AN OVERVIEW OF UPLAND RICE RESEARCH

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UPLAND RICE SOIL-PLANT-WATER RELATIONSHIPS

J. C. O'TOOLE and D. P. GARRITY

Rice (Oryza sativa L.) is a semiaquatic species, historically cultured in submerged soil, characteristic of river floodplains, deltas, and estuaries. There is little documentation on how upland rice cultural practices and varieties have evolved in many parts of Asia, Latin America, and Africa. The contrast between submerged–anaerobic soils and a free draining aerobic soil system involves differences in the chemical and physical status of water in the soil–plant–atmosphere continuum (SPAC) of upland rice. This paper examines the fundamentals of water status in the SPAC and reviews the limited information available on upland rice. Varietal improvement and agronomic practices are reviewed as a means of buffering upland rice against water deficits.

THE SOIL–PLANT–ATMOSPHERE CONTINUUM IN UPLAND RICE

During the past 15–20 yr, the multidisciplinary approach, which views soil, plant, and atmosphere as a continuum, greatly benefited research on the world's major cereal grains. These efforts to study the system, rather than its components, greatly increased our knowledge and often changed research planning, management, and interpretation. The study of water in the SPAC has increased our awareness of the interdependent mass and energy balances of crops. Gardner (1960), Cowan (1965), and Philip (1966) showed the beginnings of a unified interdisciplinary perspective. Numerous other reviews or texts have dealt with the continuum after those initial papers. Although the major cereals had substantial research on the SPAC and associated interpretation of crop water status, upland rice has rarely been the subject of such studies. This is not surprising because rainfed rice research usually suffers from lack of trained people and facilities.

Hsiao et al (1980) and Hsiao (1982) provided a conceptual review of water in the SPAC. Briefly, they emphasized that water moves passively from points of

Agronomist, Department of Agronomy; and associate agronomist, International Rice Testing Program, The International Rice Research Institute, Los Baños (mail address: P. O. Box 933, Manila), Philippines.

high to low water potential (Y): from the soil matrix to the root, into the root, through the vascular tissue to the stems and leaves, and finally to the atmosphere. These segments each have respective resistances to flow. The water movement rate along this pathway is a function of the difference in Y and the resistances across each segment. We can express flux or water movement rate using an electrical analog for any segment in the soil-to-atmosphere pathway or for the entire pathway:

$$q = \frac{\Psi_{soil} - \Psi_{leaf}}{R_{soil} + R_{root} + R_{shoot}}$$

where q is the rate of water movement (transpiration), $\Psi_{soil} - \Psi_{leaf}$ is the water potential gradient between soil and the site of evaporation from the leaf, and R_{soil}, R_{root}, R_{shoot} are the serial resistances within the pathway.

When soil water content is not limiting, the crop may transpire at rates governed by meteorological factors. During drought or below normal rainfall, the rate of water uptake will depend initially on soil water available to the root system. The limits of soil water availability are a combination of soil water-holding and transmission characteristics and crop root system factors such as rooting depth, root length density, and elongation growth.

Rooting depth and root length density were estimated by greenhouse studies and water extraction in the fields (IRRI 1973-1979, IRRI 1975b, Reyniers et al 1982). Detailed studies of water uptake by upland rice root systems in situ have only recently become available (Hasegawa and Yoshida 1982, Mambani and Lal 1983).

Yoshida and Hasegawa (1982) provide the most complete description of water uptake rates in the root system and the soil. According to them, rooting depths may vary from 0.5 m to 1.0+ m; root length density values are relatively high in the upper 0-10 cm depth, ranging from about 12 to 22 cm/cm^3; and the root system truncates to root length densities about 0.1 cm/cm^3 at depths from 0.4 m to >1.0 m, depending on the genotype.

Attention has also focused on axial resistance to water flow (Hasegawa 1981). Passioura (1982) noted the importance of this and the potential for varietal differences among rices. Thus, studies on water uptake by upland rice roots are vital in understanding crop water stress.

In addition to soil water status and location, root system configuration, and axial resistance, there is another element not often considered in SPAC studies

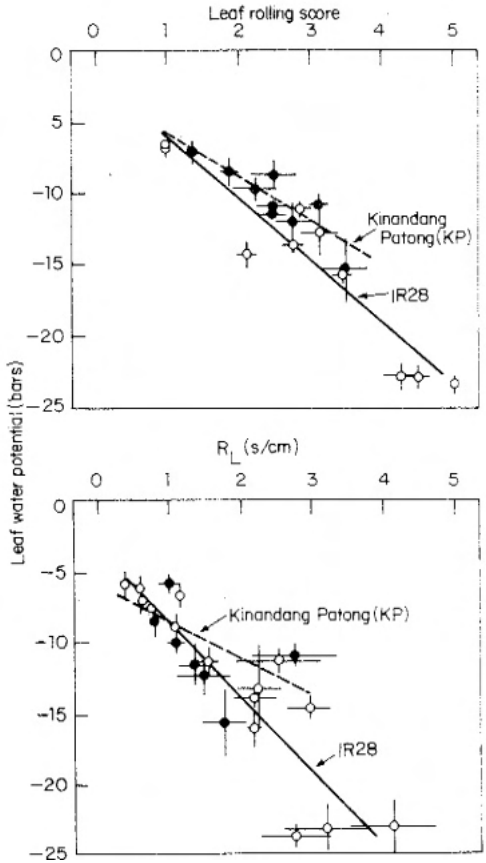
of upland crops. Depth to the water table may be a significant hydrologic factor if free water or the capillary fringe intersects the crop root zone. Because of varying hydrologic conditions in upland rice regions, the free water table (either constant depth or fluctuating with rainfall events) may have a significant effect on crop water status (Moormann et al 1977, Mambani and Lal 1983).

In addition to soil water conditions, radiation and evaporative demand of the atmosphere exert an influence on ψleaf. O'Toole and Moya (1981) demonstrated these interacting factors in determining ψleaf of upland rice. Upland adapted rice varieties were less sensitive to vapor pressure deficit during drought because of the higher root-to-shoot ratio of the upland varieties.

Thus crop water status (ψleaf) appears to be a passive physical process dependent on the flux rate. Radiation and atmospheric evaporative demand, ψsoil and the serial resistances of the pathway (see equation) influence flux rate. However, there is a lower limit of ψleaf which, when surpassed or exceeded, leads to two physiological responses affecting water and carbon dioxide diffusion: stomatal closure and leaf rolling. O'Toole and Cruz (1983) found a ψleaf threshold of $\simeq$-12 bars for initial changes in the two parameters. Both continued as ψleaf dropped from -12 to -24 bars. Between upland and lowland varieties, upland showed a greater response in both stomatal resistance and leaf rolling per bar of decrease in ψleaf. Figure 1 illustrates the difference in slope between the two varieties; however, this is only significant (0.05 level) in the leaf diffusive resistance- ψleaf relationship. Renard and Alluri (1981) found slmllar results when comparing the responses of five rice varieties to water stress. In their study, leaf rolling began at $\simeq$-13 + -15 bars.

These physiologically mediated responses decrease transpirational water loss, and stabilize or increase ψleaf within a particular range. Although stomatal closure and leaf rolling maintain ψleaf at relatively higher levels, carbon fixation decreases. Reduced growth and development is the price of maintaining relatively high ψleaf during periods of decreasing soil water availabllity.

The key factor for growth and yield is the crop water status. Both soil and atmospheric water status determine the ψleaf in the crop canopy. We know little about the transduction of ψplant into decreased growth rate or impaired yield development. Hsiao et al (1976) discussed some possible mechanisms within the context of a dynamic model of growth and yield.

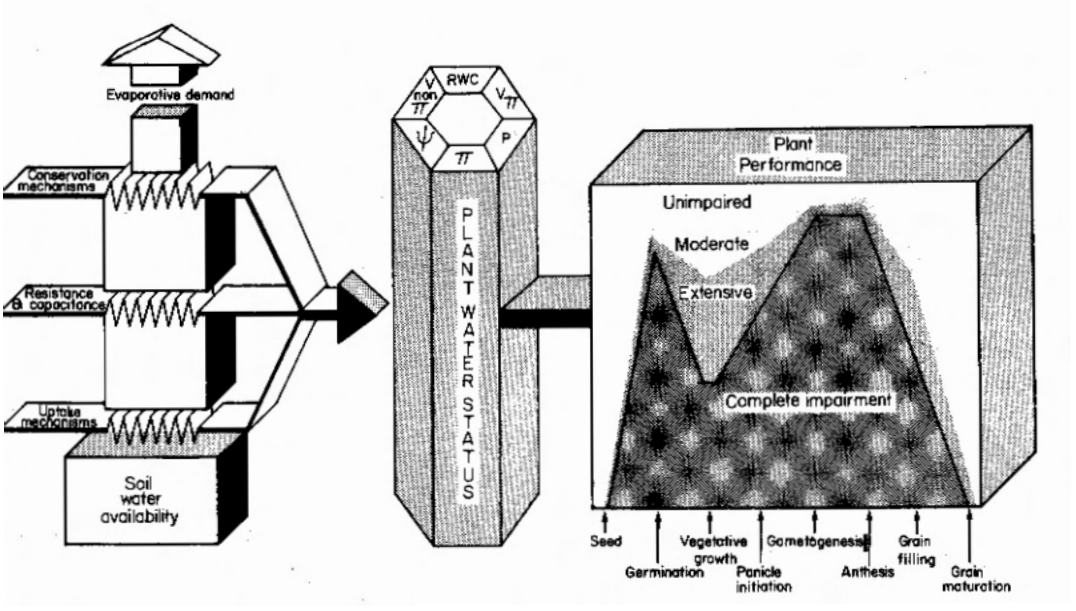


1. Relationship between leaf water potential and leaf rolling score, and leaf water potential and total leaf diffusive resistance (R_L) for 2 rice cultivars subjected to 29-day drying. Only mid-day measurements (n=12) from stress treatment are plotted. All data ± SE. X = leaf rolling score: IR28 $\hat{Y}$ = – 1.82-4.47 (X), r = .95** KP $\hat{Y}$ = –2.65-3.18 (X), r = .93**; (B) X = R_L: IR28 $\hat{Y}$ = –3.29-5.27 (X), r = .81**; KP Y = –5.89-2.69 (X), r = .48 (O'Toole and Cruz 1980).

WATER STRESS INTERACTTONS WITH GROWTH STAGES

Upland rice experiences some degree of water stress daily because it loses water by transpiration. The intensity and duration of decreased ψ_{leaf} will depend on the plant's external environment, but the effects on rice growth, development, and yield depend on its occurrence during yield-determining physiological processes and the tolerance level of those processes,

Figure 2 illustrates how the environmental water status influences the plant's internal water status and



2. Various plant characteristics which influence plant water status and their transduction into plant performance as affected by soil and climatic environments: ψ = total water potential; π = osmotic potential, P = turgor potential, RWC = relative water content, V_{π} = osmotic volume, $V_{non\ \pi}$ = nonosmotic volume (Steponkus et al 1980).

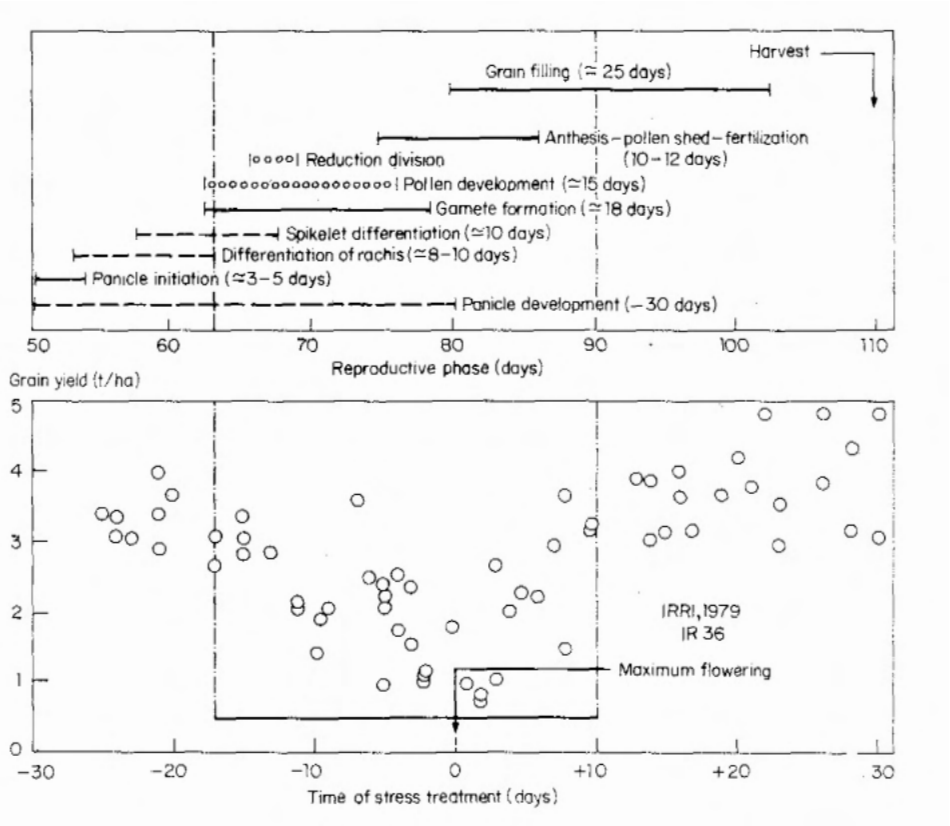
plant performance through the life cycle. There is a basal level of plant water that will not impair even the most sensitive processes or developmental stages. The range of plant water status between unimpaired plant performance and complete impairment illustrates which stages are most sensitive to decrease in plant water status,

Phenologically, the seed, usually at l0 – 15% moisture, is very tolerant of internal water deficit. However, the initial growth stages (germination and seedling establishment) are two of the most vulnerable parts of the crop life cycle. Severe stress at those stages could affect crop establishment and thereby reduce or negate yield. The vegetative growth stage is less sensitive to internal stress although water stress may reduce leaf or stem expansion and decrease photosynthetic activity. Field studies show plants that experience water stress at the vegetative growth stage can compensate in yield if the stress duration is short (O'Toole and Moya 1981, Reyniers et al 1982). Although an indirect cause, weed growth can also affect vegetative stage water stress and yield. During drought, weeds often maintain higher plant water potential (Cruz and O'Toole 1983) and continue to grow while rice growth slows or stops. We often attribute the resulting yield loss to weed competition although rice's greater sensitivity to water deficits may be the primary factor.

The reproductive stage, beginning at panicle initiation, increases in sensitivity to internal stress as the plant approaches flowering. Research shows yield losses are associated with water stress at the reproductive and grain filling stages in upland rice (Jana and De Datta 1971, Reyniers et al 1982, Cruz and O'Toole 1983).

IRRI began detailed studies on reproductive stage water stress in 1979. Figure 3 illustrates yield decline as plant water stress concides with the ≃ 65 days of reproductive and grain filling stages. All growth stages experienced the same soil and atmospheric conditions during the water stress period. Yield and percent fertility were lowest when ψ_{leaf} values of −19 to −24 bars coincided with anthesis (IRRI 1980, Hsiao 1982). Summarizing work done at Bouake, Ivory Coast, Reyniers et al (1982) stated that sensitivity to water stress was highest in the period 20 d before and after heading. They used about 60 varieties and found varietal differences for degree of susceptibility even at the crucial period of near heading to flowering. These findings agree with the response of a single variety in Figure 3.

The grain-fillingperiod, ≃20 – 25 days after flowering-fertilization, is dependent on current photosynthates and on stored assimilates translocated to the



3. Relationship between the processes occurring during the reproductive and grain-filling stages of rice development and yield decrease due to water stress. Yield reduction was greatest when maximum stress occurred at flowering (adapted from IRRI 1979).

panicle. When drought stress reduces photosynthesis, stem reserves may contribute to final grain weight, buffering yield at a growth stage when water deficits are common. Work with other cereals (Boyer and McPherson 1976, Garrity et al 1983) and several upland rice varieties documents this phenomenon. Reyniers et al (1982) used ^{14}C to measure apparent translocation of stem reserves to the grain in 14 upland rice varieties. They found significant differences among the varieties tested and proposed further study of this trait's value in breeding for drought resistance. Although no studies are available, stress effects at grain filling usually correlate with changes in grain weight.

IMPROVING WATER STRESS RESISTANCE IN UPLAND RICE

Varietal improvement

In the past 10 – 12 yr, there has been much research on breeding and selection for more drought – resistant up

land rices in Asia (Chang et al 1982), Africa (Reyniers et al 1982), and Latin America (Dr. Derly de Souza, pers. comm.).

We review the characteristics considered relevant to varietal improvement for drought resistance and which have a sufficient degree of variation in the germplasm to make breeding a rational approach.

O'Toole (1982) reviewed parameters of root systems whose alteration would improve rice water uptake during drought. A deep root system with increased root density at ≃below 30 cm, would allow continuous water uptake even if upper soil layers dried. Sufficient rooting depth variation appears available in the germplasm (IRRI 1975-80, Yoshida and Hasegawa 1982, Chang and Vergara 1975, Chang et al 1982, Reyniers and Binh 1978).

Although less known, genotypic variation exists for increased rooting ability in compacted soils (Kandasamy 1981). Further research on rooting systems in relation to soil problems such as impedance, toxicities, etc. will help design upland rice root systems to fit the environment and increase soil moisture use.

Shoot characteristics, which appear useful for breeding, and exhibit genotypic variation, are more difficult to identify. We need climate and soil descriptions of the drought-prone areas and knowledge of the growth stages at which drought occurs.

Another characteristic which needs attention is the amount of epicuticular wax on the leaves. O'Toole et al (1979) found a smaller amount of wax on rice leaves than on leaves of upland adapted species such as wheat or sorghum. The rice plant needs greater cuticular resistance to water loss from leaves and panicles. O'Toole and Cruz (1983) demonstrated a fivefold difference in epicuticular wax among 30 rice cultivars. However, even the highest levels per unit leaf area, found on African and Brazilian cultivars, were about 1/30 of that on sorghum. Thus a substantial increase in the wax may require unorthodox methods such as mutation.

The exserted rice panicle has a low resistance to transpiration and is extremely susceptible to drying when plant water flux is reduced. There are several ways to manipulate panicle morphology to protect it from sterility induced by water stress. Besides greater epicuticular wax deposits, a thicker siliceous layer merits attention. A fourfold range of variability existed among a group of cultivars sampled (Garrity 1984, this volume). The trichome density on the spikelet and the degree of exposure of the exserted panicle in relation to the leaf canopy also vary. These traits may have a significant influence on the spikelet microclimate.

Rice and other cereals exhibit osmotic adjustment in adapting to water stress (Steponkus et al 1982). The

limited work in rice has not established whether exploitable genetic differences exist for the trait.

This paper does not evaluate other shoot parameters, such as stomatal closure or leaf rolling, which are responses to decreased ψ_{leaf}. For further discussion of adaptive mechanisms in rice germplasm and their role in either maintaining relatively high plant water status or tolerating low levels, see O'Toole and Chang (1979) and O'Toole (1982).

Agronomic practices

Agronomic practices which alter water status in SPAC represent a second means of buffering the upland rice crop against water deficits. The principles of water harvesting and conservation are reviewed elsewhere in this volume. Published research on those topics for upland rice in Asia are rare.

The best water conservation practice known for rice culture is bunding. Small-scale rice farmers through many generations have bunded millions of hectares of Asian upland rice areas. In north India, where the rainy season is very short and undependable, farmers bunded vast areas of riceland but seldom submerge them. Bunding captures precipitation, but the actual rice culture is upland.

In most upland rice areas, drought results from significant gaps between rainfalls rather than low annual or seasonal totals. The major problem is that rice cannot exploit stored soil moisture effectively. Most techniques directing water to or impeding its loss from the root zone involve manipulating the soil as the crop water reservoir.

Modifying the microclimate may help retain crop water. Wind barriers decrease turbulence over a crop and increase the humidity. Both changes decrease evapotranspiration. Upland rice farmers also practice intercropping or mixed cropping with taller species such as maize or cassava. Two reports show that intercropping upland rice with maize favorably affected the water status of the rice crop (IRRI 1977, 1979). Figure 4 illustrates the buffering effect of a maize + rice intercrop on mean daily ψ_{leaf} of rice cultivars IR28 and Kinandang Patong. Figure 5 shows the change in air vapor pressure deficit and wind speed over rice intercropped between double rows of maize spaced 6 m apart.

These examples partially explain the traditional practice of growing rice in protected or intercropped stands. In drought-prone lowland or upland rice areas, this aerial modification is a side effect of fully using bunds or contours planted to cassava, maize, or firewood trees such as ipil-ipil (*Leucaena glauca*). A similar microclimatic change from shading and decreased wind speed may also contribute to successful upland rice crops under coconuts in the Philippines.

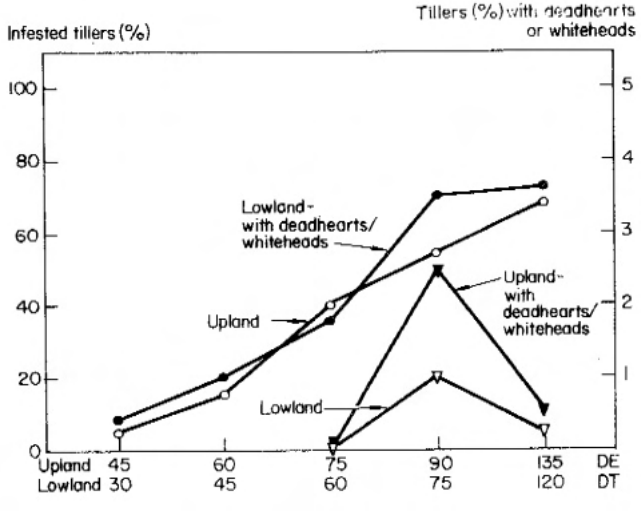
lers was provided at flowering stage when rainfall was negligible for about 3 weeks. In the lowland irrigated trial, 20-day-old seedlings were transplanted at 20-x 20-cm spacing. In bath trials, 30 kg of N and P were applied at land preparation. Percentages of infested tillers and deadhearts or whiteheads were recorded separately for each stem borer species at 2-week intervals starting at 30 DT.

M. separatella damage and infestation are shown in Figure 2. Percentages of infested tillers were similar for both trials. However, percent deadhearts or whiteheads was slightly lower in the lowland crop than in the upland.

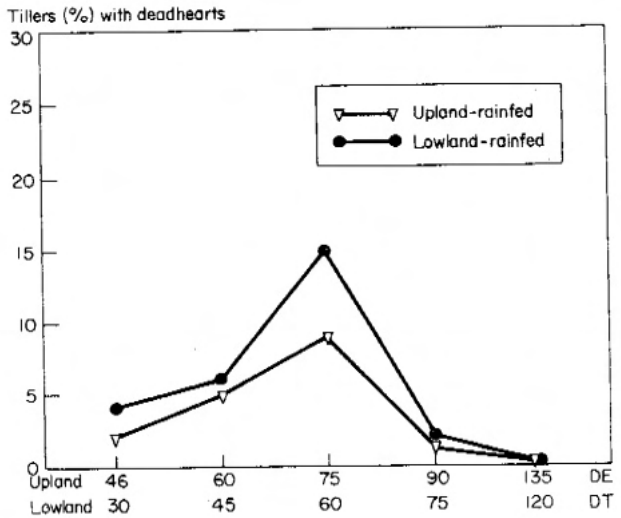
Damage caused by Diopsis spp. is shown in Figure 3. Diopsis damage was higher in the lowland crop than in the upland. Every tiller infested by Diopsis larva became a deadheart. Diopsis infestation increased from 30 to 60 DT and decreased at the onset of flowering.

Damage caused by C. partellus and S. calamistis is shown in Tables 4 and 5. C. partellus and S. calamistis infestation was more severe in upland fields than in lowland fields. Infestation began at flowering stage in both trials.

Stem borer incidence and damage were generally higher in lowlands. Borers that are major pests of upland crops such as sorghum and maize were more predominant in upland rice. These borers usually were C. partellus, S. calamistis, and sometimes armyworm Spodoptera exempta.



2. Infestation and damage, caused by *Maliarpha separatella,* at various plant ages of rice grown under upland rainfed and lowland irrigated conditions. DE = days after emergence. DT = days after transplanting.



3. Percent tillers with deadhearts, caused by *Diopsis* spp., at various plant ages of rice grown under upland rainfed and lowland irrigated conditions. DE = days after emergence, DT = days after transplanting.

CROP LOSS CAUSED BY STEM BORERS

The importance of rice stem borer species such as M. separatella and D. thoracica has been questioned. Researchers have rot found adequate criteria for assessing crop losses, especially for M. separatella. Results of crop loss assessment experiments using insecticides are frequently not significant because the yield differences between treated and untreated plots are small (WARDA 1981). In our rice stem borer studies we have emphasized crop loss assessment so as to determine the economic threshold for implementation of control measures.

M. separatella occurred in all Kenyan rice growing environments but was most abundant in lowland irrigated rice areas (80% of total borer population) (Table 1). But although percent tiller infestation was high, actual deadhearts or whiteheads damage was low (Fig. 2). Crop loss to M. separatella was not a direct function of percent of tillers infested or percent deadhearts or whiteheads. The damage was insidious. Several workers reported that unlike other stem borers, M. separatella did not produce the usual symptoms such as deadhearts or whiteheads (Akinsola 1980a). Infestation generally reduced plant vigor, caused fewer tillers to develop, and caused a higher proportion of unfilled grains (WARDA 1978).

The 1981 field trial investigated the relationship between levels of M. separatella infestation and crop

Table 4. Infestation and damage caused by *Chilo partellus* on upland rainfed and lowland irrigated rice.

Plant age[a]		Infested tillers[b] (%)		Tillers (%) with deadhearts or whiteheads[b]	
DE	DT	Upland	Lowland	Upland	Lowland
45	30	1	0	1	0
60	45	2	2	2	0
75	60	4	2	4	2
90	75	7	1	7	1
135	120	6	1	5	.5

[a]DE = days after emergence, DT = days after transplanting. [b]Average of 75 hills in 3 quadrats of 1 m^2 each.

Table 5. Infestation and damage caused by *Sesamia calamistis* on upland rainfed and lowland irrigated rice.

Plant age[a]		Infested tillers[b] (%)		Tillers (%) with deadhearts or whiteheads[b]	
DE	DT	Upland	Lowland	Upland	Lowland
45	30	2	0	1	0
60	45	5	0	3	0
75	60	12	1	10	1
90	75	13	2	13	2
135	120	9	2	7	2

[a]DE = days after emergence, DT = days after transplanting. [b]Average of 75 hills in 3 quadrats of 1 m^2 each.

yield components. On the susceptible variety, percent tiller infestation was linearly related to percent of empty grains. In another trial, three varieties with various levels of resistance were grown with early stage protection from *Diopsis* spp. Under natural *M. separatella* infestation, all three varieties differed in level of tiller infestation. Levels of damage in 35 randomly selected tillers and percent of empty grains and tunnel length due to larval feeding were recorded. Multiple regression analysis indicated that in all three varieties, tunnel length was highly related to percentage of empty grains. The slope of the linear prediction equation for the susceptible variety was greater than that for the resistant variety (Ho et al 1982).

In Malagasy, Brenière (1970) attempted to develop a method for assessing crop losses caused by stem borers, including *M. separatella*. In this method, stems with filled panicles, partly empty panicles, and dry empty panicles (whiteheads) were counted. The weights of fully developed and partly empty panicles were also recorded. Yield reduction ratio was calculated by

multiplying the total yield per hectare by the yield reduction ratio. Breniere's method gives loss in terms of real yield, but overestimates loss caused by M. separatella because it includes losses due to other causes. Under actual conditions, tillers infested by M. separatella larvae might produce partially healthy panicles that contain empty grains. Besides, percentage of empty grains fluctuated depending upon crop management. Therefore, separating stems with filled panicles from those with partly empty panicles is not possible for crops damaged by M. separatella.

Field case experiments to assess yield loss caused exclusively by M. separatella were conducted at MPFS. Introduced resistant variety IR579-48-6 and local susceptible variety Sindano were evaluated. Four 4- x 4-m plots of each variety were transplanted with 21-day-old seedlings at 20- x 20-cm spacing. Nitrogen and phosphorus fertilizers at 60 and 30 kg/ha were applied at land preparation. Immediately after transplanting, a 2.0- x 3.0- x 1.2-m nylon net cage was installed over each plot. For each variety, two cages were infested and two others were kept insect free. Cages were infested at 20, 30, and 45 DT. At 20 DT, 10 ready-to-hatch egg masses collected from the field were placed on 10 randomly selected hills (average of 50 eggs/egg mass). Five pairs of adults were released in each infested cage at 30 and 45 DT.

Yield component data were randomly collected from 10 hills in each plot. Percent of empty grains from clean and infested tillers from 30 random hills was recorded. Grains were harvested from a 4-m^2 area at the center of the plot and weighed for yield data. Actual yield loss was calculated based on percent of empty grains and number of whiteheads.

Yield components of M. separatella infested and uninfested rice crops in the field are shown in Table 6. Harvest index, number of grains per panicle, number of panicles per square meter, and percent reproductive tillers of healthy and damaged crops did not signifi-

Table 6. Yield components of 2 rice varieties, Sindano and IR579-48-6, with and without damage caused by *M. separatella* in field cage conditions.[a]

Variety[b]	Treatment	Weight of 1000 grains (g)	Harvest index[c]	Percent empty grain	Weight of filled grain/hill (g)
Sindano (S)	Infested	24.5 a	.76 a	13.5 a	19.1 a
	Uninfested	25.7 b	.84 a	4.2 b	20.5 a
IR579-48-6	Infested	19.7 a	.90 a	9.5 a	21.9 b
(R)	Uninfested	20.7 b	.88 a	5.7 b	21.9 b

[a] Means in a column followed by a common letter are not significantly different at 5% level. [b] S = susceptible, R = resistant. [c] Harvest index = $\frac{\text{dry weight of grain}}{\text{dry weight of straw}}$.

cantly differ. Weights of filled grains per hill did not differ between infested and uninfested crops. Therefore, M. separatella infestation only reduces plant vigor, decreases grain weight, and increases the unfilled-to-filled-grain ratio.

Total grain yield per hectare and yield reduction caused by M. separatella are shown in Table 7. If gross weights of harvested grain, including empty and filled grains, are taken and yields of infested and uninfested crops are compared, the resulting yield reduction is small (1 to 2%).

We propose that yield loss be assessed by percent empty grains, tiller infestation, and number of white-heads at harvest (App. 2, 3). Use of this method shows actual yield loss (column 4, Table 7) to be greater than apparent yield loss (column 3, Table 7). This indicates that damage caused by M. separatella is insidious and primarily affects crop vigor, leading to incomplete grain formation. Actual yield loss caused by this pest ranges from 4 to 7%, which is considered critical to subsistence farmers.

In Kenya, the second most important rice stem borer, Diopsis spp., attacks the rice crop during vegetative phase. Tillers attacked at this stage break from the lower part of the plant, then die. Attack at the vegetative stage can be compensated for as the plant ages (Akinsola 1973, 1980b). Feijen (1979) studied the relationship between damage and crop loss under different agronomic practices and at different growth stages. Results indicate that larval feeding can have negative or positive effects on rice yield and yield components, depending on time and level of attack, growing conditions, and variety.

The Diopsis population in rice schemes in Kenya is relatively low and fluctuates seasonally.

Further aspects of crop loss caused by stem borers on upland rainfed and Lowland irrigated rice are being investigated simultaneously with a bionomics study. We hope collaboration with national research institutes and international organizations will soon be estab-

Table 7. Grain yield and yield reduction of rice crops damaged by *M. separatella* in field cage conditions.[a]

Variety[b]	Total grain yield (kg/ha) (empty and filled)			Field grain yield (kg/ha)		
	Uninfested	Infested[c]	Difference	Uninfested	Infested[c]	Difference
Sindano (S)	2741 a	2712 a	29	2625 a	2447 a	178
IR579-48-6 (R)	2852 a	2797 a	55	2689 a	2587 a	102

[a]Means in a column and cows followed by a common letter are not significantly different at the 5% level. [b]S = susceptible, R = resistant. [c]Tiller infestation for Sindano and IR579-48-6 in infested plots were 85 and 62%, respectively.

lished for further studies on other aspects of rice crop management in East Africa.

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APPENDICES

Appendix 1. Rainfall and altitude in sites where rice is grown in Kenya.[a]

Site	Yearly rainfall (mm)	Number of years for average	Major rainy season[b] (mm)	Minor rainy season[b] (mm)	Altitude (m)
Mayenje, Tanga Kano, Aniko	1765	15	1005 (M-A)	760 (S-F)	1524
Mbita	921	19	538 (M-A)	383 (S-F)	1311
Ahero	1218	10	696 (M-A)	522 (S-F)	1219
Murinduko, Mwea	1479	43	921 (O-M)	558 (Ap-S)	1158
Mazeras	953	49	697 (Ap-S)	256 (O-M)	163
Matuga	1089	60	599 (Ap-S)	490 (O-M)	

[a]East African Meteorological Department, summary of rainfall in Kenya before 1972. Nairobi, Kenya. [b]Letters in parentheses indicate range of season from month to month (F = Feb, M = Mar, Ap = Apr, A = Aug, S = Sep, O = Oct).

Appendix 2. Equation for yield loss assessment due to tiller infestation by ***M. separatella.***

$$AYL_1/ha = (PU\ (1 - Eu) - Pi\ (1 - Ei\ (I - T + \frac{T}{r})) \times \frac{10^{-4}}{a}$$

where a = sampled area (m^2);
Pu = grain weight (filled and empty) from the uninfested crop;
Pi = grain weight (filled and empty) from the infested crop;
Eu = empty grain index of uninfested crop;
Ei = empty grain index of uninfested tillers of infested crops;
Eii = empty grain index of infested tiller;
r = compensatory ratio = $\frac{Ei}{Eii}$;
T = tiller infestation index; and
AYL_1 = actual yield loss due to tiller infestation.

Appendix 3. Equation for yield loss asssessment due to whiteheads caused by ***M. separatella.***

$$AYL_2/ha = (X_1 - X_2)\ P.\frac{ni}{n}$$

where X_1 = average grain weight (filled grains) from an uninfested hill;
X_2 = average grain weight (filled grains) from an infested hill;
P = plant population = number of hills/ha;
ni = number of whiteheads in sampled area;
n = total number of tillers (including whiteheads) in sampled area; and
AYL_2 = actual yield loss due to whiteheads.

WEED PROBLEMS AND WEED CONTROL IN UPLAND RICE IN TROPICAL ASIA

S. K. DE DATTA and M. A. LLAGAS

Weed problems are far more complex and serious in dry-seeded upland rice than in other rice production systems. Weeds can cause yield losses between 30 and 98% in tropical Asia. Considering this alarming weed situation, basic and applied research to help develop weed control technology suitable for a wide variety of local conditions is discussed. Physical, chemical, and cultural weed control methods are described.

Each method has advantages and disadvantages and no single method can solve all weed problems in all situations. Physical methods such as hand weeding and interrow cultivation may effectively control all weeds but require large amounts of labor. Selective herbicides such as butachlor, thiobencarb, oxadiazon, and propanil or 2,4-D, applied alone or in combination with other herbicides and other cultural practices, control upland rice weeds with varying success. Proper manipupulation of the crop-weed environment sometimes is effective and economical.

Integrated weed management combines two or more of these methods to minimize weed competition and maximize farmer resources without causing a harmful shift of weed species.

Economic feasibility, ecological soundness, and social relevance must be the ultimate goals of future weed control research efforts.

WEEDS OF UPLAND RICE

The kinds and extent of dominance of weeds in an area vary with the soil and biotic and climatic conditions. De Datta (1981) categorized common weeds in tropical upland rice in South and Southeast Asia as annual and perennial grasses, broadleaf weeds, and sedges (Table 1).

In India, Mukhopadhyay (1982) reported that grasses were the predominant weed group and *Echinochloa colona* (L.) Link was the most common grass. He also identified the following upland rice weeds: grasses

Agronomist and head, and research aide, Department of Agronomy, International Rice Research institute, Los Baños, Laguna (mail address: P. O. Box 933, Manila), Philippines.

Table 1. Some common weeds of tropical upland rice in South and Southeast Asia (De Datta 1981).

Annual grasses	
	Echinochloa colona (L.) Link
	Digitaria sanguinalis (L.) Scop.
	Eleusine indica (L.) Gaertn.
	Dactyloctenium aegyptium (L.) Beauv.
	Paspalum dilatatum Poir.
	Rottboellia exaltata L. f.
Annual broadleaf weeds	
	Ageratum conyzoides L.
	Amaranthus spinosus L.
	Calopogonium mucunoides Desv.
	Celosia argentea L.
	Commelina benghalensis L.
	Commelina diffusa Burm. f.
	Eclipta alba (L.) Hassk.
	Ipomoea triloba L.
	Portulaca oleracea L.
	Trianthema portulacastrum L.
Annual sedge	
	Cyperus iria L.
Perennial grass	
	Imperata cylindrica (L.) Beauv.
Perennial sedge	
	Cyperus rotundus L.

Echinochloa crus-galli ssp. hispidula (Retz.) Honda, Eleusine indica (L.) Gaertn., Dactyloctenium aegyptium (L.) Beauv., Brachiaria ramosa (L.) Stapf., Paspalum notatum Fluegge, and Cynodon dactylon (L.) Pers.; sedges Cyperus rotundus L., C. difformis L. Fimbristylis miliaceae (L.) Vahl now F. littoralis Gaud.; and broadleaf weeds Cyanotis axillaris (L.) D. Don, Digera arvensis Forsk., Bonnaya brachiata Link & Otto, and Melochia corchorifolia L.

In Indonesia, C. rotundus and Imperata cylindrica (L.) Beauv. were predominant (De Datta 1974, Eussen and Soerjani 1976).

Because of the diversity in weed vegetation in upland rice, weed control. measures vary with location. Therefore, developing appropriate weed control technology to provide control alternatives for a wide range of weed flora and socioeconomic conditions should be the major research objective for upland rice.

Competition between annual and perennial weeds

In an intermixed community of crop and weeds, there is competition for nutrients, water, space, and light. Competition begins when crop and weeds grow together and resources are insufficient to sustain the growth and development of either or both.

Annual and perennial weeds, depending on kind and density can compete harmfully with upland rice crops. Estimates of 30-98% yield losses caused by unchecked weed growth in upland rice have been reported (Mukhopadhyay et al 1972, Okafor and De Datta 1974, Carson 1975, Okafor 1979).

Okafor and De Datta (1974) evaluated the relative competitiveness of the persistent perennial sedge C. rotundus and annual weeds in upland rice. Weed-free, annual weed, C. rotundus, and C. rotundus plus annual weed communities were compared in broadcast and drilled IR5 rice in upland culture. In broadcast rice, grain yield was reduced 82% when all weeds were allowed to grow (Table 2). Annual weeds reduced yield 67%, and C. rotundus alone reduced grain yields 51%.

In a 1972-73 study, applying nitrogen to upland rice benefited C. rotundus more than the crop (Okafor and De Datta 1976). C. rotundus dry weight and rice grain yield reduction were maximum at 60 kg N/ha (Table 3).

Mukhopadhyay (1974) showed unhampered weed growth can remove 37 kg N/ha from the soil compared to 1.4 kg N/ha used by the crop. When nitrofen (2,4-dichloro-4'-nitrodiphenyl ether) was applied, weeds used 11 kg N/ha and rice used 80 kg N/ha (Table 4). The data suggest weeds can deprive rice of nutrients and cause poor yields.

WEED CONTROL IN UPLAND RICE

Physical methods

Hand weeding is still the most common weeding practice in many upland rice areas (Carson 1975, Okafor 1979 Sabio and Pastores 1981). Traditionally, two hand weedings at the right time is necessary to increase grain yield significantly. Hand weeding may be effective, but using it as the only control method has drawbacks. Moody and Mukhopadhyay (1982) found hand weeding slow and labor-intensive, expensive, impractical during bad weather, and difficult to perform at the early vegetative stage when grassy weeds are indistinguishable from rice seedlings. Weeds often regenerate when vegetative propagules are uncontrolled.

Yield trials to determine the effectiveness and econolnic suitability of selected herbicides and farmer weed control practices were conducted in farmer fields in Cavite, Philippines, from 1978 to 1980, Results showed that preemergence application of butachlor (N-bu toxymethyl-a-chloro-2',6'-diethylacetanilide) controlled weeds, resulted in a high C22 grain yield, and required less labor than hand weeding or modified farmers' practice (Table 5). The butachlor treatment

Table 2. Effect of weed density on grain yield of drilled and broadcast upland rice IR5 (Okafor and De Datta 1974).

Weed community	Drilled			Broadcast		
	Weed population[a] (no./m^2)	Grain yield (t/ha)	Yield reduction (%)	Weed population[a] (no./m^2)	Grain yield (t/ha)	Yield reduction (%)
Annual weeds	301	1.2	74	412	1.6	67
Cyperus rotundus	439	2.7	42	435	2.4	51
Annual weeds + *C. rotundus*	642	0.8	83	748	0.9	82
Weed free	79	4.7	–	34	4.9	–
LSD (5%)	67	0.4		67	0.4	

[a] 30 d after crop emergence.

Table 3. Effect of *Cyperus rotundus* L. competition on grain yield of upland rice grown at 3 nitrogen levels[a] (Okafor and De Datta 1976).

Nitrogen level (kg/ha)	*C. rotundus*		Grain yield (t/ha)	Yield reduction (%)
	Population/m^2	Dry weight (g/m^2)		
0	0	0.4	1.4	29
0	717	110.4	1.0	
60	0	0.5	4.0	35
60	717	217.1	2.6	
120	0	0.5	3.9	30
120	717	159.0	2.4	

[a]Av for 3 seasons.

Table 4. Nitrogen savings and yield increase of upland direct-seeded rice, by weed control method (Mukhopadhyay 1974).

Treatment	N uptake (kg/ha)		Yield (t/ha)
	Weeds	Crop	
Propanil, 3 liters/ha	21	65	3.0
Nitrofen, 4 liters/ha	11	80	4.0
Hand weeding, 3 times	5	78	4.0
Control (no weeding)	37	1	0

also earned the highest rate of return: US$300/ha, compared to US$156 for hand weeding and US$86 for modified farmers' practices.

The large amount of labor required for hand weeding makes it economically impractical, especially where labor is scarce and expensive. Moody and Mukhopadhyay (1982) suggest that hand weeding be combined with other weed control methods that substantially reduce labor requirements.

Interrow cultivation is also practiced as a weed control method in many areas, but its success depends greatly on climatic and edaphic conditions. It may not be feasible in heavy soil types after heavy rains (Moody and Mukhopadhyay 1982) and is even more difficult in broadcast-seeded upland rice.

Chemical control

Disadvantages of hand weeding and other physical weed control methods rnay be minimized by using herbicides. Preplant, preemergence, and postemergence; residual; follar; contact and translocated: and selective and nonselective herbicides have been evaluated for several years. Some have proved effective for upland rice.

Commonly evaluated chemicals include preemergence or residual butachlor, thiobencarb (S-4-chlorobenzyl

Table 5. Effect of weeding methods on rice yields and weding time in Lalaan, Cavite Province, Philippines, 1979 wet season[a] (Sabio and Pastores 1981).

Treatment	Application			Actual weeding time (labor days/ha)	Weeding time reduction (%)	Rice yield (t/ha)
	Rate[b] (kg ai/ha)	Time[c] (DS)				
		Chemical application	Weeding operation			
Butachlor fb hand weeding	2.00	3	40	186 a	72	2.5 a
Butachlor fb hand weedn	1.33	3	40	208 a	69	2.3 a
Hand-weeded check			28,43	664 b	0	1.9 b
Modified farmers' practice[d]			24, 29, 34	489 b	26	1.6 c
Unweeded check						0.2 d

[a]In a column, values followed by the same letter do not differ significantly at the 5% level. [b]ai = active ingredient. [c]DS = days after sowing. [d]Two animal cultivations plus one hand weeding.

diethylthiocarbamate), and nitrofen; postemergence or follar herbicides propanil (3',4'-dichloropropionanilide), 2,4-D (2,4-dichlorophenoxy1 acetic acid), and bentazon [3-isopropyl-(1H)-benzo-2,1,3-thiadiazin-4-one 2,2-dioxide]; and preplant nonselective herbicides paraquat (1,1'-dimethy1-4,4'-bipyridylium ion) and glyphosate [N-(phosphonomethyl) glycine].

Herbicide effectiveness depends on rate and time of application, weed floral composition, soil factors (soil pH, soil type), and climate (relative humidity, rainfall). Because these factors vary with location, a herbicide effective in one locality may perform poorly in another.

Moorthy and Dubey (1981) evaluated the effectiveness of some preemergence and postemergence herbicides for upland rice at Cuttack, India, during the 1979 wet season. Drought caused low yields during the experiments but treatment differences were evident. Butachlor (0.8 t/ha) produced a yield 100 kg higher than yields from the hand-weeded check and plants treated with piperophos (S-2-methyl-piperidinocarbonylmethyl OO-dipropyl phosphorodiothioate)-dimethametryn [2-(1,2-dimethylpropylamino)-4-ethyl-amino-6-methylthio-l,3,5,-tria-zine] and dinitramine (N'N'-diethyl-2,6-dinitro-4-trifluoromethyl-m-phenylenediamine) (Table 6). Oxadiazon [5-tert-butyl-3(2,4-dichloro-5-isopropoxyphenyl)-l,3,4-oxadiazol-2-one] had high weed control efficiency (83%), but treated fields yielded low because of the herbicide's phytotoxic effect on rice.

Butachlor effectively controlled *Paspalum scrobiculatum* L., *Cyperus iria* L., *C. dactylon*, *F. miliaceae*,

Table 6. Effect of herbicides on weed control and yield of upland rice (Moorthy and Dubey 1981).

Treatment	Rate of application[a] (kg ai/ha)	Dry weed weight (g/m^2)	Weed control efficiency[b] (%)	Grain yield (t/ha)
Piperophos - dimethametryn	2.0	67	80	0.7
Thiobencarb	2.0	123	59	0.4
Butachlor	2.0	58	81	0.8
Butralin	2.0	114	62	0.1
Diclofop-methyl	0.8	143	53	0.1
Dinitramine	1.5	85	72	0.7
Nitrofen	2.0	50	84	0.6
Oxadiazon	1.0	53	83	0.2
Penoxalin	2.0	163	46	0.4
Propanil	3.0	108	64	0.5
Two hand weedings	–	32	–	0.7
Unweeded check	–	303	–	0.1

[a]ai = active ingredient.

[b]Weed control efficiency= $\frac{\text{weed weight in unweeded treatment} - \text{weed weight in weed control treatment}}{\text{weed weight in unweeded treatment}} \times 100.$

and Oldenlandia umbellata L. but was ineffective against Echinochloa crus-galli (L.) Beauv., Digitaria longiflora (Retz.) Pers., and C. rotundus (Bhagat et al 1977).

Several workers have found butachlor an effective preemergence herbicide (Bhagat et al 1977, Schiller and Indhaphun 1979, Borgohain and Upadhaya 1980 Tasic et al 1980, Sabio and Pastores 1981). Butachlor performed better when it was combined with postemergence herbicides such as propanil (Carson 1975). The superior herbicidal activity and selectivity of propanil postemergence application make high grain yields possible (Mukhopadhyay 1967, Mukhopadhyay and Bag 1967, Mukhopadhyay et al 1971, Singh et al 1979, Victoria and Carvalho 1981, Singh et al 1982).

In their study of the effect of quantity and time of herbicide application on weed growth and rice yield, Singh et al (1979) found that propanil (2.0 kg/ ha) applied 24 d from sowiny controlled weeds best and gave the highest yield (Table 7). With propanil treatments, 1,000-grain weight, panicle length and number, and spikelet number per panicle were highest.

Generally, a combinatron of herbicide provided a broader spectrum of weed control than a single application. Propanil was more effective when used in combination with other herbicides. When tank-mixed with 2,4-D amine (2.88 + 0.36 kg/ha) and parathion-methyl (OO-dimethyl 0-4-nitrophenylphosphorothioate) (1.98 + 0.24 kg/ha), and applied 29 d after planting, it provi-

Table 7. Effect of herbicide level and time of application on rice growth and yield attributes, 1967 (Singh et al 1979).

Treatment	Titters (no./bush)	Panicle length (cm)	Grains (no./panicle)	Grain yield (t/ha)
Herbicide				
Propanil	21	20.1	81	5.3
Nitrofen	20	19.9	80	4.9
MCPA	17	17.4	64	4.0
2,4-D (Na-salt)	19	19.1	73	4.5
LSD (5%)	0.3	0.2	1.1	1.6
Herbicide level				
1.0	19	18.8	71	4.5
2.0	20	19.9	82	4.8
3.0	20	19.6	78	1.6
LSD (5%)	0.3	0.7	1.3	1.3
Time of application				
Preemergence	18	18.1	70	4.1
Postemergence	20	20.0	78	5.0
Preemergence + postemergence	20	19.8	77	4.9
LSD (5%)	0.3	0.2	0.1	0.3

Table 8. Control of weeds in upland rice by thiobencarb and propanil applied alone and in combination[a] (Carson 1975).

Treatment[b]	Application rate[c] (kg ai/ha)	Weed control (%)		Grain yield (t/ha)
		45 DS[d]	Harvest[e]	
Thiobencarb	1.0	54 a	19 d	3.9 ab
Thiobcncarb	2.0	66 a	28 d	4.6 a
Thiobencarb	3.0	68 a	45 c	4.3 ab
Thiobcncarb + propanil	1.0 + 2.0	80 a	13 b	5.4 a
Thiobencarb + propanil	2.0 + 2.0	86 a	90 a	5.6 a
Thiobencarb + propanil	3.0 + 2.0	86 a	90 a	5.5 a
Propanil	3.0	60 a	30 cd	5.0 ab
Propanil	4.0	78 a	14 b	4.0 ab
Weedy control	–	0 b	0 e	2.6 b
Hand weeding	–	90 a	90 a	4.6 a

[a]In a column, figures followed by the same letter are not significantly different at P = 0.05. [b]Herbicides were applied 10 d after seeding (DS). [c]ai = active ingredient.

[d]$\% \text{ control} = 100 - \frac{\text{no. of weeds per treatment}}{\text{no. of weeds per weedy control}} \times 100.$

[e]$\% \text{ control} = 100 - \frac{\text{fresh weight of weeds per treatment}}{\text{fresh weight of weeds per weedy control}} \times 100.$

ded best control of predominant weeds Acanthospermum hispidum D.C., Commelina sp., Cassia patellaria D.C., Indigofera hirsuta L., Cenchrus echinatus L., Portulaca oleracea L., and Sida sp. (Victoria and Carvalho 1981).

In field trials at Tamala, Ghana, in 1974, Carson (1975) found that propanil (2.0 kg/ha) applied 10 d after sowing in combination with thiobencarb at 1.0, 2.0, or 3.0 kg/ha provided a more sustained and broader spectrum of weed control through crop maturity and resulted in significantly higher yields (Table 8). Major weeds effectively controlled by these herbicide combinations included grasses Paspalum commersonii Lam. and Digitaria horizontalis Willd.; sedges Cyperus spp.; broadleaf weeds Commelina benghalensis L., Hyptis spicigera Lam., and Ludwigia suffruticosa Walt.

Combining propanil with butachlor (Borgohain and Upadhaya 1980), fluorodifen (4-nitrophenyl 2-nitro-4-trifluoromethylphenyl ether) (Fagade 1980), and nitrofen (Mukhopadhyay et al 1971) provided satisfactory to excellent weed control and grain yields equal to or higher than those of the hand-weeded check.

Scientists have been particularly interested in finding herbicides for difficult-to-control perennial weeds such as C. rotundus and I. cylindrica that threaten many upland rice farming areas in tropical Asia.

Dymrone [N-(α,α-dimethylbenzyl-N'-p-tolylurea] and methyldymrone[l-(α,α-dimethylbenzyl)-3-methyl-3-phenylurea] have been reported to effectively control C. rotundus (De Datta 1974, Takeaatsu et al 1976, De Datta 1980).

A 1977 wet season experiment at IRRI compared those two herbicides as well as perfluidone [1,1,1-trifluoro-N-2-methyl-4-(phenylsulphonyl) phenylmethane sulphonamide] and dinitramine for control of purple nutsedge and for selectivity in IR9575 rice (De Datta 1980). All four herbicides applied in combination with another herbicide significantly increased grain yields (Table 9). Methyldymrone was most effective against nutsedge and dinitramine performed poorly. A 2,4-D (1.0 kg/ha) postemergence application showed promise for C. rotundus control and did not injure rice. Plots treated with 2,4-D showed control equal to that in the hand-weeded check.

Another IRRI study evaluated dymrone performance (De Datta 1974). When incorporated immediately before seeding, dymrone gave excellent nutsedge control without damage to IR442-2-58 rice under upland culture (Table 10). A further application of bentazon (1.0 kg/ha) 7 d after rice emergence (DE) did not skgnificantly improve C. rotundus control because treatment with dymrone followed by (fb) butachlor fb bentazon and dymrone fb butachlor gave comparable yields. When applied alone, however, dymrone was ineffective against grasses and a butachlor follow-up was necesssary to improve weed control and grain yield.

In another experiment, Okafor (1979) obtained the highest grain yield of 4.8 t/ha using a combination of prodiamine [2,4-dinitro-N3-N3-dipropyl-6-(trifluoromethyl)-1,3-benzenediamine] (1.0 kg/ha) applied preemergence fb mecoprop [(±)-2-(4-chloro-2-methylphenoxyl) propionic acid] (1.0 kg/ha) applied at 20 DE. Prodiamine controlled annual Weeds completely and mecoprop effectively controlled C. rotundus.

New herbicides are continually being tested in fields, laboratories, and greenhouses to determine if they may be effectively integrated with other weed control methods to develop a sound weed technology package for farmer use (Singlachar 1977, Jikihara and Kimura 1979).

Cultural methods

The extent of weed infestation is influenced by variety type, row spacing, crop vigor, weed species, population density, time of weed emergence relative to the crop, soil fertility, climate, and duration of competition (Chisaka 1977 as cited in Lopez et al 1980). Therefore, improved weed control methods depend on the careful manipulation of these factors.

The effects of variety type, land preparation method, and direct weed control methods were evaluated during 1977-78 wet and dry seasons at IRRI in Los Baños, Philippines (Lopez et al 1980). One rototilling before plantiny (BP), 2 rototillings (one 15 d before planting [DBP] fb another BP), and 3 rototillings

Table 9. Effects of herbicides on control of *Cyperus rotundus* L. and grain yield of upland IR9575 rice.[a] IRRI, 1977 wet season (De Datta 1980).

Treatment[b]	Application		Weed weight[e] (g/m²)		Grain yield (t/ha)
	Rate[c] (kg ai/ha)	Time[d]	*Cyperus rotundus*	Annual weeds	
Two hand weedings	–	15 fb 30 DE	1 a	1 a	2.4 a
Dinitramine fb 2,4-D	1.5 fb 1.0	2 DS fb 15 DE	15 bc	7 bc	2.2 3
Dinitramine fb 2,4-D	1.5 fb 1.0	2 DS fb 20 DE	33 cd	16 bc	1.8 a
Methyldymrone fb dinitramine	3.0 fb 1.5	PPI fb 2 DS	55 cd	22 c	1.0 b
Perfluidone + dinitramine	2.0 + 1.5	2 DS	112 de	10 bc	0.6 b
Dymrone fb dinitramine	6.0 fb 1.5	PPI fb 2 DS	132 de	23 c	0.4 b
Dinitramine	1.5	2 DS	141 e	11 bc	0.0 c
Untreated control	–	–	6 ab	487 d	0.0 c

[a]Av of 4 replications. In a column means followed by the same letter are not significantly different at the 5% level. [b]fb = followed by; + means that the chemicals were applied separately about the same time. [c]ai = active ingredient. [d]DE = days after emergence, DS = days after seeding, PPI = preplanting incorporated. [e]Sampled at flowering of *C. rotundus.*

Table 10. Effects of dymrone on control of perennial nutsedge under simulated upland conditions (rice variety IR442-2-58).[a] IRRI, 1973 late dry season (De Datta 1971).

Treatment [b]	Rate [c] (kg ai/ha)	Total weed weight (g/m^2)	Dry weight of nutsedge (g/m^2)	Grain yield (t/ha)
Dymrone fb butachlor fb bentazon	10 fb 2 fb 2	98 ab	2 a	4.1 a
Dymrone fb butachlor fb bentazon	8 fb 2 fb 2	92 ab	5 ab	4.0 ab
Dymrone fb butachlor	10 fb 2	77 ab	3 a	4.0 ab
Dymrone fb butachlor	8 fb 2	54 a	6 ab	3.8 bc
Dymrone fb butachlor fb bentazon	6 fb 2 fb 2	79 ab	12 abc	3.5 cd
Butachlor fb bentazon	2 fb 2	62 a	18 abcd	3.5 cd
Dymrone fb butachlor	6 fb 2	64 a	14 abcd	3.4 d
Hand weeding	Twice	27 a	2 a	4.0 ab
Untreated	–	666 c	58 e	0.4 e

[a]In a column figures followed by the same letter are not significantly different at the 5% level. [b]fb = followed by. Dymrone was applied preplanting; butachlor, 3 d after seeding; bentazon, 7 d after crop emergence, [c]ai = active ingredient.

(15 DBP, 7 DBP, and BP) were tested on 3 upland rice varieties: IR43, a high tillering, high yielding semi-dwarf; lR9575, an intermediate-statured, high tillering, high yielding line; and Kinandang Patong, a tall, leafy, low tillering, low yielding traditional variety. Four weed control treatments -- dinitramine (2.0 kg/ha), dinitramine (1.0 kg/ha) fb propanil (2.0 kg/ha), 3 hand weedings (15, 30, and 60 DE), and an untreated check -- were superimposed on the main treatments.

Results indicated that increasing the number of rototillings reduced weed population and time required for weeding, and increased grain yield (Table 11). Variety type did not significantly affect amount of labor required for hand weeding or the number and dry weight of weeds. However, improved lines outyielded the traditional variety. This finding is supported by Moody and Mukhopadhyay (1982) who found a negative correlation between rice competitive ability and grain yield. They suggested that varieties that emerge rapidly, have high seedling vigor, and rapidly develop a canopy would compete more successfully with weeds than those lacking these characteristics.

