a comparative advantage over alternate crops where moisture is limiting. Patterns and sequences of crops will be studied under different agro-climatic and socio economic conditions. Most of this research will be implemented on farmers' fields in cooperating countries.

In summary, upland rice research is a major component of IRRI's GEU program. Cooperatively with rice scientists around the world, we hope, in time, to help provide upland rice farmers with varieties and technologies that will better equip them to cope with their harsh environments.

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