Another promising preplant treatment is the stale-seedbed technique, which involves the destruction of successive weed flushes through chemical, mechanical, and manual means. This technique has been tried successfully in upland rice areas in India, Sri Lanka, and the Philippines (Moody and Mian 1979 as cited in Moody and Mukhopadhyay 1982). Mukhopadhyay and Rooj (1971) found that a preplant application of 2.5, 3.75, and 5.0 1iters paraquat/ha significantly reduced weed population and increased yields of Taichung Native 1 rice, proving paraquat efficiency in controlling all weeds.

Table 11. Effect of secondary tillage and cultivar type on weed control, total weeding time, and grain yield in upland rice. IRRI, 1977 wet season (Lopez et al 1980).

Treatment	Weed population (no./m^2)	Weed biomass (g/m^2)	Weeding time (labor-days/ha)	Grain yield[a] (t/ha)
Secondary tillage[b]				
One rototilling (5 DBP)	413	160	193	0.7 a
Two rototillings (15 DBP and BP)	358	131	155	1.1 a
Three rototillings (15 DBP, 7 DBP, and BP)	320	126	136	1.0 a
Variety[c]				
IR43	362	136	152	1.2 a
IR9575	365	136	169	1.3 a
Kinandang Patong	364	144	162	0.5 ab

[a] Figures followed by the same letter are not significantly different at the 5%, 1evel. [b] Av of 3 replications, 3 upland rice cultivars, and 4 weed control treatments. DBP = days before planting, BP = before planting: [c] Av of 3 replications, 3 secondary tillage, and 4 weed control treatments.

Field experiments in India 1971–73 sought to determine if seeding method and seed rate affect crop establishment and weed growth (Pillai 1981). Results showed a positive correlation between the characters studied. Upland rice yielded higher when drilled than when broadcast. That was corroborated by Tosh et al (1981) who showed that sowing in rows resulted in higher plant populations, lower weed dry matter accumulation, and higher grain yield than did broadcast sowing. Experiments by Ahmed (1979) yielded contradictory results. Increasing seed rate, however, increased yield irrespective of the planting method used (Pillai 1981).

When nutrient-responsive weeds exist in a rice population, techniques to improve crop utilization must be developed. Polthanee (1979) investigated the effect of rate and application method of nitrogen on weed growth. During the wet season, no significant difference was observed between application method (broadcast, band-placed or plowed-down broadcast) and weed weight. As nitrogen level increased, weed weight increased proportionately. Weed weight was highest when 90 kg N/ha was band-placed and lowest when 30 kg N/ha was broadcast.

The effectiveness of different timing and methods of nitrogen fertilization and weed control was investigated using rice variety Pusa 2-21 (Soundararajan and Mahapatra 1978). Application of 100 kg N/ha in 4 split doses (25-25-25-25), at basal, late tillering, panicle primordia initiation, and booting stages, increased grain yields significantly compared with slow-release fertilizers: sulfur-coated urea, neem cake-mixed urea, or nitrification inhibitor-treated urea. High yields were obtained with three hand weedings which controlled weeds most effectively.

Biological control

Successful weed control in cropped and uncropped areas by insects, pathogens, fish, snails, etc. has been reported. However, there is little published information on such weed control in upland rice.

One study of the weed host range of the rice root nematode *Hirschmanniella spinicaudata* Sch. Stek. 1944 conducted in Ibadan, Nigeria, may be relevant (Babatola 1980). Of 45 weed species tested, the 33 rated very susceptible included grasses *E. colona*, *C. dactylon*, and *Rottboellia exaltata* L.f.; broadleaf weeds *Commelina diffusa* Burm. f. and *C. nudiflora* L.; and sedges *C. rotundus* and *C. difformis*. Susceptible species were *Ageratum conyzoides* L. and *Alternanthera sessilis* (L.) DC. The results suggest *H. spinicaudata* may have potential in biological control of principal upland rice weeds.

Integrated weed management

Each weed control method discussed has advantages and disadvantages. No single method can solve all the weed problems in a given area primarily because of differences in weed vegetation and growth habits. It is necessary, therefore, to use a suitable combination of physical, chemical, cultural, and, possibly, biological control techniques to achieve maximum benefit through minimum crop and environmental injury and reasonable weed control.

A study at IRRI during the 1976 wet season investigated the interaction between weed control, yield, variety, tillage, and herbicide (IRRI 1978). Seeds of semidwarf IR43 rice, intermediate-statured IR9575, and tall MI-48 were row-seeded in plots that had been plowed and rototilled once, twice, or three times the same day. Weed control treatments were dymrone (6.0 kg/ha) fb terbuchlor (N-butoxymethyl-6'-tert-butyl-a-chloroacet-o-toluidide)-(l.0 kg/ha), 2 hand weedings, and an untreated check. IR43 and IR9575 yielded equally and significantly higher than MI-48, regardless of tillage frequency and weed control treatment (Table 12). Highest yields were from hand-weeded plots and plots treated with dymrone fb terbuchlor (Table 13).

The effects of sowing method, seed rate, and weed control were evaluated in eastern India (Tosh et al 1981) - Two sowing methods (broadcast and row-drilled), 3 seed rates (70, 90, and 110 kg/ha), and 4 weed control treatments (nitrofen, thiobencarb, propanil, and manual) were used. Results indicated that yields were higher when rice was row-drilled than when it was broadcast, irrespective of seed rate (Table 14). This was attributed to higher plant populations and lower weed dry weight. Increasing seed rate reduced weed dry matter accumulation and increased grain yield. Maximum grain yield was obtained with propanil which reduced weed dry matter accumulation from 325 g/m^2 to 69 g/m^2.

Integrating weed control methods has proven effective and is suggested as the best control system for upland rice (De Datta 1980, Lopez et al 1980, Sabio and Pastores 1981, Tosh et al 1981, Moody and Mukhopadhyay 1982). It has also been suggested that this approach can reduce buildup of difficult-to-control perennial weeds caused by the continuous use of the same herbicide, control method, and cropping system (De Datta 1980, Moody and Mukhopadhyay 1982).

CRITICAL RESEARCH NEEDS

The following upland rice weed control topics need to be studied:

1. crop-weed competition using traditional tall rice varieties and modern rices;

Table 12. Effects of tillage on weed control and grain yield of 3 upland rices. IRRI, 1976 wet season (IRRI 1978).

Tillage treatment[a]	IR43		IR9575		M1-48		Tillage mean[b]	
	Weed weight (g/m^2)	Yield (t/ha)	Weed weight (g/m^2)	Yield (t/ha)	Weed weight (g/m^2)	Yield (t/ha)	Weed weight[c]	Yield[d]
Plowing fb 1 rototilling	131	1.5 a	144	2.1	191	1.1	155 b	1.6 a
Plowing fb 2 rototillings	114	1.7	123	2.3	132	1.1	123 a	1.7 a
Plowing fb 3 rototillings	124	1.8	110	2.1	105	1.0	113 a	1.6 a
Mean[b]	123 a	1.6 a	125 a	2.2 a	143 a	1.1 b		

[a]fb = followed by, [b]In a column or row means followed by the same letter are not significantly different at the 5% level. [c]Weeds sampled 50 d after rice emergence. [d]Av of 4 replications, 3 weed control treatments.

Table 13. Effects of tillage and weed control treatment on grain yield of upland rice.[a] IRRI, 1976 wet season (IRRI 1978).

Weed control treatment	plowing fb 1 rototilling		Plowing fb 2 rototillings		Plowing fb 3 rototillings		Weed control mean[b]	
	Weed weight (g/m^2)	Yield (t/ha)	Weed weight (g/m^2)	Yield (t/ha)	Weed weight (g/m^2)	Yield (t/ha)	Weed weight[c]	Yield[d]
Two hand weedings	35	2.3	22	2.4	25	2.3	28 a	2.3 a
Dymrone fb terbuchlor (6.0 fb 1.0 kg/ha)	181	1.9	119	2.1	109	2.0	136 b	2.0 a
Untreated control	251	0.5	232	0.7	203	0.5	289 c	0.5 b
Mean[b]	155 b	1.6 a	124 a	1.7 a	112 a	1.6 a		

[a] fb = followed by. [b] In a column or row means followed by the same letter are not significantly different at the 5% level. [c] Sampled at 50 d after rice emergence. [d] Av of 4 replications, 3 rice cultivars.

Table 14. Effects of sowing method, seed rate, and weed control treatments on rice yield and weed growth (Tosh et al 1981).[a]

Treatment	Plant population 10 DS (no./m^2)	Dry matter accumulation of weeds, 60 DS (g/m^2)	Grain yield (t/ha)
Sowing method			
Broadcast	108	171	1.5
Row	144	157	1.8
Seed rate (kg/ha)			
70	116	152	1.6
90	128	143	1.4
110	146	104	2.0
Weed control method			
Nitrofen, 2 DS (1.5 kg/ha)	151	152	1.6
Thiobencarb, 2 DS (1.5 kg/ha)	112	167	1.2
Propanil, 15 and 30 DS (1.5 kg/ha each)	158	69	2.8
Manual	146	77	2.1
Unweeded control	156	325	0.6

[a]DS = days after sowing.

2. factors that affect the competitive abilities of upland rice and seeds;
3. the biology of major upland weeds, particularly difficult-to-control weeds such as C. rotundus, I. cylindrica, Mimosa invisa, and Paspalum sp.;
4. effect of chemical weed control methods on crop and weed physiology (e.g. persistence of herbicides in crop and weeds);
5. effect of physical-environmental factors such as sunlight, temperature, and rainfall on weed biology and physiology;
6. development of resistant weed strains or ecotypes following continuous use of the same weed control method and its effect on the environment, particularly if the same or similar herbicides have been used;
7. use of biological agents such as insects and pathogens for weed control, and incorporating it into an integrated weed management program;
8. tolerance of different weed species for environmental stresses such as moisture stress and nutrient toxicity or deficiency,
9. the role of allelopathy in the control of difficult weeds in upland rice;
10. weed management strategies for various upland rice-based cropping systems;
11. economical and effective chemical control of major annual and perennial weeds by using herbicide combinations integrated with cultural practices determined by soil moisture supply, tillage, and postplanting operations; and

12. economics and effectiveness of innovative weed control techniques compared with those of existing techniques under various weeding regimes and socio-economic situations.

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UPLAND RICE WEED PROBLEMS IN IVORY COAST

P. MARNOTTE

In the humid tropical environments of Ivory Coast, weed invasion is the main reason for itinerant agriculture. Weed removal is easy the first year of cultivation after clearing. However, after a few years, and before fertility problems arise, weed invasion is so serious that fields are abandoned.

Weeds affect yield by competing for water, light, CO_2, and nutrients. Weeds also have poorly understood allelopathic capabilities (toxic emissions into the rhizosphere). Weeds also cause harvesting difficulties and their seed can contaminate harvested crops (*Rottboellia exaltata* seed mixed with rice seed).

The extent of competition depends on the weed species, crop vigor, weed development and growth speed. Weed biomasses of 15 t dry matter/ha have been measured at upland rice harvest. It is important to determine the precise composition of weed flora in a field so that the proper control strategy can be selected (Fig. 1).

In Ivory Coast, there are many weeds in upland cultivation. Poaceae, Cyperaceae, and Commelinaceae for the monocotyledons and Asteraceae for the dicotyledons are the families most often represented. The appendix provides a list of principal weeds in Ivory Coast.

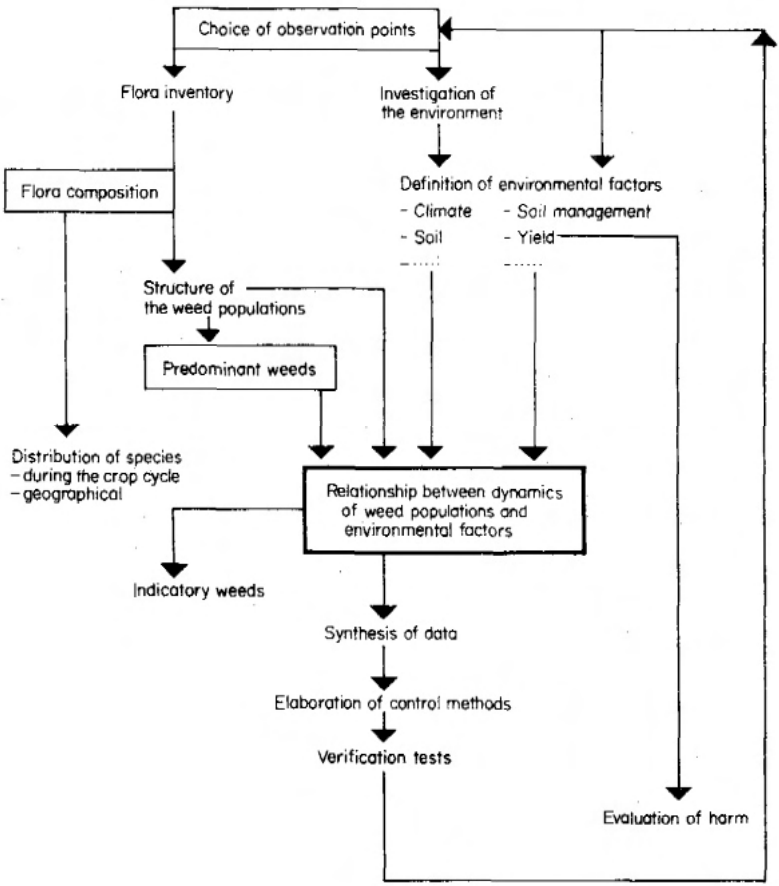
Studies of weed ecology enable analysis of the different species in relation to climate, soil, and other variations (Fig. 2).

Weed invasion studies during the entire crop rotation, and the constraints caused by weeds should be considered for the whole farming system,

Good seedbed preparation, adjustment of cycles, and crop rotation will help diminish weed competition and reinforce crop growth (Fig. 3).

The threshold of harm is the weed density that significantly reduces yield. Merlier found that when *Digitaria horizontalis* density reached 5 plants/m^2, yield losses were substantial. In a farming environment, this critical density is often exceeded and weed control is necessary.

Weed scientist, IDESSA—DCV, B. P. 635 Bouaké, Ivory Coast.

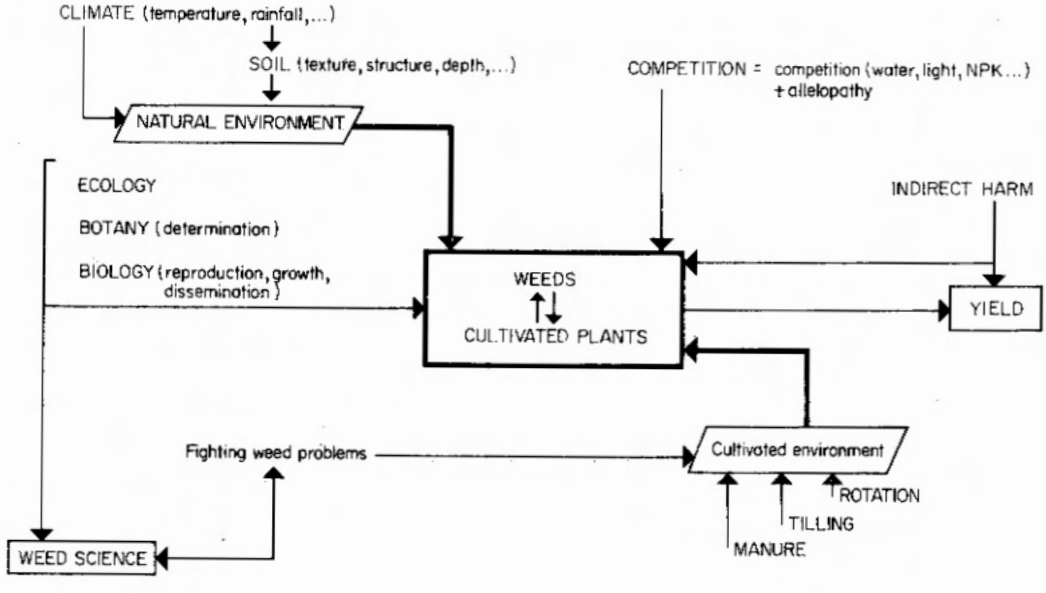


1. Procedure for studying the ecology of weed populations.

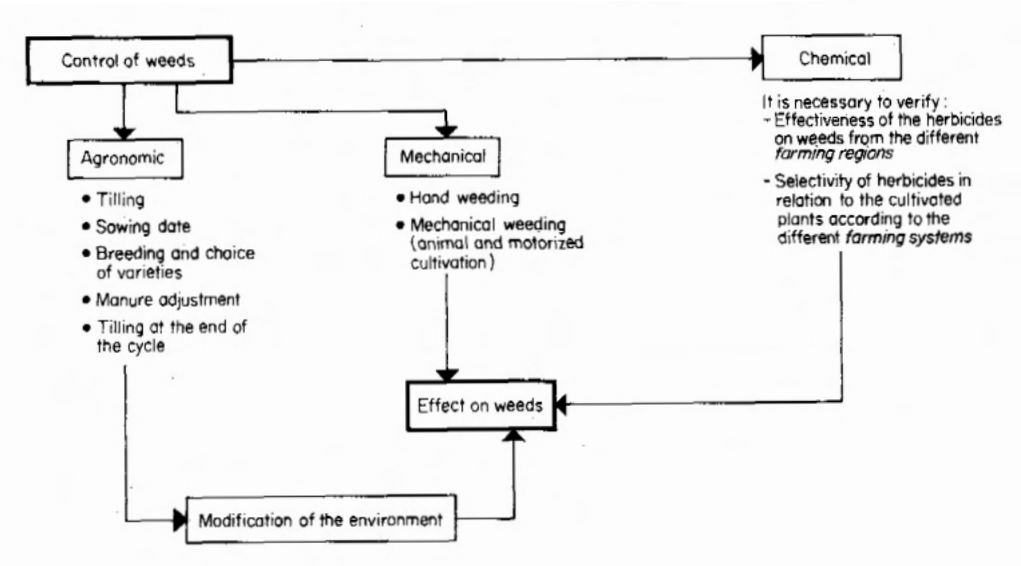
MANUAL AND MECHANICAL WEEDING

Manual weeding in upland rice is the most common weed control method in Ivory Coast. It is a labor-intensive, time-consuming operation (20-45 days/ha), that causes a bottleneck in the cropping calendar that can be resolved only by abundant manpower. Labor requirements increase when the fields have been cultivated for a long time and rainfall is high. Manual weeding is facilitated by sowing in rows rather than broadcast seeding.

Production intensification cannot be successful without more effective weed control such as mechanical weeding with animal or tractor power. Mechanical weeding can be enhanced for upland rice by sowing in twin rows (0.20 and 0.60-m interrow spacing) to allow the tractors' wheels to harmlessly pass through.



2. Relationships between weeds, cultivated plants, and environment.



3. Methods of fighting weed invasion.

CHEMICAL WEEDING

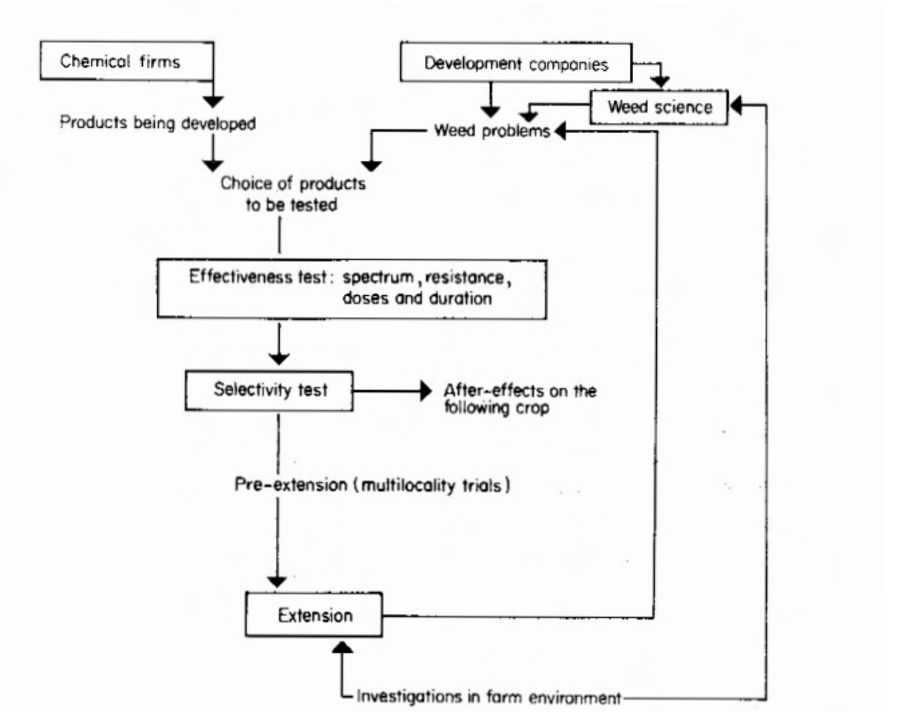
Chemical weeding is not yet widely used in Ivory Coast. However, herbicides are being tested in collaboration with chemical manufacturers (Fig. 4). Tests include:

- comparing chemical effectiveness,
- determining effective doses and the application periods,
- finding the weeds controlled by a product and the resistant weeds,
- establishing the chemical duration for various soil-climatic conditions, and
- evaluating the visible symptoms of plant toxicity.

The residual effectiveness of a herbicide is highly dependent on crop vigor. It is important to associate herbicide use with rice varieties that cover the ground rapidly and completely to prevent weed germination after the chemical has lost its effectiveness.

For products showing effectiveness against weeds, it is necessary to verify that they do not reduce rice yield. Because upland rice compensates for slight herbicide toxicity at early growth stages, certain products with slight toxicity to rice may still be recommended for farmer use. Tests on after-effects ensure that the treatment is harmless to the next crop in the rotation.

After testing, the effective herbicides are recommended for farmer use. Farmer acceptance of a herbicide is not automatic. Herbicide purchase is something new for most farmers and, often, they do not have enough



4. Procedure for testing a herbicide.

money for such purchases. In Ivory Coast, herbicides for upland rice cost about $45/ha.

The conditions for herbicide use are very exacting. Underdosing can make the herbicide useless, and overdosing can damage rice plants. Determining the optimal treatment period is critical for most post weed germination products, which must be applied at a precise stage of weed development. Postsowing and pregermination products, applied right after sowing, are easier to use.

Extension workers have the important job of training farmers to gauge and set up the spraying equipment. The introduction of low-volume sprayers (20 liters of mixture/ha) has reduced the water transport problem which was usually insurmountable when a treatment required several hundred liters of water/ha.

Herbicide products currently recommended for use in northern Ivory Coast are in Table 1.

Complete control of upland rice weed problems is not yet possible with only one herbicide treatment. However, treatments at the beginning of the cycle enable the rice to take root rapidly and to gain a competitive edge against weeds, which may start developing 30 to 45 days after sowing. Furthermore, complementary hoeing can be done rapidly.

Table 1. Herbicides recommended in Ivory Coast in 1982 for upland rice weeding.[a]

m. a.	Commercial products	Manufacturer	Amount	Formulation
Pregennination				
Oxadiazon	Ronstar 25 CE	Rhone-Poulenc	250 g/liter	CE
Butralin	Amex	Ciba-Geigy	480 g/liter	LP
Postgermination				
Thiobencarb + propanil	Tamariz	Sofaco-Procida	120 + 216 g/liter	LP
Bentazon + propanil	Basagran LP2	BASF	160 + 340 g/liter	CE

[a]CE = emulsifiable concentrate, LP = liquid for spraying,

Herbicides must be adapted to specific local problems. For example, Euphorbia heterophylla is a particular problem near Mankono, Ivory Coast.

Investigations are under way in Ivory Coast to:

- study the effect of herbicides on weeds and on crop production, and
- verify how reduced labor requirements of modern weed control methods affect local farming systems.

Appendix. Principal weeds in Ivory Coast.

CRYPTOGAMIC PTERIDOPHYTES

AZOLLACEAE

Azolla africana

MARSILEACEAE

Marsilea diffusa

PHANEROGAMIC ANGIOSPERMS

Monocotyledons

AMARYLLIDACEAE

Crinum ornatum

ARACEAE

Pistia stratiotes

Stylochiton ap.

CANNACEAE

Canna indica

COMMELINACEAE

Commelina benghalensis
C. diffisa
C. erecta
C. forskalaei
C. lagosensis
C. nigritana
Cyanotis lanata

CYPERACEAE

Bulbostylis barbata
Cyperus amabilis
C. difformis
C. esculentus
C. iria
C. rotundus
C. sphacelatus
Eleocharis mutata
Fimbristylis dichotoma
F. exilis
F. littoralis
Fuirena umbellata
Kyllinga erecta
K. squamulata
Lipocarpha sp.
Mariscus alternifolius
Scleria sp.

DIOSCOREACEAE

Dioscorea sp.

LEMNACEAE

Lemna paucicostata

LILIACEAE

Gloriosa superba

MARANTACEAE

Thaumatococcus daniellii
Thalia welwitsehii

POACEAE

Acroceras zizanioides
Andropogon gayanus
Aristida adescensionis
Axonopus compressus
Brachiaria deflexa
B. distichophylla
B. lata
B. ramosa
B. xantholeuca
Cenchrus biflorus
Chloris pilosa
C. prieurii
Ctenium elegans
Cymbopogon giganteus
Cynodon dactylon
Dactyloctenium aegyptium
Digitaria horizontalis
Echinochloa colona
E. crus – pavonis
Eleusine indica
Eragrostis aspera
E. ciliaris
E. tenella
E. tremula
Hackelochloa granularis
Hyparrhenia rufa
Imperata cylindrica
Ischaemum rugosum
Leersia hexandra
Loudetia phragmitoides
Microchloa indica
Oryza barthii
O. longistaminata
Panicum brevifolium
P. laetum
P. laxum
P. maximum
Paspalum conjugatum
P. orbiculare
P. polystachyum
P. vaginatum
Pennisetum pedicellatum
P. purpureum
P. subangustum
P. violaceum
Perotis indica
Rhynchelytrum repens
Rottboellia exaltata
Sacciolepis africana
Schizachyrium exile
Schoenefeldia gracilis
Setaria barbata
S. pallide – fusca
Sporobolus pyramidalis

PONDETERIACEAE

Eicchornia crassipes
E. natans
Heteranthera callifolia

TACCACEAE

Tacca involucrata

ZINGIBERACEAE

Aframomum sp.
Costus sp.

Dicotyledons

ACANTHACEAE

Asystasia gangetica
Dicliptera verticillata
Monechma ciliatum
Nelsonia canescens
Peristrophe bicalyculata

AMARANTHACEAE

Achyranthes aspera
Aerva lanata
Alternanthera repens
A. sessilis
Amaranthus graecizans
A. spinosus
A. viridis
Celosia trigyna
Cyathula prostrata
Gomphrena celosioides
Pandiaka heudelotii
Pupalia lappacea

ASTERACEAE

Acanthospermum hispidum
Ageratum conyzoides
Aspilia africana
A. bussei
A. helianthoides
Bidens pilosa
Blumea aurita
Centaurea perrottetii
Chrysanthellum americanum
Conyza aegyptica
Crassocephalum rubens
Eclipta prostrata
Emilia sonchifolia
Erigeron floribundus
Ethulia conyzoides
Eupatorium odoratum
Lactuca taraxacifolia
Laggera pterodonta
Melanthera scandens
Mikania cordata
Spilanthes uliginosa
Siruchium sparganophorum
Synedrella nodiflora
Tridax procumbens
Vernonia cinerea
V. pauciflora
V. perottetii
Vicoa leptoclada

BORRAGINACEAE

Heliotropium bacciferum
H. indicum

CAESALPINIACEAE

Afzelia africana
Cassia hirsuta
C. mimosoides
C. absus
C. obtusifolia
C. occidentalis
Daniellia oliveri
Detarium microcarpum
Mezoneurum benthamianum
Piliostigma thonningii

CAMPANULACEAE

Cephalostigma perrottetii

CAPPARIDACEAE

Cleome Ciliata
C. viscosa
Gynandropsis gynandra

CARYOPHYLLACEAE

Polycarpaea eriantha
P. linearifolia

COCHLOSPERMACEAE

Cochlospermum planchonii

COMBRETACEAE

Terminalia sp.

CONVOLVULACEAE

Convolvulus microphyllus
Evolvulus alsinoides
Ipomoea aquatica
I. eriocarpa
I. heterotricha
I. involucrata
I. nil
I. pes-tigridis
I. quamoclit
I. triloba
I. vagans
Jacquemontia tamnifolia
Merremia aegyptia
M. tridentata

CUCURBITACEAE

Colocynthis vulgaris
Cucumis melo
Melothria mederaspatana

EUPHORBIACEAE

Acalypha ciliata
A. segetalis
Caperonia senegalensis
Chrozophora senegalensis
Croton hirtus
C. lobatus
Euphorbia convolvuloides
E. heterophylla
E. hirta
E. hyssopifolia
E. prostrata
Jatropha gossypifolia
Mallotus oppositofolius
Micrococca mercurialis
Phyllanthus amarus
P. maderaspatensis
P. niruri
P. pentandrus
Securigera virosa

FABACEAE

Abrus precatorius
Alysicarpus rugosus
Calopogonium mucunoides
Centrosema pubescens
Crotalaria goreensis
C. juncea
C. retusa
C. vogelii
Desmodium adscendens
D. asperum
D. gangeticum
D. ramosissimum
D. tortuosum
D. triflorum
D. velutinum
Dolichos chrysanthus
Eriosema glomeratum
E. psoraloides
Erythrina senegalensis
Indigofera dendroides
I. hirsuta
I. pilosa
Mucuna puriens
Pueraria phaseoloides
Sesbania pachycarpa
Stylosanthes sp.
Tephrosia bracteolata
T. elegans
T. flexuosa
T. ehrenbergiana
T. linearis
Uraria picta
Zornia glochidiata

FICOIDACEAE

Sesuvium portulacastrum
Trianthema portulacastrum

HYDROLEACEAE

Hydrolea floribunda
H. glabra

LAMIACEAE

Haumaniastrum caeruleum
Hoslundia opposita
Hyptis lanceolata
H. spicigera
H. suaveolens
Leucas martinicensis
Neophytis paniculata
Ocimum basilicum
O. canum
Platystoma africanum
Solenostemon monostachyus

LOGANIACEAE

Spigelia anthelmia

LYTHRACEAE

Ammannia prieuriana

MALVACEAE

Abutilon sp.
Hibiscus asper
Malvastrum coromandelianum
Sida acuta
S. alba
S. cordifolia
S. linifolia
S. rhombifolia
S. urens
S. veronicaefolia
Urena lobata
Wissadula amplissima

MELASTOMACEAE

Dissotis rotundifolia

MIMOSACEAE

Acacia sp.
Albizzia zygia
Dichrostachys glomerata
Mimosa invisa
M. pigra
M. pudica
Parkia biglobosa
Schrankia leptocarpa

MOLLUGINACEAE

Glinus oppositifolius
Mollugo nudicaulis

MORACEAE

Ficus capensis
F. exasperata
Morus mesozygia

NYCTAGINACEAE

Boerhavia diffusa
B. erecta

NYMPHEACEAE

Nymphaea lotus

OCHNACEAE

Lophira lanceolata

ONAGRACEAE

Jussiaea abyssinica
J. erecta
J. repens
J. stenorraphe
J. suffruticosa

OXALIDACEAE

Biophytum petersianum
Oxalis corniculata

PAPAVERACEAE

Argemone mexicana

PASSIFLORACEAE

Passiflora foetida

PEDALIACEAE

Ceratotheca sesamoides
Sesamum radiatum

POLYGALACEAE

Polygala arenaria
Securidaca longipedunculata

POLYGONACEAE

Polygonum lanigerum

PORTULACEAE

Portulaca grandiflora
P. oleracea
P. quadrifida
Talinum triangulare

RUBIACEAE

Borreria latifolia
B. ocymoides
B. scabra
B. stachydea
B. verticillata
Kohautia grandiflora
Mitracarpum scabrum
Nauclea latifolia
Oldenlandia corymbosa
O. herbacea
O. lancifolia
Pentodon pentandrus

ROSACEAE

Parinari curatellifolia

SAPINDACEAE

Cardiospermum halicacabum
Paullinia pinnata

SAPOTACEAE

Vitellaria paradoxa

SCROFULARIACEAE

Bacopa decumbens
Lindernia numulariifolia
Scoparia dulcis
Striga asiatica
S. hermonthica

SOLANACEAE

Datura metel
Physalis angulata
P. micrantha
Schwenkia americana
Solanum nigrum
S. torvum
S. verbascifolium

SPHENOCLEACEAE

Sphenoclea zeylanica

STERCULIACEAE

Melochia corchorifolia
M. melissaefolia
Waltheria indica

TILIACEAE

Corchorus aestuans
C. fascicularis
C. olitorius
C. tridens
C. trilocularis
Triumfetta pentandra

TURNERACEAE

Wormskoldia pilosa

ULMACEAE

Trema guineensis

URTICACEAE

Fleurya aestuans
Pouzolzia guineensis

VERBENACEAE

Lantana camara
Lippia multiflora
Premna sp.
Stachytarpheta augustifolia

VIOLACEAE

Hybanthus thesiifolius

ZYGOPHYLLACEAE

Kallstroemia pubescens
Tribulus terrestris

SOIL AND CROP MANAGEMENT

CROP ESTABLISHMENT TECHNIQUES AND CULTURAL PRACTICES FOR UPLAND RICE

S. K. DE DATTA

Crop establishment techniques, cultural practices, a management intensities vary in different upland rice growing countries in Asia, Africa, and Latin America Limited animal and mechanical power, uncertain onset of monsoon season, and heavy weed competition cause poor stand establishment.

Evidence suggests that moisture conservation and weed control can be improved by practicing dry soil and straw mulch. Seeding of upland rice can be done 30 d from the onset of monsoon season.

Although many Asian and African upland rice farmers use little or no fertilizer when growing traditional varieties in drought-prone areas, nitrogen response is high if modern short to medium-statured, lodging-resistant, moderate-to-high tillerring rices are grown. In most soils, split applications of nitrogen at various growth stages give higher yields than a single basal application. Nitrogen application rate should be reduced in drought-prone areas.

On acid Ultisols and Oxisols, phosphorus response is high and consistent. Sometimes liming helps increase grain yield. Lime is often applied in acid cerrado areas in Brazil. Potassium response, particularly in light-textured soils, has been recorded and zinc response has been reported in some upland areas. Harvesting and threshing are done manually except in some Latin American countries where large combines are used.

The current level of technology suggests that substantial opportunities exist for research in upland rice land preparation, stand establishment, and nutrition.

LAND PREPARATION AND CROP ESTABLISHMENT TECHNIQUES

In most of Asia, little mechahization is used to prepare land for planting. As soon as enough rain has fallen to permit land preparation, fields are plowed and harrowed with animal-drawn implements to prepare a

Agronomist and head, Department of Agronomy, The International Rice Research Institute, Los Baños, Laguna (mail address: P. O. Box 933, Manila), Philippines.

good seedbed and to firm up the soil (De Datta and Ross 1975).

In most of India, land preparation for upland rice starts May–June when the monsoon begins. Fields are plowed with an animal–drawn country plow and then harrowed with a blade harrow. Where shifting cultivation is practiced, bushes are cut down and burned and the ashes broadcast before the land is plowed. Shifting cultivation is discouraged in hilly regions because it causes soil erosion (Pillai 1981).

Poor stand establishment is a major concern for Indian upland rice farmers. Evidence shows that dibbling in lines is more suited to light soils and that drilling is better for other soils. Optimum seed rates vary from 70 to 120 kg/ha, depending on whether seed is broadcast or drilled in rows (Table 1). Timely sowing and rapid canopy closure minimize weed growth and ensure proper stand establishment. Pande and Bhan (1964) stated that comparatively weed–free rice grown under complete soil manipulation can produce more leaf area and plant height and yield more grain.

Another way to reduce weed problems in upland rice is to do shallow cultivation or to apply a nonselective, nonresidual herbicide when weeds emerge after rains begin. Care must be taken during tillage to kill the first flush of weeds but not to cultivate so deeply that more weed seeds are brought to the soil surface. When conditions favor weed seed germination, no weed control advantage will be achieved by cultivation.

In dry soil, tillage to control weeds is futile under most cropping systems because of the longevity of buried weed seeds, weed seed dormancy, and the presence of wind–borne seeds from uncropped areas (Crafts 1975).

Table 1. Effects of seeding method and seed rate on upland rice grain yields in All India Coordinated Rice Improvement Project (AICRIP) coordinated trials (Pillai 1981).

Seeding method	Seed rate (kg/ha)	Grain yield[a] (t/ha)
Broadcast	60	2.7
	90	2.9
	120	3.5
	150	3.2
	180	3.2
Mean		3.0
Drilling	30	2.8
	50	3.0
	70	3.1
	90	3.3
	110	3.3
Mean		3.1

[a]Av of 2 to 3 locations and 3 yr (1971-73).

In Indonesia, upland rice is planted with maize, sorghum, cassava, and other crops to produce more food and minimize the chance of total crop loss in drought years. On hilly and flat lands of Burma and Bangladesh upland rice is broadcast-seeded into dry soil. In Thailand, slightly elevated areas are plowed by water buffalo and cattle, then hoed. On hills, fields are hardly cultivated.

Upland rice seeding methods commonly used in the Philippines are hilling, broadcasting, and drilling. Hilling is generally used in the Visayas region, especially in highly sloping areas. Four to eight seeds are dropped on a hill and covered with 3-5 cm of soil. Hills are 25 cm apart in shallow furrows 30 cm apart. Hilling requires 44 kg of seeds/ha.

A modification of the broadcast method is used in Luzon. The harrowed field is furrowed with a lithao, an animal-drawn furrower that has 5 wooden pegs 20 cm apart. Seeds are broadcast (88 kg/ha) and covered by passing a peg-toothed harrow, called a kalmot, over the field in the direction of the rows.

Drilling is used mostly in northern Mindanao. Seeds are dropped uniformly in furrows spaced 20-25 cm apart and covered by foot or by rake. On large farms, seeds are drilled with a seed drill on unfurrowed seedbeds. This method uses 88 kg of seeds/ha (PCARR 1977).

About 98% of African rice land is tilled manually because draft cattle are scarce. In West Africa, seed is broadcast or dibbled (De Datta and Ross 1975).

Alluri (1979) evaluated dibbling, space planting, and drilling methods of planting rice under upland culture at the International Institute of Tropical Agriculture farm in Nigeria. Seed rate was kept constant by adjusting the number of seedlings per hill -- 6 seedlings/hill at 30 x 30 cm, 3 seedlings at 30 x 30 cm, and 1 seedling at 45 x 3.3 cm. Row drilling produced the highest upland rice grain yields in moisture-stressed or nonstressed treatments. Lowland rice variety ADNY 11 outyielded upland variety OS6 under upland culture at both moisture regimes and under most planting methods (Table 2).

In Ivory Coast, West Africa, Chabalier and Posner (1978) manipulated plant density to improve upland rice yields. The closest spacing (30 x 3 cm) produced rapid growth. Lower plantiny density produced gradual, slower growth. Grain yields at both spacings were 5 t/ha.

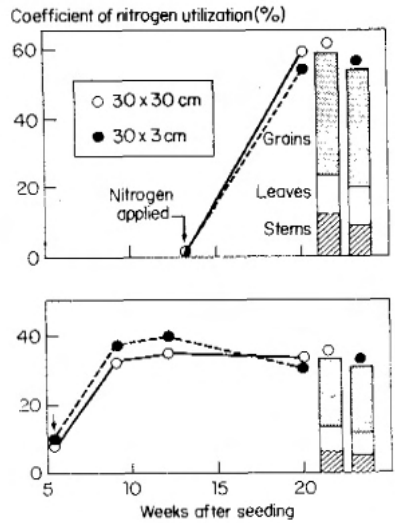
Coefficient of nitrogen utilization was closely associated with plant spacing (Fig. 1). However, under poor moisture supply, a lower seed rate is desirable because the 30 x 30 cm spacing allows the plant to regulate its growth during the growing cycle and still attain acceptable yield.

Land preparation methods in Latin America vary greatly. In Peruvian shifting cultivation areas, for

Table 2. Grain yield of OS6 and ADNY 11 under different planting methods and moisture regime in upland rice culture (Alluri 1979).

Planting method	Spacing (cm)	Grain yield (t/ha)			
		Drought stress		No stress	
		OS6	ADNY 11	OS6	ADNY 11
Dibbling	30 x 30	1.7	2.6	3.2	3.7
Space planting	30 x 10	1.9	1.9	2.5	3.3
Drilling	45 x 3.3	2.4	1.5	3.5	6.8
Av		2.0	2.0	3.1	4.6

[a] Seed rate was equalized by adjusting the number of seedlings per hill.



1. Coefficient of utilization of nitrogen applied at 30 and 90 days after seeding IRAT13 rice at 2 spacings, Bouaké (Chabalier and Posner 1978).

example, mature secondary forests are cut and burned during July-September, the drier months. Upland rice is dibbled without further land preparation. In Brazil and several Central and South American countries, upland rice fields are prepared using tractor-driven equipment. In most of Brazil, seeds are drilled with a tractor-driven seed drill, and spacing is as wide as 60 cm to discourage the spread of blast (Bl) and help rice tolerate drought.

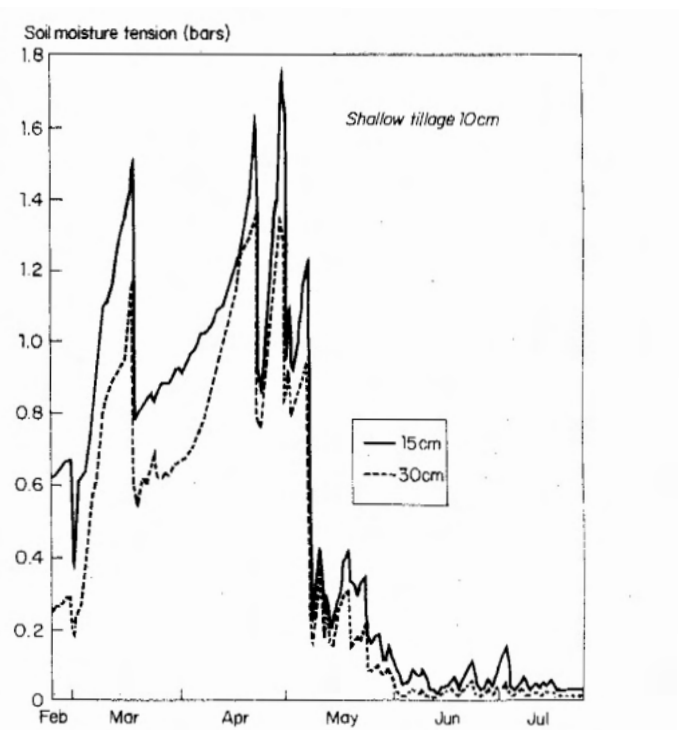
DRY SOIL MULCH AND STRAW MULCH

Bolton and De Datta (1979) and Hundal and De Datta (1982) demonstrated that moisture can be conserved in

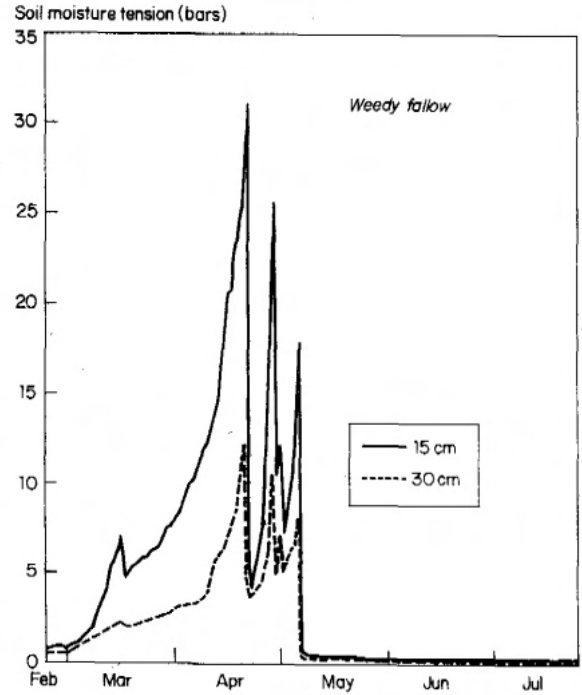
rainfed lowland rice fields by dry soil mulching during the dry season. Singh and De Datta (1979) demonstrated the same in upland rice. Their results showed lowest soil moisture tension values (85 cb and 1.75 bars) in dry soil mulch plots (Fig. 2), and the highest values (25 bars and 31 bars) in weedy fallow plots (Fig. 3). Straw mulch (3 t/ha) (Fig. 4) and weed-free fallow (Fig. 5) treatments during both years had intermediate soil moisture values.

Straw incorporation causes better vegetative growth in upland rice crops and favors high yield. In 1977-78 IR43 yielded higher in deep tillage, straw incorporation, and straw mulch treatments than in other treatment combinations, In both years, dry soil mulch plots were seeded 9 d earlier than weedy fallow plots.

After 2 yr of experimentation, bulk density and penetrometer resistance readings from upland soil were not significantly influenced by different mulching treatments. However, infiltration rate in straw mulch and straw incorporation treatments was higher than in other treatments (Singh and De Datta 1979).



2. Soil moisture tension as affected by a dry soil mulch generated by shallow tillage (10 cm deep) during the dry season followed by a dry-seeded rice crop. Tillage consisted of 3 rototillings in January-February followed by 1 rototilling in April. Rices were dry-seeded on 30 April. IRRI, 1978 dry and wet seasons (Singh and De Datta 1979).

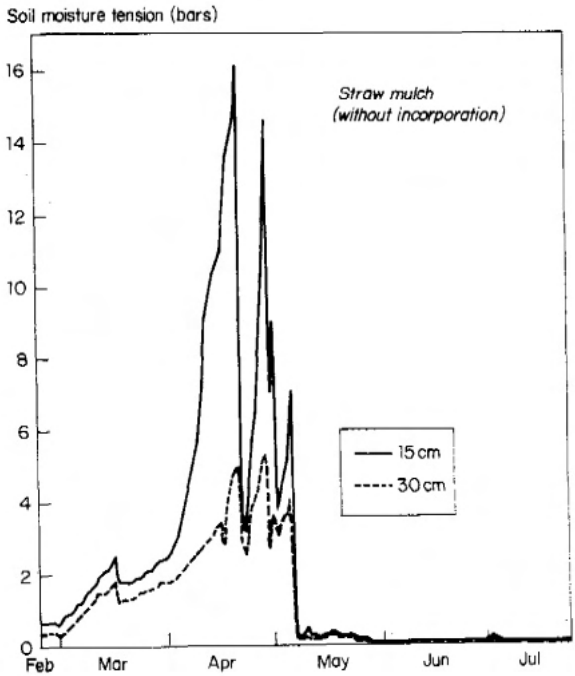


3. Soil moisture tension as affected by a dry season weedy fallow followed by a dry-seeded rice crop. Tillage consisted of 1 plowing and 3 rototillings. Rices were dry-seeded on 24 May. IRRI, 1978dry and wet seasons (Singh and De Datta 1979).

DATE OF SEEDING AND FERTILIZER NITROGEN RESPONSE

Low rainfall and high precipitation variability are of perpetual concern to farmers growing upland rice. Upland rice farmers usually seed their crops after the first heavy rains of the wet season. Sometimes, no rain follows the early seeding, causing early soil moisture stress and desiccation of the germinating seeds. At other times, too, much rain makes the soil soggy and prevents early seeding. In this case, reseeding or late seeding may be necessary. Studies by Jana and De Datta (1971) showed grain yields were lower when fields were seeded 2 or 3 mo late. Yield reductions were attributed to soil moisture stress and to reduced solar radiation received during the reproductive stage.

Several years of experiments at the IRRI farm and in two farmers' fields in the Philippines determined seeding dates and nitrogen levels necessary to produce optimum rice yields. Malabuyoc et al (1980) then reported that seedings least affected by soil moisture stress (Fig. 6) had higher grain yields than those affected by drought (Fig. 7). If the soil moisture ten-



4. Soil moisture tension as affected by 3 t straw mulch/ha (without incorporation) treatment during the dry season followed by a dry-seeded rice crop. Tillage consisted of 3 rototillings in straw mulch plots. Rices were dry-seeded on 6 May. IRRI, 1978 dry and wet seasons (Singh and De Datta 1979).

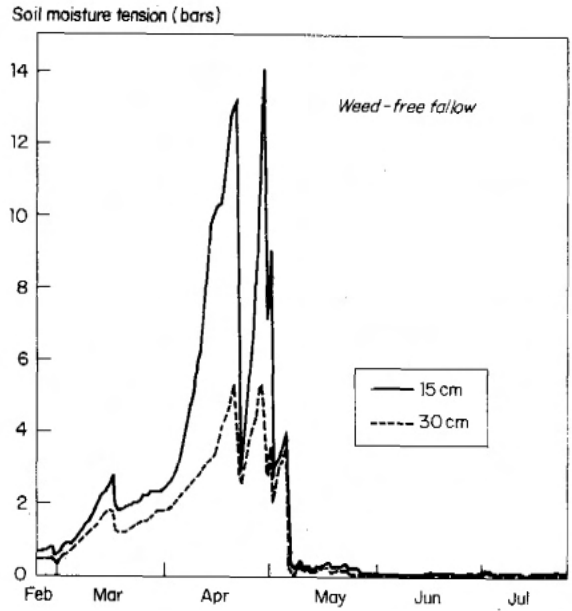
sion at 20-cm soil depth rose beyond 70 cb for 4 to 14 d, seedings with rice at the reproductive stage were the most affected.

The first 1980 seeding (4 June) yielded higher than 2 other seedings planted 1 or 2 mo later (Fig. 7).

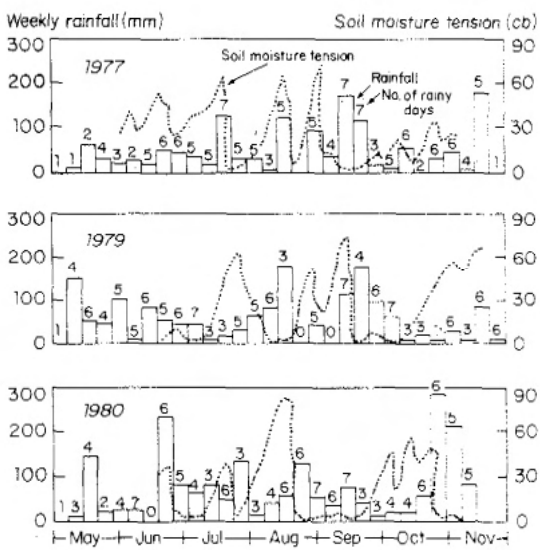
In a farmer's field in Batangas, Philippines, rices responded well to nitrogen (80 kg/ha) in 1976, 1977, and 1979 (Fig. 8). In 1980, no grain yield response to nitrogen was observed because of the residual effect of nitrogen (160 kg/ha) applied by the farmer to a preceding maize crop.

Results suggest that upland rice can be safely seeded in dry soil 30 d before the wet season begins without fear of grain yield loss or loss of viability (Malabuyoc et al 1980).

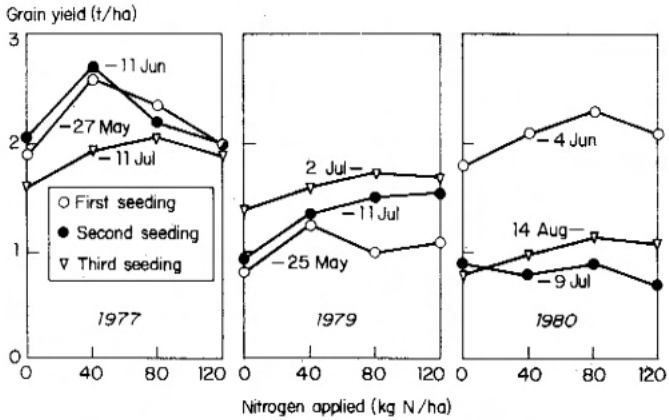
Experiments by Oelsligle et al (1976) on upland rice reported differential grain yield response to seeding date on the Pacific side of Costa Rica. Nitrogen rates were 0, 60, 120, and 240 kg/ha. Test varieties, planted on 5 seeding dates, were tall-statured Tapuripa and short-statured CICA 4. Tapuripa produced



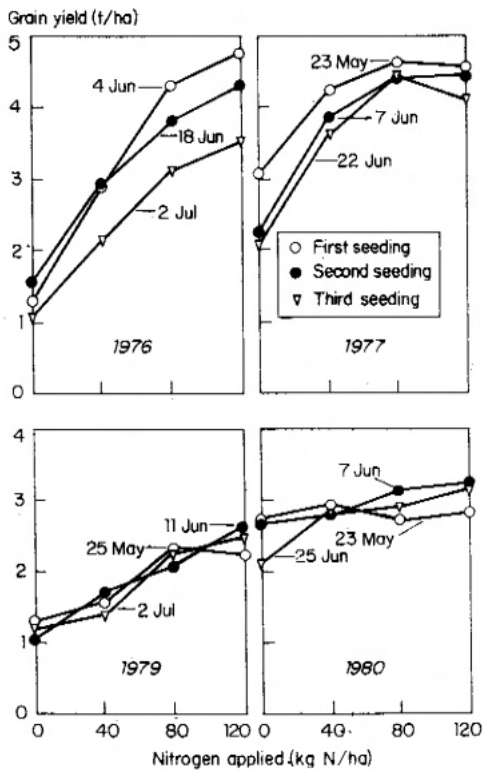
5. Soil moisture tension as affected by weed-free fallow treatment during the dry season followed by a dry-seeded rice crop. Tillage consisted of 2 rototillings in weed-free fallow plots. Rices were dry-seeded on 2 May. IRRI, 1978 dry and wet seasons (Singh and De Datta 1979).



6. Weekly rainfall and daily (3-point moving av) soil moisture tension (cb) in seeding date × nitrogen level × variety or line dryland rice experiment. IRRI farm, 1977, 1979, and 1980 wet seasons (Malabuyoc et al 1980).



7. Grain yield response of dryland rices to applied nitrogen and seeding date. IRRI farm, 1977, 1979, and 1980 wet seasons (Malabuyoc et al 1980).



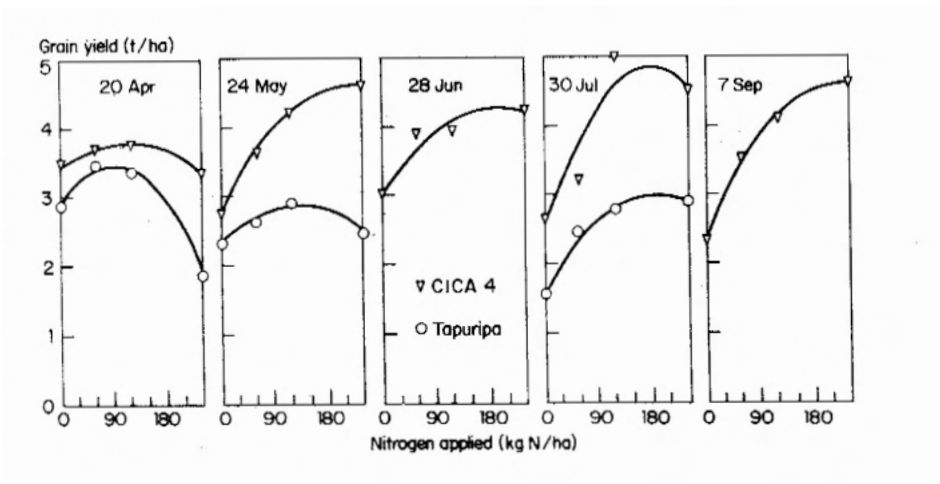
8. Grain yield response of dryland rices to applied nitrogen and seeding date. Santo Tomas, Batangas, Philippines, 1976, 1977, 1979, and 1980 wet seasons (Malabuyoc et al 1980).

no grain in the third and fifth plantings because of excessive lodging (Fig. 9). CICA 4 grain yields were consistently higher than Tapuripa yields at all planting dates.

FERTILIZER MANAGEMENT OF RICE

Many Asian upland rice farmers growing traditional varieties in drought-prone areas use little or no fertilizer. Nitrogen response is high if modern rices are grown in upland rice areas.

Studies by Singh and Singh (1976) in Banaras, India, reported a linear increase in upland rice grain yields with nitrogen application of up to 90 kg N/ha (Table 3). Nitrogen efficiency (kg rice/kg N) was better at 30 than at 90 kg N/ha. Similar results were obtained by Nair et al (1976) in Pattambi, Kerala,



9. Effect of seeding date on nitrogen response of 2 rice cultivars at Palmar Sur, Costa Rica, 1973. Symbols are average of 6 observed values. Lines were generated by regression (Oelsligle et al 1976).

Table 3. Effects of levels and methods of nitrogen application on upland rice grain yield [a] (adapted from Singh and Singh 1976).

Nitrogen applied	Grain yield (t/ha)
Without nitrogen fertilizer	1.1
30 kg N/ha, soil placement	1.4
60 kg N/ha, soil placement	1.8
90 kg N/ha, soil placement	2.0
15 kg N/ha in soil + 15 kg foliar	1.7
30 kg N/ha in soil + 30 kg foliar	1.9
60 kg N/ha in soil + 30 kg foliar	2.2

[a] Av of 1971-72 and 1972-73 crop seasons.

India. They reported that nitrogen response was linear and significant at 80 kg N/ha. However, highest nitrogen utilization efficiency was obtained using 40 kg N/ha.

In Bihar, India, substantial upland rice is grown on the Chotanagpur Plateau. Traditionally maize-growing areas in north Bihar have shifted to upland rice cultivation because excess rain has caused frequent failure of the maize crop. Experiments by Singh et al (1981) showed that 50 kg N/ha applied in split doses with or without basal application produced significantly higher grain yields (2.7-3.0 t/ha) than if 50 kg N/ha was applied as a basal dose.

In Uttar Pradesh, India, Singh and Modgal (1978) reported that fertilizer nitrogen response and grain yields were higher with semidwarf Padma than with tall traditional upland variety Nagina 22. Grain yield response increased up to 60 kg N/ha (Table 4).

Experiments by Partohardjono et al (1977a, b) in Central Lampung, Indonesia, suggested that grain yield response to nitrogen application at 20-40 kg/ha was higher when nitrogen was applied in split doses between 14 and 42 d after seeding and at panicle initiation. Without nitrogen, plants at 25 x 15 cm spacing yielded higher than those at 40 x 15 cm spacing (Table 5). Test varieties used -- Gati, Seratus Malam, and BPI 76 (Bicol strain) –- were not Bl resistant.

In another experiment in Indonesia, slow-release sulfur-coated urea (SCU) did not increase grain yield

Table 4. Effects of nitrogen treatments on grain yields of upland rice, 1980 wet season (adapted from Singh and Modgal 1978).

Nitrogen (kg/ha) at given crop growth stage[a]				Grain yield (t/ha		
S	T	PI	H	Jaya	Padma	Nagina 22
0	0	0	0	4.5	4.9	3.2
60	0	0	0	5.9	6.5	2.8
30	30	0	0	4.9	6.2	2.4
0	30	30	0	5.4	6.1	2.2
0	0	30	30	4.9	6.2	2.6
20	20	20	0	4.3	5.7	2.7
0	20	20	20	4.9	6.4	2.4
15	15	15	15	5.6	7.1	2.9
120	0	0	0	4.4	6.1	3.2
60	60	0	0	4.5	5.4	1.6
0	60	60	0	5.9	6.0	1.8
0	0	60	60	4.6	5.9	3.6
40	40	40	0	3.9	5.1	2.3
0	40	40	40	3.5	6.6	2.2
30	30	30	30	4.1	5.9	2.2

[a]S = seeding, T = transplanting, PI = panicle initiation, H = heading. LSD (5%) is 0.31 t/ha for 2 varieties at constant time of N application, and 0.9 t/ha for 2 nitrogen applications using constant variety.

Table 5. Effect of plant spacing and nitrogen rates on the grain yield of 3 varieties under upland rice culture[a] 1976-77 wet seasons (adapted from Patohardjono et al 1977a).

Spacing (cm)	Variety	Grain yield (t/ha) at nitrogen of		
		0 kg/ha	60 kg/ha	120 kg/ha
40 × 15	Seratus malam	2.2	2.8	2.4
	Gati	4.1	4.1	4.7
	BPI 76 (Bicol strain)	2.9	3.9	3.9
25 × 15	Seratus malam	1.8	3.1	2.1
	Gati	4.5	4.7	4.9
	BPI 76 (Bicol strain)	3.3	3.7	3.0
20 × 15	Seratus malm	2.9	3.0	4.6
	Gati	4.1	4.7	4.6
	BPI 76 (Bicol strain)	2.7	3.9	3.2

[a] HSD (fertilizer): 5% = 1.3 t/ha; (spacing): 5% = 0.2 t/ha.

over prilled urea applied in split doses (Table 6).

Thasanasongchan et al (1976) reported that slow-release SCU in the Philippines gave higher yields than prilled urea and ammonium sulfate when all were applied at planting, either broadcast and incorporated or placed in band. Split application gave higher yields than a single application at planting, particularly in sandy soil in Cuenca, when nitrogen sources were urea and ammonium sulfate (Table 7). Semidwarf rice IR43 yields were higher than those of intermediate-statured C22.

In Peru, local lodging-susceptible varieties did not respond to nitrogen. Improved IR42 responded positively to nitrogen, producing higher yields up to 60 kg N/ha. Grain yields ranging from 5.0 to 7.5 t/ha have been reported for some semidwarf varieties such as IR8, when 90-180 kg N/ha were used in upland conditions in Costa Rica and Peru. Sanchez (1971) attributed these high yields to high tillering capacity and lodging resistance.

DROUGHT RESPONSE OF RICE AT DIFFERENT NITROGEN LEVELS

It is generally agreed that the relative response obtained from a given increment of nitrogen is related to the supply of available moisture. Earlier studies reported that increasing nitrogen reduced yield losses caused by moderate moisture stress (De Datta et al 1974). Recent studies by Aragon and De Datta (1982) suggest that increasing nitrogen levels from 0 (no fertilizer nitrogen) to 60 and 120 kg N/ha intensified the degree of water stress and decreased leaf water potential (LWP) especially when total water application was minimal. The yield-water-fertilizer relationships of

Table 6. Effect of nitrogen sources and time of application on upland rice grain yield and nitrogen use efficiency[a] 1976-77 wet seasons (adapted from Partohardjono et al 1977b).

Nitrogen source	Nitrogen application (kg/ha) at				Grain yield (t/ha)	Nitrogen efficiency (kg rice/kg N)
	14 DS	42 DS	PI	Heading		
–	0	0	0	0	3.0	–
Urea	0	60	60	0	4.4	12
SCU	0	60	60	0	4.4	12
Urea	20	40	60	0	4.8	15
SCU	20	40	60	0	4.7	14
Urea	20	40	30	30	4.9	16
SCU	20	40	30	30	3.6	5
Urea	20	60	40	0	5.0	17
SCU	20	60	40	0	4.6	14
Urea	20	60	20	20	4.7	15
SCU	20	60	20	20	4.6	13
Urea	20	20	80	0	4.3	11
SCU	20	20	80	0	3.6	5
Urea	20	20	40	40	4.1	9
SCU	20	20	40	40	3.5	5
			HSD 5%:		0.6	
			CV (5) :		5	

[a]DS = days after seeding, PI = panicle initiation, SCU = sulfur-coated urea.

the four varieties revealed different production surfaces. Early-maturing IR52 yielded highest at 120 kg N/ha with 850 mm of water. Traditional upland Variety Kinandang Patong gave the highest predicted yield with 550 mm of water and no fertilizer nitrogen. At 120 kg N/ha and 550 mm of water, IR36 yielded best (Fig. 10).

These results suggest that in areas with uncertain moisture supply, nitrogen application rate should be reduced from that normally used for irrigated rice (Aragon and De Datta 1982).

RESPONSE TO OTHER NUTRIENTS

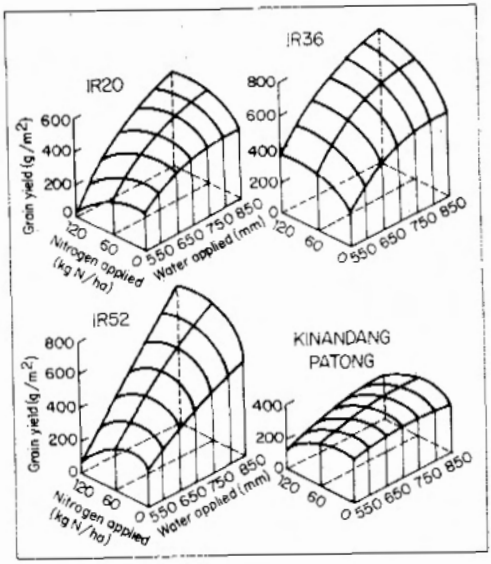
Upland rice is usually grown on acid soils. Phosphorus deficiency is common in most Ultisols in Asia and Ultisols and Oxisols in Latin America. In most instances, however, responses to phosphorus or potassium or to both, were recorded only in the presence of nitrogen. Results from India recorded by Singh and Modgal (1978) suggest that phosphorus uptake in grain and straw is significantly influenced by nitrogen application. Increases in phosphorus uptake in grain and straw were caused by increasing nitrogen applications. Similar results were obtained with potassium uptake by upland rice.

Scientists have tried to increase phosphorus nutrition by soaking seed in $Na_2HPO_4 \cdot 12H_2O$ for 24 h. Results showed marginal grain yield increases (Singh

Table 7. Effect of sources, timing, and methods of nitrogen application on grain yield of C22 and IR43 rices under upland conditions [a] (adapted from Thasanasongchan et al 1976).

Method	Source	Time of application				Grain yield [b] (t/ha)			
						C22		IR43	
		P	10 DE	30 DE	PI	Alfisol clay loam (IRRI)	Alfisol sandy [c] (Cuenca)	Alfisol clay loam (IRRI)	Alfisol sandy [c] (Cuenca)
–	–	0	0	0	0	1.8 e	1.3 e	2.2 h	1.4 h
BI	U	60	0	0	0	2.1 d	2.0 cd	2.6 g	2.2 ij
BP	U	60	0	0	0	2.2 c	2.1 bc	2.6 g	2.4 gh
S	U	30	0	15	15	2.2 c	2.1 bc	3.2 cde	3.0 bc
S	U	0	30	15	15	2.2 c	2.0 cd	3.1 def	2.9 cd
S	U	0	0	30	30	2.4 ab	2.2 ab	3.3 bed	3.0 bc
S	U	0	20	20	20	2.3 bc	2.2 ab	3.3 bcd	2.8 de
S	U	0	30	30	30	2.6 a	2.2 ab	3.4 abc	3.2 a
BI	SCU	60	0	0	0	2.6 a	2.2 ab	3.5 ab	3.2 a
BP	SCU	60	0	0	0	2.3 bc	2.3 a	3.6 a	3.2 a
S	SCU	30	0	15	15	2.4 ab	2.0 cd	3.4 abc	3.0 bc
S	SCU	0	30	15	15	2.2 c	1.9 d	2.3 bcd	2.7 ef
S	SCU	0	0	30	30	2.2 c	2.0 cd	3.2 cde	2.4 gh
S	SCU	0	20	20	20	2.2 c	2.3 a	3.3 bcd	3.2 a
BI	AS	60	0	0	0	2.2 c	2.0 cd	2.6 g	2.3 hi
BP	AS	60	0	0	0	2.1 c	2.1 c	2.6 g	2.3 hi
S	AS	30	0	15	15	2.3 bc	2.3 a	3.4 abc	3.2 a
S	AS	0	30	15	15	2.2 c	2.2 ab	3.3 bcd	3.1 ab
S	AS	0	0	30	30	2.2 c	2.2 ab	3.2 cde	3.0 bc
S	AS	0	20	20	20	2.4 ab	2.1 bc	3.3 bcd	3.0 bc
Av						2.3	2.1	3.1	2.8

[a] BI = broadcast incorporated, BP = band placement, S = split application, U = urea, SCU = sulfur-coated urea, AS = ammonium sulfate, P = planting, DE = days after rice emergence, PI = panicle initiation. [b] Means followed by a common letter are not significantly different at 5% level based on Duncan's multiple range test. [c] Farmer field, Batangas, Philippines.



10. Yield response surfaces of 4 rice varieties at different water and nitrogen levels. IRRI, 1980 dry season (from Aragon and De Datta 1982).

and Chatterjee 1980). Upland (pluvial) rice lands in West Africa are mainly on Alfisols and Ultisols -- Ultisols are most common (Moormann and Veldkamp 1978). Erosion and leaching cause rapid decrease in soil fertility in West African upland rice areas. In most upland rice-growing areas, phosphorus content of the soil is too low and phosphorus deficiency must be corrected if grain yields are to increase.

In the M'Bo plain, Cameroon, maximum phosphorus response is 200 kg P_2O_5/ha when new lands are tilled (IRAT undated report).

In Western Nigeria, where upland rice is the major system, about 100 million tons of subsidized fertilizers are applied annually (Sobulo 1980).

In Sierra Leone a single superphosphate application increases upland rice yields 35-132%. Mahapatra et al (1980a) compared a single superphosphate with rock phosphate and basic slag in upland rice on acid gravelly soil (pH 5.5) at Rokupr and on Kenema upland soils with higher clay content. The experiment used a continuous function design to allow fertilizer-soil contact from 10 to 90% of the surface area. Rock phosphate gave the lowest grain yield. Yields with basic slag and single superphosphate were comparable (Table 8).

In Brazil, upland rice is usually grown on acid Ultisols and Oxisols (pH 4-5). Aluminum saturation level varies between 50 and 80% and usually increases

Table 8. Yield response of upland rice using different sources and placement of phosphorus (40 kg P_2O_5/ha) fertilizers (adapted from Mahapatra et al 1980b).

Phosphorus source	Soil surface area (%) receiving fertilizer	Mean grain yield (t/ha)	
		Rokupr	Kenema
Control		0.75	1.81
SSP[a] 1	10	1.43	1.92
2	30	1.59	2.42
3	50	2.03	2.61
4	70	1.77	2.72
5	90	1.91	2.52
Rock phosphate			
1	10	1.34	1.95
2	30	1.67	1.97
3	50	1.71	1.84
4	70	2.14	2.16
5	90	2.01	2.29
Basic slag			
1	10	1.32	2.26
2	30	1.52	2.16
3	50	1.70	2.31
4	70	1.93	2.76
5	90	2.12	2.54
LSD (5%) Soil contact area		0.14	0.30
Soil contact × source		0.21	0.66
CV (%)		10	3

[a] SSP = single super phosphate.

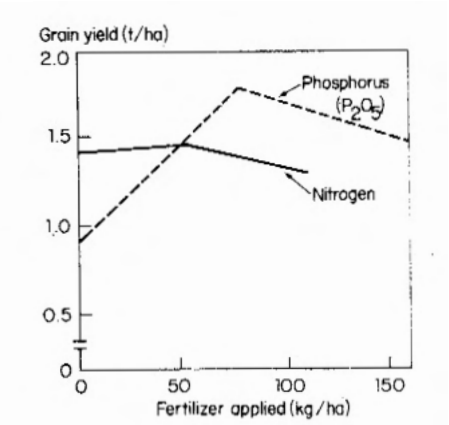
with soil depth. High aluminum saturation level restricts root growth in the subsoil even though water may be present in deeper soil horizons (CIAT 1979). In these acid soils, phosphorus deficiency is widespread and severe. Breeders and soil scientists in Brazil are trying to select rices with phosphorus deficiency tolerance.

On acid Oxisols in Brazil, lime is regularly applied with phosphorus and nitrogen to grow upland rice.

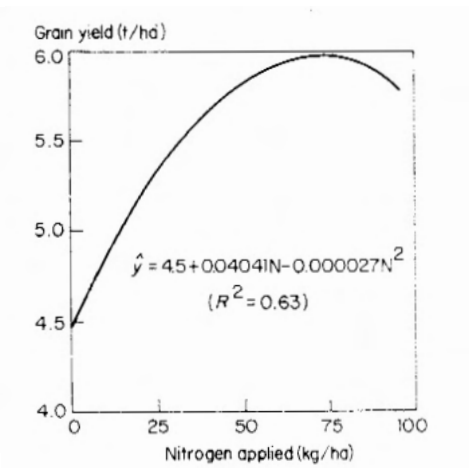
In the Llanos Orientales region of Colombia, Sanchez and Leal (1978) evaluated upland rice resposes to NPK on Oxisols (pH 3.9). They also conducted three experiments on Entisols (pH above 5.5) in the Ariari region.

On Oxisols, IR8 yielded low because of low soil fertility and high aluminum toxicity (Fig. 11). On Entisols, CICA 8 produced about 6.0 t/ha when 69-75 kg N/ha was used (Fig. 12). The highest yield was obtained when 60 kg N/ha was applied in split doses at 30, 60, and 70 d after germination. On Entisols, no phosphorus or potassium response was observed (Table 9) because phosphorus levels were already high (16-92 ppm P).

Sometimes upland rice responses to all major nutrient elements (NPK) have been recorded. For example,



11. Response of IR8 to nitrogen and phosphorus under upland rice culture in the eastern plains of Colombia (Sanchez and Leal 1978).



12. Response of CICA 8 to nitrogen application under upland rice culture in the eastern plains of Colombia (Sanchez and Leal 1978).

in Maranhao State in Brazil, NPK application doubled the yield (2.0 for untreated control vs 4.3 t/ha) on relatively fertile soil and tripled the grain yield on poor soil (1.2 vs 3.6 t/ha) (IRAT undated report).

Potassium response has been recorded in some upland rice areas in Indonesia.

In one study in Kenema, Sierra Leone (Mahapatra et al 1980b), potassium response was significant when 80 kg K_2O/ha was applied in split doses (Table 10). The difference in texture between soils at Kenema (light) and Njala (medium) explains the potassium response with

Table 9. Grain yield response to NPK of CICA 8 under upland rice culture on Entisols of Ariari, Colombia (adapted from Sanchez and Leal 1978).

Nutrients applied (kg/ha)			Grain yield[a] (t/ha)
N	P_2O_5	K_2O	
30	20	15	5.1
30	20	30	5.0
30	40	15	5.4
30	40	30	6.0
60	20	15	6.1
60	20	30	5.8
60	40	15	6.2
60	40	30	5.7
45	30	22.5	5.7
0	20	15	4.5
30	0	15	6.1
30	20	0	5.3
90	40	30	5.9
60	60	30	5.7
60	40	45	6.0

[a]Av of 3 replications.

split dose applications. The relationship between potassium concentration in the flag leaf (10 wk) and upland rice grain yield in western Nigeria was studied by Sobulo (1980). Grain yield response was significant at 25 kg K_2O/ha, and the application also increased flag leaf potassium concentration (Table 11). Less than 1% potassium in the flag leaf at heading is the critical level.

Zinc deficiency is found in lowland rice in most countries. It has also been observed in upland rice in Brazil because soils have low zinc content.

HARVESTING AND THRESHING

Rice is harvested and threshed by hand in most Asian countries. Farmers in Batangas, Philippines, and in Indonesia harvest rice by clipping the panicles from the straw with a sharp knife. Varieties with exserted panicles are preferred for upland planting in these countries. Indian farmers use hand sickles to cut the straw and grain 20–25cm above soil surface. The hand-threshed rice is sun-dried, then stored for home consumption.

Upland rice in West Africa is harvested by hand. Individual panicles are often cut, as they are in some Asian countries. Many rice grains are lost during harvesting, particularly from shattering-susceptible varieties derived from Oryza glaberrima.

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

cle. In Brazil and some other Latin American countries, upland rice is harvested using large combines.

CRITICAL RESEARCH NEEDS

The preceding observations suggest that substantial opportunity exists for research in upland rice land preparation, stand establishment, and nutrition.

The following are examples of critical research needs on cultural practices for upland rice.

1. Appropriate zero and minimum tillage techniques for hilly and flat upland rice lands must be developed to minimize soil erosion and maximize farmer utilization of power and energy resources.
2. Moisture and nutrient conservation techniques should be developed for different soil and rainfall resource levels.
3. Nitrogen responsiveness of modern upland rices should be catalogued at different planting dates by soil type, rain moisture supply, and solar radiation level.
4. Magnitude and mechanisms of nitrogen losses using ^{15}N technique should be studied. Different nitrogen sources and management practices affecting ^{15}N balance should be determined.
5. Techniques should be developed to increase upland rice nitrogen use efficiency.
6. Amelioration of phosphorus deficiency in acid upland rice soils should receive high priority. Rock phosphates, partially acidulated phosphates, and placement techniques should be evaluated at various soil pH.

Table 10. Grain yield of ROK 3 upland rice at different potassium application times (adapted from Mahapatra et al 1980b).

Rate and time of potassium application	Njala		Kenema	
	Yield (t/ha)	% over control	Yield (t/ha)	% over control
40 kg K_2O/ha				
2 splits	1.10	10	0.96	22
3 splits	1.19	20	1.03	30
4 splits	1.28	30	1.03	30
5 spIits	1.34	36	1.09	38
80 kg K_2O/ha				
2 splits	1.24	26	1.16	47
3 splits	1.34	36	1.26	59
4 splits	1.45	48	1.28	61
5 splits	1.19	21	1.13	43
Control yields	1.0		0.79	
LSD 5% (t/ha)	0.43		0.36	

Table 11. Relationship between potassium content in rice leaves and upland rice (OS6) yield (adapted from Sobulo 1980).

K_2O applied (kg/ha)	K (%) in rice leaves 6 wk	10 wk	Grain yield[a] (t/ha)
0	1.31	1.00	1.8 a
25	1.75	1.15	2.0 h
50	2.15	1.85	2.1 h

[a]Means followed by the same letter are not significantly different from each other at the 5% level.

7. Potassium nutrition in relation to soil texture and yield targets should be studied.
8. Lime requirements should be established based on soil pH, aluminum saturation at various soil depths, and phosphorus-supplying capacity of soil.
9. upland rice production systems should be inte grated with total cropping systems to help shift upland rice production from a subsistence farming system to a profitable system.

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MECHANIZATION OF SMALL UPLAND RICE FARMS

C. F. GARMAN and N. C. NAVASERO

LAND CLEARING

Bush fallow systems of upland rice cultivation require more labor than most other systems. About 60% of farmer labor is needed to clear land (Ay 1981). Stumps and tree trunks that require large amounts of energy and time to remove are left in the fields. Farmers who plant around them find it difficult to use tools and small animal- or engine-powered implements.

Because mechanization requires farmers to clear the land more thoroughly, little time is left for production activities. Additional clea-ring may not greatly increase production or total area of production.

Possible solutions to the land-clearing dilemma are:

- ready availability of efficient hand tools such as axes and digging equipment (To stay sharp longer, implements should be of high quality steel.);
- independent clearing contractors with winches, power chain saws, and axes (Johnson 1980), who are well trained in safety, maintenance, and operation of their tools;
- village organizations to plan and oversee the clearing by private contractors of a new area year (Clearing costs might be subsidized and land within the cleared blocks allocated to farmers by need, but this system might make it difficult for each farmers to get firewood from the trees that were cleared from their land, and would eliminate the light burn which helps control weeds.); or
- a no-tillage system with controlled fallows that are easy to return to cropping after the fallow. This probably would be the best system.

PLANTING

Upland rice usually is broadcast or dibbled.

Agricultural engineers, International Institute of Tropical Agriculture Farming Systems Program.

Broadcasting

Seeds are broadcast by hand and scratched into the soil. Where rice does not sprout because of poor germination or because birds or rodents eat the seeds, other crops may be planted to use as much land as possible and maximize the benefits of hand weeding (Mahapatra 1979).

Dibbling

Seeds can be dibbled randomly or in rows. Row dibbling makes weeding easier but is slower than broadcasting. Farmers with large areas to plant prefer broadcasting.

IITA has developed a rolling injection planter (RIP) designed for no-tillage maize and rice production. RIP quickly dibbles seeds into rows and promotes effective crop establishment for both no-tillage and conventional upland rice tillage. However, techniques for no-tillage upland rice cultivation for small farms are not fully developed. Weed control remains a major problem.

Scientists designed the RIP for the small farmer and rough field conditions. Its assembly is simple and easy to understand, and it is easy to adjust. Only two adjustments -- changing the metering roller for different seed sizes and adjusting the dlstance between planters to change row spacing -- enable farmers to plant a variety of crops, including rice, cowpea, and maize.

The planter has few moving parts: only the metering roller attached to and moving with the planting wheel and six moving openers. Mechanical breakdowns and maintenance are minimal. However, the planter has fixed within-row spacing and maximum speed is 3.5 km/h.

One person can push a single-row unit and pass it easily over uneven terrain. The planter's pointed openers help it plant on seedbeds with surface crop and weed residues. Small-scale farmers who plant 1 to 5 ha can afford the RIP.

Seedbed preparation

Weed control requirements help determine the type of seedbed preparation for mechanized planting. Also important is the planting surface quality needed to prevent the planter from plugging and to minimize skips in seed drop because the planter's drive wheel did not touch the ground on uneven places in the field. The RIP does not need a clean smooth field, but weed control may.

Weed control

Weeding demands about 60% of a rice farmer's time during the cropping season. Controlling weeds by hand is difficult when rice has been broadcast or randomly

dibbled. Even with dibbling in rows, the narrow spacing for rice makes weeding more difficult than hand weeding a crop like maize, which is planted in wider rows.

The crop is probably the most effective weed control when it covers the whole field and shades out the weeds. This requires good stand establishment, proper spacing of the planted variety, and rapid crop growth. Before achieving crop cover, hand weeding or herbicides are necessary.

Hand weeding with a hoe is easy when there is a smooth, loose, moist soil surface with no crop or weed residues and when weeds are small. These coditions are rare because old crop and weed residues are needed to keep the soil surface loose and moist. Plowing and harrowing are needed for a smooth soil surface.

Soil must be kept loose or soil erosion will develop when rain compacts the soil and seals the surface, causing excess runoff.

Mechanical weeding. For mechanical weeding with hand tools or powered implements, the implements must work through mulch, leave the mulch on the surface, and function on uneven surfaces. Hand hoes have evolved over the years in Africa. They are highly developed to do specific jobs with the least amount of energy. The Swiss hoe and the large-scale rotary hoe are the best available mechanical weeders. The development of better weeding implements must become an engineering priority.

Herbicide application. The ideal herbicide for the small farmer would control all weeds, be nontoxic to humans, be inexpensive, and do no harm if higher than recommended application rates were used. This herbicide does not exist nor is it expected to. What can be done from an engineering point of view is develop equipment that is safe to use, gives even application rates, and requires low human energy levels.

Most small sprayers apply spray ahead, requiring the operator to walk through the sprayed areas. If the operator wears boots, this is acceptable but boots are expensive and not always worn. The ideal applicator should apply herbicides to the side of or behind the operator.

Most knapsack sprayers have a maximum 1.5-m spray width and leave 6.6 km/ha chance for excess overlap or a line of missed weeds. Developing sprayers with wider spraying widths will allow for more even field application.

IITA is trying to solve these problems by building a hand-pulled boom sprayer, which has a pneumatic knapsack sprayer mounted on 2 bicycle wheels, a 4-m boom built on the back, and 2 handles coming forward to the operator with a lever to turn the spray valve on and off. The boom is about 2 m behind the operator. The large bicycle wheels make it pull easily. The operator does not walk through the sprayed crop. It takes about

2.5 h to spray 1 ha, including the time to mix chemicals and fill the tank. Keeping track of sprayed areas is still a problem, but one possibility is to use a dye in the spray.

CONCLUSION

Substantial work will be necessary before small farmers can produce upland rice in sufficient quantity to support the urban population. No-till cultivation in a form that the small farmer could use would be ideal. The development of a weeding device that will maintain a mulch cover on the soil and also operate on uneven soil surfaces would be a major breakthrough for upland rice production.

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MANAGEMENT OF SOIL PHYSICAL PROPERTIES FOR SOIL AND WATER CONSERVATION AND SEEDED PREPARATION IN WEST AFRICA

R. LAL

At least 75% of West African rice is grown on rainfed sloping soils with low water-holding capacity and shallow rooting depth. Even in the humid and subhumid tropics drought stress is a serious problem for rice production (Lal and Moomaw 1978, Hsiao et al 1980, Mambani and Lal 1982). Although yield on experimental plots with optimum fertilizer and soil moisture conditions is as high as 7 t/ha, the mean farm yield is only 1.2 t/ha and the national average is less than 1 t/ha (Lal et al 1981).

SOIL PHYSICAL FACTORS RESPONSIBLE FOR LOW RICE YIELD

Even a few days after a rain, low water-holding capacity and shallow rooting depth can cause rice drought stress. This affects rice production directly. Indirect problems are high susceptibility to some diseases, poor fertilizer use efficiency, and possible nutrient imbalance because of impaired uptake. High root zone temperature combined with drought stress can further limit germination, seedling establishment, root and shoot growth, and water and nutrient absorption and translocation.

The seriousness of drought stress is caused partly by the low water-holding capacity of most upland soils. Although low-activity-clay soils have a rapid infiltration rate (Lal 1979), the slaking effect of quick wetting and intense raindrop impact creates a surface seal that drastically decreases infiltration (Lal 1976, Roose 1977) and allows most rain to run off.

Unfavorable soil physical and microclimatic environments in the seed zone also result in poor stands of upland rice. Poor seed-soil contact, which prevents moisture transfer and uptake, and high seed zone temperatures in the upper 2 cm of the soil are a problem in coarse-textured gravelly soils. Soils with a lot of fine sand and silt and those with low organic matter develop a crust when dried rapidly.

International Institute of Tropical Agriculture, Ibadan, Nigeria.

A shallow-rooted crop with fibrous root system, rice cannot exploit soil moisture reserves from the subsoil horizon. Semiarid easily compacted soils (Nicou and Chopart 1979) and shallow soils developed on basement complex rocks underlain by a gravelly horizon (Babalola and Lal 1977, Vine et al 1981) also limit root penetration and development.

MOISTURE CONSERVATION

In situ conservation of soil moisture includes maintaining high infiltration capacity to absorb heavy rain, decreasing soil water evaporation, retaining infiltrated water in the root zone, and increasing the effective rooting depth for water extraction from greater soil volume.

Infiltration capacity

To eliminate runoff, the surface soil must be porous during heavy rain. Improving soil structure can open transmission pores essential for high infiltration. This section describes specific areas to improve.

Deforestation and land development

Mechanized land clearing causes soil compaction, decreases total and macroporosity, increases soil bulk density, and decreases available water retention capacity (Suebert 1975, Lal and Cummings 1979, Lal 1981). Minimal soil compaction in manual clearing, however, maintains favorable soil physical environments. Table 1 shows that mechanical clearing caused the greatest decrease in hydraulic conductivity and infiltration capacity. The slash and burn treatment was second and the slash treatment showed the least decrease. Under wheel tracks hydraulic conductivity was reduced even more drastically.

If mechanical land clearing and subsequent development is inevitable, it is necessary to restore the soil physical properties. Fallows (*Mucuna utilis*, for example) planted for 1 year immediately after clearing may alleviate soil compaction and provide organic biomass as mulch to prevent further soil degradation.

Soil conditioners and residue mulches. Expensive soil conditioners do not always improve soil structure and pore continuity. For example, experiments showed that a forested Alfisol and an Alfisol that had been tilled for 1 year and treated with bitumen had identical infiltration capacity (De Vleeschauwer et al 1978). Infiltration capacity decreased further with surface treatments with polyacrylamide and a soil penetrant (Table 2). Residue mulch applied at 6 t dry straw/ha maintained maximum infiltration rate. Besides improving soil structure, indicated by the superior

Table 1. Influence of land clearing methods on saturated hydraulic conductivity at 0-10 cm depth and on infiltration capacity (Lal and Cummings 1979).

Land clearing method	Hydraulic conductivity (cm/min)		Infiltration capacity (cm/h)	
	Initial	After clearing	Initial	After clearing
Mechanical	16.1	1.3	115	17
Slash and burn	15.2	5.0	88	44
Slash	9.8	4.8	141	62
LSD (0.05)		9.3		

Table 2. Effect of soil conditioners on infiltration capacity and on runoff later (De Vleeschauwer et al 1978).

Treament	Infiltration rate (cm/min)		Runoff		Mean wt diam (mm)
	After clearing	After 1 yr	mm	% of rainfall	
Control	2.52	1.18	35.0	8.1	2.5
Polyacrylamide	1.02	1.81	0.0	0.0	3.2
Bitumen	1.29	1.15	1.4	0.3	3.5
Soil penetrant	1.21	0.99	26.1	6.0	2.0
Mulch	1.76	2.30	0.0	0.0	3.7

Table 3. Effect of mulch rate on physical properties of an Alfisol 1 year after clearing (Lal et al 1980).

Mulch rate (t/ha)	Soil water sorptivity	Soil water transmissivity	Saturated hydraulic conductivity[a] (cm/h)	Bulk density[a] (g/cm^3)	Mean wt diam (mm)	Macropores[a] (% by vol)
0	5.56	0.32	30 a	1.32 a	1.2	26.0 a
2	7.81	0.57	45 a	1.20 b	1.4	28.0 a
4	7.50	0.67	70 b	1.17 bc	2.1	27.5 a
6	10.21	0.84	132 c	1.09 cd	2.0	29.5 a
12	15.36	1.05	129 c	1.04 d	2.4	39.5 b

[a]Values followed by a common letter are not significantly different at the 5% level.

mean weight diameter, mulch also increased the percentage of macropores and their stability. Water runoff losses were negligible with polyacrylamide and residue mulch treatments (Table 2).

Mulch rate. The amount of mulch required for effective soil and water conservation and structural stability depends on the nature and quality of the mulch material, its decomposition rate, soil properties and environmental characteristics, and potential erosion hazard (slope, erodibility, erosivity, etc.). Soil infiltration capacity depends on the mulch rate (Table 3). The mean weight diameter of the aggregates, pore

size distribution, also depends on the mulching rate. Although soil physical properties including infiltration improve with increasing mulch rate between 0 and 12 t/ha, the optimum rate may be about 4 – 6t/ha.

Cover crops and planted fallows. Appropriate grass and legume fallowing can also rapidly and significantly improve infiltration and pore size of eroded and degraded soil. Data in Table 4 show that fallowing with Stylosanthes and Psophocarpus greatly improves infiltration capacity compared to a natural weed fallow. The improvement in filtration rate is caused by an increase in the proportion of macro or transmission pores (Table 5) with resultant decrease in bulk density and increase in aggregate stability.

EVAPORATION CONTROL

Residue mulch prolongs the first and second stages of evaporation by suppressing water vapor diffusion thereby keeping the soil moist longer. Synthetic soil conditioners and polythene mulches also prevent evaporation loss. Straw mulch applied at 4 to 6 t/ha conserves more water in the root zone than bare ground (Table 6). Any kind of mulch increases soil-water storage during heavy and frequent rains. During a 2 – or 3 – month drought, residue mulch has little effect on soil water conservation, but for a 2 – to 3 – week dry spell, mulch helps conserve moisture.

SOIL CONSERVATION

Because rice has open rows, it promotes more erosion than closed canopy legumes. Providing additional ground cover with residue mulch effectlvely decreases runoff and soil loss (Table 7). With increased mulch rate, the

Table 4. Effect of cover crops on infiltration rate and field capacity of an eroded Alfisol (Lal et al 1979).

Cover crop	Infiltration rate (cm/h)	Field capacity (% wt/wt)	Soil bhlk density (g/cm³)
Brachiaria	19 ± 16	10.1 ± 4.0	1.34 ± 0.06
Paspalum	14 ± 1	9.7 ± 3.7	1.35 ± 0.04
Cynodon	18 ± 14	14.8 ± 6.2	1.30 ± 0.02
Pueraria	16 ± 14	20.1 ± 7.1	1.32 ± 0.03
Stylosanthes	16 ± 2	18.5 ± 4.6	1.33 ± 0.03
Stizolobium	21 ± 4	14.7 ± 5.0	1.33 ± 0.03
Psophocarpus	42 ± 8	21.2 ± 3.9	1.14 ± 0.04
Centrosema	18 ± 8	15.9 ± 6.5	1.33 ± 0.04
Control	13 ± 8	11.0 ± 0.5	1.42 ± 0.05
LSD (.05)	17	6.2	0.041

Table 5. Pore size distribution before and after seeding the cover crop.[a] Pore size distribution is computed from the pF curves reported by Lal et al 1979.

Cover crop	Total porosity (%) by volume		Volume of pores for different size ranges (µM)															
			>15		5-15		3-5		1.5-3		0.75-1.5		0.5-0.75		0.1-0.5		< 0.1	
	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A
Grasses																		
Brachiaria	46.4	50.2	21.0	25.1	6.5	8.2	1.8	1.1	1.0	0.7	0.9	2.5	2.1	0.4	1.9	1.1	11.2	11.1
Paspalum	51.8	55.2	26.4	28.9	4.8	7.0	2.6	2.1	0.9	2.1	1.6	1.2	1.1	0.3	1.8	0.9	12.6	12.6
Cynodon	52.3	53.7	25.8	28.1	5.8	8.0	1.0	1.3	1.7	2.7	3.1	1.6	0.5	1.0	1.6	0.2	12.8	12.8
Legumes																		
Pueraria	46.0	52.4	22.2	28.1	2.9	5.8	2.5	1.5	1.0	1.0	1.6	1.7	1.6	2.2	1.3	0.0	12.9	12.1
Stylosanthes	45.7	53.6	19.2	28.1	5.3	6.0	1.5	2.1	1.0	1.5	2.9	1.2	1.4	1.4	0.8	0.0	13.6	12.2
Styzolobium	47.7	53.5	22.3	28.2	3.3	6.4	1.9	0.7	1.4	2.9	1.6	1.2	1.5	1.3	2.7	0.0	12.8	12.9.
Psophocarpus	49.6	51.3	26.1	26.1	2.0	5.2	2.5	1.6	0.7	3.4	1.5	0.3	1.9	1.3	1.6	0.4	13.3	13.2
Centrosema	49.4	50.7	24.3	26.3	3.2	4.2	1.7	1.3	1.3	3.9	1.6	0.1	2.2	1.7	2.0	0.0	13.1	13.2
Control																		
Weed fallow	44.4	53.3	22.2	31.1	0.2	1.7	1.8	2.3	1.2	2.1	2.0	0.7	2.1	2.9	1.6	0.0	12.5	12.6

[a] B = before fallowing, A = after fallowing.

Table 6. Effects of different mulch materials on soil water storage (Harrison-Murray and Lal 1979).

Mulch material	Soil moisture content (%, wt/wt)	
	Sandy soil	Sandy clay loam
Straw	11.2	17.7
Black polythene	10.6	17.8
Clear polythene	11.3	17.9
Control	10.3	41.8
Available water capacity (%)	5.2	9.2

Table 7. Effect of mulch rate on runoff and erosion for different slopes (Lal 1976).

Mulch rate (t/ha)	Runoff	Erosion
0	$Y = 59.2\ S^{-0.04}$	$Y = 11.8\ S^{1.13}$
2	$Y = 2.1\ S^{0.66}$	$Y = 0.5\ S^{0.87}$
4	$Y = 0.8\ S^{1.05}$	$Y = 0.07\ S^{1.05}$
6	$Y = 0.001\ S^{3.3}$	$Y = 0.01\ S^{0.5}$

coefficients of regression equations relating slope witb runoff and erosion decrease by several levels. Experiments at the IITA showed that mulch at 0 t/ha had a mean runoff of 285.5 mm and 90 t soil loss/ha, mulch at 2 t/ha had 39.9 mm runoff and 4 t soil loss/ha, mulch at 4 t/ha had 13.8 mm runoff and 0.8 t soil loss/ha, and mulch at 6 t/ha had 7.8 mm runoff with 0.4 t soil loss/ha. These results were for natural and regular slope steepness ranging between 1 and 15% and slope length of 25 m. A mulch rate of 4 to 6 t/ha can, therefore, effectively prevent erosion even on steep slopes.

Other aspects of soil conservation are described in more detail in the report by Dr. Chopart.

SEED GERMINATION AND SEEDLING ESTABLISHMENT

Soil moisture content, seed zone temperature, and seed-soil contact affect seed germination and seedling establishment of upland rice. Too high seed zone temperatures can damage upland rice stands. For example, controlled environmental studies at IITA showed mean rice emergence of 62.2% at 20-25°C, 68.3% at 30-40°C, and 0 at 40-50°C.

Aggregate size and wheel compaction of the soil above and below the seeds affect seed-soil contact. Maximum rice emergence occurred at the bulk density combination of 1.1 above and 1.6 g/cm^3 below the seed zone (Table 8). The mean emergence for bulk density

combinations above and below the seed zone was 22.2% at 1.3/1.3, 43.7% at 1.1/1.3, 59.3% at 1.1/1.6 and 48.9% at 1.3/1.6. Table 8 also shows a strong interaction between bulk density and soil temperature for root elongation rates. At the uniform bulk density of 1.3 g/cm³ and temperature of 20-25°C, roots elongated faster than shoots. At the same uniform bulk density, however, root growth at 30-40°C was significantly less than shoot elongation. In contrast to shoot length, maximum root length occurred at 20-25°C. The optimum temperature range for root growth, therefore, is less than for shoot growth.

The optimum soil-water range for rice germination occurred between -0.01 and -3 bars (Table 9) on coarse-textured soils with frequent or recent rainfall. High soil-water suction (more negative) of -5 or -10 bars can inhibit rice germination more than that of other upland crops, eg, maize, cowpea, or soybean. Table 9 also shows a strong interaction between aggregate size and the soil-water potential. For example, suctions below -0.3 bar inhibited rice germination more in <2 mm particle size and whole soil than in coarse aggregates. At high suctions of -5 bar, however, rice germination was higher in fine aggregates than in coarse (Table 9).

EVALUATION OF DROUGHT STRESS IN RICE

It is difficult to evaluate how well rice varieties adapt to drought-prone upland soils. Agronomic information about tillering potential, number of leaves, and leaf blade length do not explain the ability of a plant to adapt to varying soil moisture and evaporation. Although root growth and development show how the

Tablc 8. Effect of bulk density and soil temperature on rice emergence.

Bulk density g/cm³	20-25°C			30-40°C			40-50°C		
	Emergence (%)	Shoot length (mm)	Root length (mm)	Emergence (%)	Shoot length (mm)	Root length (mm)	Emergence (%)	Shoot length (mm)	Root length (mm)
1.3	35.6	7.8	13.8	31.1	16.2	10.9	0.0	0.0	0.0
1.1/1.3	48.9	5.8	16.0	82.2	19.0	11.8	0.0	0.0	0.0
1.1/1.6	91.1	15.2	13.1	86.7	17.2	11.3	0.0	0.0	0.0
1.3/1.6	73.3	14.2	11.7	73.3	10.5	6.5	0.0	0.0	0.0
Mean	62.2	10.8	13.7	68.3	15.7	10.1	0.0	0.0	0.0

LSD (.05)	Emergence	Shoot length	Root length
Temperature	2.1	0.65	0.73
Bulk density	1.8	0.43	0.49
Bulk density for same temperature	3.2	0.74	0.85
Bulk density for different temperature	3.4	0.91	1.03

Table 9. Effect of aggregate size and soil suction on germination of rice (unpubl. data of Lal and Falayi).

Aggregate size (mm)	Percent emergence at different suctions (–bars)												Mean emergence (%)
	0	0.005	0.01	0.03	0.05	0.01	0.03	1	3	5	10	15	
<2	50.0	73.3	86.7	96.7	96.7	100	100	100	100	86.7	6.7	0	74.7
2-10	76.7	90.0	100	100	90.0	100	93.3	100	96.7	70.0	13.3	0	77.5
10-50	96.7	90.0	100	100	100	96.7	93.3	100	100	76.7	6.7	0	80.0
Whole soil	80.0	83.3	84.7	93.3	96.7	90.0	96.7	100	100	86.7	6.7	0	76.7
Mean	75.9	84.2	93.4	97.5	95.9	96.7	95.8	100	99.2	80.0	8.4	0	

LSD (0.05)

Suction	10.1
Aggregate size	2.7
Suction × aggregate size interaction	5.4
Crop × aggregate size interaction	ns
Crop aggregate size × suction interaction	ns

plant extracts water from deeper soil horizons, they do not explain how the plant copes with changes in water energy.

By evaluating wilting range, resistance to water flow or the leaf diffusive resistance and the leaf water potential, one can assess leaf water availability in relation to drought stress.

NO-TILL FARMING AND RESIDUE MULCHING FOR UPLAND RICE

No-till implies seeding untilled soil through previous crop residue. Seedbed preparation is often limited to opening a narrow slot or band wide enough to plant seeds and allow adequate seed-soil contact. Herbicides control weeds, and the residue mulch prevents runoff and erosion, decreases evaporation loss, and maintains a favorable hydrothermal condition in the seed zone. For an effective no-till system, the preseeded soil must have favorable bulk density and porosity, good pores, and water transmission properties. An adequate quantity of crop residue mulch is an essential component of the no-till system.

Maurya and Lal (1979) observed that application Of mulch at 6 t/ha produced more dry matter, increased grain weight per panicle, and decreased the floral sterility of variety TOS78, grown at IITA, Ibadan, on an Apopu (Psammentic Ustorthent) soil (Table 10). The leaf water potential of mulched rice was as much as 2 bars more than unmulched during high evaporation. The root density immediately under the mulch was more than in unmulched surface soil. Under upland conditions, TOS78 yielded 3.0 t/ha without and 5.0 t/ha with mulch.

Long-term no-till experiments in Sierra Leone (Mahapatra et al 1979) reported satisfactory rice yield. Lal and Dinkins (1979) reported that rice grain yield on a slope with conventional plowing in Liberia was only 65% of that from a no-till mulched treatment (Table 11). Without chemical fertilizers, tillage treatments did not cause differences in grain yield. The high grain yield under no-till conditions also was associated with fewer tillers than in plowed treatments (Table 12). The number of productive tillers, however, was higher in no-till than in plowed treatments.

Table 10. Effects of crop residue mulch on growth and development of TOS78 (Maurya and Lal. 1979).

Growth parameter	With mulch	Without mulch	LSD (.05)
Dry matter production 12 wk after seeding (g/plant)	17.6	15.6	7.2
Grain weight (g)/panicle	2.4	1.8	0.9
Floral sterility (%)	27.4	31.9	16.0

Table 11. Effects of tillage systems and fertilizer rates on grain yields of upland rice in Liberia (Lal and Dinkins 1979).

Tillage system	Grain yield (t/ha)	
	With fertilizer	Without fertilizer
No tillage	2.92	1.24
Conventional	1.91	1.20
LSD (0.05)	1.14	

Table 12. Rice tillering as affected by tillage methods and fertilizer treatments (Lal and Dinkins 1979).

Tillage methods	Fertilizer treatment	Tillers/m^2 at different days after seeding				
No tillage	With fertilizer	48	68	80	100	208
	Without fertilizer	52	72	136	140	145
Conventional	With fertilizer	66	100	134	144	146
	Without fertilizer	68	24	146	160	160

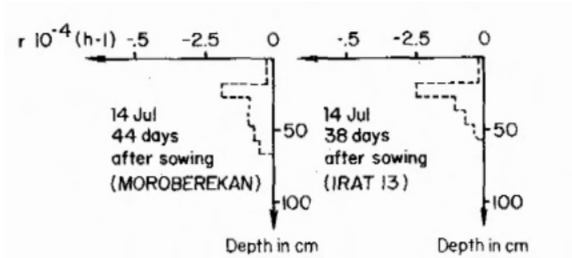
CONCLUSION AND GENERAL DISCUSSION

Before intense production can meet the increasing West African demand for rice, farmers must eliminate drought stress through better soil and water management. It will also require heavy initial capital investment to maintain adequate water on valley bottom land and a good water control and management program adapted from other Asian research.

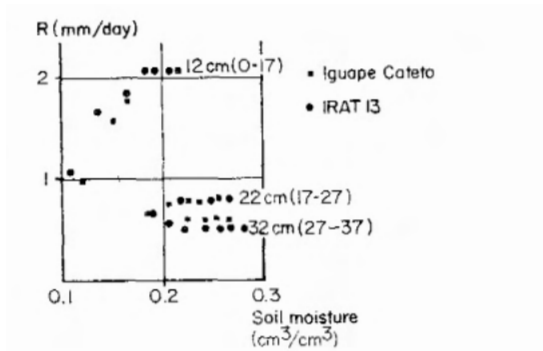
West Africa mostly produces upland rice (IRRI 1975). Rainfall variability and reliability, soil physical properties and their management, and appropriate upland rice varieties make water management problems severe and complicated. In fact, during the critical phases of rice development, upland rice should not have more than 5 to 7 rainless days.

Equally important are selection of suitable soil types with water-holding capacity in the root zone, good rooting depth, and availability of interflow water.

Soil and crop management including residue mulch and no-till farming can effectively control erosion and conserve water in the root zone. Successful application of these practices to upland rice production, however, requires the development of an appropriate agronomic package of cultural practices specifically adapted for different soils and ecological regions. This package for farmers needs a high research priority.



10. Profiles of root water extraction in deficit period.



11. Variation of the rate of root extraction by soil section for 2 cultivars.

- The part of actual transpiration (TR) of a crop can be differentiated from that of soil evaporation in the actual total consumption Ea (Fig, 10). In both experiments, evaporation represents less than 10% of the Ea.

CONCLUSION

An inventory of study methods for upland rice water transfer shows their limitations and advantages.

Their development shows the IRAT researchers' interest in reliable methods of comparing water use among varieties. They are also interested in the effects of soil and cultivation techniques on water use and the control of drought tolerance in new varieties.

Varietal comparisons have shown that the influence of soil type is obvious. On the other hand, it is difficult to differentiate the Ea of two genetically close varieties on the same soil, owing to the soil variability.

Important practical results were obtained during periods of water deficit. However, the application of these methods whenever rainfall is excessive is not reliable because rapid drainage is not easily measurable.

This is a characteristic of most ferralitic soils of West Africa.

On these soils, characterized by a hard layer that limits root development to a depth of 50 to 80 cm, the methods showed that:

- The overall balance sheet is unadapted to ferralitic soils.
- The no transfer level allows precise evaluation of Ea during periods of deficit, but is not suitable for periods of excessive rainfall.
- The in-depth flow takes into account losses by drainage. But using hydraulic conductivity estimated locally limits its application to the plot because of the variability of the hydrodynamic characteristics as well as the depth and physical properties of the hard layer.

However, it is possible to precisely estimate the root extraction of water from the soil layers by evaluating interlayer flows, which are negligible in the clay-sandy soils considered.

This method can be used to identify relatively small varietal differences. A simulation model of the water balance sheet (Forest et al 1982), based on the in situ measurements of Ea and applied over several years, would certainly produce statistically significant results.

Finally, other researchers need to verify these conclusions under different soil-climatic conditions.

ACKNOWLEDGMENTS

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UPLAND RICE IN LATIN AMERICA: ENVIRONMENT, CONSTRAINTS, AND POTENTIAL

D. R. LAING, R. POSADA, P. R. JENNINGS, C. P. MARTINEZ, and P. G. JONES

In Latin America, upland rice is much more important to total rice production than rainfed, lowland rice. Rainfed lowland rice is less than 7% of total rice area and contributes only about 10% to production.

An estimated 6.14 million ha in Latin America (1980) is in upland rice (arroz de secano) except for a few highly favored areas where phreatic water is available part of the growing season.

In the region, upland rice is grown in a very wide range of environments. For this workshop, they are classified as favored upland, moderately favored upland, and unfavored upland. Favored upland is more common in the Andean countries; moderately favored upland is in Mexico and Central America; and unfavored upland is mostly in Brazil.

This paper describes the upland rice sector in Latin America and should be read with Martinez, Seguy, and Seguy et al (this volume) who describe upland cropping systems in the region, and with Steinmetz et al (this volume), who describe methods for classifying and zoning upland rice environments.

DISTRIBUTION AND IMPORTANCE OF UPLAND RICE

Because national rice production statistics generally do not categorize different upland rice environments and estimate their area, we used International Rice Testing Program (IRTP) information for this paper. IRTP data classify the areas as more favored (favored and moderately favored) and unfavored. Table 1 shows 1980 estimated production for these systems for tropical Latin America. The data exclude the temperate, completely irrigated rice production areas in Chile, Argentina, and Uruguay. Data in Appendix 1 give production statistics by country for the three main rice production groups.

Of the estimated 14.4 million t of rough rice produced in Latin America in 1980, 7.6 million t or 53%, was upland rice. Of the total rice area, 6.14 million ha or 76% was planted with upland rice. The

Staff of the Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

Table 1. Estimated production statistics for principal rice systems in tropical Latin America and the Caribbean, 1980 (FAO 1980, USDA 1980, CIAT 1979).

Principal system	Area		Production		Yield
	thousand ha	%	thousand t	%	t/ha
Irrigated	1,902	24	6,837	47	3.59
More favored upland	2,020	25	3,478	24	1.72
Unfavored upland	4,129	51	4,129	29	1.00
Total	8,051	100	14,444	100	1.79

1. Irrigated and upland rice regions of Latin America.

more favored upland systems were about 25% of total rice area and 24% of production. The unfavored system, 51% of the total rice area, contributed about 29% of total production.

Average upland yields contrast sharply with irrigated yields. Regional average yield in 1980 was about 1.7 t/ha for the more favored upland systems and about 1.0 t/ha for the unfavored system. Average national yields for the more favored systems range from 1.1 to 3.5 t/ha, reflecting production conditions and problems in different countries. About 94% of the unfavored area was in Brazil where rainfall and diseases fluctuate yearly.

The accompanying map (Fig. 1) showing upland and irrigated systems was derived from municipal census data. In Mexico, upland areas are mainly in the southeast and on the Yucatan Peninsula. Upland rice grows throughout Central America to Panama except in Nicaragua, where irrigated production predominates. Most rice in the Carribean, including Surinam and Guyana, is irrigated.

In most Andean countries, irrigated and upland systems occur side by side because environments favor both systems. In those countries, technical benefits from research on irrigated systems apply to favored uplands. Bolivian production is mainly uplands. In Brazil, there are important upland areas in Goias, Maranhao, Mato Grosso, Minas Gerais, Mato Grosso do Sul, Sao Paulo, and Parana.

PHYSICAL ENVIRONMENT

The upland rice definition includes a wide range of Latin American rice-producing environments. The Rice Program and Centro Internacional de Agricultura Tropical (CIAT) are cooperating in a quantitative agroecological study of upland rice growing areas to characterize and classify upland environments. The study will describe the present status of rice and estimate its potential in each environment. We will define soils, landscape, climate, and agronomic conditions for each microregion (a small production area with uniform conditions).

Eight representative locations were analyzed: three favored upland sites, three moderately favored, and two unfavored. They illustrate the range of conditions and the problems in classifying rice environments for the region.

Using available production and census data, the rice production areas were located close to the relevant land system (Cochrane et al 1983). This proved somewhat inaccurate because the survey data scale must be at least 1:1 million or higher and this kind of soil survey data is unavailable. Satellite imagery located

Table 2. Environmental descriptors for eight locations representing typical sites in three upland rice production systems in Latin America.

No.	Site	Country	Mean annual rainfall (mm)	Mean growing temperature (°C)	Principal soil type classification		Base status	Al toxicity	Estimated potable water (mm)
					USDA[a]	FAO[b]			
Favored upland									
1	Villavicencio	Colombia	4096	25.6	Tropoquept	Eutric Gleysol	Moderate	Moderate	150
2	Uraba	Colombia	4805	25.9	Tropofluvent	Eutric Fluvisol	High	Low	250
3	Puerto Cortes	Costa Rica	4809	26.7	Hapludoll	Mollic Gleysol	High	Low	250
Moderately favored upland									
1	Juquilisco	El Salvador	1842	26.3	Tropofluvent	Eutric Fluvisol	High	Low	200
2	Liberia	Costa Rica	1887	28.2	Pellustert	Mollic Gleysol	High	Low	200
3	David	Panama	2364	26.9	Vitrandept	Vitric Andosol	Low	High	150
Unfavored upland									
1	Campina Verde	Brazil	1489	23.3	Haplorthox	Acric Ferralsol	Low	High	75
2	Goiania	Brazil	1399	23.1	Haplorthox	Acric Ferralsol	Low	High	75

[a]USDA 1975. [b]FAO 1974.

the major cultivated areas, and we described each area's soil and terrain and identified local meteorological stations. Table 2 lists the sample locations and selected environmental descriptors. Appendix 2 more completely describes each land system.

Soils at favored upland sites are deep and heavy-textured with a high base status and moderately high fertility. All favored sites have high moisture-holding potentials and often have access to a water table within 50 cm.

Two of the moderately favored sites have Eutric Fluvisols and Mollic Gleysols which are associated in some areas with Cambisols and Kastanozems. The latter soils have high fertility, high base status, and good working properties, and are not inferior to the best favored sites. The Vitric Andosol in Panama has a deep profile but is acid and low in fertility.

Both unfavored sites in Brazil are on a deep, loamy, well-drained Acric Ferralsol, which is highly acid and infertile with high aluminum saturation (>70%) in most areas. Goiania, however, has areas of relatively low aluminum saturation. Phosphorus is very low at both locations and highly acid subsoil restricts root development and soil water available to plants.

All locations are level or gently rolling with slopes less than 8%, which facilitates mechanized cultivation. The unfavored sites in Goias and Minas Gerais are similar to many others in Brazil. Elsewhere, upland production is dispersed, but we chose sites witn concentrated production.

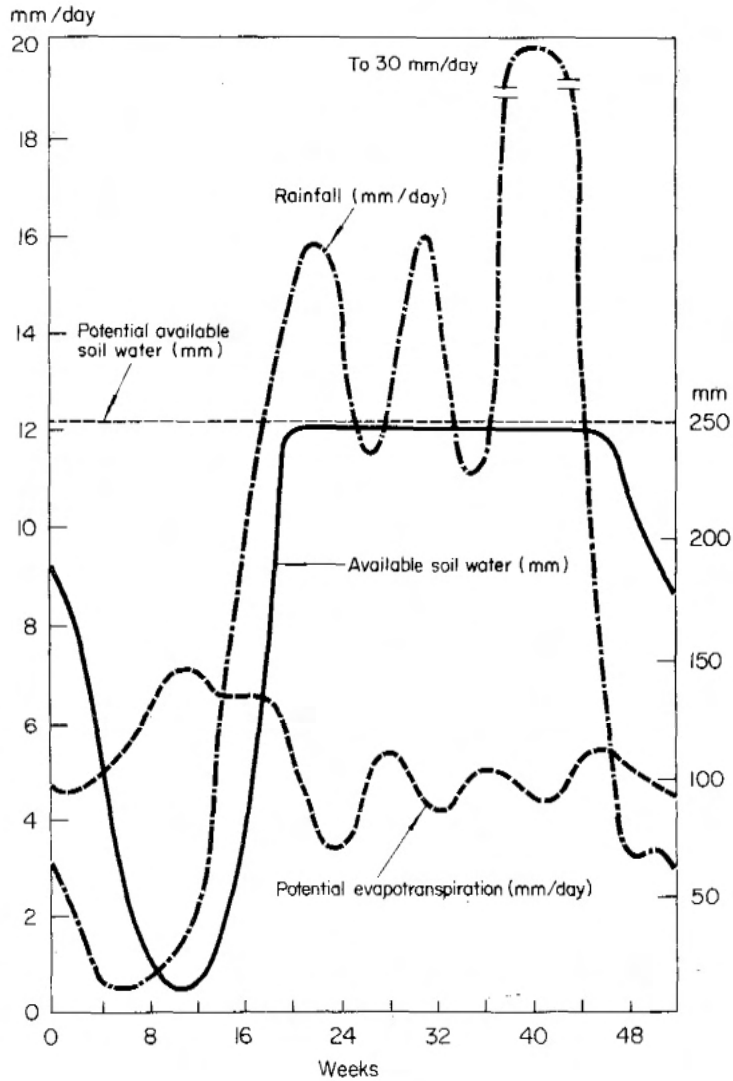
With such varied soil and terrain types, no one set of conditions characterizes favored upland sites. They may have better soils than others; however, fertile soils do not always indicate a favored-upland site because climate can limit production. Unfavored rice situations tend to have low fertility and highly acid soils.

Table 3 shows the climatic parameters for eight upland locations. Growing season length is based on crop water balance evaluations using estimated mean

Table 3. Range[a] of agroclimatic parameters for typical selected upland sites (see also Table 2).

Growing season characteristics	Favored		Moderately favored		Unfavored	
Length[b] (days)	287	365	154	210	154	182
Mean temperature (°C)	25.6	26.7	26.3	28.0	22.7	23.3
Mean evapotranspiration (mm/day)	3.8	4.8	4.4	5.9	5.2	5.8
Radiation (MJ/m^2 per day)	15.9	19.3	19.6	21.0	20.5	21.6

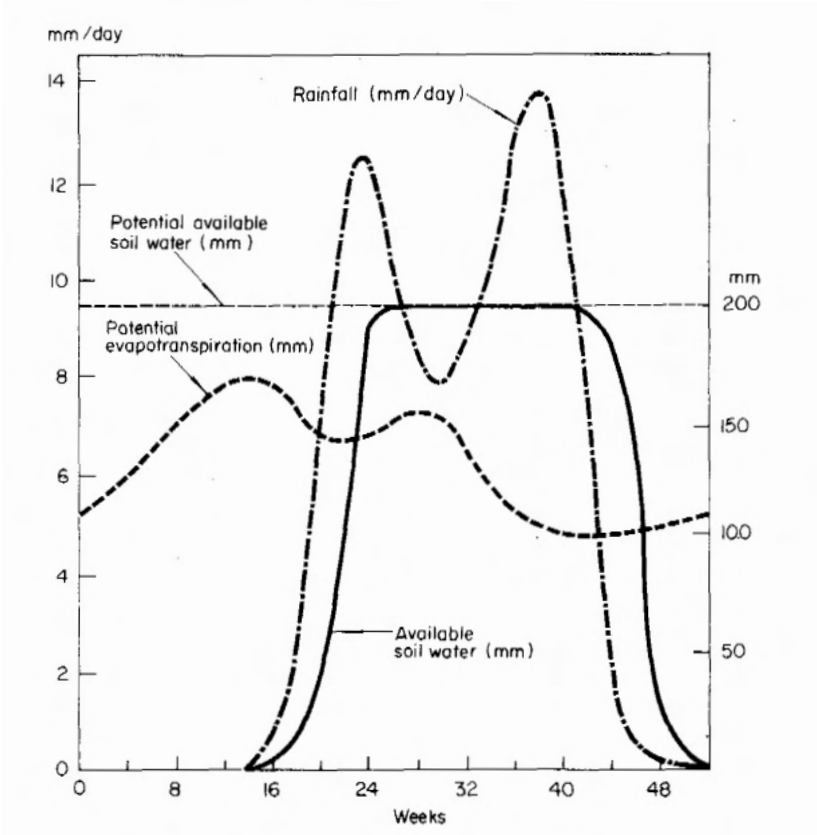
[a]Range noted in sample meteorological station data. [b]Length of growing season calculated from estimated daily soil water budgets as the number of contiguous days when available soil water is greater than 0.33 of potential available.



2. Representative precipitation, evapotranspiration, and daily soil water balance for a favored upland area, Palmar Sur Meteorological Station, Costa Rica.

weekly data for rainfall and potential evaporation. All locations have an adequate growing season of 154 contiguous days, when soil water is greater than 1/3 of potential under mean climatic conditions. Temperature and radiation are also adequate.

Mean growing season rainfall decreases from favored to unfavored sites (Table 2). But water balance calculations using long-term mean rainfall suggest that water will exceed evapotranspiration even at unfavored

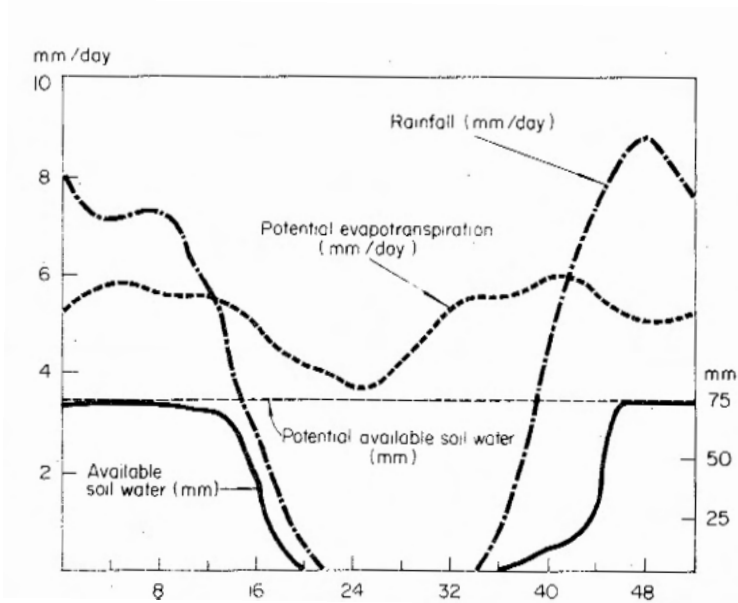


3. Representative precipitation, evapotranspiration, and daily soil water balance for a moderately favored area, Usulatan Station.

sites (Fig. 2, 3, 4). Because rainfall varies greatly at unfavored sites, moisture stress is probable during the growing season.

To illustrate the effects of reduced rainfall during the growing season, soil moisture budgets were calculated at each location for a hypothetical mid-season 1-month dry spell with 50% less rainfall than normal. The reduced growing season was calculated by adding the number of days with 1/3 less available soil moisture and those days unused by the shortened growth cycle. The results clearly distinguish the unfavored locations (Table 4). Mild stress days from reduced rainfall were those with soil water between 1/3 and 2/3 of potential.

At favored sites with a simulated 50% reduction in rainfall, there were no mild stress days. Almost all moderately favored sites experienced several mild stress days. Stress was severe at unfavored sites. The probability of a 50% monthly rainfall reduction would be higher at moderately favored and particularly at unfavored sites.



4. Representative precipitation, evapotranspiration, and daily soil water balance for an unfavored upland area, Goiania Meteorological Station, Brazil.

Columns 3 and 4 in Table 4 show another example of stress susceptibility in these environments. Days-to-stress was calculated as the number of rainless days at full potential evapotranspiration (E_t) required to reduce the available soil water to 1/3 of its potential. Column 4 is a subjective estimate of the probability of this dry spell occurring. Note that moisture stress occurs after 9 days without rain at unfavored sites with lower potential soil water availability and higher E_t. It takes more than 20 days for stress to occur at favored locations. Climate-soil interactions at unfavored locations make it highly likely for the sites to experience variable midseason water stresses. Averaqe seasonal yields at the eight locations (Table 4) reflect the stress estimates from the water balance studies.

Climate data and reduced midseason rainfall show it is impossible to classify Latin American upland rice areas only by soil quality characteristics and growing season length based on water balances under mean climatic conditions. It is equally difficult to estimate the suitability of different microregions based on these parameters alone. Without rainfall variability data, we cannot make further progress toward a quantitative classification of rice environments in the region. The CIAT study will analyze all those factors.

Table 4. Effects of rainfall variability (simulated rainfall reduction by 50% midseason for one month) at selected upland sites.

	Reduced GSD[a]	Mild stress day[b] (no.)	Days to stress[c]	Probability of dry period[d]	Yield[e] (t/ha)
Favored upland					
Site 1	0	0	23	Highly unlikely	4.50
Site 2	0	0	39	Nil	4.40
Site 3	0	0	34	Nil	3.50
Moderately favored upland					
Site 1	0-35	28-35	22	Possible	3.00[f]
Site 2	0	21-35	26	Possible	1.92[g]
Site 3	0	0-14	22	Unlikely	2.59[g]
Unfavored upland					
Site 1	98	14	9	Highly likely	1.10[g]
Site 2	64-98	14	9	Highly likely	1.20[g]

[a] Reduction in growing season (GSD) days (days with soil moisture available greater than 1/3 soil moisture holding potential) due to one midseason month with half of normal mean rainfall. [b] Mild stress days (days with soil water availability between 2/3 and 1/3 capacity) as induced by 50% reduction in rainfall for one month. [c] Days for growth before 2/3 of available soil water is exhausted if no rain falls as in footnote [a]. [d] Subjective estimate of the probability of a dry spell at least as long as the figure in preceding column. [e] Yield estimates not including traditional subsistence areas. [f] CIAT estimates from informed sources. [g] From census data where available (c).

Particularly important in this analysis is rooting depth in relation to climate. At the drier unfavored locations, the inability of rice roots to penetrate aluminum-saturated subsoils severely reduces production. It is also partly responsible for lower yields and high variability. **Veranicos** or dry spells during the Brazilian rainy season sharply limit rice production in unfavored areas.

BIOLOGICAL ENVIRONMENT

More biological constraints severely affect Latin American upland rice than irrigated rice. Combined with physical limitations, they reduce productivity and make it more unstable throughout the region. This stems from the lack of irrigation water which increases soil fertility by reducing soil acidity, eliminating drought stress, and partially controlling weeds.

Biological constraints (soil, climate, and cultural practices) interact, resulting in insect, disease, and weed problems. Some of those that are more pronounced in the unfavored areas, are described here,

Insects

Elasmopalpus lignosellus, Blissus leucopterus, and Phyllophaga spp. are widespread but sporadically occurring insects found only in upland rice. Damage from the first two is appreciable during prolonged drought in early growth but they do not reduce yield in high rainfall areas. Phyllophaga (white grubs) damage rice fields rich in organic matter, particularly converted pasture areas. The Sogatodes planthopper is a serious pest in both irrigated and upland fields because of direct feeding and as the vector of the hoja blanca virus. Most problems occur in high humidity areas with moderately high rainfall such as favored upland rice ecosystems in Colombia, Peru, and Venezuela.

Diseases

Two factors promote major fungal diseases of upland rice, such as blast (Pyricularia oryzae), brown spot (Helminthosporium oryzae), leaf scald (Rhynchosporium oryzae), and eye spot (Drechslera gigantea). Drought stress makes plants more susceptible and the longer the stress, the greater the problem. High spots in upland fields and sandy soils encourage diseases, particularly blast.

Certain soil conditions favor the development of leaf blast and other fungal diseases. Ultisols and Oxisols on South American savannas are highly acid soils and seem to enhance disease epidemics. High organic matter soils have more severe leaf diseases, especially eye spot and brown spot.

Diseases in favored uplands increase during high humidity, excessive nitrogen fertilization, and heavy seeding rates.

Weeds

Wet fields are a major problem in weed control because they prevent farmers from using heavy equipment. The resulting delay requires increased herbicide use and results in less effective weed control. When weed control is important to preserve water, drought stress also reduces herbicide effectiveness because farmers must wait until it rains to apply the chemicals. By then, weeds have passed their most susceptible stage.

UPLAND RICE VARIETIES

Appendix 3 lists commercial upland varieties in Latin America. Improved short-statured materials developed by several national programs are extensively planted in the more favored areas. Less favored areas in Brazil grow traditional varieties and those developed by the Instituto Agronomico Campinas (IAC). The traditional (or subsistence) slash-and-burn production systems use old land-race varieties.

Improved varieties exhibit considerable variation in plant type, height, maturity duration, grain quality, insect and disease resistance (Table 5), drought and adverse soils tolerance, and yield potential. Except for the improved Brazilian materials, most are well adapted in more favored conditions but very poorly adapted in less favored areas. The newer dwarf cultivars have covered the favored upland areas and much of the moderately favored areas, particularly in Colombia, Venezuela, and Central America. Only tall varieties, both improved and traditional, are found in the unfavored system.

Because of the close cooperation between CIAT and ICA, national programs have released more than 30 dwarf varieties (CIAT 1981). These contributions were an unprogrammed spin-off from breeding for irrigated conditions (Jennings et al 1981). Highly and moderately favored environments in Colombia and Central America indicate that dwarf cultivars have the highest yield potential when blast and weeds are the biggest problem. Tapuripa, Magali, Bowani, Diwani, and Eloni varieties, bred in Surinam for irrigated conditions, also grow well in Central American favored uplands especially in Panama, where they have shown a high blast resistance for about 20 years. Some other CICA7 lines also have blast resistance. Some countries grow limited commercial amounts of U.S. irrigated varieties Bluebelle, Bluebonnet 50, and Starbonnet in favored uplands. A few farmers still use than because of their earliness and

Table 5. Main agronomic characteristics of principal improved rice varieties grown in uplands in Latin America. Evaluations conducted at two sites in Colombia.[a]

Cultivar	Maturation duration (days)	Plant height (cm)	Disease reaction				*Sogatodes oryzicola* (1-5)	Grain quality	
			Leaf blast[b]	Neck blast (%)	Hoja blanca[c]	Leaf scald[b] (1-9)		White belly	Grain length[d]
CICA4	135	89	5	22	MR	6	2.5	0.6	L
CICA6	136	89	2.3 (4)	–	MR	–	1.5	0.6	L
CICA7	130	90	2	16	R	8	2.0	0.6	L
CICA8	143	94	4	75	S	5	2.0	0.8	L
CICA9	138	103	4	50	R	5	1.5	0.8	L
CR1113	141	94	1	51	S	5	5.0	0.2	L
Anayansi	145	86	3	40	–	5	3.0	1.6	L
Damaris	149	83	2	96	–	5	5.0	0.8	L
Bluebonnet 50	134	140	3	20	S	5	5.0	0.5	L
Eloni	141	90	2	–	–	3	2.0	0.8	EL
Pico Negro	133	109	–	–	–	–	–	1.0	L
IR1529 IIR 43)	132	92	4	–	–	5	2.0	2.0	L
IAC25	135	130	3 (4)	0.1	S	7	5.0	1.4	L
IAC47	130	146	3 (4)	–	S	6	5.0	3.4	L
IAC164	110	114	1 (3.4)	–	S	5	5.0	3.6	L
IAC 165	105	104	1 (3)	–	S	5	5.0	3.0	L
Diwani	131	94	1	–	MS	3	3.0	–	L
Ciwini	136	106	2.3	0	MS	3	2.5	0.2	EL
Carolino	147	144	–	–	S	–	–	2.2	L
CR201	139	103	–	–	–	3	4.0	0.4	L
Iniap 6	140	84	–	–	MR	5	2.5	0.8	L
Iniap 415	141	96	–	–	R	5	2.0	0.8	L
Iniap 7	142	100	4	–	R	6	2.0	0.4	L
Nilo 1	160	135	–	–	–	3	3.0	–	L
Tikal 2	131	94	4	98	–	5	3.0	0.6	L
Bamoa A75	136	90	–	–	–	–	–	–	L
Donato	150	109	–	–	R	–	–	–	L
Canilla	140	128	–	–	R	–	–	2.2	M
Dawn	124	90	1	86	S	5	5.0	0.6	L
Metica 1	124	75	1	0.5	R	5	3.0	0.2	L
Dourado	120	146	–	–	S	–	9.0	1.6	M

[a]Data recorded at CIAT-Palmira with disease evaluations at Villavicencio in the Colombian Llanos; (-) indicates data not available. [b]By the 1980 SES scales. [c]S = susceptible, MS = moderately susceptible, MR = moderately resistant, R = resistant. [d]L = long, EL = extra long, M = medium.

superior grain quality although they are susceptible to important pests and diseases.

To identify superior upland rice germplasm in the last 10 years, several Central American national rice programs acquired advanced breeding material from CIAT and IRRI (Espinosa 1982). In 1978 each national rice program selected their best locally adapted breeding lines for the Central American Upland Nursery (VICA). The nursery contained 60 lines, 32 named by Costa Rica, 16 by Panama, 6 by Honduras, 4 by Guatemala, and 2 by Nicaragua. After several regional plantings and evaluations in uplands, the nursery reduced the lines to 14 in 1981. This nursery probably contains good parental material for developing superior upland varieties for the region. The lines have high yield potential and blast and leaf scald resistance under favored upland conditions but are less resistant in less favored areas.

CROPPING SYSTEMS FOR UPLAND RICE

Rice in Latin America grows on medium to large farms with diverse production systems. Systems range from intensively irrigated tO extensive uplands. Average yields vary markedly. The rainfall pattern (amount and variability), cost of irrigation water, soil type, topography, and availability of infrastructure determine the type of system (CIAT 1981).

Latin American upland rice yield ranges from extremely low (cerrado of Brazil) to high (llanos of Colombia), and it is difficult to subdivide these types. For this paper, however, we analyzed each ecosystem for yield constraints, potential productivity, breeding objectives, priorities, and economic profitability (Jennings et al 1981).

Favored upland

The favored upland rice areas are flat and receive more than 2000 mm rainfall during a 6 to 8 months continuous wet season. Soils are normally alluvial, slightly to moderately acid, and well drained. Favored upland rice areas use modern dwarf varieties, improved agronomic practices, and mechanized farming. Yields average about 2.5 t/ha but better farms consistently produce between 4 and 5 t/ha. Favored upland rice areas are in parts of Venezuela, Brazil, Central America, and two major locations in Colombia.

Major problems are grassy weeds, blast, and lodging, and recently leaf scald and grain spotting have affected some areas. Hoja blanca has caused widespread damage in the eastern plains of Colombia. CICA8, developed by ICA and CIAT, has been the most productive variety, but its susceptibility to the hoja blanca virus will limit future use.

Moderately favored upland

Moderately favored areas are in Bolivia, Ecuador, Mexico, Venezuela, most of Central America, and much of sub-Amazonian Brazil. They differ from favored areas in having less rainfall, a 2- to 3-week dry period during the growing season, and less fertile soils. Dwarf varieties are grown in Central America, and in some areas in Bolivia, Ecuador, Mexico, and Venezuela whereas tall varieties are grown in Brazil. Irregular rainfall causes high yield variances, but average yield for the system is about 2.0 t/ha in Central America and 1.5 t/ha elsewhere. Several interrelated factors triggered by mild to moderate drought stress cause mineral deficiencies, diseases (particularly blast, brown spot, and lea1 scald), insects, and weeds. Occasional drought reduces yields and complicates land preparation, seeding, and timing of herbicide and fertilizer applications.

Unfavored upland

Unfavored uplands have irregular and low total rainfall, are highly mechanized, have low planting densities, and utilize tall varieties averaging 1 t yield/ha. Yields vary greatly across seasons and regions because of severe drought stress. Much of Brazil has unfavored upland rice production in acid soils with very poor water-holding capacity.

The main constraint is low total rainfall with 20- to 30-day dry periods or **veranicos** during the growing season. Drought stress affects plant growth, mineral nutrition, and severity of blast disease. Phosphorus and zinc deficiencies are common in these acid soils. The acid subsoils have high aluminum toxicity and severely limit root development.

Subsistence upland rice

Farmers in remote areas at the agricultural frontier grow subsistence upland rice without mechanization or purchased inputs. Farmers clear and burn forest or scrub, and dibble rice in widely separated holes. They shift the crop to new land after one or two harvests. Farm size is about 1 ha/family. They grow unimproved land race varieties with stable productivity averaging l t/ha or less. The farm family consumes the harvest but sometimes sells a small portion. Total area and production are estimates since statistics are not available.

Socioeconomic constraints and total dependence on family labor limit farm size, oblige wide spacing, demand native varieties, and prohibit purchased inputs. Because of the socioeconomic factors and the probable minor contribution to regional production, CIAT has not done research specifically for this ecosystem.

PAST TRENDS AND FUTURE POTENTIAL

In the past 10 yr there has been an increasing awareness of the importance of different Latin American rice production systems. Scarce statistical data on the upland systems are usually grouped with those of irrigated rice. The total Latin American rice area has increased 2.7% annually, with irrigated areas increasing 1.0%. If the annual increase is proportional, upland rice areas are increasing 1.7%/yr.

In a similar analysis, the total average rice yield has increased only 0.8%/yr, although many countries have had spectacular yield increases with irrigated rice. The predominance of upland systems with stagnant yields accounts for the low annual yield growth rate. Some technical spillovers, varieties developed for irrigated conditions, have adapted to favored upland conditions but give lower yields.

Area expansion accounts for upland rice production increases in Latin America but average yield remains constant. If the same trends continue, production increases could be smaller as upland rice moves to lower quality lands.

Before attempting any predictions about the future of Latin American rice, one must consider several factors. First, most countries prefer to be self-sufficient, Rice-deficit countries desire self-sufficiency to:

- increase employment,
- save foreign exchange,
- ensure food supplies for national security, and
- stabilize domestic prices for consumers and producers.

The limiting factor in those countries will be production resources such as land, water, industrial inputs, and technology. Rice-surplus and self-sufficient countries will face limited demand because the international market for rice is small and saturated. International rice prices are highly distorted and do not reflect real production and transportation costs. Most governments are skeptical of subsidizing rice exports, preferring to encourage resource use in other food crops.

Although domestic demand will limit rice production increases in Latin America, this does not imply low growth. At current per capita consumption levels, total consumption will reach 21.6 million t by the year 2000, 50% more than in 1980. Constant per capita consumption implies constant prices for rice and other food as well as constant income and equal consumption among income levels. If prices of other calorie and protein sources increase in relation to rice, or if income becomes more uneven, rice demand will be much

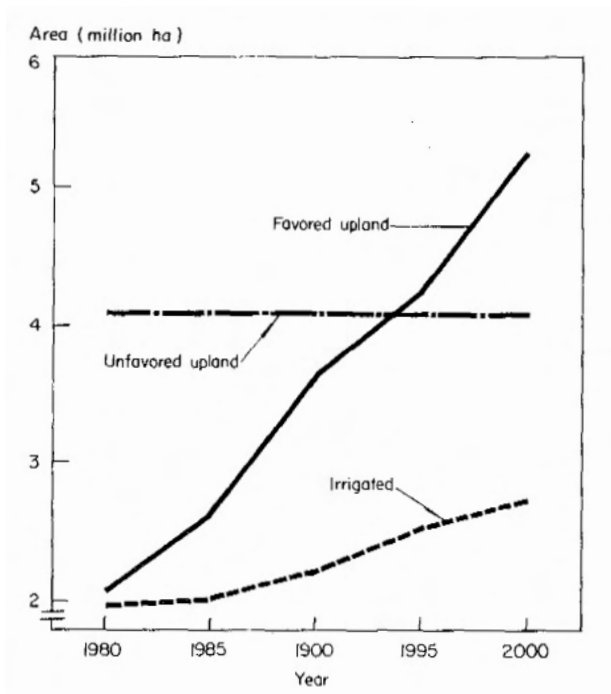
higher. It is impossible to predict how governments will react in such circumstances.

Governments can affect rice production by:

- investing in infrastructure (construction of irrigation facilities or road and other facilities in new agricultural areas);
- investing in agricultural research. (The amount and orientation of research resources and research results will affect competitiveness among crops and production systems.); and
- establishing prices and fiscal policies that will improve profitability and thus farmers' incentives to adopt new technology.

We considered these factors in predicting future Latin American rice production. Global predictions are summaries of country studies that evaluate trends in area and yield increases, supply and demand, strength of the national rice program, and government rice policies.

Figure 5 shows estimates (to year 2000) of the three main rice production systems. Because of the system's near zero or negative profitability and high production variability, the projected unfavored rice areas will remain constant. Irrigated rice areas are



5. Projected estimates of area planted in three main rice production systems in Latin America.

expected to increase by 800,000 ha, or 2% annually because availability of new high-yielding, high-profit varieties is a strong incentive for continued investment in irrigation by governments and private farmers. The favored upland area will increase by 3.2 million ha or 5% annually because of unused lands suitable for favored upland production. After estimating changes in areas and yield for the other systems, most countries projected the rest as favored upland increases.

Despite irrigated system increases expected in Brazil, the more favored nonirrigated systems, including the moderately favored and the varzeas, will be increasingly important. In tropical South America, however, favored uplands will become the most extensive system. In the Caribbean, irrigated areas will continue to account for rice area expansion and favored and unfavored upland areas will remain constant. In Central America, favored upland areas will increase.

Table 6 summarizes by country the expected average yield increases for favored upland systems. Countries that currently have high yields are not expected to have further large increases. In other countries the yield increase projections have been based on current yield and the strength of the national rice research program. Because Venezuela has large areas of available fertile land in the Orinoco Valley and Delta, the optimistic prediction of an additional 1.1 t/ha is reasonable.

Irrigated production systems will probably continue to be the most important rice source in Latin America except in Brazil. Irrigated production will nearly double by the year 2000 (Fig. 6). Despite rapid growth in favored upland areas, production should still be less than from irrigated systems until about 1995. For Brazil, however, where present production is equal for both systems, favored uplands should produce twice that of the irrigated areas by 2000. With no significant international rice trade, these estimates are sensitive to changes. In tropical South America and the Caribbean, favored upland systems will also increase rapidly but irrigated areas should continue to be the major production source.

During the next 20 years, Central America will continue to use favored upland systems as its main rice source. Irrigated rice will not increase substantially because of lack of irrigation infrastructure and competition from other crops.

By 2000, the projected total rice production would be 28.9 million t, exceeding a constant per capita consumption projection by 7.3 million t (Fig, 6). Per capita consumption of rough rice will only need to increase from the present 45 kg to 58 kg to make up this difference. Past consumption trends suggest that rice

Table 6. Projected estimates from 1980 to 2000 of average favored upland rice yields in tropical Latin America.[a]

Country	Yield (t/ha)					Percentage increase
	1980	1985	1990	1995	2000	
El Salvador	3.50	3.50	3.50	3.50	3.50	0
Guatemala	3.40	3.40	3.40	3.40	3.40	0
Bolivia	3.18	3.18	3.18	3.18	3.18	0
Peru	2.80	2.80	2.80	2.80	2.80	0
Colombia	2.80	2.80	2.80	2.80	2.80	0
Honduras	2.80	2.80	2.80	2.80	2.80	0
Panama	2.60	2.80	3.00	3.20	3.50	35
Mexico	2.36	2.56	2.77	3.00	3.24	37
Costa Rica	2.30	2.50	2.70	2.90	3.20	39
Ecuador	1.91	2.08	2.27	2.48	2.71	42
Venezuela	1.70	1.90	2.20	2.50	2.80	65
Brazil	1.59	1.78	1.99	2.23	2.50	57
Guyana	1.30	1.45	1.61	1.80	2.00	53
Paraway	1.10	1.22	1.35	1.50	1.65	50

[a]Predictions are based on past yield trends and the strength of the national rice research program.

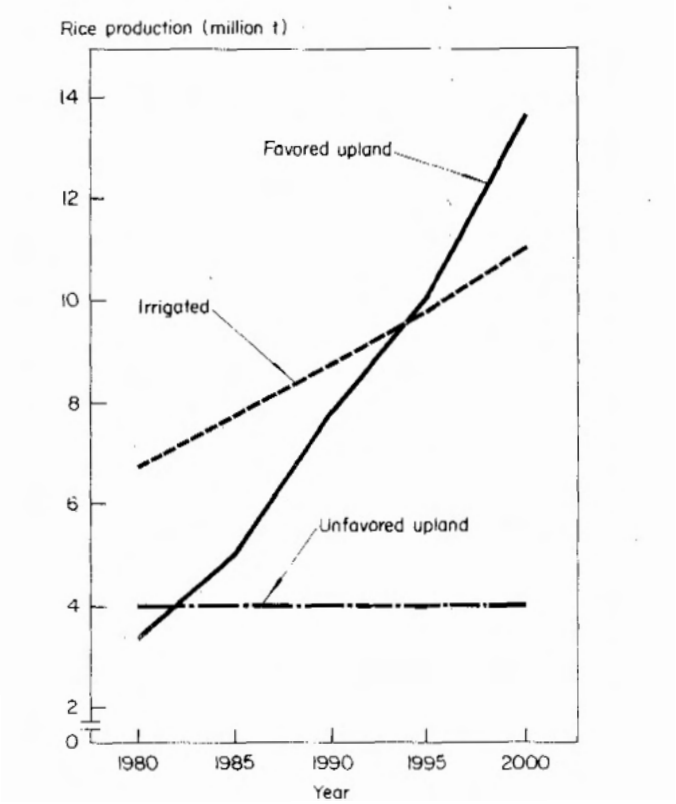
is rapidly becoming a main calorie source after cane sugar.

These projections are useful because it is probable that upland rice will continue to be an important food source. Second, despite a rapid increase in irrigated rice, the demand for new upland production will be high. Parallel improvements in technology and productivity will alleviate this land pressure. Third, with the low present per capita consumption, there is a large market for milled rice in local countries if its price is competitive with other calorie and protein sources.

REGIONAL UPLAND RICE RESEARCH

In the last 10 years, most countries producing upland rice have conducted national research to develop new technology. The CIAT-IRRI International Rice Testing Program (IRTP) for Latin America has effectively linked research groups since 1977. In addition, the Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (IRAT) has a program with the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) on the upland sector.

Imported germplasm has been particularly important for certain characteristics. Varieties developed by the Cereal Program at IITA have proved outstanding as potential parental sources for acid soil tolerance in CIAT studies for the less favored acid soils in the Colombian llanos. Some IRAT materials are excellent sources of resistance to dirty panicles and blast. West African materials from IRAT and IITA have also proved



6. Projected rice production in the three main systems in tropical Latin America from 1980 to 2000. Predictions are based on trends in area expansion, relative profitability, land availability, and other factors.

useful in Brazilian research at CNPAF, Goiania.

Although upland rice breeding has been neglected, there recently has been more interest in upland problems. A network of researchers and collaboration is also developing which parallels that in the irrigated sector.

Table 7 shows upland rice research personnel by discipline within each national program and the total researchers in the region as of September 1982. The 179 professional scientists in 24 countries are inadequate, given the projected importance of upland rice and the range of problems remaining to be resolved.

Table 7 also indicates that about half the regional researchers are working on upland rice. This is almost exactly the ratio of upland rice contribution to total production and is an indication that governments are allocating limited available , resources to the topic. The basic problem, however, is that national rice research resources are very inadequate. Many

Table 7. Number of rice research personnel in Latin America: data estimated for September 1982. [a]

Country	Personnel (no.)						
	Upland rice research					Irrigated rice research	Total
	Agronomy	Germplasm development	Pathology	Soils physiology	Subtotal		
Mexico	7	3	1	0	11	10	21
Guatemala	2	2	0	0	4	0	4
Belize	1	1	0	0	2	1	3
El Salvador	1	1	0	0	2	0	2
Honduras	4	1	0.5	0.5	6	1	7
Nicaragua	1	1	0	0	2	2	4
Costa Rica	1	1	1	0	3	0	3
Panama	3	4	2	0	9	0	9
Haiti	0.5	0	0.5	0.5	1.5	1.5	3
Ecuador	1	1	1	0.5	3.5	4.5	8
Colombia	0.5	0.5	1	0.5	2.5	9.5	12
Venezuela	1	0.5	0.5	0.5	2.5	4	6.5
Guyana	1	1	1	1	4	4	8
Brazil	17	4	3	5	29	11	40
Peru	1	1	0.5	1	3.5	13	16.5
Bolivia	1	1	0.5	0.5	3	0	3
Paraguay	1	0	0	0	1	2	3
Uruguay	0	0	0	0	0	2	2
Surinam	0.5	0	0	0	0.5	1.5	2
Argentina	0	0	0	0	0	3	3
Chile	0	0	0	0	0	2	2
Cuba	0	0	0	0	0	10	10
Dominican Republic	0	0	0	0	0	5	5
Jamaica	0	0	0	0	0	2	2
Total	44.5	23	12.5	10.0	90.0	89.0	179

[a] Information obtained originally at 3d IRTP Conference, CIAT, 1979, and updated with more recent information.

countries are not gaining full benefit from new rice technology because they have inadequate adaptive research. The international research centers provide critical input but the barrier to more rapid rice development in many countries is very low research investment.

There is a reasonable distribution of personnel among the upland research disciplines although some countries are critically lacking in certain research areas. The in-service training opportunities offered by the international centers were fundamental, but further training to fill vacancies and meet staff turnover will be necessary.

There is a much greater genotype-environment interaction in upland rice than in irrigated rice, and we need to select more varieties in the production regions. More training opportunities in breeding and selection and follow-up support should be available. The approximately 23 professionals devoted to upland germplasm development are not sufficient. Brazil's large research effort on problems of unfavored rice emphasizes the research deficiency for more favored areas in other countries.

CONCLUSION

With large areas of potential upland rice land in Latin America and predictions for increasing future rice demand, upland rice will probably become more important in the next 20 years. The more favored upland systems will have to receive increased research attention.

Solving increased productivity and production problems requires coordinated research. The most outstanding problems are the development of:

- varieties with stable or more lasting resistance to blast and other important fungal diseases,
- varieties with better root adaptation to acid soils, and
- research recommendations for upland fertilizer usage (type and placement), effective weed control methods, and a pasture phase that utilizes grass-legume forage combinations in an upland rotation.

If these problems receive sufficient research resources at international and national levels in the next 5 to 10 years, upland rice production in the more favored systems can widely expand in tropical Latin America.

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APPENDICES

Appendix 1a. Area planted in the three main production systems in tropical Latin America, 1980 (FAO 1980, USDA 1980, CIAT 1979).

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

[a]Includes rainfed lowland rice data. Estimate of area planted is about 520,000 ha in the Varzeas of Brazil, 20,000 ha in the Pozas of Ecuador, and a small area in the Dominican Republic. [b]Includes traditional (subsistence) manual upland. Estimated area in tropical Latin America is 950,000 ha mainly in Brazil, Colombia, Panama, Bolivia, and Costa Rica.

Appendix 1b. Estimated average yields for three main rice presentation system groupings in tropical Latin America, 1980 (CIAT 1979).

	Yield (t/ha)		
	Irrigated	More favored upland[a]	Unfavored upland[b]
Brazil	3.18	1.59	1.0
Mexico	4.72	2.36	1.0
Tropical South America			
Bolivia	–	3.18	1.0
Colombia	5.50	2.80	1.0
Ecuador	3.82	1.91	–
Paraguay	2.40	1.10	–
Peru	5.70	2.80	1.0
Venezuela	3.44	1.72	–
Central America			
Costa Rica	4.60	2.30	1.0
El Salvador	5.00	3.50	–
Guatemala	–	3.40	1.0
Honduras	5.00	2.80	–
Nicaragua	2.50	1.30	–
Panama	5.50	2.60	1.0
Caribbean			
Guyana	2.40	1.30	–
Cuba	2.20	–	–
Dominican Republic	3.50	–	–
Haiti	2.20	1.10	1.0
Jamaica	1.50	–	–
Tropical Latin America	3.6	1.7	1.0
Excluding Brazil	3.8	2.2	1.0

[a]Includes rainfed lowland rice data. Estimated average yield for tropical Latin America in this system is 2.5 t/ha. [b]Includes traditional (subsistence) manual upland. Estimated average yield for regional production is 1 t/ha.

Appendix 1c. Estimated total production from three main production system groupings for tropical Latin America, 1980 (FAO 1980, USDA 1980, CIAT 1979).

	Production (thousand t)		
	Irrigated	More favored upland[a]	Unfavored upland[b]
Brazil	2477	2477	3894
Mexico	345	87	23
Tropical South America	2781	475	136
Bolivia	0	54	38
Colombia	1695	59	93
Ecuador	195	102	0
Paraggay	50	11	0
Peru	411	67	5
Venezuela	430	182	0
Central America	100	379	73
Costa Rica	9	180	3
El Salvador	20	35	0
Guatemala	0	31	3
Honduras	5	14	13
Nicaragua	55	7	0
Panama	11	112	54
Caribbean	1134	60	3
Guyana	206	49	0
Cuba	459	0	0
Dominican Republic	380	0	0
Haiti	83	11	3
Jamaica	6	0	0
Tropical Latin America	6837	3478	4129
Excluding Brazil	4360	1001	235

[a]Includes rainfed lowland rice figures. Estimated total production for the region from the system is 1.6 million t. [b]Includes traditional (subsistence) upland rice figures. Estimated total regional production from the system is 950,000 t.

Appendix 2. Description of sample sites of upland rice environments

Favored upland site no. 1: Colombia

Villavicencio area on the Colombian Llanos Orientales. Land system 208 (Cochrane et al 1982). Eastern sloping plains predominantly sediments from the eastern Andean cordillera.

Soils

Land system 208 consists of lands of 3 types. The first, on higher land between water courses, is a deep loamy Haplustox (Orthic and Plinthic Acrisol). It represents 45% of the area of system 208. It has high aluminum saturation, low pH, and very low fertility. The second type is a Tropudult (Dystric Fluvisol), also equalling 45% of the area. It is lower lying than the first, with less perfect drainage but many similar properties. Irrigated rice is grown on both soils. Upland rice is confined to the third type, a Tropaquept. This soil consists of recent fluvial deposits that may or may not have an active adjacent water course on phreatic water. It has medium depth loam soils, low slope, moderate pH and cation exchange capacity, high to moderate organic matter, and moderate phosphorus. The estimated potential soil moisture availability is 150 mm.

Meteorological station
Villavicencio

Latitude: 4° 8'N
Longitude: 73° 34'W
Elevation: 422 m

Favored upland site no. 2: Colombia

The Atrato River valley runs north into the gulf of Uraba on the, Colombian Atlantic coast. The principal rice growing areas are on the coastal plain around Turbo and Villanueva around 8°N and further south between 6°N and 7°N. The intervening lands south of the gulf are poorly drained marshes and slopes are minimal.

Soil

Eutric Fluvisol (Je 18-3a, FAO Soil map of the world) with associated Haplic and Dystric Gleysol. The major soil type has high base status, high inherent fertility, and heavy texture. The estimated soil moisture availability is more than 250 mm and roots my reach a water table. The main rice growing area is intermediate between the following meteorological stations.

Meteorological stations

Turbo	Quibdo
Latitude: 8°7'N	5°42'N
Longitude: 76°43'W	76°38'W
Elevation: 2 m	73 m

Favored upland site no. 3: Costa Rica

The coastal plain and Valle de Diquis running southeast from Puerto Cortes at 83°30'W and 8°50'N. It is flat low-lying land originally used for banana production.

Soil

Fluvaquentic Hapludoll associated with Fluvaquentic Haplaquoll (Assoc. Suelos Costa Rica 1978) equivalent to Mollic Gleysol with associations of Eutric Histosol and Dystric Regosols (FAO Soil map of the world). The basic soil has a deep, dark-colored, heavy-textured profile with high base saturation, high fertility, and poor drainage. Estimated soil moisture availability is more than 250 mm with roots reaching phreatic water.

Meteorological stations

Caracol	Palmar Sur
Latitude: 8°40'N	8°57'N
Longitude: 83°l'W	83°28'W
Elevation: 32 m	7 m

Moderately favored upland site no. 1: El Salvador

On the El Salvadorean south coast about 13°20'N, 80°40'W, the coastal plain is near Jiquilisco and northeast almost to Zacatecoluca on either side of Rio Lempa. Slopes are low to almost level, rising 15 m in 20 km from coast. Irrigation is evident in parts (Landsat image, 11 Feb 1976, MSSband 5), with small cultivators.

Soil

Eutric Gleysols (Gc 20-2a FAO Soil map of the world) predominate, associated with Eutric Regosols and Pellic Vertisols. There are some inclusions of Vitric Andosols. This area has generally deep, lighter, loamy textured soils with high base status and high inherent fertility. Hydromorphic characters, are usually present within 50 cm in dominant soil. Estimated soil moisture availability is 200 mm.

Meteorological stations

Jiquilisco	Usulutan
Latitude: 13°20'N	13°20'N
Longitude: 88°34'W	88°26'W
Elevation: 54 m	70 m

Moderately favored upland site no. 2: Costa Rica

The major commercial production areas are on Guanacaste Peninsula, and around Liberia and Santa Cruz with rolling to flat river valley land. Rice is sown in May in rotation with sorghum sown in October.

Soils

Type Pellustert (Assoc. Suelos Costa Rica, 1978) is black, plastic and adhesive when wet, and hard and cracked when dry. It is found on level ground without good drainage. This equates to region Gm 13.3a, Mollic Gleysol on the FAO map but there is some doubt about the value of a 1:5,000,000 map in this highly variable area. Other soils of the region are Fluventic Ustropept with Fluventic Haplustoll. These equate to the FAO Bc 13-3a, or, Chromic Cambisol and Haplic Kastanozem, but again value of a 1:5,000,000 map is doubtful in this variable area. These are deep, little-developed, heavy-textured soils. Estimated available soil moisture is 200 mm, and soil depth is uncertain.

Meteorological stations

Santa Cruz	Filadelfia
Latitude: 10°16'N	10°27'N
Longitude: 85°37'W	85°35'W
Elevation: 49 m	16 m

Moderately favored upland site no. 3: Panama

The coastal plain from 82°-83°W and from 8°20'-8°30'N is a level to gently sloping coastal outwash comprised of volcanic ash from Volcan de Chiriqui. Many paleo-channels of Rio Chico are visible on the plain. The cultivation extends west from the town of David and slightly inland excluding poorly drained histosolic areas to the border with Costa Rica.

Soil

Vitric Andosol (Tv23-2ap FAO Soil map of the world) with associations of Chromic Luvisol and Eutric Regosol, and local inclusions of heavier Pellic Vertisol. The slopes are slight with local steeper slopes between 8% and 30% especially to the north near the foothills and in deeper divided regions. The major soil is light loam-textured, fairly deep, but acid and with inherently low fertility. The estimated soil water availability is 150 mm with no access to water table.

Meteorological stations

Puerto Armuelles	Alanje
Latitude: 8°17'N	8°18'N
Longitude: 82°52'W	82°32'W
Elevation: 15 m	0 m

Unfavored upland site no. 1: Brazil, Minas Gerais

Production centers around Campina Verde, Prata, Gurinhata, Itaitaba, and Frutal areas. All are on flat to gently rolling country, with slopes generally less than 8%.

Soil

Acric ferralsol (Fa2-2a, FAO Soil map of the world) with a Brazilian classification of Latosol vermelho oscuro distrofico. It is a deep, well-drained loam, with very low pH, moderate organic matter (1-3%), high aluminum saturation (70%), and very low nutrient status (particularly phosphorus). Available soil moisture would be reasonable if roots could penetrate to the necessary depth. Because this is unlikely, the estimated available water-holding potential is 75 mm.

Meteorological stations

Monte Alegre de Minas	Catalao
Latitude: 18°52'S	18°10'S
Longitude: 48°52'W	47°59'W
Elevation: 755 m	856 m

Unfavored upland site no. 2: Brazil, Goias

The major production area is centered on Landsystem 56 (Cochrane et al 1983) around Jatai and around Rio Verde and Parauna on Landsystem 51. It is gently rolling to flat terrain formed on sediments from a sandstone plateau to the east.

Soil

Acic Ferralsol (Soil Fa2-3a, FAO soil map of the world) with a Brazilian classification of Latosol vermelho oscuro distrofico. It is a deep, well-drained soil with heavier texture than that of unfavored site no. 1 but otherwise equal. The estimated available soil moisture is 7 mm. (Note: The problem of large distances between meteorological stations in this area is alleviated by the uniformity of climate.)

Meteorological stations

Monte Alegre de Minas	Goiania
Latitude: 18°52'S	16°41'S
Longitude: 48°52'W	49°17'W
Elevation: 755 m	728 m

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Appendix 3. Principal upland rice varieties grown in Latin America, 1979-80.

Country	Area (thousand ha)		Variety name	Percentage upland rice[a]	Type of variety[b]
	Total	Upland			
Brazil	6231	5327	IAC47	–	I
			IAC25	–	I
			IAC164	–	I
			IAC165	–	I
Mexico	133	60	Navalato A 71	23	I
			CICA4 and 6	7	I
			Macuspana A 75	4	I
			Sinaloa A 68	3	I
			Grijalva A 71	5	I
			Traditional cultivars	3	T
Bolivia	55	54	Bluebelle	–	I
			CICA8	–	I
			Dourado	–	T
			Bluebonnet 50	–	I
			IR43	–	I
			Pico Negro	–	T
Colombia	422	114	CICA8	80	I
			CICA4	10	I
			Miramono	2	T
			Other traditional cultivars	8	T
Ecuador	104	33	Canilla	–	T
			Donato	–	T
			SML	–	I
			Pico Negro	–	T
			Iniap 6, 7 and 415	–	I
Paraguay	32	11	Rexoro	–	I
			Fortuna	–	T
Peru	100	16	Fortuna	5	T
			Carolino	16	T
			Peru 65	–	T
			CICA8, CICA9	–	I
			Chancay	2.5	I
Venezuela	231	97	Araure 1 and 2	–	I
			Llanero	–	T
Costa Rica	82	80	CR1113	90	I
			CR201	3	I
			CR5272	7	I
El Salvador	14	10	X-10	60	I
			Masol 1 and 4	10	I
			CICA9	6	I
			Nilo 1 and 3	12	I
			CR1113	6	I
			Centa A2 and A3	–	I
Guatemala	12	11	Tikal 2	60	I
			Lebonnet	20	I
			Bluebonnet	5	I
			Americanito and Lira Blanco	10	T
			ICTA-Tempisque, Virginia and Cristina	5	I
Honduras	19	16	CICA 4, 6, 8 and 9	65	I
			Bluebonnet 50	7	I
			Traditional cultivars	19	T
			CR1113, Tikal 2	3	I
Nicaragua	41	19	Bluebonnet 50	23	I
			CICA8	5	I
			CR1113	9	I
			CICA4	5	I

Appendix 3 continued

Country	Area (thousand ha)		Variety name	Percentage upland rice[a]	Type of variety[b]
	Total	Upland			
Panama	99	92	CICA8	21	I
			CICA7	42	I
			Eloni	5	I
			T5430	1	I
			CR5272 and CR1113	10	I
			Linea 4444	5	I
			Anayansi	5	I
			Traditional cultivars	–	T
Guyana	121	35	Starbonnet	–	I
			Traditional cultivars	–	T
Haiti	43	11	Folton and Buffalo	–	T
			Ti-Fidele	–	T
Surinam	36	2	Traditional cultivars	–	T
Belize	6	3	CICA4, 8 and 9	–	I
			CR1113	–	I
			Bluebonnet 50 and Belle Patna	–	I

[a]Unofficial CIAT preliminary estimates based on information from qualified sources; (–) indicates information not available at time of writing, [b]I = improved variety, T = tall, unimproved variety.

CLIMATE FOR UPLAND RICE IN AFRICA

T. L. LAWSON

The growing demand for food has forced unprecedented efforts to produce more food on a smaller area, in less time, and increase the total agricultural production area. In Africa (Chabrolin 1977), as elsewhere, rice production has increased because farmers have expanded their total crop area (Chandler Jr. 1979).

Rice-based cropping systems in Africa evolved with little or no water control on well-drained upland soils, in contrast with mostly lowland rice culture in Asia (De Datta 1975, Moormann and van Breemen 1978). Expanding production area has meant using more uplands, often without assessing their physical resources. To increase productivity, however, it is vital to thoroughly evaluate these environmental resources to determine crop growth and yield of each genetic type.

This paper describes the physical resource base for upland rice production in Africa, and assesses its potential for reasonable or high yields.

THE AFRICAN ENVIRONMENT AND UPLAND RICE PRODUCTION

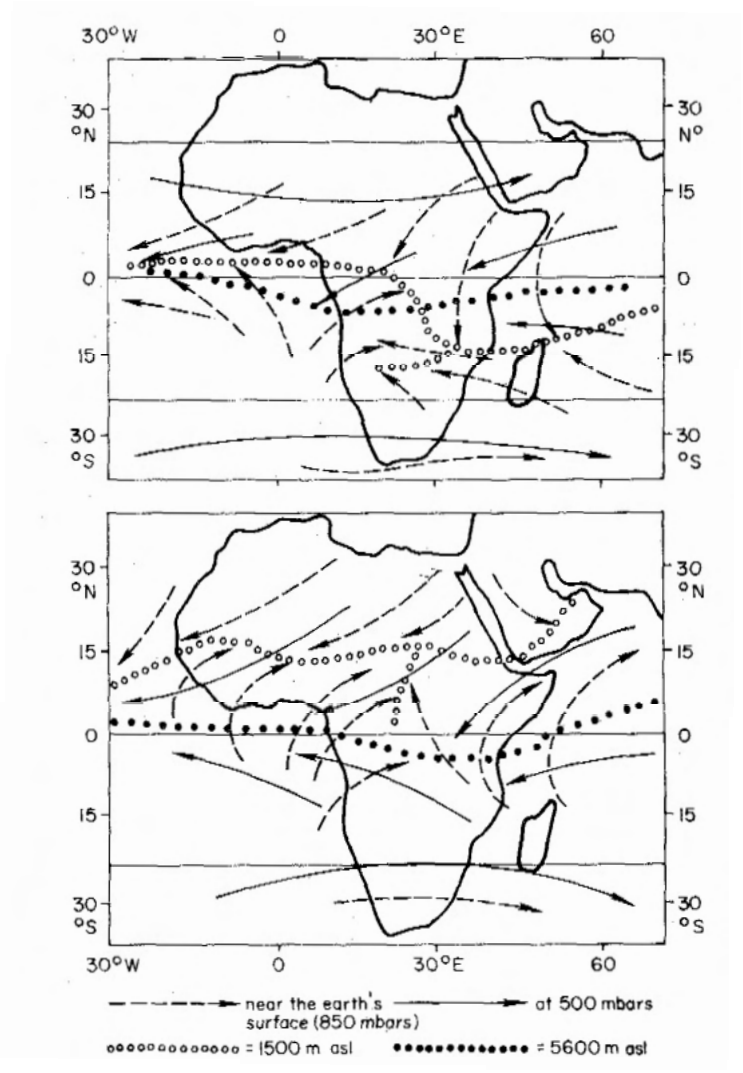
Moisture availability

Readily available moisture is the most important factor in rice growth, and therefore determines an area's suitability for rice production. Because upland rice depends solely on rainwater retained in the soil, two environmental factors, rainfall and evapotranspiration, combined with soil water-holding capacity, control the crop moisture supply. To determine where rice can grow, it is useful to analyze the rainfall distribution and evapotranspiration for Africa.

Rainfall seasonality and distribution. The movement of the intertropical convergence zone (ITCZ) controls rainfall throughout Africa. The displacement and intensities of three semipermanent high pressure systems: the Azore-Saharan High, the South Atlantic High, and the Indian Ocean High make up the zone (Flohn 1960, Lawson et al 1979).

The contrasting characteristics of land and sea surfaces underlying these pressure cells cause distinct

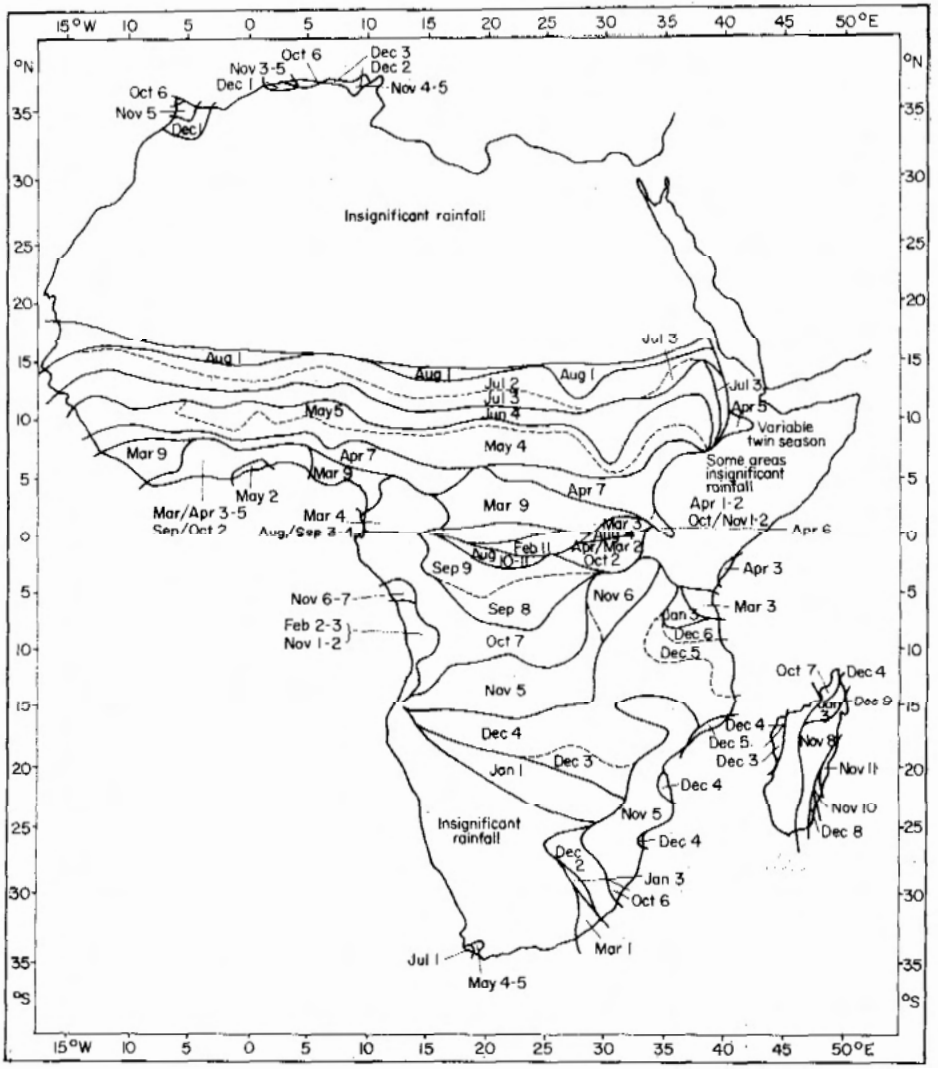
Agroclimatologist, International Institute of Tropical Agriculture, Ibadan, Nigeria.



1. Circulation over Africa during January (top) and July (bottom) at the 850 m and 500 mbar levels. Arrows: winds; dots: convergence zones (Nieuwolt 1977). asl = above sea level.

moist and dry air masses. As the air masses move long distances, they become more concentrated and make a sharp discontinuity in humidity when they converge in the ITCZ. The alternate advance and retreat of the air masses (Fig. 1) brings areas under humid and dry weather periods for different lengths of time depending on proximity to the coast, especially in West Africa (Lawson 1969).

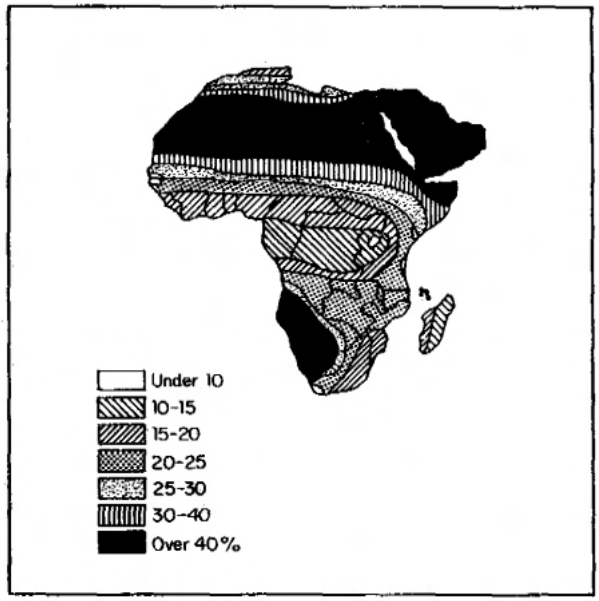
This makes a definite rainy season. When it begins and how long it lasts depends on how far the area is from the source of the moist air (West Africa) or



2. The month of onset and number of days with consecutive mean monthly rainfall of 100 mm or mote (Thompson 1965) in Africa.

how close it is to the equator (Central and parts of East Africa) (Fig. 2). In East central Africa, the relationship is less distinct because of the mountain's influence.

In Africa, except for an irregular zone covering southwest Benin, southern Togo, and southeast Ghana, there is less rain in shorter periods. In Central Africa, there is a similar decrease north and south from the maximum rainfall area on the equator. East Africa, except the area of northern Mozambique westward through Zimbabwe, is a region of irregular low rainfall, with large areas in Kenya and Somalia receiving 400 to 800



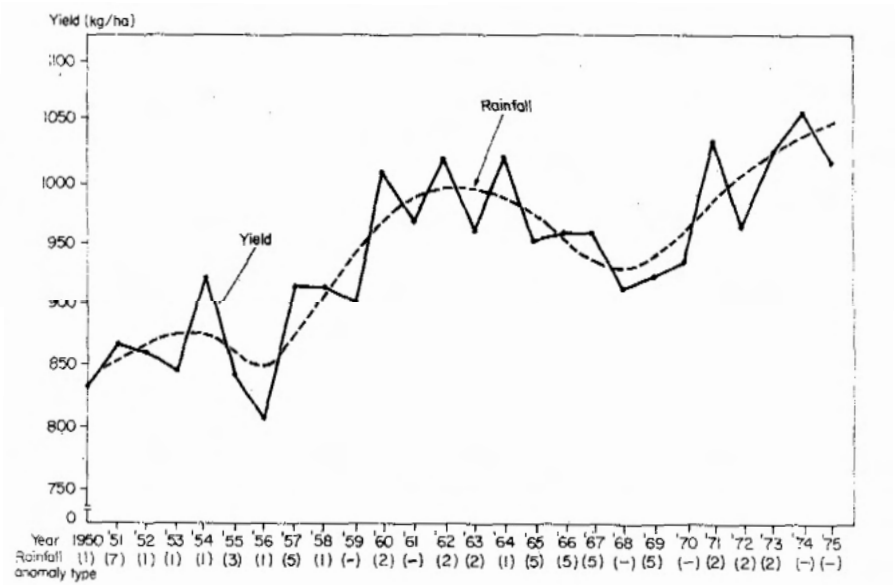
3. Rainfall variability in Africa (percentage departures from normal (Koeppe and De long 1958).

mm or less in a year. Regardless of annual amount, most rain falls at high intensities frequently exceeding 100 mm/h over short duration (Lawson and Juo 1979, Rodier 1964). The erosive potential necessitates careful assessment of cultural practices.

If upland rice needs at least 1,600 mm annual rainfall (Moormann and van Breemen 1978), the areas suitable for high production are very limited. According to Cocheme (1971), however, a minimum of 600 mm of rain is enough if it is evenly distributed. Then a far greater area than that outlined by the 1,600 mm isohyet could be planted if distribution was favorable. Rainfall regtilarity then is extremely significant in successful wide-scale rice production in tropical Africa.

Rainfall variability. Rainfall changes between years and seasons and within seasons are characteristic of the climate (Schove 1977, Nicholson 1976). On a large scale these changes may bring shifts in rainfall belts as in the Sahel drought years of the early 1970s. They may also bring about adjacent contrasting rainfall zones (Nicholson 1976). In general, annual rainfall variability decreases with increasing rainfall (Fig. 3).

Figure 4 (Lawson 1981) illustrates how this variability affects regional rice yield in West Africa. Rainfall anomaly Type 1 (Lawson 1981) has near or below normal rainfall south of 10°N latitude, and above nor-

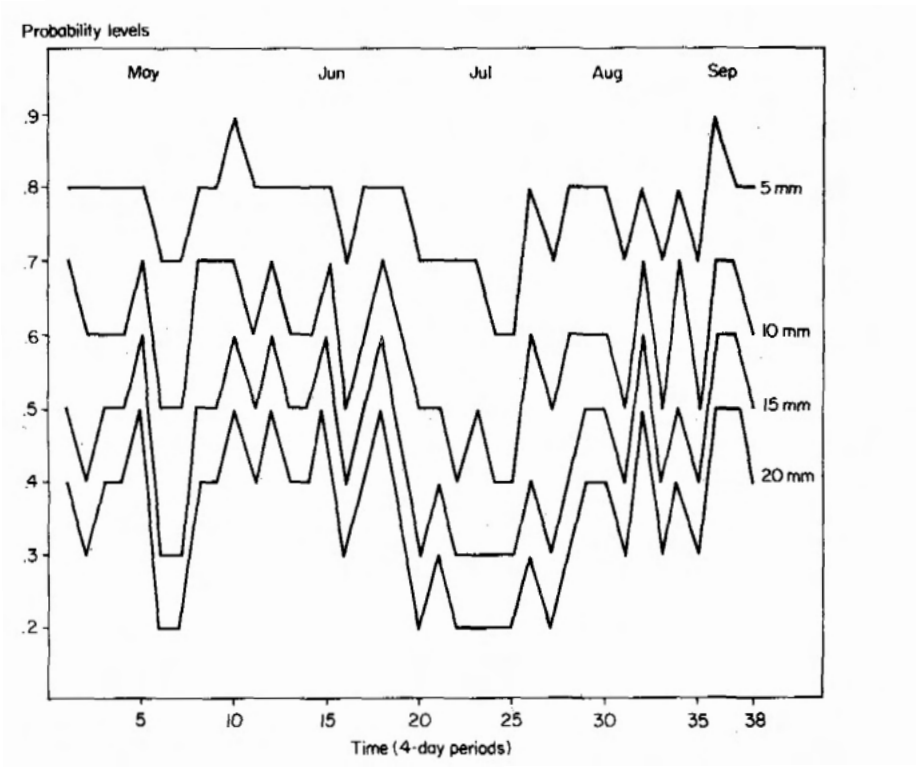


4. Rice yield by year and associated rainfall anomaly type (rainfall anomaly types from Nicholson 1976, rice yield data from Palacpac 1977).

mal rainfall north of 10°N. Type 2 anomaly has normal or above normal rainfall south of 10°N but Type 2 is mostly contained between this latitude and the Guinea Coast. It has below normal rainfall north of 10°N and roughly typifies the Sahel drought of the late 60s and early 70s. Third in significance is Type 5 with average to above normal rainfall except in some isolated areas of below normal rainfall. Type 5 and its close relative, Type 3, apparently lower rice production while Types 1 and 2 increase production (Lawson 1981).

Variations in rainfall may occur as a late start and/or early cessation of rain, often resulting in a too short growing season (Lawson 1980). This is particularly true of the savanna and drier regions, areas with less than 6 humid months. Shorter-term rainfall variations may also occur between seasons (Fig. 5, Lawson 1980) or within seasons (Fig. 6, Stern et al 1981). How these affect the crop depends strongly on its stage of growth, evapotranspiration, and on soil moisture reserve.

Moisture demand-evapotranspiration. Mean potential evapotranspiration ranges from 3.5 mm/day in the wetter areas to about 7.0 mm/day in the drier regions (Lawson 1967, Kowal and Knabe 1972). Actual values of mean maximum evapotranspiration for rice range from 4.0 mm/day to 6.0 mm/day (Lawson 1980). Peak moisture demand for specific short periods can obviously be higher, but usually potential evapotranspiration is much more con-



5. Trend in probabilities of given rainfall amount (Lawson 1980).

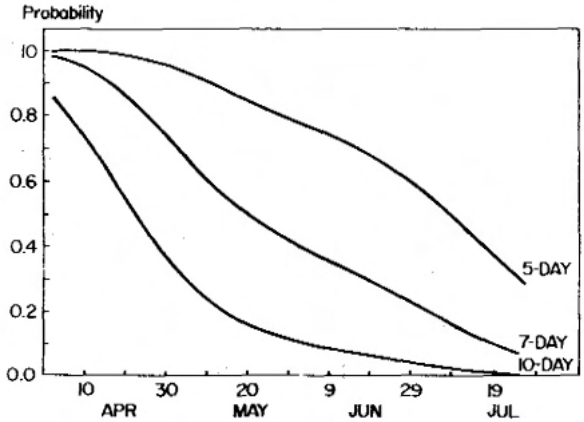
servative than rainfall (Tanner 1967). Therefore, a generalized mean value is acceptable in water balance analysis. The mean value of 5.0 mm/day (Cocheme 1971) as average daily water requirement for rice in West Africa is valid for planning purposes (Lawson 1980).

Three main regimes of potential evapotranspiration have been recognized for West Africa (Lawson 1967):

- a double maxima, double minima regime at or north of 15°N latitude,
- a single maximum and single minimum regime south of that latitude but excluding the coastal areas, and
- a coastal regime with no clearly defined maxima or minima.

Moisture balance. Because of the conservative nature ot potential evapotranspiration, one may consider water balance in terms of rainfall variability alone. Short-term intraseasonal variation in rainfall should not have a pronounced effect an rice if there is a good soil moisture reserve (Kalms 1979, Table 1).

Most tropical African soils, however, have poor physical characteristics and low moisture-holding capacity (D'Hoore 1968, Obi 1977, Bennema 1977, Lal 1977).



6. The probability of a dry spell of 5,7, or 10 days at Kandi, Benin (11°05'N, 2°20'E). within 30 days following the date on the time axis (Stern et al 1981).

Plant roots often can only exploit a few decimeters because of gravel and other hard layers (Riquier 1969, Bennema 1977). Because rice is a shallow rooting crop, the amount of soil from which moisture is available is very limited (Hasebe et al 1963 Moormann and van Breemen 1978). Under these conditions meteorological and agricultural droughts become closely associated and are detrimental to yield (Table 2, Alluri et al 1979). To alleviate this major problem, farmers must choose-land carefully. Appendix 1 is a soil distribution map of Africa (Kellog 1975) with legend and explanatory notes.

Solar radiation

The importance of solar radiation to high rice yields has been documented (Rao and Deb 1974, Tanaka et al

Table 1. Effect of available soil moisture reserve on rice yield (12% moisture), Bouake, Ivory Coast (Xalms 1979).[a]

Year	Rice yield (t/ha)				Seasonal rainfall (mm)
	Moroborekan		IRAT 13		
	Class 1 soil (150 mm)	Class 3 soil (60 mm)	Class 1 soil (150 mm)	Class 3 soil (60 mm)	
1976	–	1.3	3.4	1.8	490
1977	2.2	3.9	5.0	3.8	800
1978	1.2	0.8	2.4	1.0	380
Mean	1.7	1.3	3.6	2.2	–

[a]**Values** in parentheses indicate available moisture reserve.

Table 2. Grain yield of OS6 and ADNY11 under different methods of planting and moisture regimes.[a]

Planting method[b]	Grain yield (t/ha)			
	Dry land (drought stress)		Dry land (no drought stress)	
	OS6	ADNY11	OS6	ADNY11
Dibbling (30 × 30 cm)	1.7	2.6	3.2	3.7
Space planting (30 × 30 cm)	1.9	1.9	2.5	3.3
Drilling (45 × 3.3 cm)	2.4	1.5	3.5	6.8
Av	2.0	2.0	3.1	4.6

[a]Adapted from Table 16, Alluri et al 1979. [b]Number of seedlings per hill was adjusted to maintain same plant population in all cases.

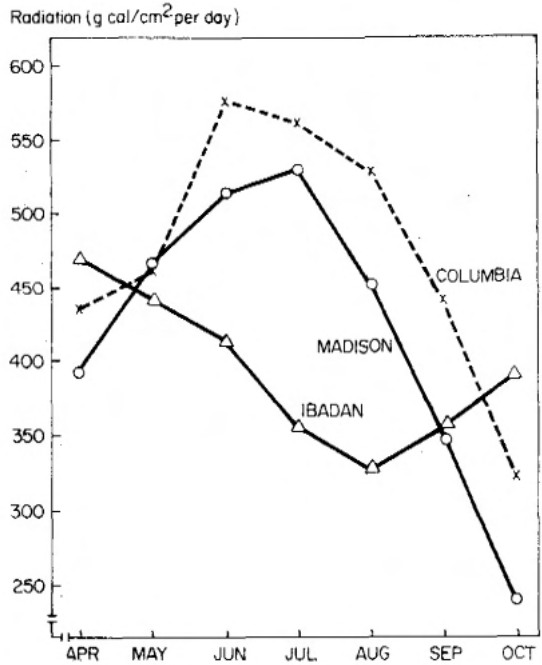
1966). The work of Wada et al (1973) and Yoshida and Parao (1976) have shown that the reproductive and ripening phases are the most sensitive in their response to light. The amount of radiation over Africa's potential rice growing areas will affect production.

Recent studies in the humid tropics cannot substantiate Africa's presumed high light levels for rice cropping cycles (Lawson et al 1979). Insolation in Ibadan, Nigeria (7°26'N, 3°54'E), during the growing season is considerably less than that received during the same period at typical middle latitude locations: Madison, Wisconsin (43°15'N, 89°31'W), and Columbia, Missouri (38°58'N, 92°20'W) (Fig. 7, Lawson 1980).

Higher radiation that prevails in lower rainfall areas (Table 3) also contributes to higher evaporative demand. Insufficient soil moisture may then reduce the efficiency of the radiation. Even with full efficiency, the higher radiation still is suboptimal for a positive yield response because it is less than 500 cal/cm^2 daily^{-1} (Yoshida and Parao 1976).

Photoperiod

Table 4 shows day length for tropical northern hemisphere latitudes. Differences between the longest and the shortest day over the moisture/cropping cycle range from zero at the eauator to 2.40 h at 20°N latitude. Despite the trend toward the use of photoperiod-insensitive varieties, there is still use for sensitive varieties to meet specific objectives. Chang and Oka (1976) showed the benefit of using these varieties in areas that have erratic or false start rains to ensure



7. Global radiation at Ibadan (7°26'N, 3°54'E), Columbia, Mo. (38°58'N, 92°20'W), and Madison, Wis. (43°15'N, 89°31 W), based on observation at IITA and data from Court (1974) (Lawson 1980).

Table 3. Annual rainfall and mean monthly global radiation for selected months and stations in Africa.[a]

Station	Location		Annual rainfall (mm)	Global radiation (cal/cm^2 daily)			
	Lat	Long		Jan	Apr	Jul	Oct
Mopti	14°30'N	4°12'W	541	366	500	474	438
Daru	8°00'N	10°51'W	2420	428	490	336	415
Bouake	7°41'N	5°02'W	1210	378	429	332	398
Ibadan	7°24'N	3°53'E	1271	385	434	341	401
Monrovia	6°18'N	l0°48'W	5131	404	443	321	395
Port Harcourt	4°46'N	7°01'E	2471	355	397	292	357
Yangambi	0°53'N	24°31'C	2629	411	446	345	412
Entebbe	0°04'N	32°29'E	1513	474	440	402	435
Nairobi	1°16'S	36°45'E	944	547	458	321	472
Narok	l°08'S	35°50'E	672	520	448	404	493
Dodoma	6°15'S	35°44'E	553	485	424	420	497
Mbeya	8°50'S	33°25'E	894	385	395	529	512

[a]Global radiation for the West African stations adapted from Lawson (1980); values for Central and East African stations from Griffiths (1972); rainfall figures from Lebedev 1968, except for Ibadan and Yangambi.

Table 4. Monthly mean day length in hours and hundredths by latitude in the northern hemisphere (Cocheme and Tranquin 1967, Peguy 1970).

Lat	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0°	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10	12.10
5°	11.80	12.00	12.00	12.20	12.30	12.40	12.30	12.20	12.10	12.00	11.90	11.80
6°	11.82	11.93	12.09	12.25	12.39	12.46	12.43	12.31	12.15	11.99	11.86	11.79
7°	11.76	11.90	12.08	12.28	12.44	12.52	12.48	12.34	12.16	11.97	11.81	11.73
8°	11.72	11.87	12.08	12.30	12.49	12.58	12.54	12.38	12.17	11.95	11.77	11.67
9°	11.66	11.84	12.08	12.33	12.53	12.64	12.59	12.41	12.17	11.93	11.72	11.62
10°	11.61	11.80	12.08	12.35	12.58	12.70	12.65	12.45	12.18	11.91	11.68	11.56
11°	11.56	11.77	12.07	12.38	12.63	12.76	12.70	12.48	12.19	11.88	11.63	11.50
12°	11.51	11.74	12.07	12.40	12.68	12.82	12.75	12.51	12.19	11.86	11.58	11.40
13°	11.45	11.71	12.06	12.43	12.73	12.88	12.81	12.55	12.20	11.84	11.54	11.38
14°	11.40	11.67	12.06	12.45	12.78	12.94	12.87	12.59	12.21	11.82	11.49	11.32
15°	11.35	11.64	12.05	12.48	12.83	13.01	12.93	12.62	12.22	11.80	11.44	11.26
16°	11.29	11.61	12.05	12.51	12.88	13.07	12.98	12.66	12.22	11.78	11.39	11.20
17°	11.24	11.58	12.05	12.53	12.93	13.13	13.04	12.69	12.23	11.76	11.35	11.14
20°	11.00	11.60	12.00	12.60	13.10	13.30	13.20	12.90	12.20	11.60	11.20	10.90

Table 5. Mean maximum and minimum temperatures (°C) at representative stations for selected station.

Station	Location		Temperatures (°C)							
	Lat	Long	Maximum				Minimum			
			Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct
Mopti	14°30'N	4°12'W	30.2	39.8	33.9	33.7	14.1	22.6	23.5	23.6
Daru	8°00'N	10°51'W	32.2	33.3	28.9	31.7	19.4	22.2	21.7	21.7
Bouake	7°41'N	5°02'W	33.6	34.2	29.8	31.2	20.4	21.9	20.8	20.9
Ibadan	7°24'N	3°53'E	32.8	32.8	27.8	30.0	21.1	22.8	21.1	22.2
Monrovia	6°18'N	10°48'W	30.0	30.6	26.7	28.3	22.8	22.8	22.2	22.2
Port Harcourt	4°46'N	7°10'E	31.1	31.7	28.9	29.4	21.1	22.8	21.7	21.7
Kisangani	0°26'N	25°14'E	31.1	31.1	28.9	30.0	20.6	21.1	19.4	20.0
Entebbe	0°04'N	32°29'E	26.7	25.6	24.4	26.1	17.8	18.3	16.7	17.2
Nairobi	1°16'S	36°45'E	25.0	23.9	20.6	24.4	12.2	14.4	10.6	12.8
Narok	1°08'S	35°50'E	26.7	24.4	21.1	26.1	7.8	10.6	7.8	7.8
Dodoma	6°15'S	35°44'E	29.4	28.3	26.1	30.6	18.3	17.8	12.8	16.7
Mbeya	8°50'S	33°25'E	22.8	22.2	21.7	26.7	13.9	12.8	7.8	12.2

reliable harvest before dry season. In humid areas, farmers can use photoperiod-sensitive varieties to time flowering so that rice reaches maturity at the end of the rains.

Air temperature

In West Africa (Lawson 1980), maximum temperatures at the onset of the rainy/cropping season exceed the 25-30°C optimum for photosynthesis in rice and other C_3 plants (Monteith 1977). Although rice adjusts its photosynthetic rate to temperature changes (Osada 1964, Yamada et al 1955), those high temperatures do stimulate growth and eventually reduce total dry matter (Yoshida 1977).

High temperature also increases evaporation and drought stress. More significant is the respiration rate increase during high nighttime temperatures (Table 5), and many scientists agree this increase is partly responsible for the low yield of many tropical cereals.

In east and south central Africa, altitude-induced cool temperature may be too low for good or optimal upland rice growth. Cold-tolerant varieties merit consideration.

Soil temperature

Like air temperatures, soil temperatures at the beginning of rains rise to excessively high values (Lawson 1980). This is detrimental to optimum rice development according to reported values for various crop stages (Table 6). Even in humid areas such as Onne, near Port Harcourt in Nigeria, soil temperatures during this period frequently exceed 45°C at 2.5 cm and 35°C at 5 cm

Table 6. Varying temperatures at different growth stages of the rice plant (Yoshida 1981).

Growth stage	Critical temperatures (°C)		
	Low	High	Optimum
Seedling	10	45	20-35
Seedling emergence and establishment	12-13	35	25-30
Rooting	16	35	25-28
Leaf elongation	1-12	45	31
Tillering	9-16	33	25-31
Initiation of panicle primordia	15	–	–
Panicle differentiation	15-20	38	–
Anthesis	22	35	30-33
Ripening	12-18	30	20-25

(Lawson unpubl.). The high temperatures decline rapidly once the rains become steady but this quickly reverses during transient drought periods.

Winds

Surface winds are usually light and often the days are calm (Lawson 1980). In contrast, gusty winds come with thunderstorms. During calm periods, inefficient transport of water vapor and carbon dioxide may restrict crop photosynthesis. During thunderstorms, strong winds may cause lodging and mechanical damage. Therefore, when choosing sites, one must consider the degree of exposure and select varieties and/or cultural practices appropriate to the environment.

The environment and pests and diseases

Pests and diseases are key factors in rice production. They are influenced by environment and there have been some associations between specific environmental factors and certain pests and diseases. However, it is often difficult to show clear-cut relationships because of the complex interactions. For example, blast is strongly associated with drought, but several blast incidences have been reported in very humid areas (Buddenhagen 1978).

There is still no doubt that certain tropical environment conditions make crops susceptible to attack or create necessary conditions for disease development. High moisture in the air, for example, helps maintain temperatures in the narrow range suitable for many organisms. High humidity also promotes dew formation and maintenance on leaf surfaces for many hours, even in the dry areas and seasons. This condition favors fungal growth.

A better understanding of the interaction between disease and environment needs careful study. This would

help us understand the reactions of varieties in different localities.

CONCLUSION

Upland rice cultivation is and will probably remain the dominant rice production system in Africa.

Extensive areas of the continent have more than enough rainfall to meet the water requirement of the crop during the growing season. In many of these areas, however, high rainfall variability with resultant drought risk accentuated by poor moisture-holding capacity of most upland soils constitutes a major constraining factor. It is important to improve the rooting system of rice to help it withstand transient droughts.

Areas of high stable rainfall with moderate daytime temperatures are marked by less solar radiation. This prevents effective use of the available moisture as it limits the photosynthetic rate. Solar radiation is less than optimal over most of the region.

Temperatures elsewhere can be too high (West Africa) or too cool (East Africa) for optimum dry matter production and yield. Cultural practices and varietal selection should aim at reducing their impact. Similar measures should help control wind damage.

A concerted effort to understand environmental influence on pests and diseases should help control them and improve yield.

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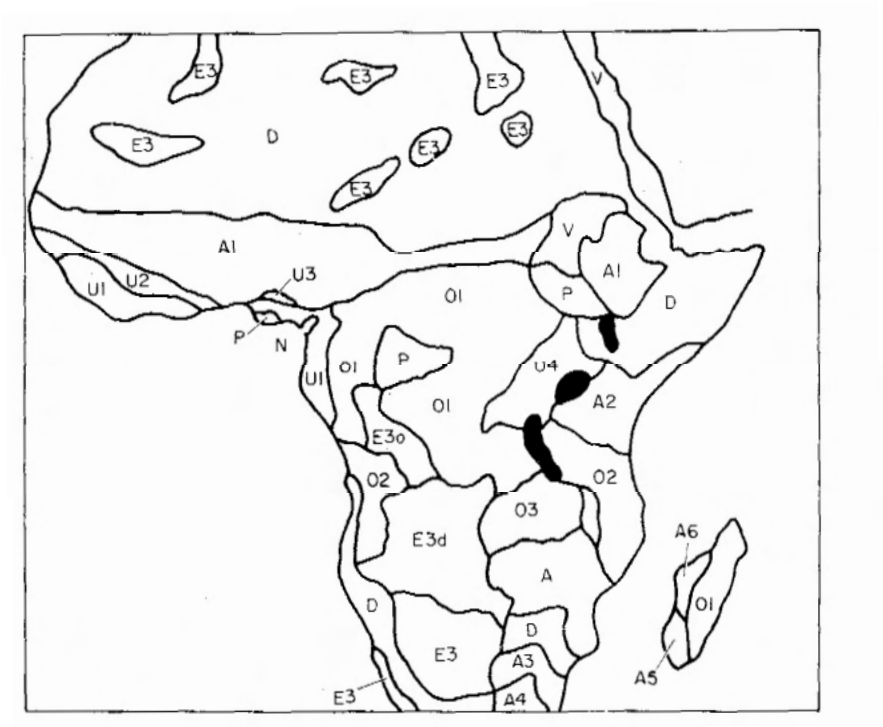
Appendix 1. A simplified soil map of Africa according to *U. S. Soil taxonomy classification* (Kellog 1975). Legend and descriptive notes (adopted from IITA [1979] Upland rice research for Africa):



Ultisols: Coarse, and medium-textured acid soils with clayey acidic subsoils.

U1 Tropudults and Plinthudults with some Orthox, Aquults, Aquepts, and Aquents in restricted areas.

U2 Paleustults and Plinthustults with Paleustalfs, and Aquepts and Aquents.

U3 Paleustult and Plinthustults.

U4 Tropudults with Orthox.

Oxisols: Strongly weathered, fine or coarse-textured soils with little variation in texture with depth.

O1 Orthox with Tropudults.

O2 Ustox with Ustalfs.

O3 Ustox with Ustults.

Alfisols: Coarse to medium-textured, high base saturation soils with clayey subsoils.

A1 Paleustalfs and Plinthustalfs with Tropepts and some Aqualfs, Aquolls, Aquents, and Vertisols in restricted areas.

A2 Rodustalfs and Paleustalfs with Vertisols and Mollisols.

A3 Ustalfs with Ustox.

A4 Udalfs.

A5 Plinthustalfs with Ustorthents.

A6 Ustalfs with Troporthents.

Inceptisols: Young soils with limited profile development,

P Aquepts with some Aquents.

Entisols: Young soils derived from alluvial materials with no horizon development.
E3 Psamments.
E3d Psamments with Orthox.
E3e Psamments with Ustox.

Vertisols: Dark clayey soils formed under drier climate containing large amounts of swelling clay minerals (montmorillonite).
V Vertisols (Usterts with Aquepts).

Andisols: Soils derived from volcanic ash containing large amounts of amorphous materials (allophane).
N Andisols with Tropudults, Tropudalfs, and Tropohumults.

Aridisols: Soils of arid region, such as desert soils.
D Aridisols, some are saline.

UPLAND RICE GROWING ENVIRONMENT: METHODS FOR CHARACTERIZATION AND ZONATION IN ASIA

L. R. OLDEMAN

Climatic, soil, physiographic, and management components and their interactions determine crop growth and sequences. Each crop requires plant growth factors: water, energy, heat, nutrients, atmospheric gases, and mechanical support. Each crop requires its own specific arrangement of growth factors for optimal performance. Each land unit possesses a certain arrangement of these growth factors.

To grow a crop in an area that does not have the specific set of growth factors, farmers have two options. They can adjust. the environment to the needs of that crop. For example, irrigate to satisfy water requirements, fertilize to supply soils with nutrients, or terrace if the slopes are too steep for cultivation. Farmers can also adapt the crop or cropping sequence to the existing environment.

Although farmers often use a combination of the two options it is essential to inventory and describe the natural environment in terms of water, temperature, energy, nutrient status, and mechanical support.

Many attempts have been made to describe and classify regions using growth factors. Although the natural environment consists of the inseparable climatic and soil factors, few people have tried to combine the two.

CHARACTERISTICS OF ASIAN CLIMATIC ENVIRONMENT

Southeast Asia has a humid tropical climate. Although the term humid tropics implies excessive moisture, extra rainfall occurs only at certain times of the year, while drought may occur in the same area at another time. The great rainfall variability poses innumerable problems to farmers. Humid tropics also implies isothermal conditions, meaning that seasonal variations in temperature are minimal. Although this is true for the equatorial belt, seasonal variations become greater as one moves to higher latitudes. The humid tropics also have low radiation values, but the values increase considerably during the dry season,

Visiting scientist, International Rice Research Institute, Los Baños, Philippines.

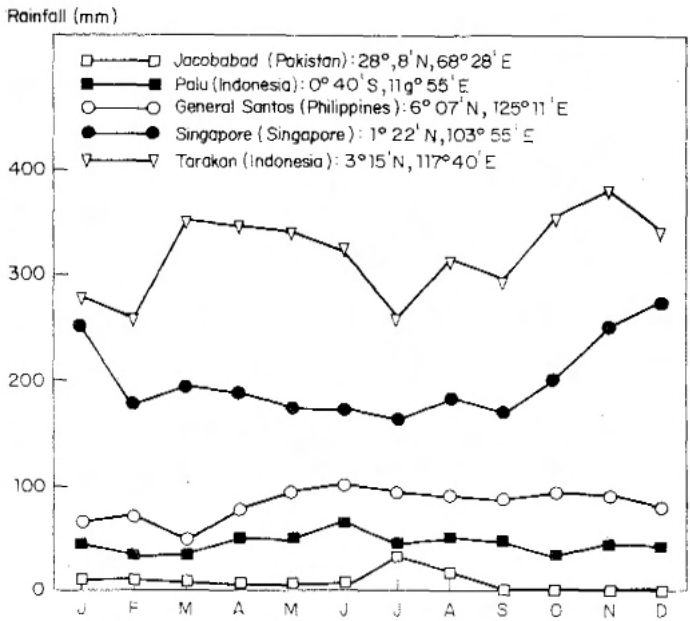
particularly at higher latitudes. In this paper it is not possible to discuss the various climatic variables in detail, but I will attempt to show the variability of these essential characteristics for plant growth and development.

Rainfall

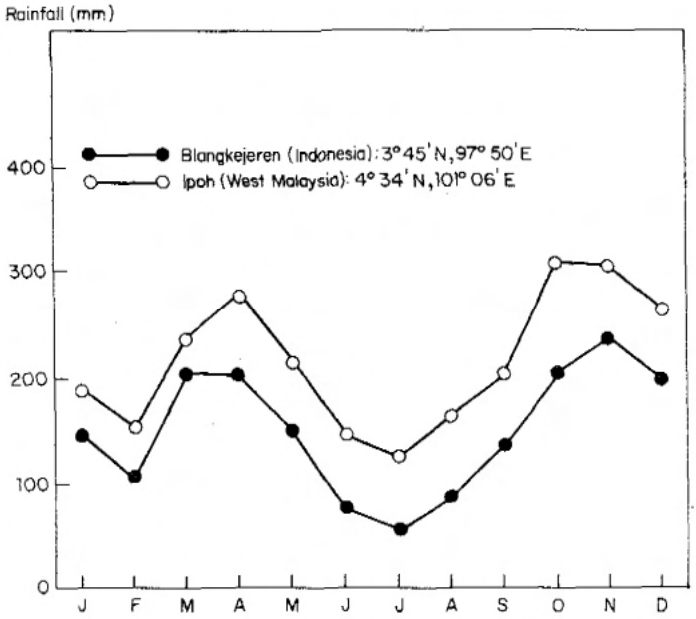
Rainfall is the most variable and least predictable element of the agroclimatic environment. But most farmers depend on rainfall as their water source for crops. It is essential to describe rainfall types, and group them into certain classes. Monsoons, the moving path of the intertropical convergence zone, influence rainfall distribution. Mountain chains may enhance the monsoonal effects on windward sides or reduce them on leeward sides.

Because the arrival and retreat of the monsoons vary from year to year, establishing rainfall patterns requires long-term rainfall records. Fortunately, a very dense network of long-term observation sites exists throughout Asia. It is therefore possible to recognize three major groups of rainfall regimes.

Rainfall variations throughout the year are minimal. There is no clear distinction between wet and dry seasons. These regions are in the equatorial belt where the monsoonal influence is less pronounced and mountain ranges either enhance or depress rainfall.



1. Mean monthly rainfall regimes with minimal seasonal variation.



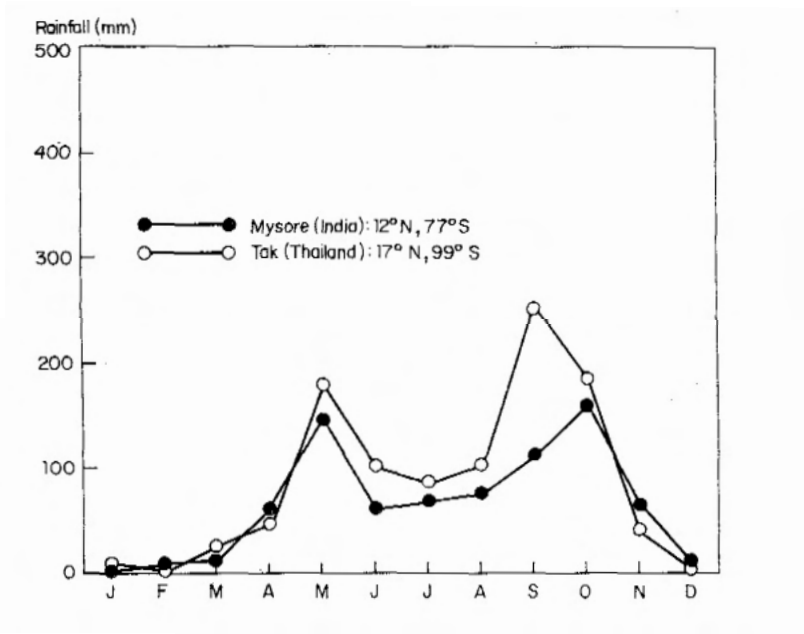
2. Mean monthly rainfall regimes with distinct bimodal variation (two rainy seasons).

The other region outside the monsoons' influence is the arid and semiarid region, located 30°N or S of the equator (Fig. 1).

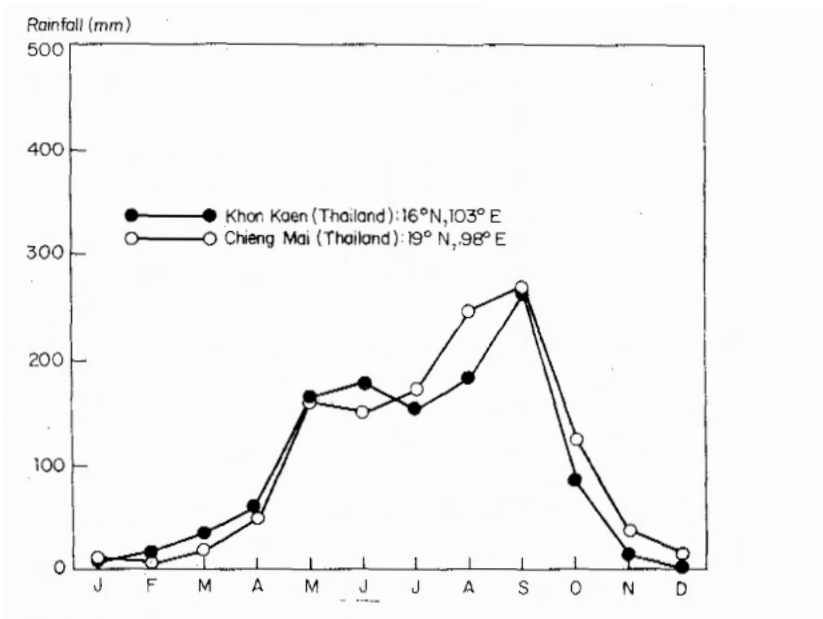
Rainfall distribution shows two peaks. This bimodal rainfall distribution generally occurs only north of the equator in Asia and has two types. The intertropical convergence zone causes one type when it moves north in April and south in October. Close to the equator where the monsoonal influence is small, these peaks are equal.

Farther north, however, the first peak occurs about May as the result of the intertropical convergence zone. The second peak is a combined effect of the intertropical convergence zone and the monsoon.

The intensity of the dry periods between the two peaks further distinguishes the bimodal profiles. Figure 2 shows the short dry season in February distinctly separated from the more pronounced dry season about July. Figure 3 shows two different dry seasons separated by 1 mo (May) with significantly higher rainfall. In Figure 4 the difference between the two peaks is not significant. It appears that the rainy season starts in May and lasts until October, but rainfall in June, July, and August is very variable. This becomes clear when 10-d totals are considered. Figure 5 indicates peaks of rainfall generally occur in the third decade of May and first decade of June. Only

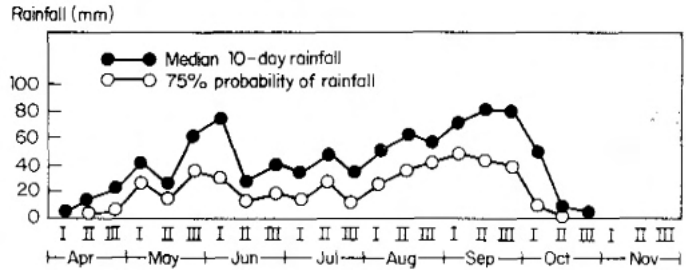


3. Mean monthly rainfall regimes with distinct bimodal variation (two dry seasons).



4. Mean monthly rainfall regimes with vague bimodal variation.

after the first 10 d of August until the first 10 d of October can the area expect heavy rainfall.



5. Mean 10-day rainfall distribution at Khon Kaen, Thailand.

Rainfall distribution shows only one peak. Monomodal rainfall regimes are the most common types in Asia, clearly influenced by the monsoons. South of the equator, the northwest monsoon brings humid air from the South China Sea between October and March. North of the equator, the southwest monsoon brings humid air from the Indian Ocean between May and October.

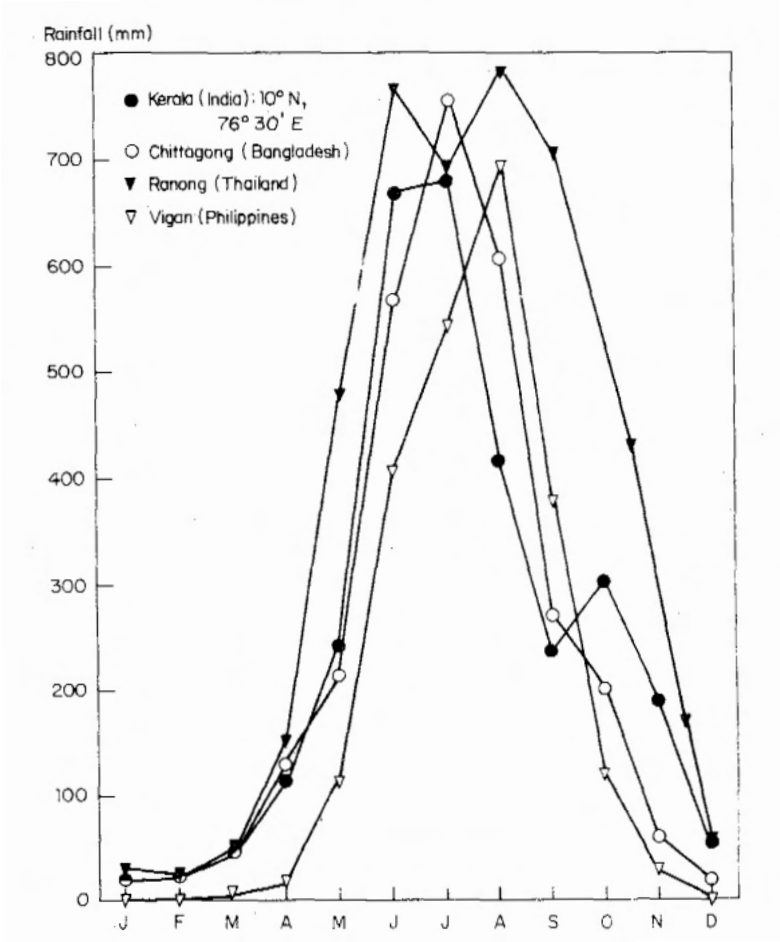
Mountain formations may enhance the effect of these monsoons on the windward side and reduce them on the leeward side. Figure 6 illustrates four rainfall profiles on the windward sides north of the equator. When the southwest monsoon meets mountain formations, it produces extremely heavy rain. Figure 7 illustrates a similar situation, but the excessive rainfall results from humid air off the South China Sea, arriving on the east coasts of the Philippines, Malaysia, and Thailand. Later in the year, it arrives on the west coast of Sulawesi (Indonesia) south of the equator.

Generally monomodal rainfall distributions have some months with more than 200 mm rain and some with less than 100 mm. Sometimes rain never reaches either the upper or the lower limit. Figure 8 illustrates representative profiles north of the equator, while Figure 9 illustrates monomodal profiles south of the equator. Profiles with extreme dry seasons are usually at higher latitudes north or south of the equator, while those with less pronounced dry periods are close to the equator.

The great variability of Asian rainfall profiles emphasizes the need to classify them into homogeneous groups according to their intensity and length of wet and dry seasons.

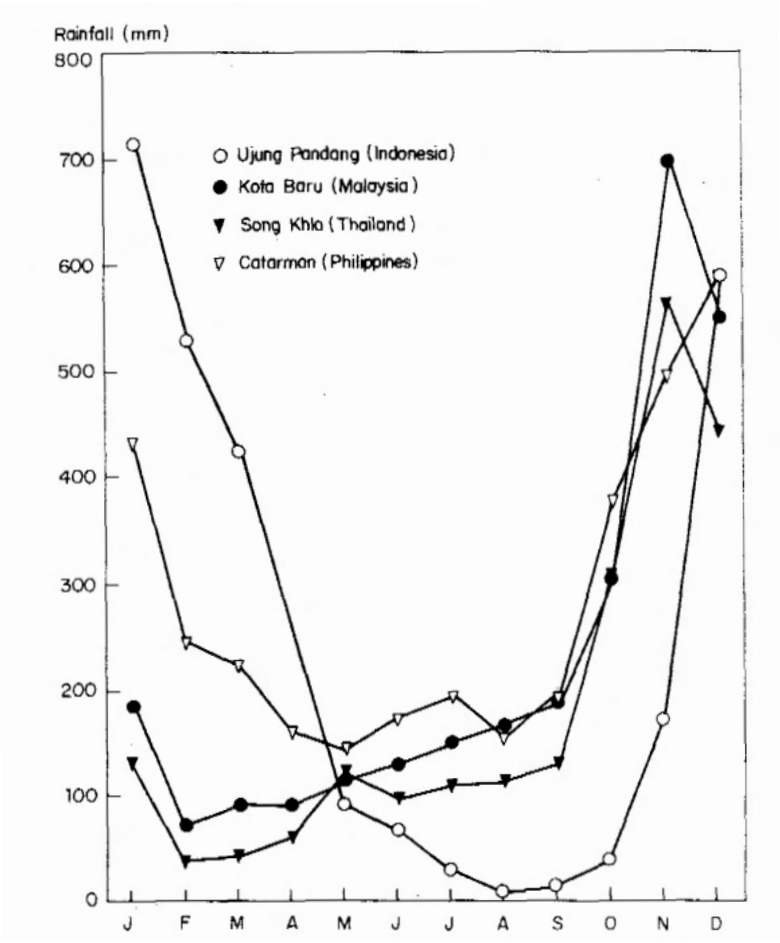
Temperature

Isothermal conditions prevail in the equatorial belt. The seasonal variation in air temperature during the year is relatively small. In these regions the height above sea level correlates strongly with air temperature. Seasonal variation, however, becomes significant at higher latitudes.



6. Mean monthly rainfall regimes on windward slopes facing the southwest monsoon.

Air temperature and altitude. The air temperature drops with increasing altitude up to the tropopause, where the temperature over equatorial latitude is about −72.5°C in July at an altitude of 16 km, and about −82°C in January at 18 km. The zero °Celcius isohyet is about 4,800 m above sea level during both seasons (Wubbe 1980). Oldeman (1980) calculated the Linear regression between altitude and monthly mean maximum and minimum temperature for Indonesia, based on climatic records prepared by Boerema (1946). He found that maximum temperature dropped 0.61°C/100 m with a sea level temperature of 31.1°C in July, while minimum temperature dropped 0.51°C/100 m with a sea level temperature of 21.6°C in July. In October, the regression equations were $\underline{Y}$ max = 32.2°C - 0.64$\underline{x}$ and $\underline{Y}$ min = 22.8°C - 0.55$\underline{x}$ ($\underline{x}$ is expressed in 100 m). Figure 10 il-

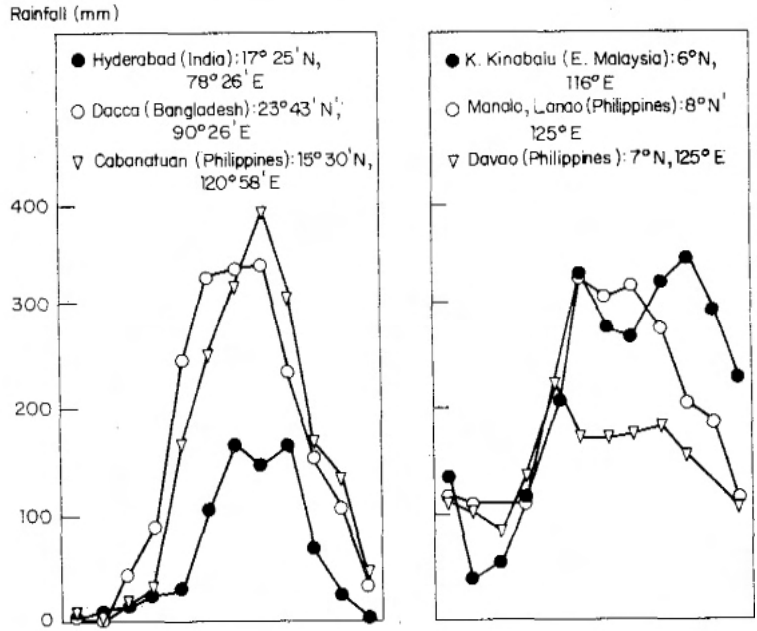


7. Mean monthly rainfall regimes on windward slopes facing the northwest monsoon.

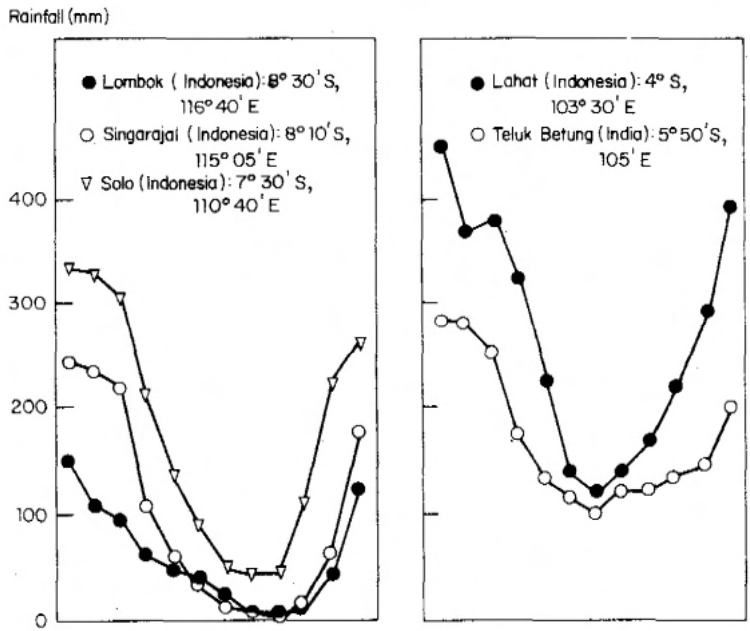
lustrates the relationship between annual maximum and minimum temperatures and altitude for Indonesian sites. Figure 11 shows mean monthly maximum and minimum temperatures for locations at different altitudes.

Although seasonal variations in the equatorial belt are small, local effects may lead to some more pronounced variations. Along coastal plains, temperature variations are small throughout the year, Farther inland, however, daytime temperatures during dry season may. be considerably higher, and nighttime temperatures considerably lower than in coastal regions (Table 1).

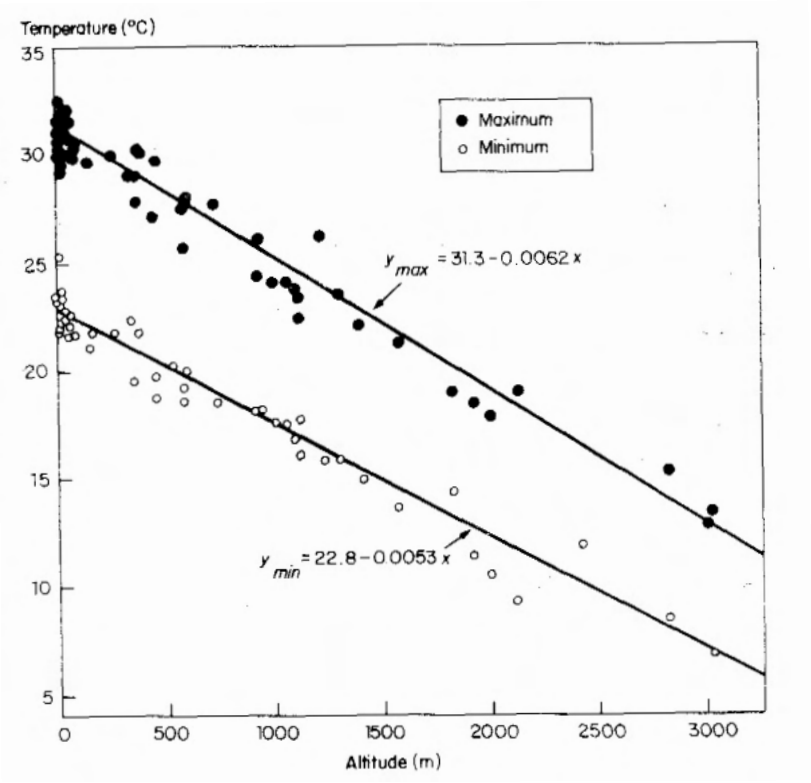
Air temperature and latitude, In the humid equatorial region, the seasonal variation in maximum and minimum temperatures usually is about 2 to 3°C, but seasonal variation becomes important at latitudes 12°



8. Mean monthly rainfall regimes with monomodal distribution north of the equator.



9. Mean monthly rainfall regimes with monomodal distribution south of the equator.



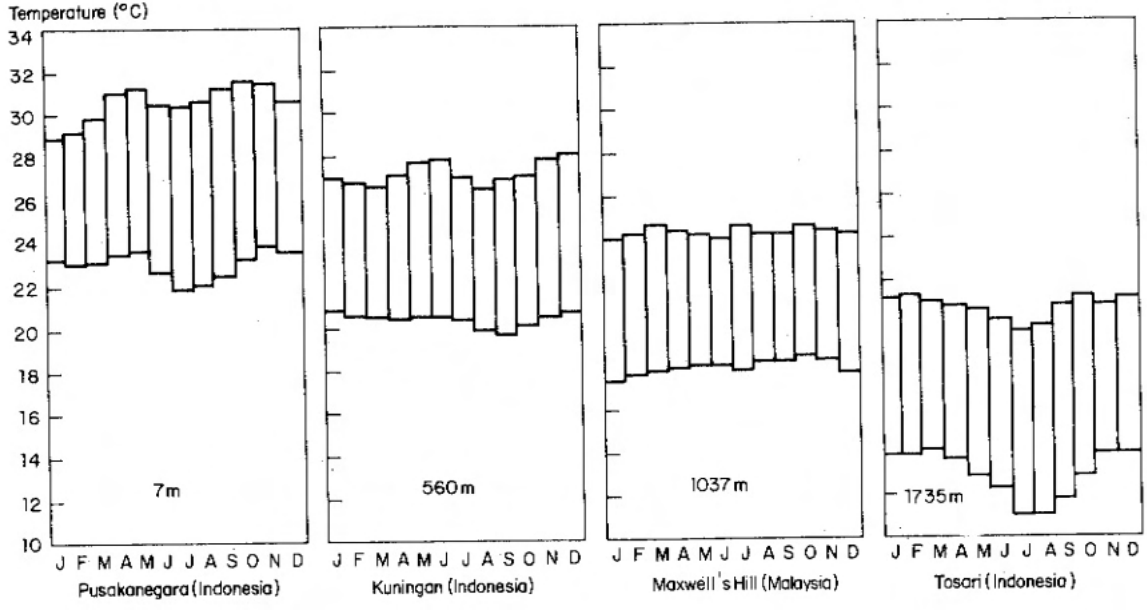
10. Relation between altitude and mean annual maximum and minimum temperatures for Indonesian sites.

north or higher (Fig. 12). Figure 13 shows some monthly maximum and minimum temperature regimes in relation to latitude.

The data show that we also need to classify environments into temperature regimes. Altitude and latitude are both determining factors and can be used to approximate homogeneous zones with respect to temperature.

Radiation

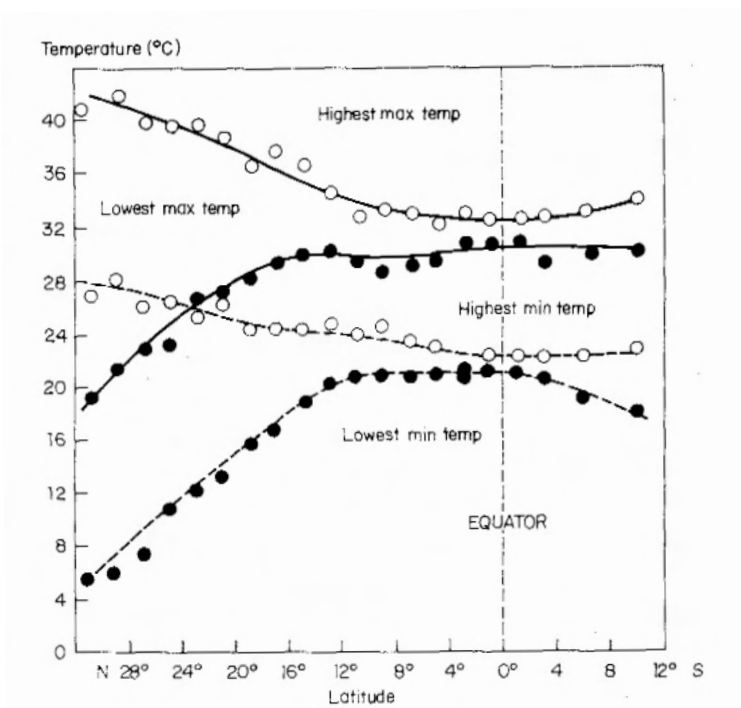
Compared to rainfall and temperature, radiation will never drop to values that impede crop performance. However, crop production clearly correlates with radiation. Reliable information on radiation is seldom available. Equipment to measure it is new and expensive compared to rainfall and temperature instruments. Scientists measure sunshine duration more frequently and convert sunshine hours to radiation intensity (Frere and Popov 1979, Oldeman and Frere 1982, Mani and Rangarajan 1982). If n is the hours of sunshine received during one day, N is the daylength (the astro-



11. Mean monthly maximum and minimum temperature regimes at various altitudes in the equatorial region of Southeast Asia.

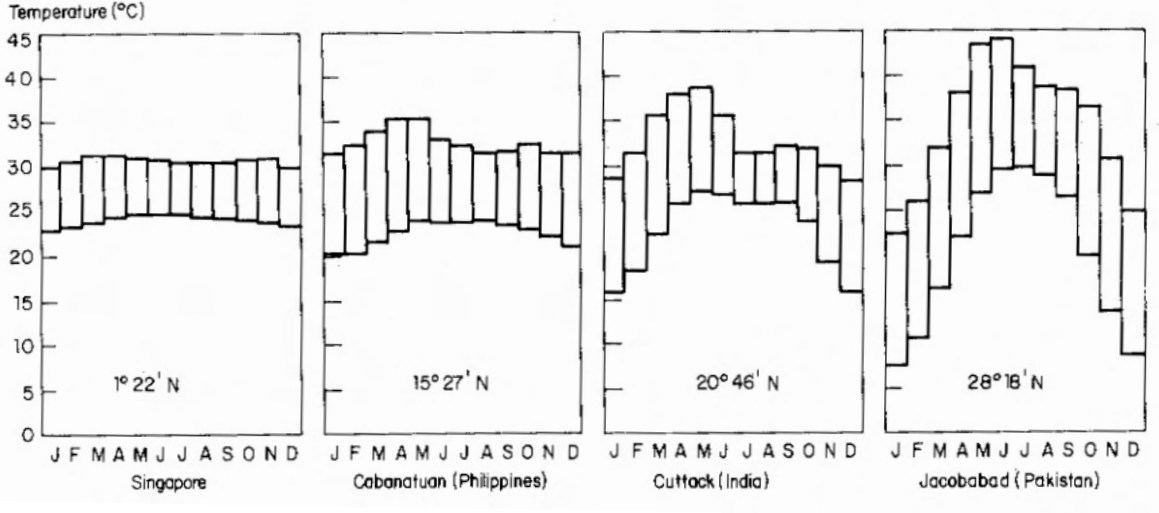
Table 1. Maximum and minimum temperatures for a coastal and an inland location at sea level in Indonesia.

Month	Coastal location temp (°C)		Inland location temp (°C)	
	Maximum	Minimum	Maximum	Minimum
Jan	31.6	22.0	32.3	21.3
Feb	31.9	21.9	32.2	21.4
Mar	32.3	21.9	32.6	21.3
Apr	32.5	22.3	33.2	20.2
May	32.7	22.2	33.2	19.2
Jun	32.3	21.7	33.2	18.3
Jul	32.3	21.3	32.8	17.3
Aug	32.6	21.2	34.0	17.5
Sep	32.8	21.3	34.9	18.4
Oct	32.7	21.6	35.7	19.5
Nov	32.5	22.0	35.2	20.4
Dec	31.8	22.0	33.7	21.2



12. Effect of latitude on the annual variation in maximum and minimum temperatures.

nomically possible sunshine duration), and Ra is the value of solar radiation on a horizontal surface at the limit of the atmosphere, one can calculate solar radiation (Rg) by $Rg = Ra\ (a + b\ \frac{n}{N})$. The coefficients a



13. Mean monthly maximum and minimum temperature regimes at various latitudes.

and b have various values, but for practical uses Frere and Popov (1979) sussest these values.

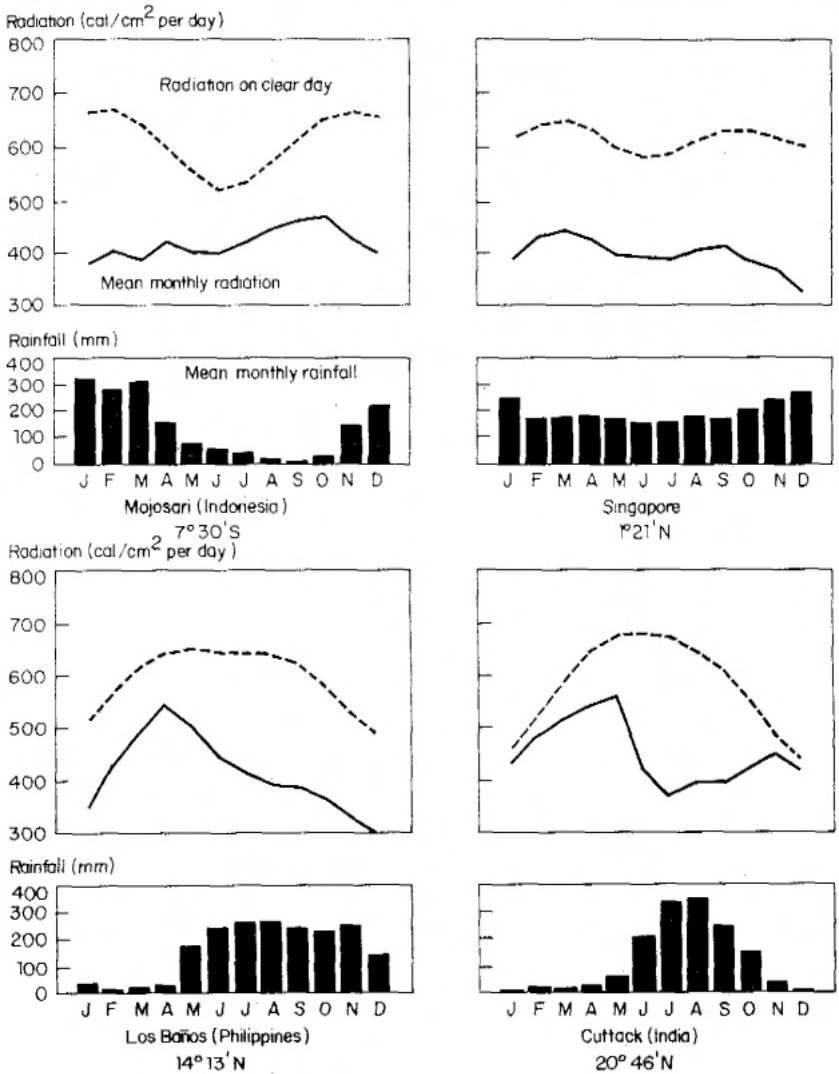
- For the dry tropical zones: a = 0.25 and b = 0.45.
- For the humid tropical zones: a = 0.29 and b = 0.42.

For equatorial regions Ra varies from 820 to 925 cal/cm^2 per day. This implies that solar radiation received at the earth's surface on a clear day (n/N = 1) varies from 575 to 650 cal/cm^2 per day during the year. On a completely overcast day (n/N = 0) the solar radiation varies from 240 to 270 cal/cm^2 per day during the year. Ra values show more variation at higher latitudes (at 20° north, Ra values vary from 660 to 965 cal/cm^2 per day and at 30° north from 520 to 1,000 cal/cm^2 per day). Despite cloud cover, radiation values show smaller seasonal variations in the equatorial belt than at higher latitudes.

If radiation in the equatorial belt varies seasonally it is more closely related to the cloud cover or the rainy season. The rainy season on both sides of the equator coincides in many instances with the peak of exterrestrial radiation (around December and January south of the equator, around June and July north of the equator). Figure 14 shows some solar radiation profiles. The profiles show that radiation intensity relates to exterrestrial radiation and to rainfall patterns.

Evaporation

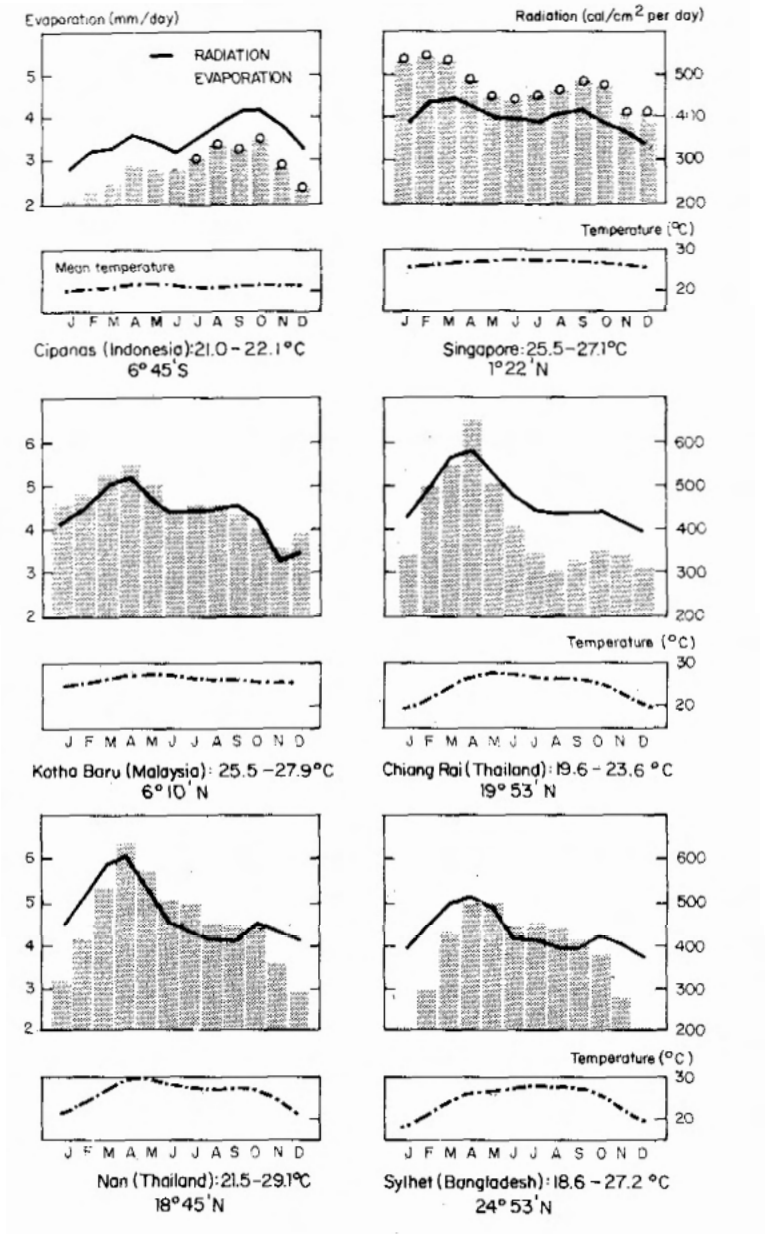
Evaporation requires energy. To evaporate water 1 mm deep requires an equivalent of 59 g cal/cm^2. This energy comes from atmospheric factors: radiation, temperature, air movement, and vapor pressure deficit. Standard equipment, such as the Class A pan, measures evaporation directly, but by knowing environmental controlling elements, one can also estimate evaporation. Figure 15 shows the monthly evaporation at six locations illustrating that evaporation is a function of radiation intensity and air temperature. It appears that monthly variation in evaporation in the equatorial tropics is related more to radiation than to temperature. With a more pronounced seasonal variation in air temperature at higher latitudes, seasonal variation in evaporation is also more pronounced. It is possible to estimate evaporation only if one has information on radiation (sunshine duration) and temperature. Windspeed and humidity are generally less variable during the year than the other factors. But in areas with long pronounced dry seasons, relative humidity will drop and the vapor pressure deficit consequently will increase. In coastal areas, sea winds, particularly during the dry season, may also become an important element.



14. Mean monthly radiation, monthly radiation on clear days, and mean monthly rainfall for 4 locations.

Of the atmospheric factors in tropical Asia, rainfall shows the greatest seasonal variation. There may be rainless periods for several months, but during the wet season, heavy rainfall often leads to flooding.

Air temperature shows small nonsignificant seasonal variations in the equatorial region although temperature differences exist between locations at different altitudes. Higher altitudes show more pronounced seasonal variations and winter temperatures may impair tropical varieties. During the dry season, high air temperatures also may be a constraint. The solar posi-



15. Mean monthly evaporation, mean monthly radiation, and mean air temperature at 6 locations.

tion and the cloud cover determine radiation fluctuations. Although they will not hinder crop growth, they do set a limit to grain production. Evaporation, a derived climatic variable, is directly correlated to radiation and temperature.

CHARACTERIZATION OF THE AGROCLIMATIC ENVIRONMENT

Because upland rice depends on rainfall, this factor should receive the highest priority. And because water goes to the plant via its root system, soil characteristics and water-holding capacity should also receive high priority.

To describe the fluctuation in actual available soil moisture, we need to incorporate the atmospheric water balance with the inherent soil moisture characteristics, and then compute cumulatively. This will indicate dry seasons, conditions suitable for upland cropping, and also conditions where moisture surpluses are suitable for wetland conditions.

To classify these conditions, we need to define climatic factors for a dry month, then amend the description for soil conditions that deviate.

Rainfall variability

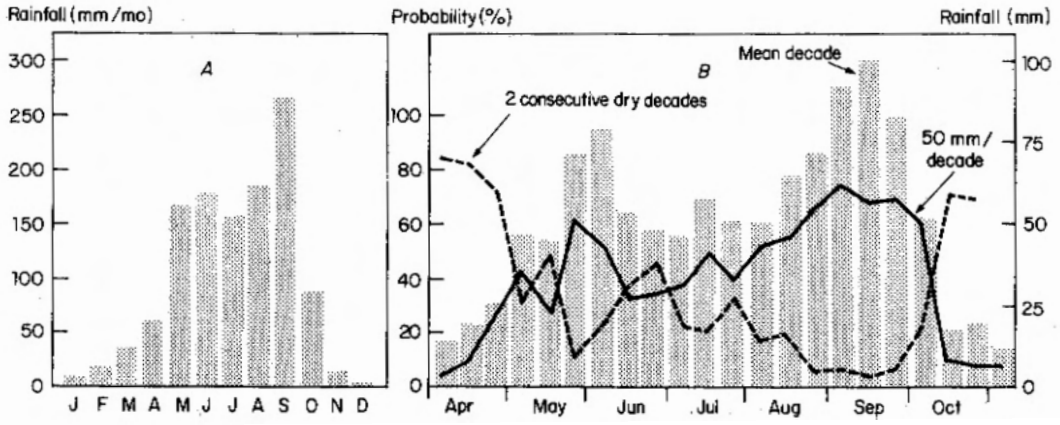
Abundant rainfall data are almost always mean monthly values. For agricultural planning this information is inadequate, because farmers want to know how much rain they can expect in less than monthly intervals. Weekly or 10-d rainfall totals for at least 25 yr would be far better. Then it is possible to calculate the rainfall probability during a specific 10-d period or the probability of having consecutive dry periods (Fig. 16).

Such data are useful for recommending agricultural activities at certain locations, but long-term records for 10-d periods are seldom published.

It is possible to express the probability of rainfall as a function of the mean monthly rainfall. Hargreaves (1975) found the following significant correlation for a number of locations in southern USA: P75 = 0.84 P mean - 23. Oldeman and Suardi (1977) established similar relationships for Indonesia: P75 = 0.82 P mean - 30, and later Oldeman and Frere (1982) for Thailand: P75 = 0.76 P mean - 20. Data for Bangladesh show the following relationship: P75 = 0.76 P mean - 32. All regression equations are highly significant (r^2 over 0.95). If rainfall for a certain month is at least 100 mm in 3 out of 4 yr, the mean monthly rainfall should be at least 158 mm (Indonesia), 158 mm (Thailand), or 175 mm (Bangladesh). Nieuwolt (1981) used the same approach but calculated the 80% probability: P80 = 0.78 P mean - 32.

Potential evapotranspiration

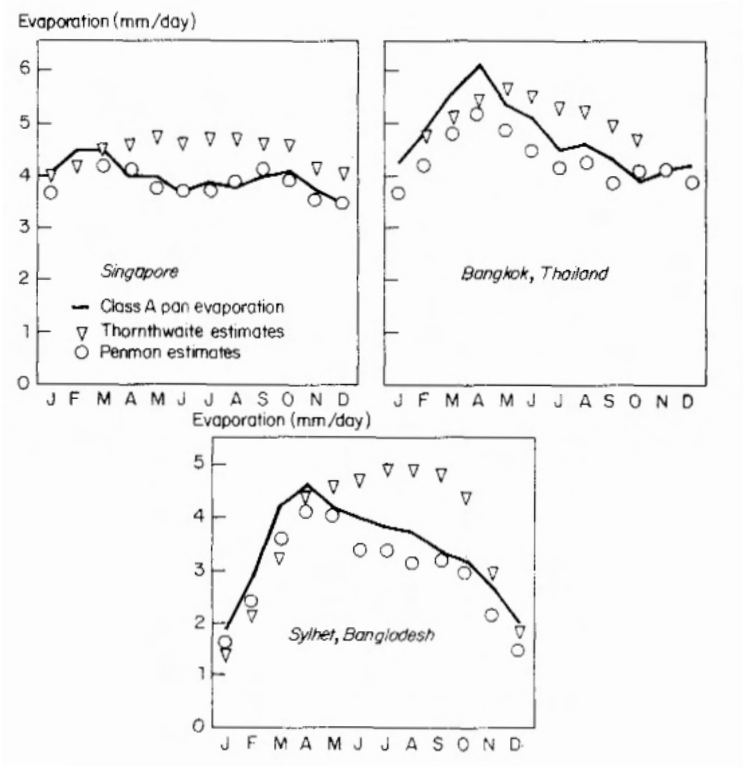
The potential evapotranspiration (PET) is the maximum quantity of water evaporated by a uniform cover of dense short grass when water supply to the soil is unlimited. Thornthwaite (1948) developed a method to estimate PET based on the mean air temperature and site



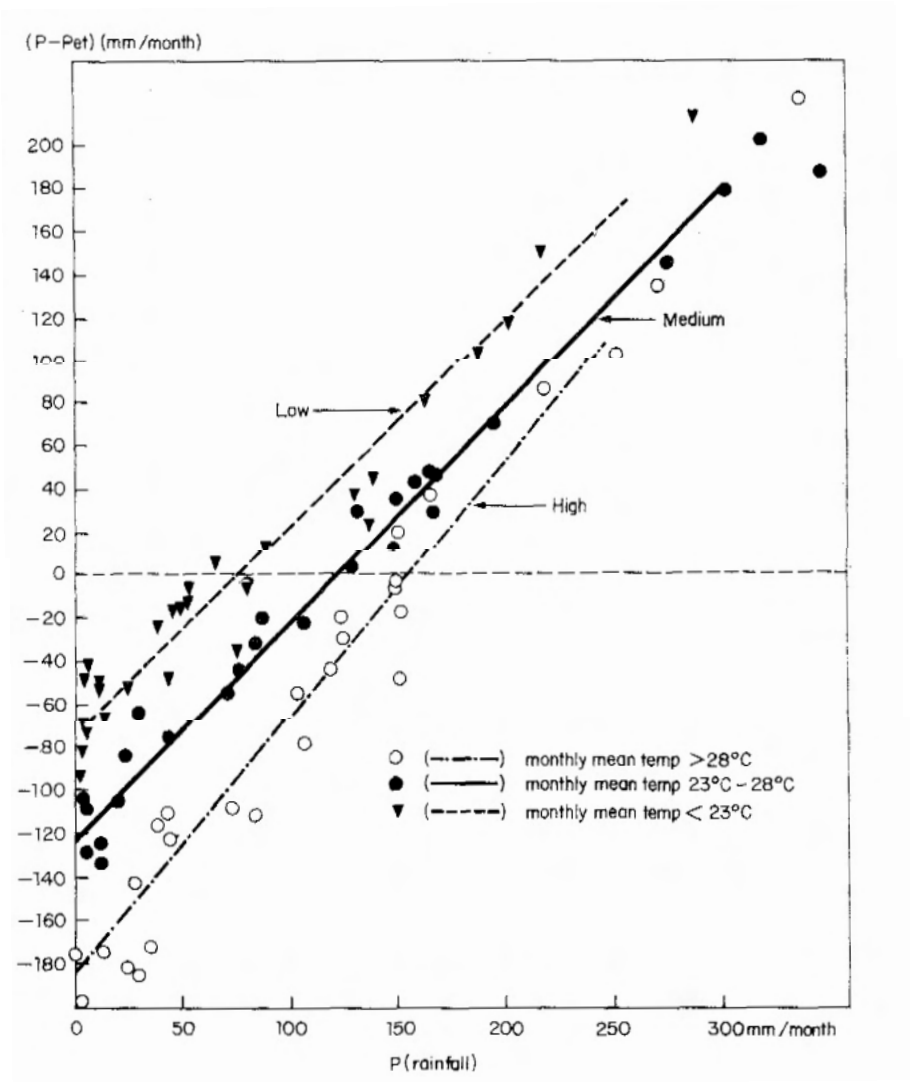
16. A: Mean monthly rainfall at Khon Kaen, Thailand. B: The probability of receiving at least 50 mm rain in 10 days the probability of having at jeast 2 consecutive decades with less than 50 mm, and the mean 10-day rainfall at Khon Kaen.

latitude. The method is for temperate climates where mean air temperature variation over the year is more important than solar radiation reaching the earth's surface. For tropical regions, however, monthly temperature variation is much lower than monthly fluctuations of solar radiation. Thornthwaite's estimates, particularly during the wet season, are too high. Papadakis (1961) suggested that the Thornthwaite method of computing PET gave results that were too low for the dry season in the tropics. Penman (1948) introduced a formula to calculate PET based on air temperature, solar radiation, vapor pressure, and windspeed. Frere and Popov (1979) developed a simplified Penman formula to estimate PET. Oldeman and Frere (1982) developed a scheme to calculate PET based on Frere and Popov's approach (Fig. 17). If data on solar radiation and air temperature are available, the modified Penman should be used.

Unfortunately few locations have climatic variables needed to calculate PET. But the Food and Agriculture Organization (FAO) agroclimatic data bank has collected long-term climatic data for many locations where PET is calculated. Our interest is in the dif-



17. Class A pan evaporation and estimated potential evaporation according to Thornthwaite and Penman (modified) for 3 locations in Asia.



18. Estimation of P – PET (rainfall – potential evapotranspiration) based on mean monthly precipitation for 3 temperature groups.

ference between rainfall (P) and PET. Because P shows much greater variation than PET and because P and PET are related to some degree (PET is lower in the rainy season), there is an obvious relationship between monthly P and monthly (P - PET). Three temperature regimes show this relationship in Figure 18. The regression equations are as follows:

($\underline{P}$ - $\underline{PET}$) = 1.014 $\underline{P}$ - 120.55 ($\underline{r}^2$ = 0.99) ($\underline{T}$ mean - between 23°C and 28°C)

$(P - PET) = 1.207\ P - 183.91$ ($r^2 = 0.91$) (T mean greater than 28°C)

$(P - PET) = 0.978\ P - 73.12$ ($r^2 = 0.96$) (T mean less than 23°C).

This means that we can expect surplus water from atmospheric sources when the mean monthly precipitation is

- more than 70 mm if the mean air temperature is below 23°C,
- more than 120 mm if the mean air temperature is between 23°C and 28°C, and
- more than 150 mm if the mean air temperature is more than 28°C.

If only precipitation and temperature data are available, we can use these threshold values to estimate if there is a surplus or deficit in the atmospheric water balance.

The water balance

To estimate the dry period length (or growing season length), calculate a cumulative water balance. Then a dry period is that time in the year when the soil moisture content drops below a value, where water is not directly available to the plant or crop, or when the actual evapotranspiration falls below the potential evapotranspiration.

Hounam et al (1975) states that "drought in the agricultural sense does not begin with the cessation of rain but rather when the available stored water in the soil will support actual evapotranspiration at only a fraction of the potential evapotranspiration."

Huke (1982) defines a dry month as any month duriny which actual evapotranspiration falls below potential evapotranspiration. Actual evapotranspiration is a function of the available soil water content. D. A. Rijks (pers, comm., 1981) established a simple relationship between the actual soil water content (S_i), the total available soil water content or water-holding capacity (S_a), the actual evapotranspiration (ETA_i) and the potential evapotranspiration (PET_i) as follows:

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

Thornthwaite and Mather (1957) developed a water budget concept for different soil water-holding capacities and prepared a series of tables to estimate soil moisture storage after various amounts of PET have occurred. Scientists use their method successfully in temperate climates. Frere and Popov (1979) developed a cumulative water balance concept established over the

whole growing seasan for a given crop for successive 10-d periods. They considered the water balance as the difference between precipitation and water lost by the crop and the soil, taking into account water retained by the soil. To determine water requirement, multiply PET by the crop coefficient for the particular 10 d related to the phenological stage of the crop. A simple formula describing the accumulation of water in the topsoil is (P. M. Driessen, pers. comm., 1981)

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

where S_i is the soil water content at the end of a time interval i,

S_i-1 is the soil water content at the start of a time interval i,

P_i is the rainfall during that time interval i,

E_i is the evaporation from a free water surface, and

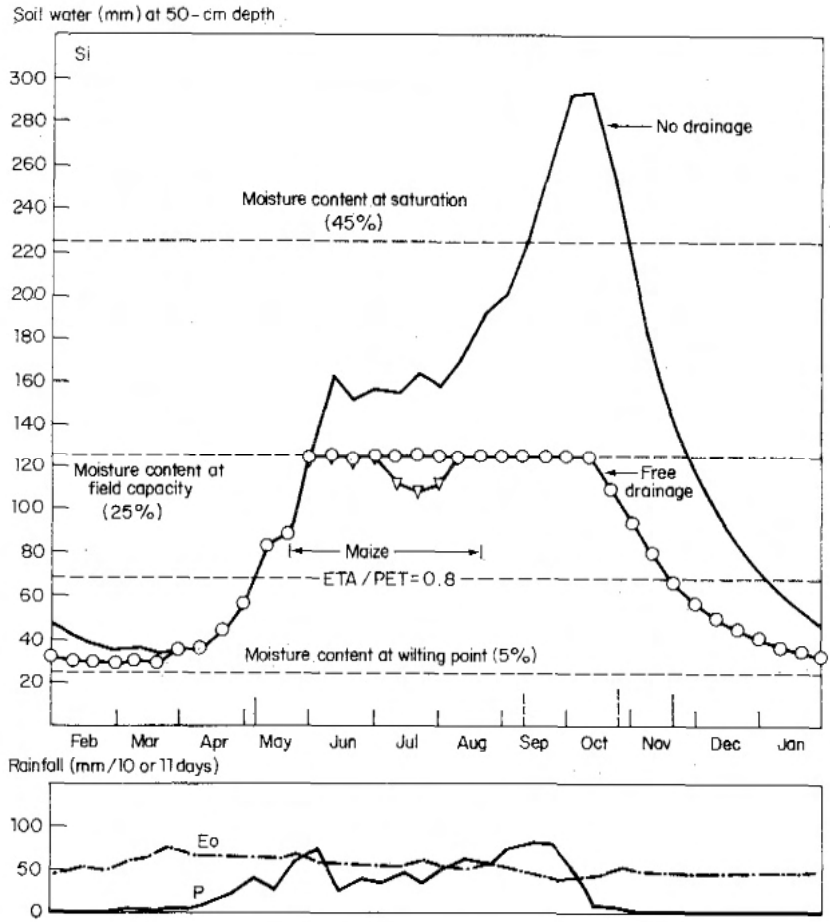
fE is the fraction of the amount of water that evaporates from the soil relative to the open water evaporation. It is the average of the fraction at the start and the end of the time interval: $fE = 0.5\ (fE_{i-1} + fE_i)$.

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

$$fE_{i-1} = \frac{S_{i-1} - S_w}{S_s - S_w}$$

Because we do not know the value of S_i, we need to estimate it and then calculate. If the estimated S_i value and the calculated S_i value differ more than a certain percentage, use a new value of S_i until the difference is smaller than a certain percentage (iterative approach). In this way one can determine the moment when the soil water content has reached a certain level, for example 50% of the soil moisture-holding capacity. This then defines the onset of the growing Season. Similarly, one can determine the end of the growing season (Fig. 19). This method, repeated for years, can then predict the onset and the end of the growing season.

Although these methods are straightforward, they are not used to describe the agroclimatic environment. Is it possible to determine the dry period based on the mean monthly rainfall data only? These amounts are the most variable and will have the greatest impact on the dry period, particularly in areas where precipitation is fully effective with free drainage and rain as the only water source.



19. Cumulative water balance based on 10-day rainfall and evaporation data and soil moisture characteristics for free drainage on bare soil, no drainage on bare soil, and free drainage with maize crop.

Assume an average moisture-holding capacity of 200 mm water/1 m soil profile or a stored water reserve of 100 mm for the first 50 cm. Assume also that the upland crop will feel drought when the ratio of actual evapotranspiration and potential evapration is less than 0.8 or when a soil water content of 40 mm water is left (see Rijks formula). This means a reserve of 60 mm of directly available water. Crops will be affected when PET - P becomes greater than 60 mm or P - PET = -60 mm. Using the relationship between (P - PET) and P, we find that precipitation per month should be at least 60 mm (1.014 P - 121 = -60).

To have a monthly precipitation of at least 60 mm in 3 or 4 yr, we can use any of the equations developed in the rainfall variability section and find a mean monthly precipitation of 105-110 mm. Therefore, a dry

month could be a month receiving less than 100 mm precipitation. This figure of 105 mm is an average value probably useful for many upland rice areas, where the soil moisture-holding capacity is around 20% and the mean air temperatures are between 23 and 28°C. In cooler climates or in soils with higher moisture-holding capacities, mean monthly rainfall figures will become lower (Table 2). Also deeper rooting varieties and varieties less sensitive to drought conditions will reduce the required monthly mean evapotranspiration.

Agroclimatic classification systems for Asia

Many attempts have been made to classify and delineate regions with homogeneous agroclimatic conditions. Perhaps, the first classification was proposed by Mohr (1933) for Indonesia. He based it on the total number of wet and dry months during a year, calculated from long-term records of monthly rainfall. He defined a wet month as any month during the year when rainfall exceeded evaporation, which he estimated to be 100 mm. A dry month was any month with less than 60 mm.

Schmidt and Ferguson (1951) used the same criteria for wet and dry months, but calculated the number of wet and dry months year by year and then computed average values. They grouped zones according to the ratio of dry and wet months, introducing a Q factor. A location with 2 dry months (and thus 10 wet months) has a Q value of 0.2.

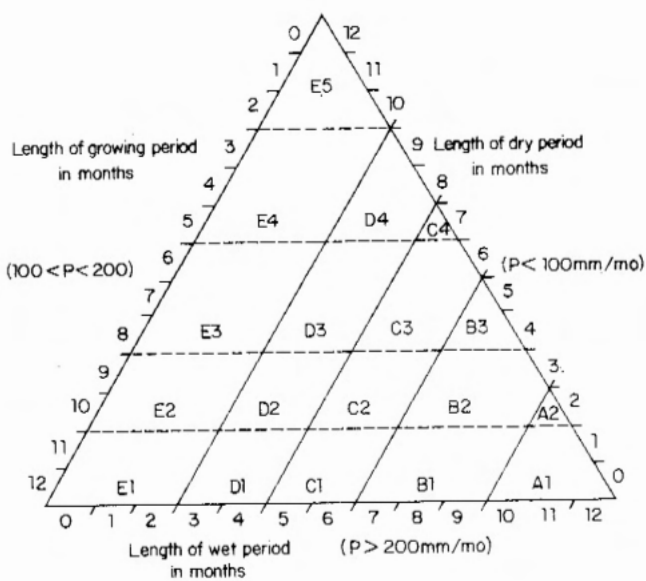
Van der Eelaart (1973) delineated agroclimatic zones for Thailand, classified by the number of consecutive humid months during which soils have sufficient moisture for optimum growth without irrigation or additional water sources. A month is humid when precipitation plus stored soil moisture is greater than the potential evapotranspiration. He fixed the level of total available soil moisture at 50 mm water. A dry month is a month when rainfall plus stored soil moisture is less than half the potential evapotranspiration. A very humid month was arbitrarily chosen as a month with more than 200 mm rainfall.

Table 2. Mean monthly precipitation required to satisfy crop water demands at full canopy stage at 3 levels of air temperature and 3 values of the soil moisture-holding capacity.

Water-holding capacity (%)	Required monthly precipitation (mm) at air temperature of		
	<23°C	23-28°C	>28°C
10	85	145	195
20	45	105	160
30	20	65	130

Oldeman (1975) developed the system of classification, proposed by a workshop at IRRI in 1973 (TRRI 1974), for wetland rice-based cropping systems. A monthly rainfall of at least 200 mm was the minimum to satisfy the water requirements for wetland rice. A dry month was a month when most upland crops during their full canopy stage would suffer from some drought. The lowest limit was 100 mm/month. The consecutive number of wet months (less than 3, 3-4, 5-6, 7-9, more than 9) delineated zones at the highest level. These five classes were subdivided according to the length of the consecutive dry period (less than 2 months, 2-3, 4-6, 7-9, more than 9). This method recognized a total of 18 agroclimatic zones (Fig. 20).

Manalo (1975, 1976) developed an identical grouping for the Philippines and Bangladesh, while Zaki and Nieuwolt (1981) prepared an agroclimatic map for Malaysia using the same concept. Panabokke (1979) designed an agroecological zone map for South and Southeast Asia. He defined an agroecological zone map as a major area of land broadly homogeneous in its rainfall regime and consisting of soil groups that reflect broad similarities in soil profile development. He recognized six rainfall regimes, based on rainfall intensity in the wet period (rainfall exceeds potential evapotranspiration), the degree of rainfall variability during the



20. System of agroclimatic classification for rice-based cropping patterns, based on mean monthly rainfall (Oldeman and Frere 1982).

wet season (bimodal regimes), and the length of the dry period following the main growing season. On separate maps he delineated seven soil groupings using the UNESCO soil map of the World.

- Group 1 Fluvisols, Gleysols
- Group 2 Xerosols, Yermosols
- Group 3 Lithosols, Regosols, Cambisols, Andosols
- Group 4 Vertisols
- Group 5 Luvisols, Nitosols
- Group 6 Avisols, Ferralsols
- Group 7 Histosols

He then superimposed the sail regions on the rainfall regimes to delineate the agroecological zones.

Nieuwolt (1981) introduced an agricultural rainfall index (ARI), which expresses rainfall as a percentage of potential evapotranspiration. Instead of using mean monthly rainfall, he calculated the amount of rainfall that can be expected in 4 out of 5 yr (dependable rainfall) using the formula P80 = 0.78 P mean - 32. He then defined the growing season as the months when ARI is more than 100%.

The FAO agroecological zones project (1978, 1980) also uses the length of growing season concept, to mark the time when water availability allows crop growth and temperature is not limiting.

The growing period is that time of the year when precipitation exceeds half the potential evapotranspiration plus time to evapotranspire an assumed 100 mm of water from excess precipitation stored in the soil. A normal growing period must have a humid period when precipitation exceeds full evapotranspiration.

Temperature regimes are very important. The tropics are regions where the monthly mean temperature, corrected to sea level temperature, is more than 18°C every month. The subtropics have one or more months during the year when mean monthly temperatures, corrected to sea level, are below 18°C, but all months are above 5°C.

We can then subdivide the tropics according to the 24-h mean temperature regimes during the growing period. The warm tropics have temperatures of more than 20°C during the growing period, the moderately cool tropics have mean temperatures of 15-20°C during the growing period, the cool tropics have mean temperatures of 5-15°C, and the cold tropics have mean temperatures below 5°C.

Huke (1982) developed agroclimatic maps of South and Southeast Asia using the system developed by Oldeman and Manalo, retaining limits of 200 mm and 100 mm for wet and dry months. For East Asia, however, including most of China, Japan, Korea, with a more temperate climate, moisture losses in the cold winter months are

so low that the 100 mm and 200 mm limits have no significance. Therefore, Huke developed an additional series of maps using dry season length as the primary mapping determinant. A dry month is a month when the potential evapotranspiration exceeds the actual evapotranspiration. The method for the dry month calculation is based on Thornthwaite's water budget model. (Thornthwaite and Mather 1957).

A review of the systems shows some common approaches. The systems are all based on a water balance concept and consider precipitation, potential evapotranspiration, and soil moisture storage values. The simplest approach may be a water balance model with a fixed soil moisture storage. One can then modify the characterizations according to actual information on water-holding capacity. Another important factor not considered in the water budget approach is the runoff water source which is related to the macrophysiography and microphysiography of the terrain. Without that information an environmental characterization is incomplete. We need to find ways to incorporate the topography so that we can quantify runoff water.

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FAVORABLE RAINFALL PERIODS IN UPLAND RICE REGIONS OF BRAZIL

S. STEINMETZ, F. N, REYNIERS, and W. T. H. LIU

Upland rice cultivation which is of great economic and social importance to Brazil, represents about 60% of the total rice production of 8 million t/yr. Variable rainfall distribution, especially dry spells (veranicos), affects the crop negatively during the reproductive period. Upland rice is the second most risky crop in the country.

The Brazilian national upland rice research program (EMBRAPA 1981) recognizes two types of production in terms of risk: favorable and unfavorable. One aim Of this program is to accurately define favorable and unfavorable regions in order that research and development strategies may be designed for them.

Although a few maps show climatic areas suitable for rice based on monthly and annual average data, we require more precision (Camargo et al 1977).

This study compares favorable rainfall periods in several upland rice production regions. We will use the term favorable period when there is a 66% probability of more than 50 mm of rain in 10 days. This will make the comparison between stations easier. The same level sufficiently approximates the potential evapotranspiration of the localities Compared (Hargreaves et al 1979). Although 50 mm is a high level of demand, we chose it because dry spells often occur during the reproductive stage, when water demand and the potential for damage are highest. The 66% probability of success is a reasonable limit for upland rice.

We believe this preliminary study can begin to provide

- a methodology to use for zoning,
- rainfall distribution characteristics for favorable and unfavorable regions, and
- a potential varietal cycle and sowing date,

Agrometeorologist, EMBRAPA/CNPAF, Caixa Postal 179-74000 Goiânia, Goiás; agrophysiologist, IRAT, present address, CNPAF, Caixa Postal 179-74000 Goiânia, Goiás; and agrometeorologist, CETEC, Caixa Postal 2306-3000 Belo Horizonte, Minas Gerais - Brazil.

METHOD

Computing rainfall probabilities and favorable periods

We concur with others (Thom 1958, Gigou 1973, Hargreaves 1973) that for short periods, rainfall probability follows the law of distribution of the incomplete gamma function. Newton's approximation method computed its parameters (Thom 1958). Therefore, for each calendar period, we adjusted the rainfall observed. We used Campo Maior data to compare real and estimated probabilities and found a correlation coefficient of 0.91 for 36 periods during the rainy season.

We plotted the distribution of the rainfall probability of >50 mm for 10-day periods with an increment of 5 days for 7 mo overlapping the growing season and then analyzed the graph to determine the favorable periods.

Rainfall stations

The stations we chose have at least 25 yr of daily rainfall observations and are in upland rice production regions. In western Brazil, however, few stations are that old and they cannot provide the daily data.

We checked the reliability of rainfall stations by comparing their annual rainfall data with others in the region and eventually selected 20 stations (Table 1).

Table 1. Stations studied for their rainfall frequency distribution.

Name	State	Latitude (S)	Longitude (W)	Altitude (m)	Number of years of data
Camp Maior	Piaui	4.49	42.11	125	47
Teresina	Piaui	5.05	42.49	74	40
Grajau	Maranhao	5.49	46.08	163	25
Carolina	Maranhao	7.20	47.28	193	29
Conc. do Araguaia	Para	8.16	49.17	150	27
Porto Nacional	Goias	10.43	48.25	237	28
Goiás	Goias	15.55	50.88	495	27
Caceres	Mato Grosso	16.04	57.41	118	26
Inhumas	Goias	16.81	49.30	800	29
Goiânia	Goias	16.41	49.16	729	27
Estrela do Sul	Minas Gerais	18.45	47.41	461	34
Tapirai	Minas Gerais	19.53	46.01	610	38
Terra Roxa	Sao Paulo	20.00	48.00	478	31
Aquidauana	Mato G. do Sul	20.28	55.48	207	28
Jaguariuna	Sao Paulo	22.42	47.00	–	34
Usina Rasgao	Sao Paulo	23.23	47.02	650	48
Buri	Sao Paulo	23.48	48.35	563	38
Santa Clara (Guarapuava)	Parana	23.38	51.58	740	28
Sao Mateus do Sul	Parana	25.52	50.23	760	42
Capinzal	Santa Catarina	27.21	51.37	447	27

Ways of comparison

We sampled the stations and compared them on an east-west, north-south axis and in the cerrados region. This grouping allowed better visualization of the variability.

RESULTS

East-west variation in three Northeast Brazilian states

We compared four stations between 5°S and 8°S latitude. The easternmost is Campo Maior, longitude 42°W, and farther west is Conceição do Araguaia, longitude 49°W (Fig. 1).

Between these limits, moving westward, the favorable periods tend to lengthen the season but not always. Season length can even decrease, as in Carolina.

Variation from north to south in Central Brazil

To clarify variations in the number of favorable periods from North to South, we selected six stations between 47°W and 51°W. The northernmost is Conceição do Araguaia and the southernmost is Santa Clara (Guarapuava) in Paraná (Fig. 2).

There is no favorable period in Santa Clara although it rains from October to April. But during the whole season the probability of having >50 mm/10 days is less than 50%.

In between, from north to south, the number of favorable periods decreases, even if there are some irregularities as in Porto National. Although this station is farther north than Goiânia, it has fewer periods.

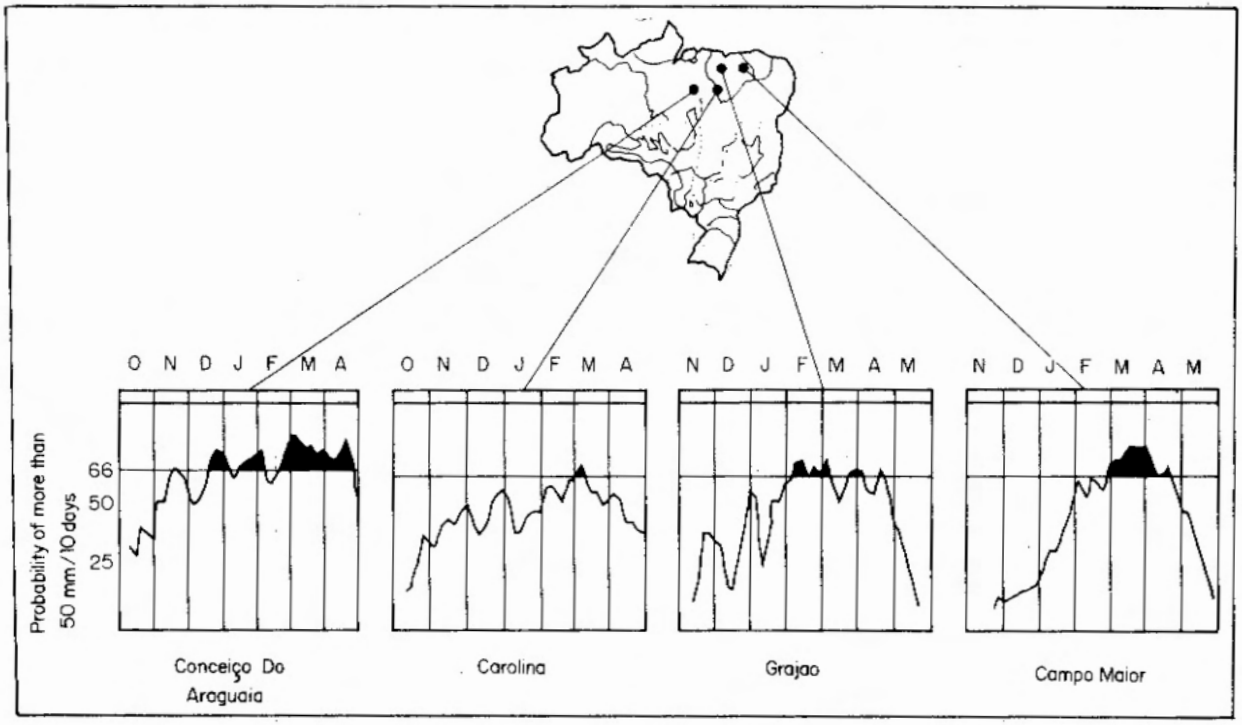
Variations in the cerrados

In the central cerrados region, which grows more than half of Brazil's upland rice, vegetation is savannah-type.

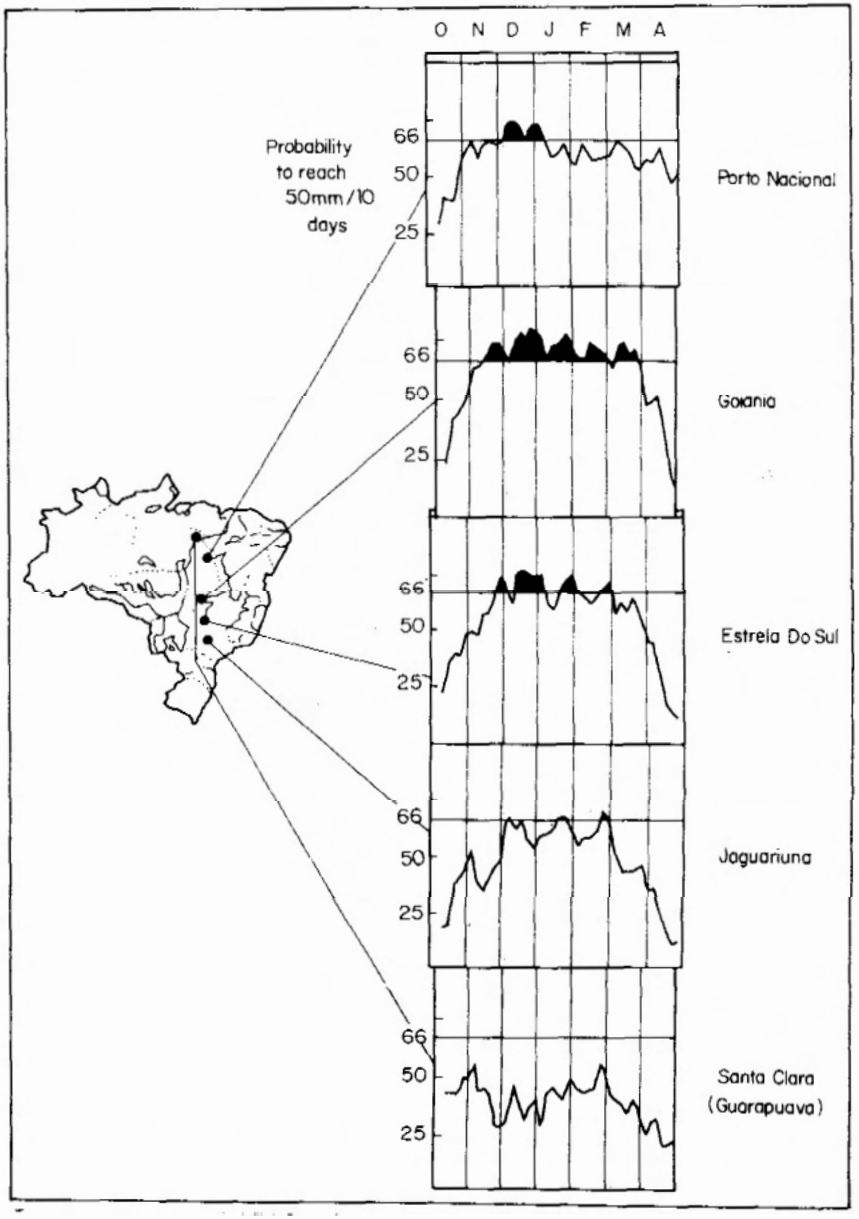
Most stations in Figures 1 and 2 are in the cerrados. As we observed variations inside the region, we saw another pattern which we did not try to identify. For example, both Caceres, a station in the western part, and Aquidauana in the southwest, have favorable periods from mid-December to late February. But Goiás, similar to Goiânia, and Tapirai, slmilar to Estrela do Sul, follow the variation pattern already described (Fig. 3).

DISCUSSION

The distribution of the probability of >50 mm/10 days varies among the stations compared. The number and



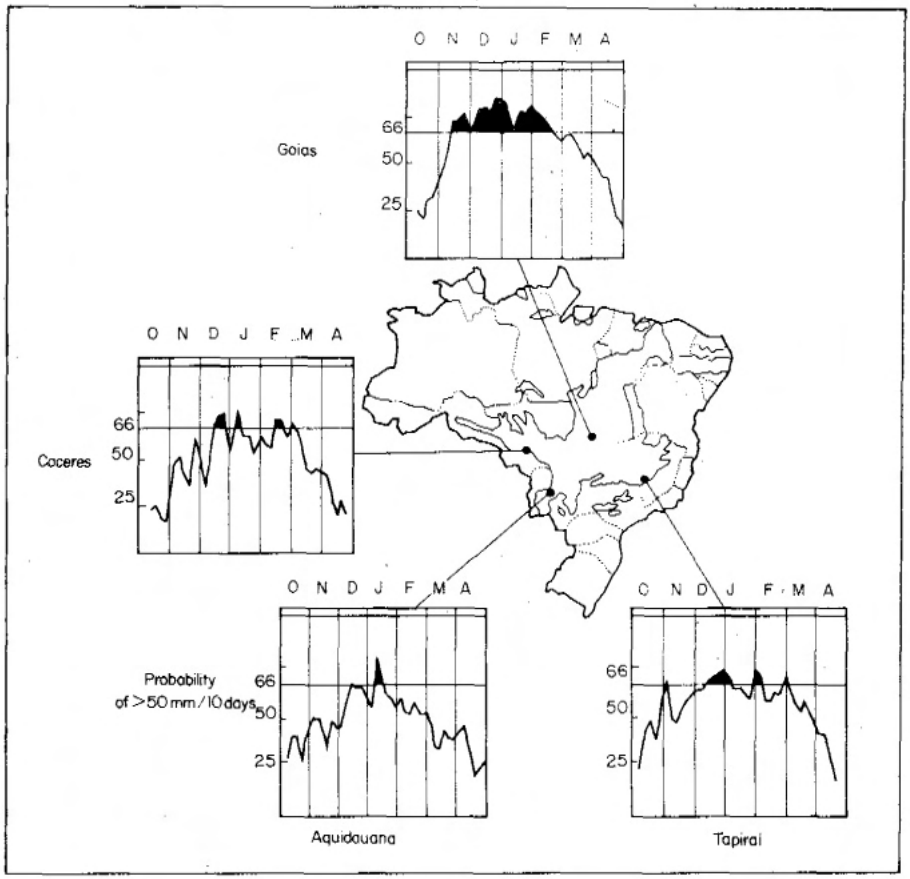
1. East-West variations in Brazilian states of the probability to reach 50 mm/10 days during the growing period of upland rice. Periods are 10 days with increments of 5 days. Dashed periods are favorable for upland rice.



2. North-South variations in Brazilian states of the probability to reach 50 mm/10 days during the growing period of upland rice. Periods are 10 days with increments of 5 days. Dashed periods are favorable for upland rice.

sequence of favorable periods also vary. Because of the low number of stations in this study, it is impossible to define favorable and unfavorable regions.

The southern part of the upland rice area (Aquidauana or Guarapuava station of Santa Clara) has fewey favorable periods than the northern areas (Coiania or Conceicão do Araguaia).



3. Variations in the Brazilian cerrados of the probability to reach 50 mm/10 days during the growing period of upland rice. Periods are 10 days with increments of 5 days. Dashed periods are favorable for upland rice.

This method of comparing rainfall regimes allows us to evaluate the suitability of the area for growing rice. We could nof do this using monthly rainfall data. For example, Goiańia seems more favorable than Carolina or Porto Nacional, but comparison of the monthly rainfall data indicates the opposite.

The distribution probabilities of the two stations (Table 1) in ,the states of Paranā and Santa Catarina in the south, are of the same type as that in Guarapuava (Fig. 2). With practically no favorable period, this region has a very high climatic risk. Because upland rice production in this region is important, we should look for an explanation.

This methodology defines the most appropriate varietal cycle for a region. For example, Carolina or Jaguariuna stations should use short-duration varieties of about 100 days. With a longer rainfall season, the

choice of variety duration will also depend on the best planting time. To choose this, we can also use frequency distribution to minimize the risk of having a dry spell during the reproductive phase.

CONCLUSION

The use of rainfall distribution frequency to compare 20 climatic stations in upland rice production regions of Brazil permits us to define favorable and unfavorable regions for this crop. The data confirm the assumptions of the national upland rice research program.

The rainfall frequency approach for short periods will be an efficient tool in defining favorable climatic zones for upland rice. However, evapotranspiration and soil water-holding capacity need more accurate estimation.

We can also apply this principle in crop management to help choose varieties with long or short duration, planting times, or any other agronomic techniques that depend on rainfall regime.

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PLANT PROTECTION

DISEASE PROBLEMS IN UPLAND RICE

V. A. AWODERU

Upland rice in the WARDA region depends on rainfall for all moisture. It is grown on freely drained soil without stagnant water or bunds to retain water. These conditions are found in the moist forest and savanna zones.

Average upland rice yield varies from 0.7 to 1.5 t/ha. Low yield has been attributed to several factors, in- cluding inadequate plant protection against weeds, diseases, and insect pests. Aluko (1970) demonstrated that brown spot (BS) (Helminthosporium oryzae syn. Drecshlera oryzae) causes 12-43% yield loss in upland rice production in Nigeria. Leaf blast (Bl) (Pyricularia oryzae), neck blast (NBI.) (Pyricularia oryzae), leaf scald (LSc) (Rhynchosporium oryzae), and false smut (FSm) (Ustilaginoidea virens) also reduce upland rice yields. Raymundo and Fomba (1979) reported that the most widespread and economically important disease in Sierra Leone is Bl, which causes 3.2-14.5% yield loss in ROK 3, Mange 2, and CCA. Losses more than 80% have been estimated for more susceptible varieties. Bl has caused 9.8-39.2% yield loss in Nigeria (Awoderu and Esuruoso 1974).

Although LSc affects upland and lowland rice, it is more prevalent in upland rice where up to 45% of a field can be infected. LSc is widespread in Nigeria, Niger, Liberia, Benin, Ivory Coast, Sierra Leone, Senegambia, Upper Volta, Mali, and Guinea-Bissau.

FSm is a major disease wherever it occurs. Heavy infections have been recorded in Ivory Coast, Sierra Leone, and Nigeria.

In West Africa, upland rice is grown in the humid or moist tropical zones, the Guinea Savanna, and the Sahel (Sudan Savanna). During 1977-78 monitoring tours organized by WARDA, the incidence of diseases (Table 1) and their relative prevalence in the different zones were recorded (Table 2). There were major disease problems in the humid tropical and savanna ecosystems.

West Africa Rice Development Association, P. O. Box 1019, Monrovia, Liberia.

Table 1. Upland rice disease incidence in Africa.

Disease	Causal organism	Incidence[a]														
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Fungal																
Seedling blast	*Pyricularia oryzae*		X					X		X		X				
Leaf blast	*Pyricularia oryzae*	X		X	X	X	X			X	X	X	X	X	X	X
Neck blast	*Pyricularia oryzae*	X		X	X	X	X			X	X	X	X	X	X	X
Node blast	*Pyricularia oryzae*			X						X		X				
Brown leaf spot	*Helminthosporium oryzae*	X		X	X	X	X			x	X	X	X	X		X
False smut	*Ustilaginoidea virens*											X				
Sheath blight	*Rhizoctonia solani*	X		X	X	X	X			X	X	X	X			
Leaf scald	*Rhynchosporium oryzae*	X		X	X	X				X	X	X		X		X
Stem rot	*Helminthosporium sigmodeum*	X			X							X				
Narrow brown leaf spot	*Cercospora oryzae*		X							X	X	X	X			
Sheath blotch	*Pyrenochaeta oryzae*		X							X	X	X	X			
Sheath rot	*Acrocylindrium oryzae*			X		X						X				X
Dirty panicle	Several fungi and bacteria	X		X	X	X					X	X	X			
Foot rot	*Gibberella fujikuroi*			X	X	X				X		X	X			
Viral and bacterial																
Bacterial leaf streak	*Xanthomonas translucens* f. sp. *oryzicola*		X		X	X										
Bacterial blight	*Xanthomonas oryzae*				X			X			X					
Pale yellow mottle	Virus		X		X											

[a]X = present, A = Benin, B = Gambia, C = Ghana, D = Ivory Coast, E = Liberia, F = Mali, G = Mauritania, H =Niger, I = Nigeria, J = Senegat, K = Sierra Leone, L = Togo, M = Upper Volta, N = G. Bissau, O = Guinea.

Table 2. Diseases of upland rice in major West African climatic zones.

Disease	Causal organism	Relative prevalence [a]		
		Humid tropical [a]	Guinean Savanna	Sudanian Savanna (Sahel)
False smut	*Ustilaginoidea virens*	XX	X	–
Sheath blight	*Rhizoctonia solani*	X	X	X
Pale yellow mottle	Virus	X	–	–
Grassy stunt		X	–	–
Seedling blast	*Pyricularia oryzae*	XX	XX	X
Leaf blast	*Pyricularia oryzae*	XX	XX	X
Neck rot	*Pyricularia oryzae*	XX	XX	X
Brown spot	*Helminthosporium oryzae*	XX	X	–
Leaf scald	*Rhynchosporium oryzae*	XX	XX	–

[a] – = absent, X = not common, XX = prevalent.

DISEASE-RESISTANT VARIETIES

WARDA in Monrovia, Liberia, organizes the Initial Evaluation Trial (IET) and the Coordinated Variety Trial (CVT) in the moist forest and dry savanna forest zones to test rice varieties for yielding ability, days to maturity, and reaction to major upland rice diseases. Results of these trials are shown in Tables 3-5.

In the 1981 IET, IR145, IR5853-198-1-2, IR8235-84 IRAT165, and IRAT166 were highly resistant to Bl and yielded well.

Varieties with NBl resistance were ROK16, DJll-307-3-1-5, IR45, IR9669-SEZ, IR8235-84 IR8235-1-94, IR9559-1-2-31 IR5931-81-1-1, IR6115-1-1-1, IR6023-10-1-1, 3IRAT13, IRAT133, IRAT142, IRAT144, IRAT146, IRAT160, IRAT161, IRATl62, IRAT165, IRAT166, IRAT169, IRAT184, ITA132, ITA135, ITA183, ITA208, ITA233, ITA-234, TOX95-5-1-1-1, TOX728-1, SEL IRAT194/1/2, and M18.

Varieties IR9671-1-4-6-8, IRAT142, IRAT146, IRAT-165, and ITA183 were resistant to LSc, and IRAT146, IRAT162, IRAT166, and IRAT168 had BS resistance.

IRAT165 was resistant to B1, NB1, and LSc and IRAT166 was resistant to BL, NB1, LSc, and BS. Of all varieties tested, these two showed the broadcast spectrum of resistance to major upland diseases. Resistant varieties yielded from 2.0 to 3.0 t/ha.

In the short-duration, upland savanna trial (Table 3), most varieties had a high level of resistance to B1, NB1, BS, and LSc. Those varieties also exhibited resistance at several West African sites.

Yields varied from 1.1 t/ha for C168 planted in Bouaké, Ivory Coast, to 4.7 t/ha for IRAT110 planted at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. C168 was moderately susceptible to Bl at IITA; susceptible to NBl at Farakoba, Upper Volta; and moderately susceptible to LSc at Bouaké.

Table 3. Reaction to major diseases, yield, and maturity period of short-duration upland savanna rice varieties.[a]

Characteristics	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
							Ivory Coast, Bouake								
Duration (days)	105	105	105	103	105	125	103	100	128	128	97	99	132	132	132
Yield (t/ha)	2.7	2.7	2.6	2.6	2.4	2.4	2.3	2.2	2.1	2.0	1.6	1.5	1.3	1.1	1.1
Leaf blast	R	HR	R	HR	HR	MR	HR	R	HR	R	R	HR	MR	R	R
Neck blast	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
Brown spot	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
Leaf scald	R	R	R	HR	HR	HR	R	HR	R	R	HR	HR	MS	MS	MS
							Longorola, Mali								
Yield (t/ha)	3.9	3.9	3.4	4.1	4.3	3.2	2.4	3.7	2.8	2.1	2.9	2.2	1.9	1.4	1.5
Leaf blast	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
Neck blast	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
Brown spot	R	R	R	R	R	MR	MR	HR	R	R	R	MR	R	R	R
Leaf scald	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
							IITA, Nigeria								
Duration (days)	100	105	100	95	105	113	100	100	115	118	100	–	115	120	120
Yield (t/ha)	4.0	4.4	4.5	4.1	4.0	3.0	4.0	4.1	3.8	3.2	4.1		3.7	3.0	1.7
Leaf blast	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	–	MR	MS	MS
Neck blast	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	–	HR	HR	HR
Brown spot	MR	HR	HR	HR	HR	HR	HR	HR	HR	HR	MR		HR	HR	HR
Leaf scald	HR	MR	MR	HR	MR	MR	HR	MR	MR	MR	MR	–	HR	HR	HR
							Sefa, Senegal								
Duration (days)	92	94	90	90	92	105	89	89	101	100	89	–	105	106	–
Yield (t/ha)	3.3	2.4	3.8	3.1	3.3	1.3	3.1	2.8	1.5	1.3	3.1	–	2.0	2.4	–
Leaf blast	R	R	MR	HR	R	MR	R	R	R	HR	HR	–	MS	MR	–
Neck blast	HR	HR	HR	HR	HR	R	HR	HR	HR	HR	HR	–	R	HR	–

Upper Volta															
Duration (days)	92	96	94	93	94	107	87	86	104	101	83	83	112	112	112
Yield (t/ha)	4.2	4.7	4.9	5.3	5.1	2.5	4.3	4.6	3.6	2.7	4.2	3.0	1.2	1.6	1.6
Leaf blast	HR	HR	HR	HR	HR	HR	HR	HR	HR	R	HR	HR	HR	MR	MR
Neck blast	HR	HR	HR	HR	HR	HR	HR	HR	HR	R	HR	HR	R	S	R
Leaf scald	HR	HR	HR	HR	HR	HR	HR	HR	HR	MS	HR	HR	R	R	MR
Sotouboua, Togo															
Duration (days)	112	105	114	95	110	110	110	110	110	112	109	120	125	130	–
Yield (t/ha)	2.7	2.9	1.8	3.2	2.7	2.5	2.7	2.3	2.0	2.7	2.6	2.0	3.1	2.3	–
Leaf blast	MS	MS	HS	HS	HS	MS	S	S	HS	MS	MS	HS	S	HS	–
Neck blast	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	–
Brown spot	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	–
Leaf scald	MR	R	HR	HR	HR	R	HR	HR	R	R	R	R	R	HR	–
Farakoba, Upper Volta															
Duration (days)	108	101	109	94		105	114	105	105	114	114	117	133	127	–
Yield (t/ha)	3.1	4.4	3.7	5.5	3.1	3.6	2.1	3.3	2.4	2.6	2.4	2.0	0.6	0.5	–
Leaf blast	HR	HR	HR	HR	HR	HR	R	HR	HR	HR	R	HR	HR	HR	–
Neck blast	HR	HR	HR	HR	HR	HR	R	HR	HR	HR	R	HR	HR	HR	–
Leaf scald	MR	HR	R	HR	R	R	MR	HR	HR	MR	MR	MR	MR	R	–

[a]No data were available on duration in Mali, brown spot and leaf scald in Senegal, brown spot in Upper Volta. A = IRAT144, B = IRAT109, C = IRAT133, D = IRAT110, E = IRAT142, F = 62-155-C1, G = IRAT146, H = IRAT112, I = M18, J = TOX86-3-1, K = IRAT147, L = Dourado Precose, M = TOX516-19-SLR, N = C168, and O = B529C-MD-20-3-6-C1.

Table 4. Reaction to major diseases, yield, and duration of moist zone upland rice varieties.[a]

Characteristics	A	B	C	D	E	F	G	H	I	J	K	L	M	N
							Contuboel, Guinea Bissau							
Duration (days)	131	127	129	108	130	130	132	130	122	128	143	129	146	144
Yield (t/ha)	3.6	3.3	3.3	3.2	2.9	2.9	2.9	2.8	2.7	2.7	2.6	2.0	1.4	0.9
Leaf blast	HR	HR	HR	HR	HR	MS	HR	HR	MS	HR	HR	HR	HR	HR
Brown spot	HR	HR	HR	HR	HR	S	HR	HR	S	HR	HR	HR	HR	HR
Leaf scald	MS	MS	MR	HR	HR	HR	HR	HR	HR	HR	HR	HS	HR	HS
							Odienne, Ivory Coast							
Duration (days)	132	131	132	102	130	129	129	129	132	132	145	132	–	145
Yield (t/ha)	3.2	4.0	2.9	2.3	2.8	4.1	2.0	3.1	2.9	3.5	3.0	2.9	–	2.0
Leaf blast	HR	HR	HR	MR	HR	HR	R	HR	HR	HR	R	HR	–	R
Neck blast	HR	HR	HR	MS	HR	HR	S	HR	HR	HR	MR	MR	–	MR
Brown spot	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	–	HR
Leaf scald	R	MS	MR	MR	R	MS	R	MS	R	R	MS	MR	–	MS
							Suakoko, Liberia							
Duration (days)	122	124	121	106	110	122	120	107	108	118	124	123	140	130
Yield (t/ha)	2.6	2.3	2.3	1.2	1.7	2.4	1.6	2.6	2.1	2.8	2.3	2.5	3.0	2.5
Leaf blast	HR	R	R	HR	R	R	HR	R	R	R	MR	R	HR	HS
Neck blast	*MR*	MR	MS	HS	S	MR	S	MS	MR	MR	S	MS	S	S
Brown spot	S	S	S	MS	S	MS	S	MS	S	S	S	S	S	S
Leaf scald	*MR*	S	S	S	S	S	MS	S	S	S	MS	MS	MS	S

Ibadan, Nigeria														
Duration (days)	115	107	114	106	110	113	128	110	116	117	114	117	–	–
Yield (t/ha)	1.7	1.7	2.3	4.7	1.3	1.9	0.4	1.6	1.5	1.9	0.8	1.8	–	0.2
Leaf blast	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	–	HR
Ncck blast	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	–	HR
Brown spot	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	–	HR
Sefa, Senegal														
Duration (days)	102	101	102	89	100	99	113	100	99	102	105	112	122	124
Yield (t/ha)	1.2	1.8	0.9	3.6	0.3	1.4	1.0	1.7	1.5	1.7	1.5	0.7	1.7	0.6
Leaf blast	MR	R	MR	MR	MR	MR	MS	R	MR	HR	MS	MS	MR	HS
Neck blast	R	HR	HR	HR	HR	R	HR	R	R	HR	HR	HR	HR	HR
Leaf scald	R	R	R	R	HR	HR	HR	R	HR	R	R	MR	MR	R
Rokupr, Sierra Leone														
Duration (days)	120	98	89	70	79	88	94	88	86	91	91	95	87	121
Yield (t/ha)	1.6	1.3	1.5	0.4	1.4	1.5	1.6	1.5	1.1	1.6	1.6	1.4	1.4	1.2
Leaf blast	MR	HR	MR	MR	MR	MR	MR	MR	MR	MR	R	MR	MR	**MS**
Neck blast	R	R	MS	S	R	MR	MR	R	MR	MR	R	R	R	R
Brown spot	S	MR	MS	MS	MS	MS	MS	MR	MS	MR	MR	MR	MR	**MS**
Leaf scald	S	MS	MR	MS	MR	MS	MR	MS	MS	MS	MS	MS	**MS**	S

[a] No data were available on neck blast in Guinea Bissau, leaf scald in Nigeria, and brown spot in Senegal. A = IRAT104, B = IRAT138, C = IRAT132, D = DJ11-509, E = ITA116 (TOX 86-1-3), F = IRAT170, G = C22, H = Sel IRAT 194/1/2, I = TOX494-SLR, J = IRAT156, K = TOX516-19-SLR, L = IRAT136, M = TOX515-11-SLR, and N = COL 38.

Table 5. Reaction to major diseases, grain yield, and duration of moist upland rice varieties.[a]

Characteristics	A	B	C	D	E	F	G	H	I	J	K	L	M	N
							Gognoa, Ivory Coast							
Duration (days)	107	111	107	128	107	–	107	–	–	128	–	–	128	109
Yield (t/ha)	2.5	1.6	1.7	1.3	1.4	–	1.6	–	–	2.2	–	–	1.5	1.3
Leaf blast	MR	R	HR	HR	HR	–	HR	–	–	R	–	–	HR	HR
Neck blast	HR	MR	R	R	MS	–	HR	–	–	HR	–	–	MS	R
Brown spot	HR	HR	HR	HR	HR	–	HR	–	–	HR	–	–	HR	HR
Leaf scald	HR	HR	HR	HR	HR	–	HR	–	–	HR	–	–	HR	HR
							Suakoko, Liberia							
Duration (days)	98	100	98	113	96	104	95	127	–	106	104	126	105	100
Yield (t/ha)	2.7	2.7	2.5	2.5	1.6	2.8	1.7	2.6	–	3.3	2.6	1.0	3.8	3.1
Leaf blast	HR	HR	HR	HR	R	R	HR	R	–	HR	HR	HS	R	HR
Neck blast	MR	MS	MR	MR	S	MS	MR	MS	–	MR	MR	HS	MS	MS
Brown spot	S	S	MS	S	MS	HS	MR	S	–	MR	S	S	S	S
Leaf scald	S	S	MS	MS	S	S	S	HS	–	S	MS	HS	S	S
							Ikenne, Nigeria							
Duration (days)	106	108	105	122	106	109	104	142	103	112	114	116	109	103
Yield (t/ha)	4.3	4.4	4.3	3.6	3.6	3.9	3.6	2.6	2.2	4.6	3.8	1.8	4.7	3.8
Leaf blast	HR	HR	HR	MR	MR	S	MR	MR	MS	MR	HR	HS	MR	MR
Neck blast	HR	HR	R	MR	MR	MS	R	R	S	R	MR	MS	R	R
Brown spot	HR	HR	MR	R	MR	MR	MR	MR	HS	HR	R	S	HR	MR

Rokupr, Sierra Leone														
Duration (days)	98	99	96	116	121	103	92	136	96	111	114	129	106	103
Yield (t/ha)	0.9	1.2	1.2	1.3	1.3	1.4	0.8	1.5	0.6	1.3	1.4	0.7	1.5	0.9
Leaf blast	MS	MR	MR	MS	MR	MR	MR	MS	MS	MR	MS	MS	MS	MR
Neck blast	MR	MR	MR	R	MR	MR	MR	S	MS	MR	MR	MR	MR	MR
Brown spot	MS	MR	MR	MS	MS	MR	MS	MS	S	MS	MS	S	MS	MS
Leaf scald	MS	S	S	S	MS	MS	MS	S	MS	MS	MS	MS	MR	MS
Sotouboua, Togo														
Duration (days)	99	99	96	113	98	105	92	125	90	100	110	120	105	104
Yield (t/ha)	4.1	3.8	2.5	2.1	4.0	3.5	4.0	1.3	3.2	3.6	3.1	0.3	4.8	4.5
Leaf blast	S	MS	S	MS	MS	MS	R	MR	MS	HR	S	HS	MR	S
Neck blast	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
Brown spot	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
Leaf scald	HR	HR	HR	SR	HR	HR	HR	MR	HR	HR	HR	HR	MR	HR
Farakoba, Upper Volta														
Duration (days)	93	95	94	122	94	96	86	134	90	104	105	136	99	95
Yield (t/ha)	5.4	5.0	5.6	3.0	4.8	4.5	5.2	1.0	1.3	3.9	3.7	0.4	5.1	4.9
Leaf blast	HR	HR	HR	HR	HR	HR	HR	HR	R	HR	HR	R	HR	HR
Neck blast	HR	HR	HR	HR	R	HR	HR	R	S	HR	HR	MR	MS	HR
Leaf scald	HR	HR	HR	HR	HR	HR	HR	R	HR	HR	HR	R	HR	HR

[a]No data were available for leaf scald in Nigeria and brown spot in Upper Volta. A = IRAT144, B = IRAT109, C = IRAT133, D = ROK16, E = DJ8-341, F = ITA11.7, G = IRAT1.12, H = CR10.15, I = DHARIAL, J = M55, K = TOX502-13-SL, L = IR2922-2-2-41, M = DJ12-539-2, and N = IRAT110.

The following varieties, with yields, were resistant to Bl, BS, NBl, and LSc: IRAT144 (2.7 t/ha, Bouaké; 3.1 t/ha, Farakoba), IRAT142 (2.4 t/ha, Bouaké; 3.1 t/ha, Farakoba), IRAT109 (2.7 t/ha, Bouaké; 4.4 t/ha, Farakoba), and IRAT133 (2.6 t/ha, Bouaké; 3.7 t/ha, Farakoba).

In the moist upland, medium-duration rice variety trial (Table 4), most varieties showed varying levels of Bl, NBl, BS, and LSc resistance, depending on location. IRAT170 had resistance to all four diseases. IRAT132, IRAT138, ITA116, C22, and other varieties were more vulnerable in Suakoko (Liberia) and Rokupr (Sierra Leone) than at other locations. Yields varied from 0.2 t/ha (COL 38) at Suakoko and Rokupr to 4.7 t/ha (DJ11-50.9) at IITA. In this trial, disease incidence was generally very high and yield was low.

The four major diseases were common at all short-duration moist upland trials sites (Table 5). Varieties were more prone to infection at Suakoko and Rokupr. Yields in this zone were low, but IRAT144 was moderately susceptible to highly resistant to the diseases at the various locations. IRAT144 yield ranged from 0.9 t/ha in Rokupr to 4.3 t/ha in Ikenne, Nigeria, indicating that it can adapt to moist and savanna ecologies.

DISEASE MANAGEMENT

In addition to screening for disease-resistant varieties, an upland rice program must develop disease control measures. Disease management within the program should include

1. Surveillance and forecasting projects. It is necessary to:
   a. develop expertise in identifying rice diseases,
   b. conduct systematic surveys of major and minor rice diseases and their seasonal occurrence and distribution, and
   c. develop appropriate sampling techniques.
2. Crop loss assessment. It is necessary to have reliable data on crop losses attributable to each upland disease. These data are lacking in many countries. It is necessary to:
   a. determine research requirements to establish realistic economic losses for major (potential) upland rice diseases, and
   b. assess crop loss in relation to different degrees of severity of major rice diseases in the system.
3. Pesticide management. Although pesticide management is expensive and hazardous, it is a necessary standby during an unexpected disease outbreak. Efforts should be made to:

a. identify fungicides and antibiotics effective against major rice diseases,
b. investigate various dosages and application frequencies for selective fungicides and antibiotics for disease control, and
c. determine application techniques (foliar, spray, broadcasting, slurry, etc.) that will not pollute the immediate environment.

4. Horizontal and multiple resistance. Because horizontal and multiple resistance are the most feasible and economic means of disease control, more work needs to be done to:
   a. develop screening techniques for determining varietal resistance to major diseases;
   b. determine the existing race patterns of major diseases, identify sources of resistance to these races, and collaborate with IRRI on international rice disease nurseries;
   c. determine sources of vertical, horizontal, and multiple resistance to major diseases from locally collected and introduced rice varieties; and
   d. coordinate findings and cooperate with the rice breeder to develop varieties with high, stable, and broad-spectrum resistance to major diseases.

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ADAPTING COOPERATIVE RESEARCH PROGRAMS TO NEW STRATEGIES FOR RICE BLAST RESISTANCE

J. L. NOTTEGHEM

In Japan 70 years ago, researchers began work to create blast (B1)-resistant rice varieties (Toriyama 1972). After several failures, rice research centers planned two kinds of strategies to use resistant varieties.

The first proposes to manage vertical genes, a specific, qualitative resistance sometimes called true resistance (Kiyosawa 1967). Crill (1981) discussed this resistance during a previous workshop on B1 and upland rice, organized in Brazil by the International Rice Research Institute and the Empresa Brasileira de Pesquisa Agropecuaria.

The second strategy uses horizontal resistance, called general, slow blasting (Ahn 1981), or field resistance (Kiyosawa 1967). Ahn (1981) and Notteghem (1981) examined this second type of resistance.

This separation applies very well to certain host-parasite combinations but not as well to others. In the case of B1, it is a reality experienced daily by breeders and plant pathologists. There are numerous examples of completely resistant varieties that were destroyed by B1 a few months or years later. Scientists also observe much quantitative resistance, expressed by different levels of varietal resistance. On this basis, we must revise cooperative programs.

THE INTERNATIONAL RICE BLAST NURSERY (IRBN) TEST

All plant pathologists and breeders who deal with resistance to blast know the IRBN test which was perfected by Ou (1963). The method is successful because one can obtain a strong blast epidemic and screen a large number of varieties.

The varieties in the IRBN nursery undergo a heavy attack of exogenous spores, and the resistant varieties are easily distinguished. The IRBN network is an efficient tool for revealing vertical resistance genes.

In 1979, the results of the IRBN show that none of the varieties tested is resistant in more than 26 of the 28 experimental locations. This means that 8% of the locations have virulent strains for all genes or

DCV-IDESSA, Bouaké, Ivory Coast.

gene combinations for vertical resistance. This is true even though the varieties are only sown on a 0.8-m row. The conclusion is that no strong vertical gene exists among the varieties already tested. Given the large size of the sample already screened, one wonders if such genes exist.

On a national scale, the IRBN test is not very useful because it is carried out in few locations, usually one, five at most (India). Thus, it does not test varieties against a representative sample of the country's strains.

To use the IRBN network to find the strongest vertical genes, we must:

- introduce a larger number of varieties that have never been tested,
- test varieties whose resistant genes have been identifled by genetic analyses,
- increase the number of locations for testing varieties with resistance genes,
- avoid weighing down the experimentation with many sibling lines that have probably inherited the same vertical resistance genotype, and
- isolate susceptible strains with vertical genes and verify by greenhouse inoculations that the damage is from a virulent strain and not from adverse environmental conditions.

In its present form, the IRBN test cannot evaluate the quality of horizontal-resistance varieties. In fact, these varieties slow down the B1 epidemic, until it does not affect the yield. However, in the IRBN, the epidemic develops rapidly in susceptible varieties and numerous spores severely attack varieties with horizontal resistance. Therefore, sufficiently resistant varieties among the crops of the Ivory Coast -- IRAT13, IRAT10, etc. -- have been eliminated from IRBN tests.

Often scientists identify a strain as more pathogenic, when it is only the environment that favors B1. It would be interesting to test a series of check samples at IRBN with vertical resistance and different levels of horizontal resistance. We would then have more precise experimental conditions for a more detailed analysis of the results.

COOPERATIVE EXPERIMENTATION ON HORIZONTAL RESISTANCE

IRRI began tests in 1981 after the B1 and upland rice workshop in Brazil and the rice B1 symposium in Montpellier. The experiments are examining effectiveness of resistance and verifying that tested varieties are classified in the same order despite environmental conditions or the parasite strain. As yet, there are no conclusions from this trial.

This approach is very important for it is the first experimentation to tell if the general resistance to Bl is stable. This program should continue, perhaps after simplifying experimental procedures.

THE CREATION OF A CENTER

One of the recommendations of the March 1981 Rice Blast Symposium was to create an experiment center to collect *Pyricularia oryzae* strains from all geographical origins. This center would study conditions that lead to successful Bl control by using resistant varieties.

Vertical resistance

By collecting strains, we can obtain genes for vertical resistance from the virulent and avirulent strains. By inoculating a series of these pathogens into varieties of known resistance and then inoculating the same pathogens into varieties of unknown resistance, we can then compare the two reactions. This will give us a clue to their resistance more quickly than by genetic analysis.

Scientists may test varieties they suspect have a strong gene or for their resistance qualities before recommending them for a region.

Horizontal resistance

The use of horizontal resistance poses some questions. Is horizontal resistance effective regardless of strain? Will it be stable with time?

Horizontal resistance stability is possible according to Van der Plank (1968). But according to Parlevliet and Zadoks (1977), with increasing aggressiveness, the fungus can adapt to different situations. This could happen with Bl. Thus, it is important to see if widespread use of a variety is accompanied by an increase of aggressiveness of the pathogen.

Two work methods are possible. When researchers want to promote a variety possessing strong horizontal resistance, it is possible to sample Bl strains and set them aside. Their pathogenicity could then be compared with that of strains which later develop on the same variety.

A quicker technique is to compare the pathogenicity of a sample of strains from a region which uses a variety with horizontal resistance with strains from other regions without this variety.

Varieties behave differently in different countries. For example, the EMBRAPA station in Goiania, Brazil, considers IAC25 susceptible, but it suffers very few losses in the Ivory Coast. By comparing Bl strains from Brazil and the Ivory Coast, we could see

if they differ in their pathogenicity, or if IAC25 susceptibility in Brazil is caused by a more favorable environinent for the disease.

Such studies could help estimate the environmental influence on horizontal resistance.

CONCLUSION

After varieties with nonidentified vertical resistance and varieties with vertical resistance genes failed, new resistance strategies provide some hope. We only possess partial experimental confirmation for using these strategies with B1. We still need to test these strategies for long-term protection. It is important to reorient research and reinforce cooperative programs.

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INSECT PESTS OF UPLAND RICE IN AFRICA

E. A. AKINSOLA

Insects are a major rice problem. They attack all plant parts and growth stages of rice. Climate influences insect bionomics and population size over several generations. Rainfall, relative humidity, and temperature are important factors that substantially influence insects within the rice ecosystem. Because upland rice is grown under varying vegetational and climatic conditions insect occurrence and abundance vary.

DISTRIBUTION OF INSECTS

Certain insect pests prefer one ecosystem to another. Aquatic insects such as the caseworm Nymphula depunctalis that harm irrigated rice are not found on upland rice. Stalk-eyed flies Diopsis sp. are numerous where there is high humidity. Although they are found on upland rice, they are more abundant on irrigated and lowland rice. The same is true for gall midge Orseolia oryzae . Armyworms Spodoptera sp. usually attack upland rice. When they occur on irrigated and lowland rice, they are normally confined to the border areas because larvae are unable to swim and die in flooded fields. Soil insects such as mole cricket Gryllotalpa africana and termites Macrotermes sp. attack upland rice:

Most major insect pests of irrigated and lowland rice also attack upland rice, but their seasonal and relative abundance vary. Stem borers are the most important insect pests of rice in Africa. They belong to two insect orders, Lepidoptera and Diptera. The major species are Maliarpha separatella Rag., Chilo zacconius Bles., Chilo diffusilineus (J. de Joannis), Chilo partellus (Swinhoie), Scirpophaga subumbrosa Meyr., Sesamia calamistis , Hamps, Sesamia botanephaga Hamps (Lepidoptera); Diopsis thoracica Westw and Diopsis apicalis Dalm (Diptera). Some borers are oligophagous, and Sesamia sp. are found more abundantly on upland rice, especially on rice planted near maize which appears to be the preferred host plant. Table 1 shows insect pest occurrence in different ecosystems.

Entomologist, West Africa Rice Development Association, P. O. Box 1019. Monrovia, Liberia.

Table 1. Relative occurrence[a] of major insect pests in rice ecosystems in Africa.

Insect	Upland	Lowland	Irrigated
Maliarpha separatella	X	XX	XX
Chilo zacconius	X	XX	XX
Chilo diffusilineus	XX	X	X
Chilo partellus	XX	X	X
Scirpophaga sp.	X	XX	XX
Sesamia sp.	XX	X	X
Diopsis sp.	X	XX	XX
Nymphula depunctalis	–	XX	XX
Orseolia oryzae	–	XX	XX
Nephotettix sp.	X	XX	XX
Epilachna similis	XX	X	X
Spodoptera sp.	XX	X	X
Gryllotalpa africana	XX	–	–
Aphids	X	–	–
Termites	XX	–	–

[a] X = present but not abundant, XX = abundant, – = not observed.

YIELD LOSSES

Data on upland rice yield losses caused by insect pests are not readily available, but existing general information shows that insect damage is a serious problem especially as potential upland rice yields are lower than those of other rice systems. In Ivory Coast about 1 t/ha or 25% of production is lost to insects (Bremiere 1969). In Djibelor, Senegal, insecticide application increased yield by 25% (Veracambre 1977). About 30% of irrigated rice yield is lost to insects in Ghana (Agyen-Sampong 1977), and in Nigeria yield losses range from 25 to 30%. Estimates of upland rice yield losses to insect pests on upland rice in Africa range from 14.4% (Cramer 1967) to 30%. Implementation of an effective insect control strategy for the vast upland rice areas of Africa would raise productivity substantially.

RESEARCH ON INSECT PESTS

More information is available about irrigated and lowland rice ecosystems because they have received research priority and because rice research institutes are often located in irrigated, lowland areas. A few countries, however, have developed comprehensive research programs on upland rice insects.

The insect research program in Ivory Coast involves screening for varietal resistance to the major pests, and biological and integrated pest control (Goli 1981). Several hundred rice varieties have been screened, of which Moroberekan, Madeba D, OS6,

Kototouro S7, and S1 show stem borer resistance (Monnet 1979a).

Sophisticated, expensive insect control methods are impractical for present-day African upland rice farmers. Therefore the program emppasizes host plant resistance. Developing artificial mass-rearing techniques for stem parers has speeded varietal resistance studies at Bouaké.

Cochereau (1978) observed that Sesamia calamistis was the most important stem borer on upland rice at Man, Ivory Coast; it accounted for 46% whiteheads and 64%. of borer papulation. Maliarpha separatella, an important irrigated rice pest, infested 39% stems and represented 25% of the borer population. Sesamia is the principal stem borer on upland rice in the west, central, and southwest regions of Ivory Coast (Monnet 1979b). Major pests are Diopsis and Sesamia before flowering, and Sesamia and Maliarpha, after (Monnet 1979b). Biological control studies were initiated fairly recently and a number of egg and larval parasites of stem borers have been identified. Studies on effects of chemical application on natural enemies and preliminary investigations into the introduction of exotic natural enemies have been initiated.

In Nigeria, surveys determined major upland rice pests. Stem borers are the principal pests. Maliarpha separatella, Chilo zacconius, and Sesamia calamistis are widely distributed (Obasola et al 1981). Chilo is dominant in the uppermost savannas. Maliarpha attacks upland fice in rain forest zones. Nineteen termite species harm upland rice, Macropterus sp. was the most common and destructive. Armyworms Spodoptera exempta and the ladybird beetle Apilachna similis also are important pests.

Studies have also been conducted on varietal resistance to stem borers. Among several hundred varieties and lines screened, IR1108-3-5-5-2, ARO 16, SML 140/5 x IR8, SML 140/10 x IR8, and SML 140/10 x TN1 are promising (Akinsola 1979). Other studies have evaluated chemical control methods and identified natural enemies of insects.

In Sierra Leone stem borers, mainly Chilo and Maliarpha, and armyworms are major problems on upland rice. Two aphids, Hysteroneura setariae (Thos.) and Tetraneura nigriabdominalis (Sasaki), and some termites, notably Pericapritermes socialis (Sjost), harm upland rice (Akibo-Betts and Raymundo 1980).

In Kenya, major upland insects are stem borers M. separatella and S. calamistis, leaf miner Trichispa sericea, and termite Macrotermes sp. (Malinga 1982 pers. comm.). Several rice varieties and lines have been screened for resistance to stem borers. Results indicate that RP967-11-1-2 and RP967-24-5-6 have field resistance to M. separatella and S. calamistis.

WARDA'S INSECT PEST PROGRAM

From 1974 to 1979 WARDA conducted regionally coordinated insecticide trials to identify effective chemicals for controlling insect pests for all West African rice ecosystems.

WARDA also sponsored seminars and training courses to discuss insect problems of rice in West Africa. Seminars were held in May 1973 in Monrovia, Liberia, and in Bobo-Dioulasso, Upper Volta, in September 1979. In January 1982, WARDA hosted a 3-week training course on integrated pest management for rice in West Africa cosponsored with the Consortium for International Crop Protection, University of California, Berkeley.

CONCLUSION

Little is known about insect pests of upland rice in Africa. Because the upland ecosystem is vast and important more research should study insect pest problems. Experience has shown that pest outbreaks intensify with improved rice cultivation. Adequate plant protection from insects must be incorporated as an important component of any upland rice improvement program. Entomological studies at the Upland Rice Special Research Project probably will follow the example of older centers while also studying the peculiar problems of upland rice, such as the effect of cropping systems on insect pest occurrence.

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STEM BORER INCIDENCE IN RICE ECOSYSTEMS IN KENYA, EAST AFRICA

DANG THANH HO

Irrigated rice is grown on about 7,000 ha in Kenya (Munyua 1978). Hectarage of upland rainfed flooded and lowland swamp rice is unknown. The demand for rice in Kenya and other East African countries is increasing each year, but large areas of potential rice land cannot be exploited because of technical and economic constraints (Buddenhagen and Persley 1978).

Insect damage is a major problem in large irrigated rice areas, but is minor in small upland rice areas (Soto and Siddigi 1978). Yellow mottle virus disease is common in irrigated areas and fungal diseases such as leaf blight, grain discoloration, and neck blast are more common in upland rainfed rice. Upland rice is grown with low-level technology and yields are low.

Stem borers are important in rice insect pests, but actual crop losses to them are undetermined. Other rice insects reported to cause damage include leaf feeding beetles, mainly Trichispa sp., and Dicladispa sp.; casewom; and several species of plant bugs (Stenocoris sp., Aspavia sp.) that feed on developing grains. Caseworm is becoming more important in irrigated rice (WARDA 1981).

Four stem borers are recorded on rice in Kenya: Diopsis spp. (Diopsidae, Diptera), composed mainly of D. thoracica and smaller populations of D. apicalis; Chilo partellus Swin Pyralidae, Lepidoptera); Maliarpha separatella Rag (Pyralidae, Lepidoptera); and Sesamia calamistis (Noctuidae, Lepidoptera). The sugarcane borer Eldana saccharina Walk infrequently infests upland rice (Breniere 1976). Distribution of rice stem borers and other insect pests varies by rice-growing environment. Different levels of crop management and water availability substantially affect insect adaptability.

Research to determine stem borer incidence and damage in various rice ecosystems was initiated at the ICIPE in 1981. This paper reports results of surveys

International Centre for Insect Physiology and Ecology, P. O. BOX 30772, Nairobi, Kenya.

and experiments on upland rainfed and lowland irrigated rice ecosystems.

RICE ECOSYSTEMS IN KENYA

A survey of rice cultivation in Kenya showed that, in some parts of the country, rice is a newly introduced crop and farmers in rice production are fewer than those involved in other crops such as sorghum, maize, millet, or sugarcane. Rice cultivation in Kenya is confined to four ecosystems: lowland irrigated, upland rainfed, swampy lowland, and flooded swamp.

Lowland irrigated rice is grown where irrigation water is permanently available through pumps or gravity flow. Average rice farm size is 0.8 to 1.6 ha. Lowland irrigated rice is the best managed of all rice ecosystems. Fertilizer and pesticides sometimes applied to it would never be used for upland rainfed or swampy lowland rice. Rice farmers in irrigated areas are financially supported by the government. They have more rice production knowledge than farmers cultivating upland or swamp rice because research and extension workers devote more effort to irrigated areas than to individual upland or swamp rice farms.

Upland rainfed, swampy lowland, and flooded swamp rice are cultivated mainly by substandard farmers. Little research has been conducted on upland rice and none on swampy lowland and flooded swamp rice. Swampy lowland rice is grown in marginal swamplands or lake areas in western Kenya. Tall rice varieties are grown in valley bottoms and flooded swamp with standing water at 30 cm deep. Total upland rainfed, swampy lowland, and flooded swamp rice area is smaller than that planted to irrigated lowland rice. The average upland rainfed rice farmer farms 0.4 to 0.8 ha. Irrigated rice yields average 5.6 t/ha, which is the highest in tropical Africa, and substantially higher than yields of other Kenyan ecosystems (Munyua 1978). Average upland rainfed rice yield is 1.2 t/ha, which can be increased if crop management is improved.

In Kenya, upland rainfed rice can be grown where annual rainfall is more than 900 mm and at 1,500 m altitudes (Appendix 1). Rice is grown during the major rainy season when the 6-month consecutive rainfall is higher than 500 mm.

SURVEY OF RICE STEM BORERS

A rice insect survey in western, central, and coastal provinces of Kenya in August 1981 and July 1982 determined the incidence of stem borer and other insects in various rice ecosystems. Four sites were surveyed in

the western province, two in the central, and three in the coastal. Rice stalks from 20 random hills each of various growth stages were dissected at each location. Infestation was recorded as percent hills infested and percent tillers infested. Species composition and average number of larvae or pupae recovered per hill were recorded.

Stem borer infestation of irrigated lowland rice in Ahero and Mwea is shown in Table 1. C. partellus was absent during the survey. The most common borer was the white borer M. separatella. Stalk-eyed borer Diopsis spp. occurred more frequently than the pink borer S. calamistis. Tillers produced from stubble after harvest were infested with M. separatella and Diopsis spp. This carry-over stem borer population could be eliminated by destroying crop residue. M. separatella was found at all crop growth stages and Diopsis was found only during early vegetative stage.

Stem borer infestation in upland rainfed rice is shown in Table 2. In locations where rice had been planted for only 1 or 2 years in Mayenje and Tanga Kano (western provinces) or Mazeras (coastal province), M. separatella was not found, which indicates that alternative host plants (if any are available) and rice crop residue are important to population buildups of this insect. In West Africa, an alternative host plant for M. separatella is Andropogon tectorum (WARDA 1977). In Punjab, India, M. separatella has infested sorghum (Sandhu and Ramesh Chandler 1975). In Kenya, however, alternative host plants and sorghum infestation by this stem borer have not been observed.

Rice stem borer incidence in upland rice is less than in lowland irrigated rice. Percentage of infested hills in upland rice is one-half of that in lowland rice. C. partellus infestation was more frequent in upland rice than in lowland rice. In Murinduko, a small upland rice area about 20 km from a large rice area in Mwea, the upland crop was free of rice pests (Table 2). In the coastal province where rice has been grown for decades, infestations of C. partellus and S. calamistis, also major pests of sorghum and maize, were higher than in western and central provinces where rice was recently introduced.

Stem borer infestation in flooded swamp and swampy lowland rice is shown in Table 3. In swamps with 50-cm-deep water, only M. separatella was found at the lower internodes. M. separatella has also infested deep flooded rice in other areas (Akinsola 1980a). In Aniko, in a swampy lowland area where rice had been planted for only 2 seasons, M. separatella was not found and Diopsis spp. was the predominant borer.

Table 1. Stem borer infestation on rice grown in irrigated lowlands.

Year	Site[a]	Variety or sample[a]	Stage[b] (DT)	Infested hills (%)	Infested tillers (%)	No./hill[c]				Species composition[c] (%)			
						C	D	M	S	C	D	M	S
1981	Ahero, WP	IR1561-228	30	0	0	0	0	0	0	0	0	0	0
	Ahero, WP	BR51-76-4	125	90	49	0	0	5	2	0	0	86	14
1982	Ahero, WP	Unknown	40	100	16	0	.4	.4	0	0	58	42	0
1981	Mwea, CP	Basmati (R)	40	100	22	0	0	3	0	0	0	100	0
	Mwea, CP	BG-90-2 (MR)	40	100	33	0	0	4	.2	0	0	95	5
	Mwea, CP	Sindano (S)	40	100	58	0	0	7	0	0	0	100	0
1982	Mwea, CP	Basmati	PH	43	5	0	.2	.2	0	0	46	54	0
Mean				76	26	0	.1	2.8	.6	0	17	80	3

[a]R = resistant, MR = moderately resistance, S = susceptible. [b]DT = days after transplanting, PH = postharvest. [c]C = *C. partellus*, D = *Diopsis* spp., M = *M. separatella*, S = *E. calamistis.*

Table 2. Stem borer infestation on upland rainfed rice.

Year	Site[a]	Variety or sample	Stage[b]	Infested hills (%)	Infested tillers (%)	No./hill[c]				Species composition[c] (%)			
						C	D	M	S	C	D	M	S
1981	Mbita, WP	BR51-74-6	60 DS	92	25	0	0.03	0.2	0	0	12	88	0
1981	Mayenje, WP	IR1561-228	60	30	5	0	0.7	0	0	0	100	0	0
1981	Tanga Kano, WP	Sindano	H	13	1.5	0	0.1	.07	0	0	67	33	0
	Tanga Kano, WP	Unknown	H	20	3	0	0.3	0	0	0	100	0	0
1982	Murinduko, CP	Unknown	50 DS	0	0	0	0	0	0	–	–	–	–
1981	Mazeras, Co P	Unkown/S1	PH	33	5	0	0	0.2	0.6	0	0	12	88
–	Mazeras	– /S2	H	33	3	0.2	0	0	0	100	0	0	0
–	Mazeras	– /S3	90 DS	33	2	0	0	0	.2	0	0	0	100
1982	Mazeras	Mbuyu	H	40	10	1.5	0	.4	.2	60	0	30	10
–	Mazeras	Basmati	H	20	15	1.0	0	.2	.2	25	0	55	20
1982	Matuga, Co P	Unknown	100	60	15	.2	.4	.4	.2	18	30	35	17
Mean		–	–	37	8	.3	.12	.13	.14	22	30	25	23

[a]WP = western province, CP = central province, Co P = coastal province. [b]DS = days after seeding, H = harvest, PH = post-harvest. [c]C = *C. partellus,* D = *Diopsis* spp., M = *M. separatella,* S = *E. calamistis.*

Table 3. Stem borer infestation on flooded swamp and swampy lowland rice.

Year	Site[a]	Sample or variety	Stage[b]	Infested hills (%)	Infested tillers (%)	No./hill				Species composition (%)			
						C	D	M	S	C	D	M	S
				Swampy lowland									
1982	Aniko, WP	–/unknown	60 DS	53	5	0	.9	0	0	0	100	0	0
				FIooded swamp									
1981	Ramisi, Co P	S1/unknown	H	50	12	0	0	1.0	0	0	0	100	0
	Ramisi, Co P	S2/unknown	PH	62	12	0	0	.6	0	0	0	100	0
Mean		–	–	56	12	0	0	.8	0	0	0	100	0

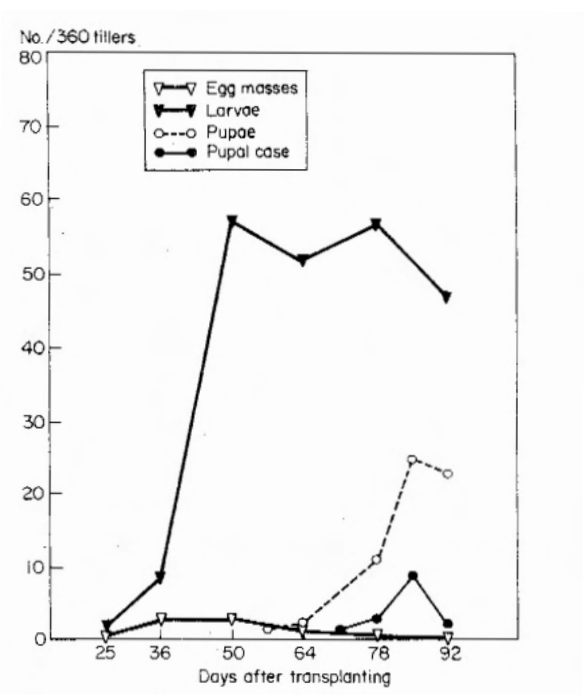
[a]WP = western province, Co P = coastal province. [b]DS = days after seeding, H = harvest, PH = postharvest. [c]C = *C. partellus,* D = *Diopsis* spp., M = *M. separatella,* S = *E. calamistis.*

POPULATION DYNAMICS OF STEM BORERS

M. separatella population dynamics was studied during the short rainy season (Jul to Nov) 1981 at Mbita Point Field Station (MPFS), ICIPE. Twenty-one-day-old seedlings were transplanted in 10- x 20-cm spacing. Plants were sampled at 2-week intervals beginning 3 weeks after transplanting. Individual tillers were dissected and the number of immature M. separatella was recorded. M. separatella life cycle is 50 to 70 days in the field. Larval population increased from 20 days after transplanting (DT) to 50 DT, reaching its peak at about 40 DT and fluctuated slightly until harvest (Fig. 1).

Upland rainfed and lowland irrigated rice trials were conducted simultaneously in the 1982 long rainy season (Mar to Jul). The upland trial was conducted at MPFS where 0.2 ha was planted to rice. The field station also grows crops such as sorghum, maize, and cowpea. The upland trial simulated upland rice growing by subsistence farmers in Kenya. The lowland irrigated trial was in the Ahero irrigation project where irrigated lowland rice is grown in about 1,200 ha.

IR1561-228-3-3 was planted in the lowland trial and Sindano in the upland. Upland rice was seeded when the rain started. Seeds were sown in rows 20 cm apart at 20-cm spacing. Supplemental irrigation with sprink-



1. Population dynamics of *Maliarpha separatella* over the rice crop's growth cycle.

favored as favored production. The unfavored category is reported separately. Estimated production statistics for 1980 are given in Table 1. The data exclude the temperate irrigated rice production areas in Chile, Argentina, and Uruguay. Data in Appendix 1 give production statistics by country for upland rice in tropical Latin America.

Of the estimated 14.4 million tons of rough rice produced in tropical Latin America in 1980, 7.6 million tons or 53% was produced under upland conditions. Upland rice was grown on 6.14 million hectares -- 76% of the total rice area sown. Favored upland production systems represent 25% of the rice area and 24% of production. Unfavored upland, 51% of the rice area, produced 29% of the crop.

Average yield for the upland systems contrasts sharply with that of irrigated systems. Favored upland systems yielded an average 1.72 t/ha in 1980. Unfavored systems averaged 1.00 t/ha. Estimated average national yields or favored upland systems vary from 1.1 to 3.5 t/ha between countries, reflecting a wide variation in production conditions and constraints. About 94% of the unfavored upland rice was grown in Brazil, where large annual fluctuations in productivity and production occur.

Figure 1 shows upland production systems in Latin America, based on municipal-level census data. Upland areas in Mexico are in the southeast and on the Yucatan Peninsula. Upland rice is planted throughout Central America except in Nicaragua, where irrigated production predominates. Most rice in the Caribbean, including Surinam and Guyana, is produced with irrigation.

Irrigated and upland systems occur side by side in many Andean countries. These countries are benefiting most from technical advances in irrigated rice research that can also be used in favored upland areas. Most rice in Bolivia is grown under upland culture.

Table 1. Estimated production of principal rice systems in tropical Latin America and the Caribbean, 1980 (FAO 1980, USDA 1980, CIAT-IRRI 1979).

Principal system	Area		Production		yield
	thousand ha	%	thousand t	%	(tlha)
Irrigated	1,902	24	6,837	47	3.59
Favored upland[a]	2,020	25	3,478	24	1.72
Unfavored upland	4,129	51	4,129	29	1.00
Total	8,051	100	14,444	100	1.79

[a]Proportion of favored and unfavored uplands provisionally estimated from data provided by IRTP conference participants.

1. Irrigated and upland rice regions of Latin America.

PHYSICAL ENVIRONMENT

Upland rice is grown in a range of environments as wide as or wider than for many other crops. A quantitative agroecological study of upland rice growing areas in Latin America is now underway that will characterize and classify environments by present crop status and develop a base that can be used to estimate the future potential of each environmental area. Soils, landscape, climate, and agronomic conditions are being defined for

microregions -- relatively small production areas with uniform production conditions and municipal-level statistical subdivisions. Until these studies are complete, the working classification of favored upland, moderately favored upland, and unfavored upland is being used.

In this paper, representative locations for each working classification have been selected for discussion to illustrate the range of conditions and to point out certain problems related to developing a quantitative classification of rice environments for the region.

Available production and census data were used to locate the rice near relevant land systems (Cochrane et al 1983). This approximation to the land system is somewhat inaccurate because the scale of survey data must be at least 1:1 million and soil survey data are generally not available at this level. Satellite imagery was used to locate the major cultivated areas. Terrain and soil at each sample area were described and the relevant meteorological station identified. Table 2 lists the sample locations and selected environmental descriptors.

Soils at favored upland sites are generally deep and heavy textured, with a high base status and moderately high fertility. Moisture-holding potential. is generally high and hydromorphic features are present, and access to a water table within 50 cm is common.

Eutric Fluvisols and Mollic Gleysols are present at some moderately favored sites and sometimes are associated with Cambisols and Kastanozems. Most soils at moderately favored sites have high fertility and base status, good working properties, and are not inferior to soils at favored sites. Vitric Andosols in Panama have a deep profile but are quite acidic and have low fertility.

Some unfavored sites in Brazil are on deep, Loamy, well-drained Acric Ferralsols. In most areas they are highly acid and infertile with high aluminum saturation (>70%), although at Goiania, areas of relatively low aluminum saturation do occur. Phosphorus is often low and available soil water is limited because of restricted root development in the highly acid subsoil. Many sites are on level or gently rolling terrain with slopes generally less than 8%, which can encourage mechanized cultivation.

No one set of conditions uniquely classifies sites as favored upland. Although there are more good soils at the favored end of the upland spectrum, hospitable climate is also essential. On the other hand, there is a definite tendency toward low fertility and highly acid soils in unfavored rice situations. Another difficulty encountered in classifying rice environments is

Table 2. Environmental characteristics of 8 locations representing typical sites in each of 3 upland rice production systems in Latin America (USDA 1975, FAO-UNESCO 1974).

Site	Country	Mean annual rainfall (mm)	Mean growing temperature (°C)	Principal soil type classification		Base status	Al toxicity	Water (mm)
				USDA	FAO			
Favored upland								
Villavicencio	Colombia	4096	25.6	Tropquept	Eutric gleysol	Mod.	Mod.	150
Uraba	Colombia	4805	25.9	Tropofluvent	Eutric fluvisol	High	Low	250
Puerto Cortes	Costa Rica	4809	26.7	Hapludoll	Mollic gleysol	High	Low	250
Moderately favored upland								
Juquilisco	El Salvador	1842	26.3	Trop ofluvent	Eutric fluvial	High	Low	200
Liberia	Costa Rica	1887	28.2	Pellustert	Mollic gleysol	High	Low	200
David	Panama	2364	26.9	Vitrandept	Vibic andosol	Low	High	150
Un favored upland								
Campina Verde	Brazil	1489	23.3	Haplorthox	Acric ferralsol	Low	High	75
Goiania	Brazil	1399	23.1	Haplorthox	Acric ferralsol	Low	High	75

Table 3. Range of agroclimatic parameters for typical selected upland sites (see also Table 2).

Growing season	Favored	Moderately favored	Unfavored
Length[a] (days)	287 -365	154 -210	154 -182
Mean temperature (°C)	25.6- 26.7	26.3- 28.0	22.1- 23.3
Mean E_t^b (mm/day)	3.8- 4.8	4.4- 5.9	5.2- 5.8
Radiation (MJ/m^2 per day)	15.9- 19.3	19.6- 21.0	20.5- 21.6

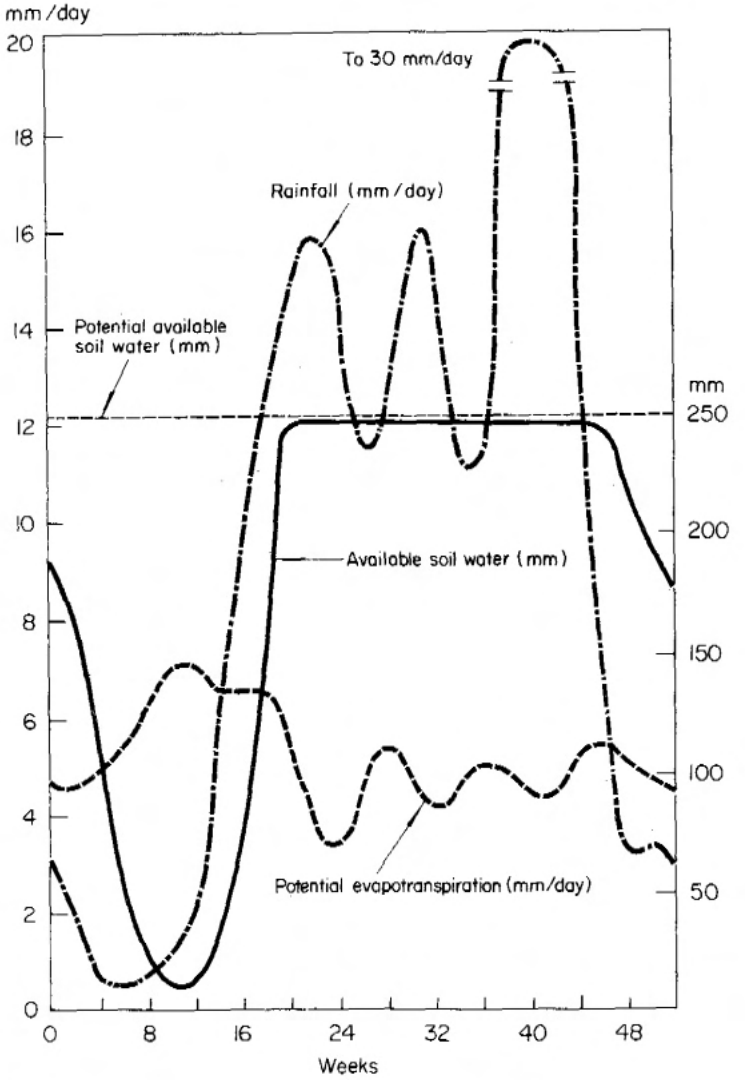
[a] Length of growing season calculated from estimated daily soil water budgets as the number of contiguous days when available soil water is greater than 0.33 of potential available. [b] Potential evapotranspiration.

illustrated by an analysis of data of crop climate for these locations.

Table 3 gives the range of climatic parameters for the selected upland conditions. Growing season length is based on crop water balance evaluations using estimated mean weekly data for rainfall and potential evaporation. All locations have adequate growing season length (minimum 154 contiguous days when available soil water is greater than 1/3 of soil water-holding capacity under mean climatic conditions). Temperature and radiation are also adequate for rice at all locations. Although mean growing season rainfall decreases from favored to unfavored sites (Table 2), calculations of water balances, using long-term mean rainfall, suggest that water supply is greater than potential evapotranspiration, even at unfavored sites (Fig. 2, 3, 4). However, rainfall varies substantially at the lower rainfall sites, increasing the probability of stress during the growing season.

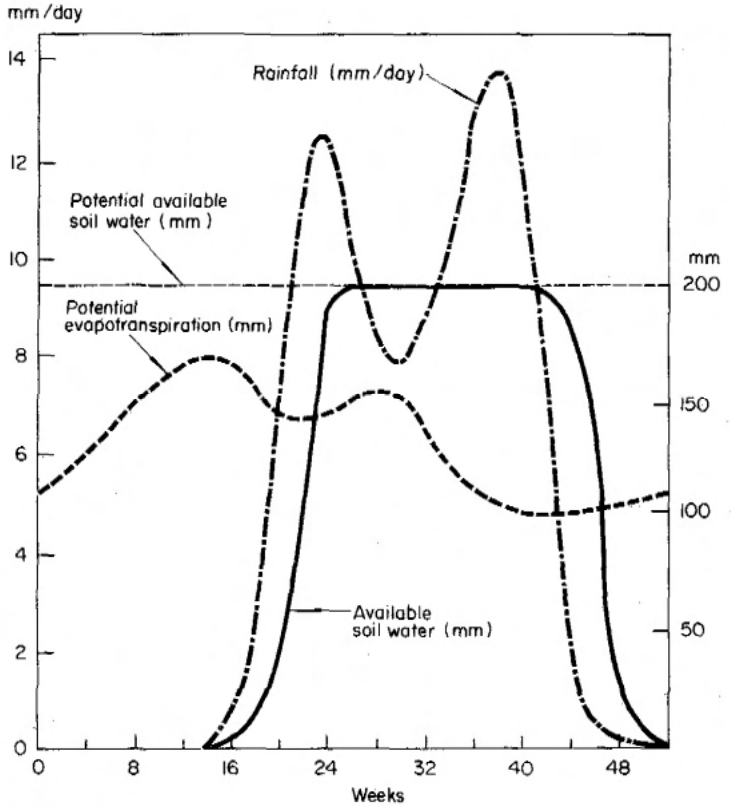
To determine the possible effects of variation (reduction) in growing season rainfall, soil moisture budgets were calculated at each location using a hypthetical l/month midseason dry spell during which only 50% of normal rainfall was received. The reduction in growing season days was calculated as the number of days when available soil moisture was less than l/3 of soil water holding capacity plus the unusable part af the season caused by a short growth cycle. The results of this exercise (Table 4) clearly distinguish the unfavored locations.

Mild stress days induced by reduced rainfall were defined as those days with soil water between 1/3 and 2/3 of water-holding capacity. At favored sites no mild stress days were encountered with a simulated 50% rainfall reduction. Almost all moderately favored sites were predicted to have several mild stress days. Stress was predicted to be quite severe at the unfavored sites. The probability of a 50% reduction in monthly rainfall increases from favored sites to unfavored sites.



2. Representative precipitation, evapotranspiration, and daily soil water balance for a favored upland area, Palmar Sur Meteorological Station, Costa Rica.

Columns three and four in Table 4 show an alternate example of relative stress susceptibility across these environments. The days-to-stressparameter was calculated as the number of rainless days required at full potential evapotranspiration (E_t), to reduce the soil water to 1/3 of potential available water. The fourth column is a subjective estimate of the probability of a dry spell of this duration occurring. There is marked difference between unfavored sites that have an estimated 9 days-to-stressand favored sites that have

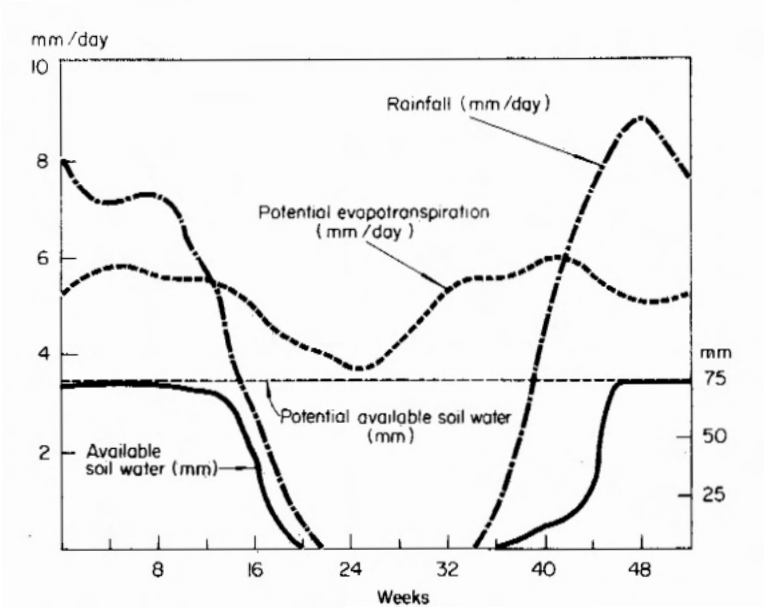


3. Representative precipitation, evapotranspiration, and daily soil water balance for a moderately favored area, Usulatan Station.

more than 20 days-to-stress. Climate-soil interactions at unfavored locations make it highly likely that they will experience variable midseason water stresses. Average district yields obtained at the locations (Table 4) are a good reflection of the various stress estimates derived from the water balance studies.

These climate data and the demonstration of effects of reduced midseason rainfall indicate it is not possible to derive a useful quantitative classification of upland rice environments in Latin America based only on soil quality characteristics and estimates of growing season length under mean conditions. It is equally difficult to estimate relative suitability of different microregions using these parameters alone. Without rainfall variability data further progress toward a quantitative classification of rice environments in the region cannot be completed. Data collection that will allow an analysis of all these factors is now proceeding.

Rooting depth of upland rice in relation to climate is of particular importance in the analysis. At



4. Representative precipitation, evapotranspiration, and daily soil water balance for an unfavored upland area, Goiania Meteorological Station, Brazil.

Table 4. Effects of rainfall variability (simulated 50% midseason rainfall reduction for 1 month) at selected upland rice sites.

	Reduced GSD[a]	Mild stress day[b]	Days to stress[c]	Probability of dry period[d]	Yield[e] (t/ha)
Favored upland					
Site 1	0	0	23	Highly unlikely	4.50
Site 2	0	0	39	Nil	4.40
Site 3	0	0	34	Nil	3.50
Moderately favored upland					
Site 1	0-35	28-35	22	Possible	3.00 I
Site 2	0	21-35	26	Possible	1.92 C
Site 3	0	0-14	22	Unlikely	2.59 C
Unfavored upland					
Site 1	98	14	9	Highly likely	1.10 C
Site 2	64-98	14	9	Highly likely	1.20 C

[a] Reduction in growing season days (GSD) (days with available soil moisture greater than 1/3 soil moisture holding potential) due to one midseason month with 50% of normal mean rainfall. [b] Mild stress days are days with soil water availability between 2/3 and 1/3 capacity, as induced by reduction in rainfall by 50% for 1 month. [c] Days of growth available before 2/3 of available soil water is exhausted if no rain falls as in footnote 1. [d] Subjective estimate of the probability of a dry spell as least as long as the figure in the preceding column. [e] From census data where availabe (C) or from CIAT estimates from informed sources (I); yield estimates not including traditional subsistence areas.

drier locations, the inability of rice roots to penetrate subsoils with a high level of aluminum saturation is a serious production constraint and is partly responsible for the lower yields and high yield variability in unfavored rice areas, particularly in Brazil,

where dry spells during the rainy season are a well-documented limitation to increased rice production.

BIOLOGICAL ENVIRONMENT

Upland rice in Latin America is severely affected by more biological constraints than irrigated rice. Physical and biological constraints lead to lower productivity and greater production instability, and often result from the absence of the modifying effects of irrigation water, which increases soil fertility by reducing soil acidity, eliminating drought stress, and partially controlling weeds.

Biological constraints vary quantitatively and qualitatively across upland ecosystems. Soils, climate, and cultural practices interact in various unusual ways to encourage complex insect, disease, and weed problems. Some of these, which are invariably more pronounced in the unfavored upland ecosystems, are described here.

Insects

Elasmopalpus lignosellus, Blissus leucopterus, and Phyllophaga spp. are widespread but sporadic insects found only in upland rice. Substantial damage by the first two often occurs when the crop undergoes prolonged drought stress during the early growth stages. They generally do not cause yield reductions in higher rainfall ecosystems. Phyllophaga (white grubs) cause losses in ricefields rich in organic matter, particularly in converted pasture areas. The Sogatodes planthopper causes direct feeding damage and is the vector of hoja blanca virus in irrigated and upland conditions. The insect is most serious in areas with high relative humidity and moderately high rainfall. Sogatodes is a particular problem in favored upland rice ecosystems in Colombia, Peru, and Venezuela.

Diseases

In Latin America drought stress and sandy soils contribute to the development of the major fungal diseases of upland rice -- blast (Bl) Pyricularia oryzae; brown spot Helminthosporium oryzae; leaf scald Rhynchosporium oryzae; and eye spot Drechslera gigantea. Drought stress makes plants susceptible, and the longer the stress period the greater the degree of leaf disease incidence. High spots in upland fields and sandy soils encourage disease. Water stress is particularly important to Bl infection, but is also a factor with the other diseases mentioned.

Crops on some soils are particularly disease prone while crops on other soils have a remarkable absence of

infection under similar climatic conditions. Ultisols and Oxisols in the savannas of South America favor leaf blast and other fungal diseases. These highly acid soils appear to contribute to disease epidemics especially when planted to upland rice. High organic matter soils are often associated with leaf diseases, especially eye spot and brown spot. Diseases are encouraged by high relative humidity, excessive nitrogen fertilization, and heavy seeding rates, particularly in favored upland areas.

Weeds

Weed control in upland rice is hampered by soil moisture conditions. Excessive moisture makes it difficult to bring ground equipment into the fields when weeds are most sensitive to herbicides. Delays in application require heavier herbicide dosages and result in less effective weed control. On the other hand, when weeds should be controlled to save water reserves, drought stress reduces herbicide effectiveness. Herbicide application must often be delayed until weeds develop past their period of greatest susceptibility.

More detailed commentary on the biological problems of upland rice cropping systems in Latin America is discussed by Martinez (1984) and Seguy (1984). In those papers the specific production constraints within each principal rice ecosystem are delineated and cultural practices are outlined.

UPLAND RICE CULTIVARS IN LATIN AMERICA

Improved short-statured materials developed by several national programs are extensively planted, especially in favored areas. Traditional cultivars and cultivars developed by the Instituto Agrono'mico Campinas (IAC) are grown in less favored areas in Brazil. Old land race cultivars are planted in traditional (or subsistence) slash-and-burn production systems. Upland cultivars grown commercially in Latin America are listed in Appendix 2.

Improved varieties vary in plant type, height, maturity duration, grain quality, insect and disease resistance (Table 5), drought and adverse soil tolerance, and yield potential. Except for Brazilian materials, most improved varieties are well adapted to favored conditions but are poorly adapted to less favored environments. In recent years, semidwarf cultivars have dominated in favored upland areas and many moderately favored areas, particularly in Colombia, Venezuela, and Central America. Only tall varieties, improved and traditional, are planted in the unfavored uplands. Collaboration between national and

Table 5. Agronomic characteristics of principal improved rice cultivars grown in upland conditions in Latin America. Evaluations conducted at 2 locations in Colombia.[a]

Cultivar	Maturation (days)	Plant height (cm)	Disease reactions				Sogatodes oryzicola (1-5)	Grain quality	
			Leaf blast	Neck blast	Hoja[b] blanca	Leaf scald (1-9)		White belly	Grain length
CICA 4	135	89	5	22	MR	6	2.5	0.6	L
CICA 6	136	89	2.3 (4)	–	MR	–	1.5	0.6	L
CICA 7	130	90	2	16	R	8	2.0	0.6	I.
CICA 8	143	94	4	15	S	5	2.0	0.8	L
CICA 9	138	103	4	50	R	5	1.5	0.8	L
CR 1113	141	94	1	51	S	5	5.0	0.2	L
Anayansi	145	86	3	40	–	5	3.0	1.6	L
Damaris	149	83	2	96	–	5	5.0	0.8	L
Bluebonnet 50	134	140	3	20	S	5	5.0	0.5	L
Eloni	141	90	2	–	–	3	2.0	0.8	EL
Pico Negro	133	109	–	–	–	–	–	1.0	L
IR 1529 IIR 43)	132	92	4	–	–	5	2.0	2.0	L
IAC 25	135	130	3 (4)	0.1	S	7	5.0	1.4	L
IAC 47	130	146	3 (4)	–	S	6	5.0	3.4	L
IAC 164	110	114	1 (3.4)	–	S	5	5.0	3.6	L
IAC 165	105	104	l (3)	–	S	5	5.0	3.0	L
Diwani	131	94	1	–	MS	3	3.0	–	L
Ciwini	136	106	2.3	0	MS	3	2.5	0.2	EL
Carolino	147	144	–	–	S	–	–	2.2	L
CR 201	139	103	–	–	–	3	4.0	0.4	L
Iniap 6	140	84	–	–	MR	5	2.5	0.8	L
Iniap 415	141	96	–	–	R	5	2.0	0.8	L
Iniap 7	142	100	4	–	R	6	2.0	0.4	L
Nilo 1	160	135	–	–	–	3	3.0	–	L
Tikal 2	131	94	4	98	–	5	3.0	0.6	L
Barnoa A75	136	90	–	–	–	–	–	–	L
Donato	150	109	–	–	R	–	–	–	L
Canilla	140	128	–	–	R	–	–	2.2	M
Dawn	124	90	1	86	S	5	5.0	0.6	L
Metica 1	124	75	1	0.5	R	5	3.0	0.2	L
Dourado	120	146	–	–	S	–	9.0	1.6	M

[a] Data recorded at CIAT-Palmira with disease evaluations at Villavicencio in Colombian Llanos; (–) indicates data not available. [b] *S* = susceptible, MS = moderately susceptible, MR = moderately resistant, R = resistant, M = medium, L = long, EL = extra long.

international rice programs has produced more than 30 semidwarf cultivars that have been released by national programs in the region (CIAT 1981). Although these cultivars have improved upland rice production in several countries, they were unexpected and unprogrammed spinoff from breeding programs for irrigated environments (Jennings et al 1981). Results at highly and moderately favored environments in Colombia and Central America indicate that semidwarf cultivars have the highest yield potential where blast and weeds are the most important yield constraints.

It is worth noting that cultivars grown successfully in upland conditions such as Tapuripa, Magali, Bowani, Diwani, and Eloni were bred in Surinam for

irrigated fields. They produce well in favored upland conditions in Central America, especially in Panama, where they have shown a high level of blast resistance that has held for about 20 years. Additionally, some sister lines of CICA 7 have stable resistance under these conditions.

Some cultivars developed in the United States for irrigated conditions, including Bluebelle, Bluebonnet 50, and Starbonnet, are still grown on a limited commercial scale in favored upland conditions in some countries. Although these varieties have some serious shortcomings, such as susceptibllity to important pests and diseases, they are utilized because of their earliness and superior grain quality.

In Central America some efforts have been made to identify superior germplasm for upland conditions (Espinosa 1982). For the past 10 years several Central American national rice programs have acquired advanced breeding materials from CIAT and IRRI. In 1978 each national rice program decided to select their best locally adapted breeding lines to be included in a special upland nursery called VICA (Central American Upland Nursery). This nursery was made up of 60 lines, of which 32 were named by Costa Rica, 16 by Panama, 6 by Honduras, 4 by Guatemala, and 2 by Nicaragua. After several plantings and evaluations in upland conditions in those countries, the number of lines in the nursery was reduced to 14 in 1981. Among these lines there is probably good parental material for developing superior upland cultivars for Latin America. They have high yield potential and resistance to, blast and leaf scald in favored upland conditions but are affected by these diseases in less favored environments.

UPLAND RICE CROPPING SYSTEMS

Rice in Latin America usually is grown on medium to large farms, but great diversity in production systems exists. Systems include intensive production under irrigated conditions and large areas of upland condition. Average yields in the different systems vary markedly. Rainfall pattern (amount and variability), cost of irrigation water, soil type, topography, and availability of infrastructure are the principal factors determining the system utilized (CIAT 1981).

Upland rice is grown on a broad continuum of ecosystems ranging from extremely low (cerrado, Brazil) to high levels of productivity (llanos of Colombia). It is difficult to subdivide this continuum accurately into discrete subsystems. Nevertheless, the classification used in this paper is a crucial exercise to analyze each ecosystem in terms of yield constraints, potential productivity, breeding objectives, priori-

ties, and economic profitability (Jennings et al 1981).

Favored upland rice

Favored upland rice production is generally confined to flat areas that receive more than 2000 mm of rainfall during 6 to 8 months of rainy season. Normally there are no marked dry periods during the rainy season. Soils are alluvial, slightly to moderately acid, and well drained. Farmers use improved agronomic practices and mechanized cultivation methods to grow modern semidwarf cultivars. Yields average 2 5 t/ha but better farms produce between 4 and 5 t/ha. The system is found in parts of Venezuela, Brazil, Central America, and at two major locations in Colombia.

Major constraints are grassy weeds, rice blast, and lodging. More recently leaf scald and grain spotting have become important in some areas. Hoja blanca virus disease has recently caused widespread damage in the eastern plains of Colombia. CICA 8, developed in a collaborative program between ICA and CIAT, has been the most productive variety for this system in several countries. Its susceptibility to the hoja blanca virus will limit its future usefulness.

Moderately favored upland rice

Moderately favored upland rice is cultivated in some areas in Bolivia, Ecuador, Mexico, Venezuela, in most of Central America, and in much of sub-Amazonian Brazil. These areas receive less rainfall than favored uplands and an annual 2-3 week dry period during the growing season is common. Soils often are less fertile than in favored areas. Dwarf varieties are grown in Central America and in some areas in Bolivia, Ecuador, Mexico, and Venezuela. Tall varieties are grown in Brazil. Irregular rainfall causes substantial yield variation, but average yields are 2.0 t/ha in Central America and 1.5 t/ha elsewhere. Constraints include several interrelated factors triggered by mild to moderate drought stress, including mineral deficiencies, diseases (particularly blast, brown spot, and leaf scald), insects, and weeds. Occasional drought reduces yields and complicates land preparation, seeding, and timing of herbicide and fertilizer applications.

Unfavored upland rice

Unfavored upland rice is cultivated in areas with irregular and low rainfall, is highly mechanized, has low planting densities, and utilizes tall varieties. Yields average 1 t/ha. Severe drought stress in most

years causes yields to vary widely across seasons and regions. Acid soils with poor water-holding capacity predominate. Much of the rice produced in Brazil is grown under this system.

The main constraint is low total rainfall combined with dry periods during the growing season that may persist for 20 to 30 days. Drought stress affects plant growth and mineral nutrition, and increases the severity of blast disease. Phosphorus and zinc deficiencies are common in the acid soils. Root development in the acid subsoils with high aluminum toxicity often is a severe problem.

Subsistence upland rice

Subsistence upland rice cultivation is in remote areas at the agricultural frontier. No mechanization and no purchased inputs are used. Forest or scrub is cleared and burned and rice is planted in widely separated holes using pointed sticks. New land is cleared after one or two harvests. Farm size is roughly 1 ha/family. Cultivars are unimproved land races. The system is stable and productivity averages 1 t/ha or less. Production is consumed by the farm family although a small portion sometimes is sold. Total area and production can only be estimated because statistics are not available.

Major constraints are socioeconomic -- total dependence on family labor limits farm size, obliges wide spacing, demands native cultivars, and prohibits the use of purchased inputs. Research specifically for this ecosystem has not been carried out because of its probable minor contribution to regional production and because of the nature of the principal constraints.

PAST PRODUCTION TRENDS AND FUTURE POTENTIAL

Only in the past 10 years has there been an increasing awareness of the different rice production systems in Latin America. Statistical data on the various upland systems are scarce and often include irrigated production. For Latin America as a whole, area planted to rice has increased 2.7% annually. Average annual growth for irrigated areas has been 1.0%. Assuming that the annual increase has been proportionally equal for all irrigated crops, it can be concluded that areas planted to upland rice have increased by an average 1.7% annually.

A similar analysis can be done for yield trends. Total average rice yield for all systems has been growing at a low rate of 0.8% annually. The low annual yield increase compared to spectacular yield increases in irrigated systems in many countries is due to larger

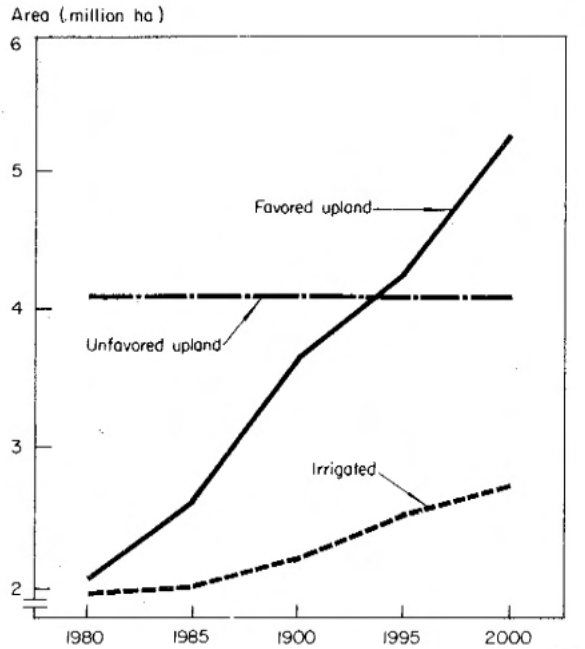
areas of the upland systems where yields have tended to remain stagnant. Some technical spillovers from the irrigated systems have occurred, especially in favored upland systems. Cultivars developed for irrigated conditions have been successfully adapted to favored upland conditions but with lower average yields.

In summary, upland rice production increases in Latin America have been made through area expansion while average yield has remained constant. If the same trends were to continue, average yield increases could be expected to be similar as upland rice expands to lower quality lands.

Several factors must be considered before predictions about the future of the Latin American rice sector is attempted. First, there is a general tendency toward self-sufficiency in most countries in the region. Rice deficit countries are seeking self-sufficiency to increase employment, save foreign exchange, ensure food supplies as means of national security, and stabilize domestic prices for consumers and producers. In these countries the limiting factor will not be demand, but production resources such as land, water, industrial inputs, and technology. Rice surplus countries and self-sufficient countries will face demand constraints because the international rice market is generally small and saturated. International rice prices are highly distorted and do not reflect real production and transportation costs. Most governments are skeptical of subsidizing rice exports and prefer to induce changes in resource use and encourage other food crops.

Although domestic demand will limit rice production increases in Latin America, that does not imply a low rate of growth. At current per capita consumption levels, total rough rice consumption by the year 2000 will reach 21.6 million tons -- 50% more than in 1980. Constant per capita consumption implies constant relative prices for rice and other food substitutes as well as other income levels and distribution of consumption among income classes. If prices of other sources of calories and proteins increase in relation to rice or incomes become more unevenly distributed, demand for rice will be much higher. Government reaction in such circumstances is impossible to predict.

Governments can affect the development af the rice sector mainly through three types of activities: a) investments in infrastructure (investments could be oriented toward either the construction of irrigation facilities or the construction of roads and facilities in new agricultural areas), b) investments in agricultural research (the amount and orientation of resource allocation to research and the results of the research will affect the relative competitiveness among crops and production systems), and c) prices and fiscal



5. Projected estimates of area planted in three main rice production systems in Latin America.

policies that will affect relative profitability and farmers' incentives to adopt new technology.

These factors have been considered in making the following predictions about the future structure of the rice sector in Latin America. World predictions are summaries of country by country studies. In each country past trends in area and yield increases, supply-demand situation, strength of the rice national program, and government policies in the rice sector have been considered.

Projected estimates of cultivated area planted to rice in the year 2000 in the three main production systems in tropical Latin America are made in Figure 5. The area for the unfavored rice production system will remain constant over time. The principal basis for this assumption is the near zero or negative profitability of the system and the high annual production variability. Irrigated rice areas are expected to increase by 800,000 ha, representing an annual 2% growth rate. Although this is an optimistic assumption, the availability of high yielding varieties and the associated relative profitability of the system are strong incentives for continued government and private investment in the irrigation infrastructure. The favored up land area is expected to increase by 3.2 million

hectares, implying a 5% annual growth rate. Given the area of underutilized lands suitable for favored upland rice cultivation in many countries, this is a reasonable rate of increase. In most countries projections for increased favored upland production have been estimated as residuals after changes in areas and yield in other systems have been assumed.

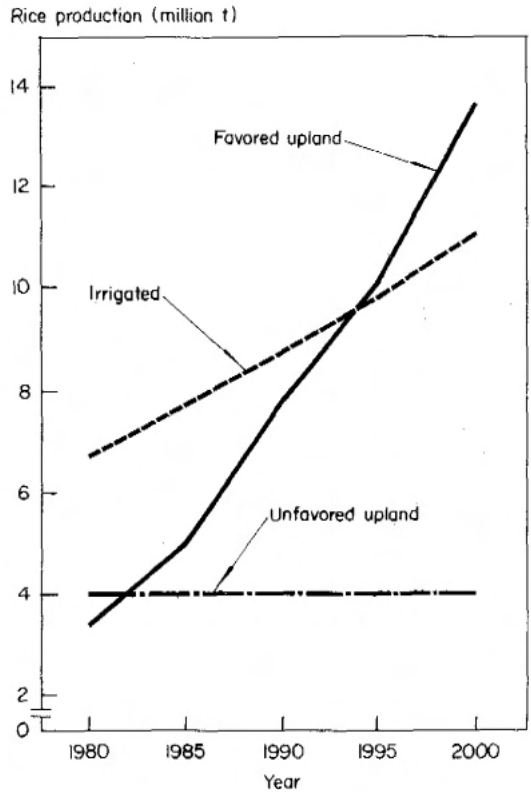
In Brazil the favored nonirrigated systems, including moderately favored and varzeas, are predicted to be increasingly important, in addition to increases expected in irrigated production. In tropical South America the relation between favored upland irrigated systems will probably be inverted, with favored upland becoming the most extensive system. In the Caribbean countries irrigated cultivation will continue to account for the majority of rice area expansion and favored and unfavored upland areas are expected to remain constant. In Central America the area of favored upland systems is expected to increase.

Table 6 summarizes expected average yield increases for favored upland systems by country. Countries that currently have relatively high yields are not expected to have additional large increases. Yield increase projections for other countries are based on an evaluation of the current strength of national rice research programs and current yield levels. Venezuela is expected to record the largest increase of 1.1 t/ha. This assumption is probably reasonable given the large areas of fertile land available in the Orinoco Valley and Delta.

Irrigated production systems will probably continue to be the most important sources of rice in Latin America, excludlng Brazil, for sometime. Irrigated pro-

Table 6. Projected estimates of average yields in tropical Latin America far the favored-upland production systems from 1980 to 2000.[a]

Country	Yield (t/ha)					Increase (%)
	1980	1985	1990	1995	2000	
El Salvador	3.5	3.5	3.5	3.5	3.5	0
Guatemala	3.4	3.4	3.4	3.4	3.4	0
Bolivia	3.2	3.2	3.2	3.2	3.2	0
Peru	2.8	2.8	2.8	2.8	2.8	0
Colombia	2.8	2.8	2.8	2.8	2.8	0
Honduras	2.8	2.8	2.8	2.8	2.8	0
Panama	2.6	2.8	3.0	3.2	3.5	35
Mexico	2.4	2.6	2.8	3.0	3.2	31
Costa Rica	2.3	2.5	2.7	2.9	3.2	39
Ecuador	1.9	2.1	2.3	2.5	2.7	42
Venezuela	1.7	1.9	2.2	2.5	2.8	65
Brazil	1.6	1.8	2.0	2.2	2.5	57
Guyana	1.3	1.5	1.6	1.8	2.0	53
Paraguay	1.1	1.2	1.4	1.5	1.6	50



6. Projected rice production in the three main systems in tropical Latin America from 1980 to 2000. Predictions are based on trends in area expansion, relative profitability, land availability, and other factors.

duction is expected to nearly double by year 2000 (Fig. 6). Despite the estimated rapid growth of favored upland systems, production will still be less than from irrigated systems until about 1995. In Brazil, however, where irrigated and upland production are now equal, favored upland systems should produce twice as much rice as irrigated systems by the year 2000. Because there is significant international trade in rice, these estimates are quite sensitive to changes in irrigated rice yields. In tropical South America and the Caribbean favored upland systems will increase production rapidly but irrigated systems should continue to be the major source of production. During the next two decades the Central American countries will probably continue to rely on favored upland systems as their main sources of rice. Irrigated rice areas in these countries are not expected to increase substantially

because they lack irrigation infrastructure and because of competition from other crops.

Projections indicate total rice production (Fig. 6) by 2000 should be about 28.9 million tons, exceeding a constant per capita consumption projection by 7.3 million tons. Per capita consumption of paddy rice will only need to increase from the present 45 kg to 58 kg to make up this difference. A per capita paddy rice consumption of 58 kg is equivalent to 37.7 kg of milled rice, a figure far below present per capita consumption in Asian countries. Past consumption trends suggest that rice is becoming a main source of calories, after cane sugar, for the human population of tropical Latin America.

These admittedly rather fragile projections are useful in several respects. First, it is highly probable that upland rice systems will continue to be an important source of rice for regional consumption in many countries in tropical Latin America. Second, despite an expected rapid growth in irrigated systems, the derived demand for production in new upland areas will be high. This latter land pressure will be alleviated by parallel improvements in technology and productivity. Third, there is a large potential market for milled rice in the region, if price is competitive with other sources of calories and proteins, despite the present low per capita consumption levels.

UPLAND RICE RESEARCH

Most of the countries with upland rice production have developed national research efforts over the past 10 years to evolve new technologies to overcome production constraints. The CIAT-IRRI International Rice Testing Program (IRTP) for Latin America has proved an effective linkage of the various groups since 1977. International research organizations are also studying the upland sector. There is a relatively new upland program at CIAT and basic IRRI work and IRRI materials received through IRTP are being utilized. In addition Institut de Recherches Agronomiques et des Cultures Vivrieres (IRAT) has developed a collaborative upland program with Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA).

Materials developed elsewhere have been particularly important in providing sources of germplasm for particular characteristics. In CIAT studies, cultivars developed by the cereal program at IITA have proved outstanding as potential parental sources for acid soil tolerance for the unfavored acid soil areas in the Colombian Llanos. Some IRAT materials are excellent sources of resistance to dirty panicles and blast. Various West African materials from IRAT and IITA have

also proved useful in the Brazilian research at Centro Nacional de Pesquisa -- Arroz, Feijao (CNPAF), Goiania.

Thus, upland research has not received all the attention it has deserved in the past, particularly in breeding, but there has been considerably more interest in it during recent years. A network of researchers and of research collaboration is also developing which is parallel to and associated with well-developed regional research collaboration in the irrigated sector.

CONCLUSIONS

In view of the large areas of underutilized land suitable for upland rice in Latin America and of predictions as to future demand for rice in the region it is reasonable to assume that upland rice will increase in importance during the next 20 years. Upland production systems at the favored end of the spectrum will certainly need increased research attention.

Constraints to increased productivity and production are highly researchable but require concerted and coordinated action. Among the key regional problems that will need resolution, the following are probably the most important:

1. development of cultivars with stable or more long lasting resistance to blast and other important fungal diseases for all upland systems;
2. development of rice cultivars with improved adaption characteristics for acid soil areas, particularly with respect to root development; and
3. increased national level research, particularly on a wide range of agronomic factors in upland conditions including fertilizer use (type and placement), effective weed control methodologies, and, where possible, the incorporation of a pasture phase in the upland rotation that utilizes grass-legume forage combinations.

Given that sufficient research resources are allocated for these and other tasks at both the international and national level, over the next 5 to 10 years, the way will be open for substantial increases in upland production, especially in the favored systems.

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APPENDICES

Appendix 1a. Rice area planted to 3 main production systems in tropical Latin Ametica, 1980 (FAO 1980, USDA 1980, CIAT-IRRI 1979).

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

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

Appendix 1b. Extended average yields for 3 main rice system groupings in tropical Latin America, 1980 (CIAT-IRRI 1979).

	Yield (t/ha)		
	Irrigated	Favored upland[a]	Unfavored upland[b]
Brazil	3.2	1.6	1.0
Mexico	4.7	2.7	1.0
Tropical South America			
Bolivia	–	3.2	1.0
Colombia	5.5	2.8	1.0
Ecuador	3.8	1.9	–
Paraguay	5.7	2.8	–
Peru	5.7	2.8	1.0
Venezuela	3.4	1.7	–
Central America			
Costa Rica	4.6	2.3	1.0
El Salvador	5.0	3.5	–
Guatemala	–	3.4	1.0
Honduras	5.0	2.8	–
Nicaragua	2.5	1.3	–
Panama	5.5	2.6	1.0
Caribbean			
Guyana	2.4	1.3	–
Cuba	2.2	–	–
Dominican Republic	3.5	–	–
Haiti	2.2	1.1	1.0
Jamaica	1.5	–	–
Tropical Latin America	3.6	1.71	1.0
Excluding Brazil	3.8	2.2	1.0

[a]Rainfed lowland rice data are included in favored upland. Estimated average yield for tropical Latin America in this system is 2.5 t/ha. [b]Traditional. (subsistence) manual upland is included in unfavored upland. Estimated average yield for regional production is 1 t/ha.

Appendix 1c. Estimated total production from 3 main production system groupings for tropical Latin America, 1980 (FAO 1980, USDA 1980, CIAT-IRRI 1979).

	Production (thousand t)		
	Irrigated	Favored upland[a]	Unfavored upland[b]
Brazil	2477	2477	3894
Mexico	345	87	23
Tropical South America	2781	475	136
Bolivia	0	54	38
Colombia	1695	59	93
Ecuador	195	102	0
Paraguay	50	11	0
Peru	411	67	5
Venezuela	430	182	0
Central America	100	379	73
Costa Rica	9	180	3
El Salvador	20	35	0
Guatemala	0	31	3
Honduras	5	14	13
Nicaragua	55	7	0
Panama	11	112	54
Caribbean	1134	60	3
Guyana	206	49	0
Cuba	459	0	0
Dominican Republic	380	0	0
Haiti	83	11	3
Jamaica	6	0	0
Tropical Latin America	6837	3478	4129
Excluding Brazil	4360	1001	235

[a] Rainfed lowland rice is included in figures for favored upland. Estimated total production for the region from the system is 1.6 million t. [b] Traditional (subsistence) upland rice is included in figures for unfavored upland. Estimated total regional production from the system is 950,000 t.

Appendix 2. Principal rice cultivars grown in upland conditions in Latin America. 1979-80[a].

Country	Area (thousand ha)		Variety name	Percentage upland rice	Variety[b]
	Total	Upland			
Brazil	6231	5327	IAC 47	–	I
			IAC 25	–	I
			IAC 164	–	I
			IAC 145	–	I
Mexico	133	60	Navalato A 71	23	I
			CICA 4 and 6	7	I
			Macuspana A 75	4	I
			Sinaloa A 68	3	I
			Grijalva A 71	5	I
			Traditional cultivars	3	T
Bolivia	55	54	Bluebelle	–	I
			CICA 8	–	I
			Dourado	–	T
			Bluebonnet 50	–	I
			IR43	–	I
			Pico Negro	–	T
Colombia	422	114	CICA 8	80	I
			CICA 4	10	I
			Miramono	2	T
			Other traditional cultivars	8	T
Ecuador	104	33	Canilla	–	T
			Donato	–	T
			SML	–	I
			Pico Negro	–	T
			Iniap 6,7 and 415	–	I
Paraguay	32	11	Rexoro	–	I
			Fortuna	–	T
Peru	100	16	Fortuna	5	T
			Carolino	16	T
			Peru 65	–	T
			CICA 8, CICA 9	–	I
			Chancay	2.5	I
Venezuela	231	97	Araure 1 and 2	–	I
			Llanero	–	T
Costa Rica	82	80	CR 1113	90	I
			CR 201	3	I
			CR 5272	7	I
El Salvador	14	10	X-10	60	I
			Masol 1 and 4	10	I
			CICA 9	6	I
			Nilo 1 and 3	12	I
			CR 1113	6	I
			Centa A2 and A3	–	I

Appendix 2 continued

Country	Area (thousand ha)		Variety name	Percentage upland rice	Variety[b]
	Total	Upland			
Guatemala	12	11	Tikal 2	60	I
			Lebonnet	20	I
			Bluebonnet	5	I
			Americanito and Lira Blanco	10	T
			ICTA-Tempisque, Virginia and Cristina	5	I
Honduras	19	16	CICA 4, 6, 8 and 9	65	I
			Bluebonnet 50	7	I
			Traditional cultivars	19	T
			CR 1113, Tikal 2	3	I
Nicaragua	41	19	Bluebonnet 50	23	I
			CICA 8	5	I
			CR 1113	9	I
			CICA 4	5	I
Panama	99	92	CICA 8	21	I
			CICA 7	42	I
			Eloni	5	I
			T 5430	1	I
			CR 5272 and CR 1113	10	I
			Linca 4444	5	I
			Anayansi	5	I
			Traditional cultivars	–	T
Guyana	121	35	Starbonnet	–	I
			Traditional cultivars	–	T
Haiti	43	11	Folton and Buffalo	–	T
			Ti-Fidele	–	T
Surinam	36	2	Traditional cultivars	–	T
Belize	6	3	CICA 4, 8 and 9	–	I
			CR 1113	–	I
			Bluebonnet 50 and Belle Patna	–	I

[a]Unofficial CIAT preliminary estimates based on information from qualified sources; (–) indicates information not available at time of writing. [b]I = improved variety, T = tall, unimproved variety.

UPLAND RICE IN BRAZIL

EMBRAPA

Rice is a staple food for the Brazilian people and an important source of income for large, medium, and small producers. Production must continually increase to meet the demands of a growing population, but annual production varies substantially because nearly 70% of it is from upland rice.

Upland rice in Brazil is cultivated under diverse climatic conditions and land characteristics. Producers are inclined to spend less on high technology and more for production stability, and to emphasize cultivation in areas where there is less risk of natural disaster and greater potential for yield increases.

DEFINITION

Many classification systems are used to describe rice cropping. All are based on water availability.

According to a 1976 classification proposed by Centro Nacional de Pesyuisa de Arroz e Feijao (CNPAF) research teams, Brazil has four basic rice cropping systems: 1) rice cropped in lower elevation floodplains using controlled irrigation and high technology, 2) rice cropped in low elevation floodplains with no controlled irrigation that depends on river water levels, 3) rice cropped without irrigation on low elevation floodplains that depend on rainfall or groundwater levels near the soil surface, and 4) upland rice grown on soils with good drainage and low water retention capacity unaffected by groundwater levels, and dependent on rainfall as the sole water source. This latter system is defined as upland rice.

Upland rice represents 77% of the rice area in Brazil and accounts for about 66% of national rice production. It is cultivated during the rainy period mainly in the central region of the country, which has a monomodal rainfall regime with a May-September dry season and October-April wet season. Rainfall is high (1,200 mm annually), but short dry periods during the growing season determine the success or failure of the rice crop. Climatic variations within the upland region have prompted scientists to divide upland culture into favorable and unfavorable systems.

PRODUCTION SYSTEMS

Upland rice production systems in Brazil vary because of climate, regional infrastructure, and farmers' goals for future land use.

When upland areas were first opened for agricultural development, rice was the crop of choice. As frontier areas are developed, rice is still the first crop cultivated because it easily adapts to new land, performs better than other crops in poor soils, and improves soil fertility. After several years rice begins to be replaced by pasture, maize, and soybean. For example, the states of Minas Gerais, Sao Paulo, and Parana planted from 5.4 to 9.6% less upland rice in 1980 than in 1970 (Table 1). Frontier states Rondonia, Maranhao, Mato Grosso do Sul, and Mato Grosso expanded upland rice cultivation by 1.9 to 13.4%.

In the central-west region and parts of the southeast, where production is frequently affected by veranicos (dry periods), rice is cropped for 1 to 3 years to minimize the cost of establishing pasture. Some farmers interplant rice with grass as early as the first year.

Upland rice farmers use minimum inputs and technology. Inadequate rainfall reduces fertilizer efficiency and low fertilizer application rates, usually 100-200 kg of 6-30-16 NPK + Zn/ha, do not meet plant nutrient requirements. Farmers often apply natural rock phosphate to reduce soil acidity and provide phosphorus.

In much of Brazil, especially in the Amazon region of the north and northeast, farmers seek to produce only enough rice to feed their families. Very little surplus is marketed. Upland rice is intercropped with maize, kidney bean, cassava, watermelon, melon, pumpkin, gourd, fava bean, okra, cotton, and other crops. About 70% of production is grown on 4- to 10-ha farms. In Rondonia, the major rice growing state of the north,

Table 1. Changing upland rice production areas in Brazil.

State	Percent total area planted to upland rice		Change (%)
	1970	1980	
Rondonia	0.3	2.2	1.9
Maranhao	14.5	19.9	5.4
Minas Gerais	21.5	11.9	–9.6
Sao Paulo	13.5	6.0	–7.5
Parana	13.3	7.9	–5.4
Mato Grosso do Sul	5.4	10.1	4.7
Mato Grosso	4.6	18.0	13.4
Goias	27.0	24.1	–2.9

and in Acre, Para, Piaui, and Roraima, low income farmers practice shifting cultivation in forested areas where soil is easily exhausted and weeds are a major constraint. Both traditional and mechanized upland rice systems are used in Roraima.

In most of south and southeastern Brazil, upland rice is cultivated using relatively high technology levels. A substantial amount of rice is grown with controlled irrigation in some states, but upland rice is the major source of production. Although there are some areas of traditional farming in the south, most farms are large, mechanization is used in all phases of production, and areas are usually planted to wheat or soybean after the second year rice crop is harvested. Rio Grande do Sul and Santa Catarina are major upland rice producers in the south.

CLIMATIC CHARACTERISTICS

Upland rice is grown in almost every Brazilian state and in many different climatic regions. In the Cerrados region, where the greatest concentration of upland rice is located, the predominant climate types, according to the hopper classification system, are Aw (rainy tropics) in the lowlands, and Cwh_l (rainy temperate with dry winter) in the central plateau.

Tables 2 and 3 show data on rainfall, temperature, solar radiation, and potential evapotranspiration during the rainy season for 26 sites that are representative of climatic conditions in Brazil. Figure 1 shows their geographic location.

Rainfall

Annual rainfall in Brazil varies from less than 500 to more than 3,000 mm, Figure 2 shows annual rainfall distribution for the different regions and identifies the representative upland rice growing areas listed in Table 2. Using the rainfall data for the selected sites the following observations can be made:

1. Rainfall regimes are monomodal and most locations have a distinct rainy and dry season. In the central-west region (Goiania, Porto Nacional, and Diamantino) the season lasts from October/Novenber through March/April. In the north (Grajau, Caxias, and Altamira), the rainy period begins in December/January. Boa Vista has a May-June rainy period which differs from other locations. Xanxere and Guarpuava receive more rain during the winter seasons and the dry period is not so distinct as in most locations.
2. The rainy season, defined as the months when rainfall exceeds 200 mm, varies among locations. Rains usually last 4-5 months, although some areas (Porto Velho and Porto Nacional)

Table 2. Rainfall characteristics in some producing areas of upland rice of Brazil.

Station	Location				Rainfall (mm)												Number rainy months (P> 200 m)	Number dry months (P< 100m)	Growing period[d]		
	State	Latitude (N)	Longitude (W)	Altitude (m)	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun			Number months	Total rainfall (mm)	MAI[c]
Imperatriz	MA	05°32'	47°30'	123	10	7	40	92	152	198	241	256	309	219	89	19	4	6	6	1.375	1.3
Grajau	MA	05°48'	46°27'	154	8	4	28	70	142	154	170	212	281	163	69	16	2	6	5	985	1.1
Caxias	MA	04°52'	43°21'	77	8	3	13	29	66	96	169	243	288	283	72	19	3	8	4	983	1.4
Carolina	MA	07°20'	47°28'	183	10	5	40	119	190	217	243	226	294	167	47	8	4	5	6	1.337	1.2
Goiania	GO	16°41'	49°17'	729	10	3	36	143	237	271	234	210	198	110	30	5	4	5	6	1.293	1.0
Porto Nacional	GO	10°43'	48°25'	237	2	3	35	142	233	284	274	229	273	150	36	1	6	5	7	1.443	1.2
Parana	GO	12°33'	47°47'	275	2	2	29	108	227	261	218	214	184	84	8	1	4	6	5	1.104	1.0
Catalao	GC	18°10'	47°58'	857	2	4	37	143	240	341	315	234	229	82	28	9	5	6	6	1.502	-
Diamantino	MT	14°25'	56°27'	258	7	9	52	146	224	297	320	295	299	142	47	12	5	5	6	3.581	-
Caceres	MT	16°04'	57°41'	118	11	7	36	94	157	197	215	206	171	78	48	20	2	7	5	946	0.9
Cuiaba	MT	15°36'	56°06'	172	6	12	40	130	165	194	216	198	232	116	52	14	2	5	5	1.005	1.2
Gen. Carneiro	MT	15°43'	52°45'	478	4	5	49	129	210	268	300	240	214	94	30	8	5	6	5	1.232	-
Uberaba	MG	19°44'	47°55'	743	13	10	70	130	218	292	274	240	202	107	38	30	5	5	5	1.226	1.2
Guarapuava	PR	25°24'	51°28'	1108	102	112	157	163	157[b]	153[b]	188	141	134	113	119	136	0	0	5	613	0.8
Londrina	PR	23°21'	51°09'	610	58	46	89	150	131	165	208	190	143	94	88	80	1	6	5	644	-
Campo Grande	MS	20°27'	54°37'	566	36	29	62	162	164	191	229	199	140	101	81	50	1	5	5	945	0.8
Aquidauana	MS	20°28'	55°48'	207	44	30	71	139	138	198	234	193	150	116	98	57	1	5	4	775	0.8
Ponta Pora	MS	22°32'	55°43'	650	59	50	112	197	164	177[b]	189	173[a]	162	131	122	107	0	2	6	1.062	-
Franca	SP	20°33'	47°26'	1036	16	11	65	131	206	270	250	220	187	81	40	22	4	6	5	1.133	1.0
Porte Velho	RO	08°46'	63°55'	128	13	33	120	188	205	285	389	303	320	233	106	36	6	3	7	1.923	2.0
Altamira	PA	03°12'	52°45'	80	51	23	30	41	66	108	220	272	334	276	178	73	4	6	5	1.280	-
Conceicao de Araguaia	PA	08°15'	49°12'	150	7	15	64	163	196	227	253	252	263	163	60	8	4	5	7	1.517	1.2
Teresina	PI	05°05'	42°44'	79	8	6	10	28	60	105	175	236	311	254	91	15	3	7	4	976	1.3
Xanxere	SC	26°51'	52°24'	541	172	191	274	250	163	180	233	207	194	193	194	235	5	0	5	977	0.9
Boa Vista	RR	02°48'	60°42'	99	378	236	107	63	62	44	31	38	54	129	298	382	4	6	4	1.294	–
Sena Madureira	AC	09°08'	68°40'	135	36	45	126	173	193	274	316	285	266	231	125	66	5	3	7	1.739	1.6

[a] The growing season was defined using the following criteria: 1) Rainfall (R) of 1st month > 150mm; 2) R 2nd month > 150mm; 3) R of 3rd, 4th ... > 200 mm; 4) The last month only is considered to belong to the growing season if 150 mm < R < 200 mm; 5) A tolerance of 5% on the monthly rainfall was observed to establish the growing period. [b] Months in which the rainfall does not reach the values established to define the growing season.

[c] $\text{MAI} = \dfrac{\text{75\% probability of rainfall}}{\text{Potential evapotranspiration}}$

[d] The growing period was defined based mainly on the air temperature.

Table 3. Temperature, solar radiation, and potential evapotranspiration during the growing season in some upland rice producing areas of Brazil (Azevedo 1974, Brazil Ministry of Agriculture 1969, Hancock et al 1979).

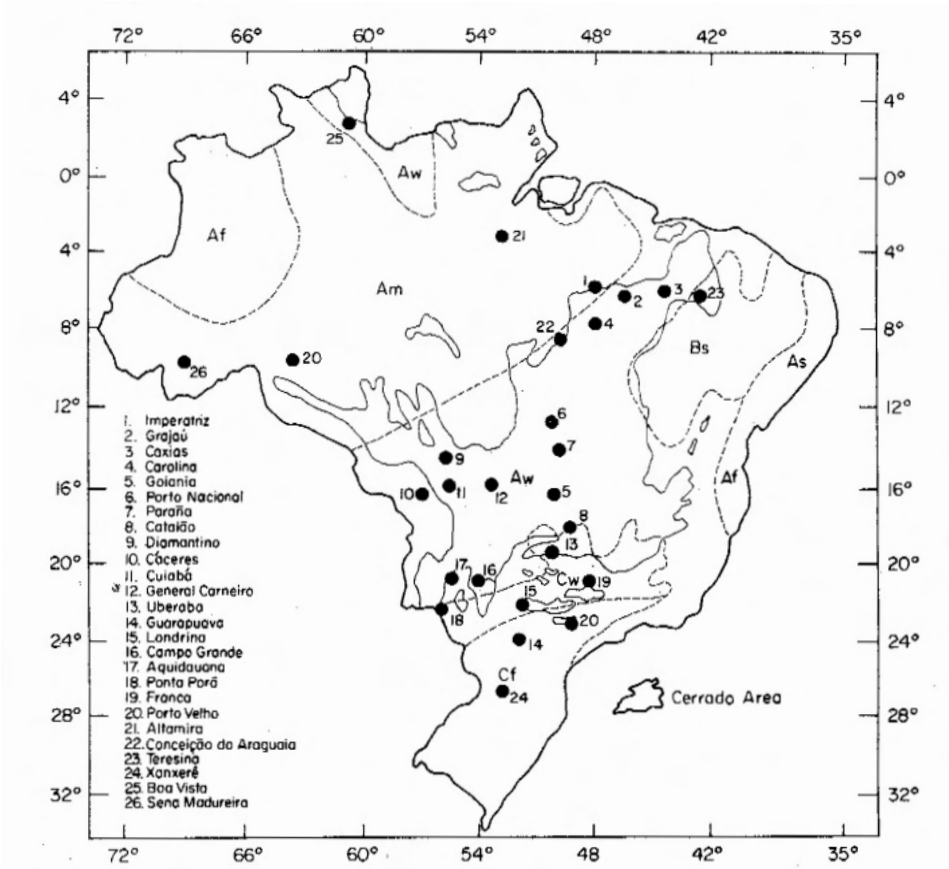
Station	State[a]	Air temperature (°C)			Solar radiation (cal/cm^2 per day)	Potential evapo-transpiration (mm/mo)
		Mean	Max	Min		
Imperatriz	MA	25.4	31.6	24.9	453	146
Grajau	MA	25.5	31.0	21.0	459	140
Caxias	MA	26.3	32.3	22.5	453	139
Carolina	MA	25.9	32.0	21.6	450	138
Goiana	GO	23.0	29.2	17.9	495	142
Porto Nacional	GO	25.6	31.5	21.5	463	143
Parana	GO	25.6	–	–	496	151
Catalao	GO	22.5	27.7	18.5	501	163
Diamantino	MT	–	–		–	–
Caceres	MT	26.4	32.4	22.5	479	149
Cuiaba	MT	26.5	32.7	22.5	476	148
General Caneiro	MT	–	–	–	–	–
Uberaba	MG	22.9	–	–	520	148
Cuarapuava	PR	18.1	24.2	13.2	510	130
Londrina	PR	–	–	–	–	–
Campo Grande	MS	24.l	30.1	39.2	516	151
Aquidauna	MS	26.3	32.5	21.9	516	160
Ponta Pora	MS	–		–	–	–
Franca	SP	21.3	27.0	16.8	490	134
Porto Velho	RO	26.4		–	397	123
Altamira	PA	–	–	–	–	–
Conseiçao do Ardguaia	PA	25.3	–	–	447	136
Teresina	PI	26.5	32.1	22.6	455	141
Xanxere	SC	19.6	27.2	13.6	538	140
Boa Vista	RR	–	–	–	–	–
Sena Madureira	AC	25.1	–		395	119

[a]See footnote [a] of Table 2.

have a 6-month season, and some have 2 rainy months (Grajau, Guiaba, and Caceres). Some areas (Guarapuava and Ponta Pora) never receive more than 200 mm during one month.

3. The upland rice growing season usually ranges from 5 to 6 months, but Teresina, Aquidauana, and Boa Vista have 4-month seasons, and Porto Velho, Conceicao de Araguaia, and Sena Madurei-ra have a 6-month growing season.
4. Total rainfall during the growing season ranges from 775 mm at Aquidauana to 1,923 mm at Porto Velho.
5. Moisture availability index (MAI), which is defined as

$$\text{the ratio } \frac{\text{25\% probability of rainfall}}{\text{Potential evapotranspiration}}$$



1. General climatic types in Brazil (by Koppen) and representative upland rice producing areas discussed in Tables 1 and 2.

during the growing season is highest (2.0) in Porto Velho and lowest (0.8) in Guarapuava, Aquidauana, and Campo Grande.

Although the cerrado (savannah) region receives adequate total precipitation for successful upland rice cultivation, there are often veranicos (dry spells) that last from 1 to 3 or more weeks. Studies at EMBRAPA /CNPAF show that a 10-day water deficit during the reproductive phase of rice reduces yield by as much as 40%. Frequent losses are caused by veranicos in Goias, Mato Grosso do Sul, Mato Grosso, and in parts of Minas Gerais and Maranhao. High evapotranspiration, low soil moisture holding capacity, and aluminum toxicity compound the effect of veranicos and increase crop losses.

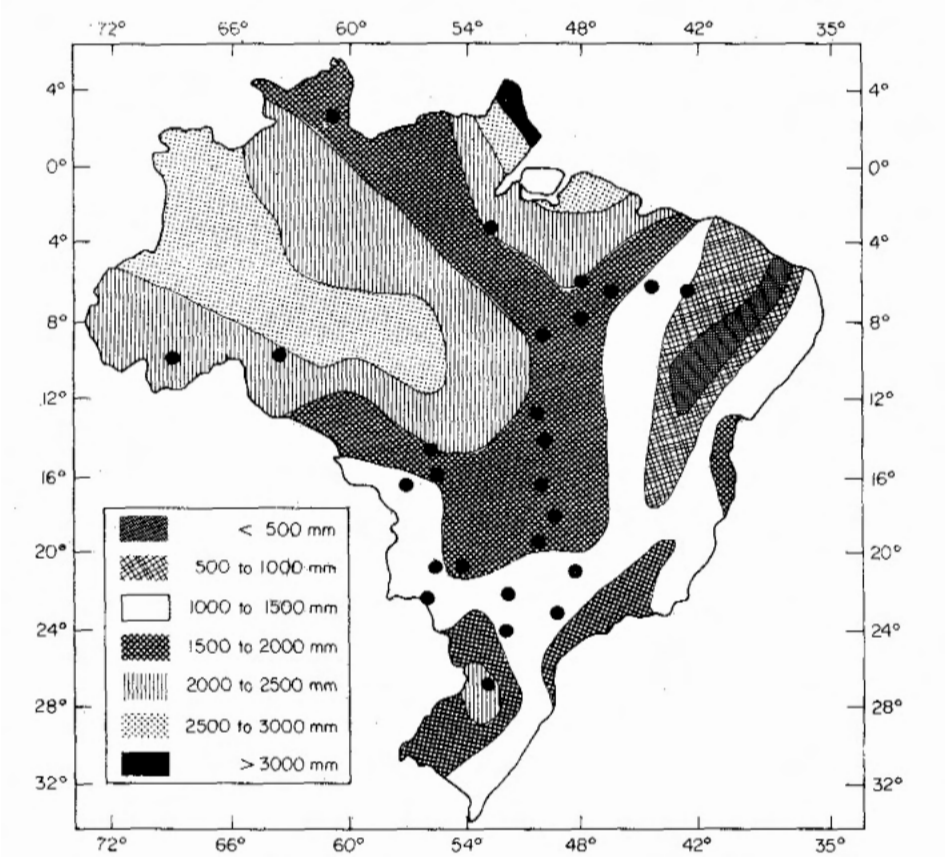
Little research has been conducted on rainfall patterns in the cerrado area, but preliminary studies at EMBRAPA have divided upland areas into favorable and unfavorable regions, depending upon the probability of

veranico during rice production (EMBRAPA 1981). More research needs to be conducted to locate and document upland areas by rainfall frequency so that technologies compatible with climatic risk can be developed and recommended. More detailed rainfall information is discussed in Favorable rainfall periods of upland rice production regions in Brazil, presented at the Workshop on Upland Rice, Bouaké, Ivory Coast.

Temperature, solar radiation, and potential evapotranspiration

Air temperature data (Table 3) show that all locations except Guarapuava and Xanxere have average temperatures above 20°C and average minimum temperatures above 15°C. Temperature does not limit rice cropping.

Sena Madureira and Porto Velho receive the lowest amounts of solar radiation (395 and 397 cal/cm^2 per day) during the growing season, and Xanxere (538 cal/cm^2 per day) receives the highest levels. Solar



2. Annual rainfall in Brazil and location of selected representative upland rice growing areas discussed in Table 2.

radiation for other sites ranges from 450 to 520 cal/ cm^2 per day.

Spikelet number increases as solar radiation increases up to 500 cal/cm^2 per day (Yoshida and Parao 1976). Although the lower radiation values recorded at Porto Velho and Sena Madureira probably do not limit rice production at current yield levels, solar radiation levels must be considered when attempting to increase productivity by using higher technology.

Potential evapotranspiration values range from 140 to 150 mm/month during the growing season in most locations. Lowest evapotranspiration values are recorded in Sena Madureira (119 mm/month) and Porto Velho (123 mm/ month). Highest evapotranspiration is in Catalao (163 mm/month) and Aquidauana (160 mm/month).

SOILS

Most rice production in Brazil is in the central region, in areas dominated by cerrado. Cerrado makes up 22% of Brazil's area (Fig. 3).

Oxisols predominate. Fifty-two percent are Dark-Red and Yellow-Red Latosols. There also are substantial areas of Hydromorphic Laterite and Yellow-Red Podzol soils.

Soil mineralogy

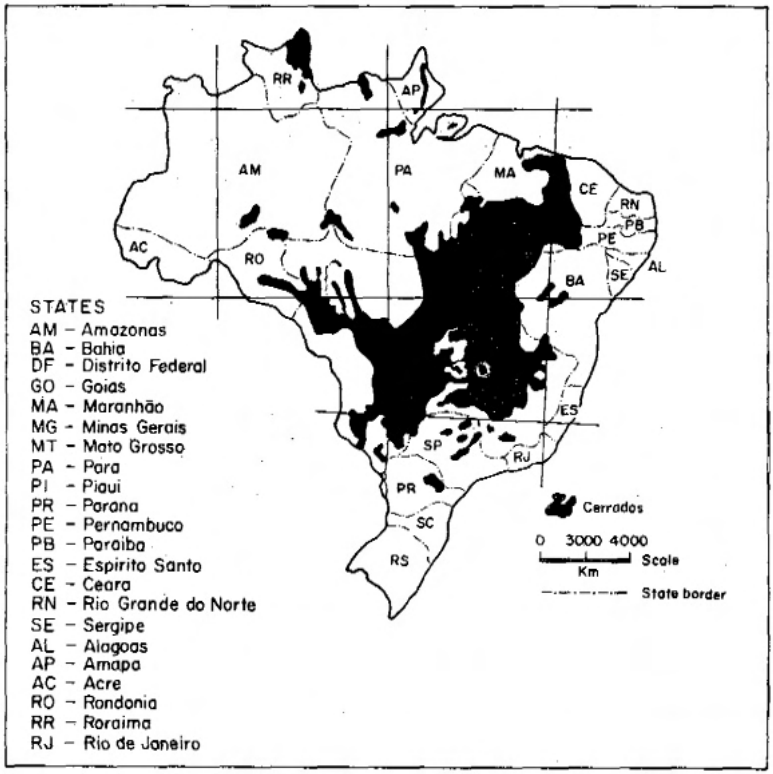
Although Brazilian soil mineralogy studies are scarce, they indicate that the mineralogical composition of the soil clays in central Brazil is mainly lattice 1:1 clays such as kaolinite and halloysite; oxides of iron, aluminum, and titanium; and insoluble minerals such as quartz. Gibbsite, hematite, and goethite are found at some sites. Advanced weathering firmed resistant microaggregates gathered by aluminum and iron oxides that cause the clay soils to have permeability equal to that of medium-textured soils, which encourages root development.

Soil physical conditions

Brazilian soils usually have good physical characteristics, in terms of friability, porosity, permeability, and depth, all of which facilitate root growth. Soil texture ranges from extremely clayey (83%) to extremely sandy. Even the clay soils have low water-holding capacity (Lopes 1977). Studies show that water availability can be reduced by 2/3 or more by tensions of 1/10 to 1 bar, independent of soil texture.

Soil chemistry

Brazilian soils, in general, and cerrado soils, in particular, have the following characteristics: N, P,



3. Brazilian cerrado region.

K, S, and Zn deficiency; Ca and Mg deficiency and low soil Ca and Mg retention capacity when they are applied as fertilizer; high exchangeable aluminum levels that are toxic to rice plants and cause phosphorus to be immobilized; low cation exchange capacity (CEC) and low total bases; high phosphorus fixation capacity; and medium organic matter content with reduced activity caused by low pH, high iron and aluminum oxide content, and low microorganism activity.

Liming and fertilization are difficult because of high phosphorus fixation, low CEC, and easily unbalanced soil nutrient content. High phosphorus fixation capacity linked with an extremely low Level of available phosphorus is one of the most limiting factors to crop development in Brazilian soils.

DISEASES

Fourteen fungal diseases and two nematodes attack upland rice in Brazil. Virus and bacterial diseases are not found. Leaf blast (Pyricularia oryzae), brown spot (BS) (Helminthosporium oryzae), leaf scald (Rhynchos-

porium oryzae), narrow brown leaf spot (NBLS) (Cercospora oryzae) and glume discoloration (Gld) (Phoma Ghina) are the most common and serious of diseases. Other diseases of less economic importance are secondary basal node rot (Fusarium oxysporium), white-tip nematode (Aphelenchoides besseyi), root-knot nematode (Meloidogyne javanica), false smut (Ustilaginoidea virens), kernel smut (Tilletia barclayana), leaf smut (Entyloma oryzae), and stackburn (Alternaria padwickii).

Blast is endemic and occurs every year with varying intensities. It is one of the most serious rice diseases, particularly in central west Brazil. Brown spot attacks rice grown in poor soils in the northern states. Leaf scald is found throughout Brazil. It is the most serious upland rice disease in Para, Amazonas, Acre, Rondonia, and Amapa and causes substantial damage in Maranhao. It is common in northern Brazil in areas with Dark Red Latosol soils. Leaf scald is the most serious disease during the first year of rice cultivation on newly opened lands in central Brazil, but there is little yield loss information for the disease.

NBLS usually occurs after booting, is sporadic, and does not affect production substantially. In 1981, however, it caused significant yield losses in Rorarima.

Gld reduced grain yield and quality significantly in Goias, Mato Grosso do Sul, and Mato Grosso during 1979-80. Continuous rainfall at panicle emergence increases disease incidence.

Secondary basal node rot is becoming more important in cerrado soils. Other diseases occur sporadically and cause little harm.

INSECTS

Upland rice is affected by insect pests, predators, and parasites. Common insects in the central-west region that sometimes reduce grain production are subterraneous termite (Syntermes spp. Isoptera-Termitidae), thrips (Frankliniella rodeos Thysanoptera-Tripidae), rice stink bugs (Oebalus ypsilongriseus, O. poecilus, Tibraca limbativentris Hemiptera-Pentatomidae), leafhoppers (Exitianus obscurinerves, Balclutha sp., Hortensia sp, Graphocephala sp. Homoptera-Cicadellidae), planthopper (Sogatodes oryzicola Homoptera-Delphacidae), spittlebugs (Deois flavopicta, Deois spp. Homoptera-Cercopidae), armyworms (Mocis latipes, Spodoptera frugiperda Lepidoptera-Noctuidae), lesser cornstalk-borer (Elasmopalpus lignosellus. Lepidoptera-Pyralidae), stem borer (Diatraea spp. Lepidoptera-Pyralidae), rice beetles (Diabrotica spciosa, Chaetocnema sp. Coleoptera-Chrysomelidae), and cutting ant (Acromyrmes spp., Atta spp. Hymenoptera-Formicidae).

The beetles Oediopaguerini and O. sternalis (Coleoptera-Chrysomelidae) have caused damage in Maranhao and Para, and panicle borer Neobaridia amplitarsis (Coleoptera-Curculionidae) recently damaged rice in Mato Grosso.

Insect damage often causes yield losses of as much as 29% in the central-west region. Lesser cornstalk borer and spittlebug sometimes damage seedlings and cause large areas to be replanted. Lesser cornstalk borer is most active in dry periods and spittlebug damages upland rice during rainy periods.

WEEDS

Although weeds are one of the most serious upland rice constraints in Brazil, they are not a problem during the first 2 years new lands are cropped. After the second crop year weed competition is a continual production barrier and, without adequate control, can reduce yields by 50% in years with good rainfall and by 70% if dry periods occur. High weed control costs and low rental demand for upland ricelands after the second year cause farmers to replace rice with pasture or other more economically viable crops.

The most common weed species in upland rice areas are the grasses Digitaria sanguinalis, Setaria geniculata, Cenchrus echinatus, Cynodon dactylon, Eleusine indica, Brachiaria plantaginea, and Imperata brasiliensis; sedges Cyperus rotundus and Cyperus spp.; and broadleaf weeds Sida rhombifolia, Cassia tora, Cassia occidentalis, Bidens pilosa, Amaranthus spinosus, Ipomoea spp., Portulaca oleracea, Ageratum conyzoides, Commelina spp., Galinsoga purviflora, Acanthospermum australe, Acanthospermum hispidum, Solanum sp., Borreria spp., Emilia sonchifolia, Euphorbia hirta, Alternanthera ficoidea, Amaranthus spp., and Sonchus oleraceus.

Weeds reduce rice grain yield through competition for water, nutrients, and light and also reduce the quality of the harvested product. If not controlled early in the production cycle, weed populations increase to harmful levels.

Although weeds are usually controlled by manual or mechanical weeding, chemical control is used in some areas. Because weed competition is most severe during the early development of the upland rice crop, efficient weed control is necessary to avoid or minimize yield reduction. Frequent rains early in the crop cycle enhance weed growth and limit manual and mechanical controls, making chemical methods necessary. Integrated weed control techniques are best for upland rice grown in unfavorable conditions and rational utilization of chemical weed control is best in favorable conditions.

BRAZILIAN UPLAND RICE VARIETIES

The active germplasm bank of the National Rice and Bean Research Center (EMBRAPA/CNPAF) has already documented more than 800 traditional varieties of upland rice in Brazil. Small producers, especially subsistence farmers, who use traditional farming methods, are the predominant users of these varieties. However, a few improved modern varieties have been developed for upland areas, and most of these are adapted to unfavorable conditions, although they are extensively planted in favorable regions.

Preferred maturity period for rice varies by upland region in Brazil. In unfavorable uplands medium-duration (120-140 days) and short-duration (100-120 days) varieties are planted. In favored uplands with long rainy seasons, longer-duration varieties, although unavailable, would be selected to mature after the rainy season ends to simplify harvest. Producers currently utilize medium-duration varieties that were developed for unfavorable uplands.

Most Brazilian upland rice varieties are tall, especially when planted in favorable conditions. Height varies between 1.2 m in unfavorable areas and 1.8 m in favorable ones. Varieties have low tillering capacity and are planted at low density to minimize yield losses under limited rainfall.

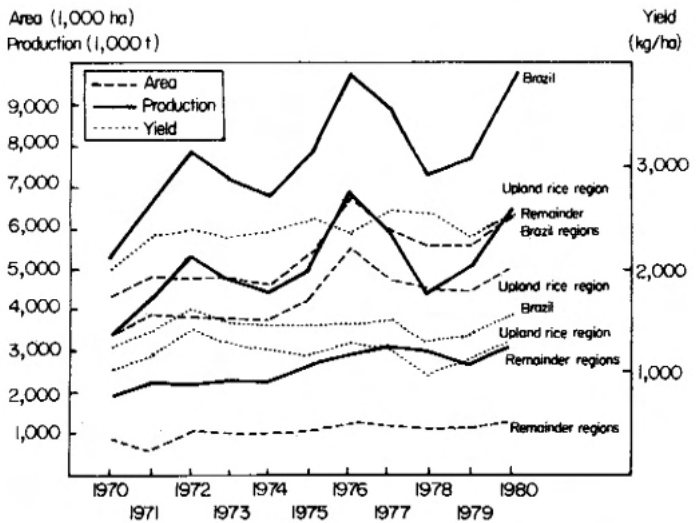
Most varieties have long, broad leaves and substantial foliar area. Leaves are decumbent and glabrous. In favorable conditions foliage causes shade that promotes the spread of pathogens. Plants have long panicles with many glabrous spikelets without aristae and with long, hyaline grains.

Some varieties have blast resistance, but no variety with multiple pest resistance has been developed.

UPLAND RICE YIELD AND PRODUCTION

Although there is no separate information available on upland and irrigated rice yields and production, approximate levels can be estimated by using statistics from states within the primary upland and irrigated areas. Production statistics from Maranhao, Minas Gerais, Sao Paulo, Parana, Mato Grosso do Sul, Mato Grosso, Goias, and Rondonia, where upland rice is the primary system, are used to represent Brazilian upland production in this paper. Other states were selected to represent irrigated production, although all states have some upland producing areas.

Figure 4 shows the fluctuation of relationships between upland rice area, production, and yield from 1970 to 1980. Upland area and production tend to fluctuate more sharply than irrigated areas; however, both areas show a gradual increase at all three levels.



4. Crop area, yield, and production of rice in Brazil.

Table 4. Growth of upland rice area and yield in Brazil 1970-80.

Production region	Area increase (%)	Yield increase (%)
Brazil	44.8	28.3
Uplands	49.8	27.6
Others	21.1	33.5

The growth of area and yield for major upland rice producers in Brazil for 1970-80 is shown in Table 4. Upland rice area increased substantially above other areas, but irrigated yields increased slightly more than upland yield.

Table 5 shows 10-year average upland rice yields in major Brazilian upland rice producing states.

OBJECTIVES OF UPLAND RICE IMPROVEMENT

The current upland rice breeding program in Brazil seeks to develop modern varieties for favorable and unfavorable conditions. Major goals for favorable uplands are to develop high yield potential; lodging resistance; l30- to 150-day maturity, brown spot (*Helminthosporium oryzae*) resistance; good tillering ability; phosphorus utilization efficiency; long, slender, translucent grains; 1 m height; high vegetative vigor; and resistance to pasture spittlebug (*Deois* sp.). For unfavorable upland conditions, goals are

Table 5. Average rice yield for major upland rice growing states in Brazil, 1970-80.

State	Average yield 1970-80 (t/ha)
Rondonia	1.6
Maranhao	1.3
Minas Gerais	1.1
Sao Paulo	1.1
Parana	1.3
Mato Grosso do Sul	1.2
Mato Grosso	1.5
Goais	1.0
State average	1.2
Irrigated areas	2.4
Brazil	1.4

drought resistance, blast resistance, high yield, 100- to 120-day maturity, tolerance for soil stresses (aluminum toxicity, low phosphorus), 100-120 cm height, lodging resistance, and resistance to lesser cornstalk borer (Elasmopalpus lignosellus) and stem borer (Diatraea saccharalis).

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ENVIRONMENTAL CHARACTERIZATION AND CLASSIFICATION

RICE PRODUCTION CALENDAR FOR THE IVORY COAST

J. DALLARD

Rice culture in the Ivory Coast can be categorized as upland, irrigated, or intermediate. Table 1 shows the climatic characteristics of the Ivory Coast, and Table 2 describes land and soil characteristics at major rice-growing locations.

Upland rice is grown in four rainfall zones. Two zones have monomodal rainfall and two have bimodal (Table 3, Fig. 1). Upland rice is planted between April and mid-June and harvested in July and October.

Year-around rice production is possible where there is constant, adequate supply of irrigation water.

Intermediate production is usually along rivers, and almost every site has a different growing season, depending on local rainfall, river water regime, and soil type. Only the rivers that flow into the Niger River (primarily the Bagoue and the Baoule Rivers) are in areas favorable to flooded rice production. Most intermediate rice is grown in the Boundiali and Odienne regions, where long-duration varieties are usually sown in late June.

Widely varying climates in the Ivory Coast require rice varieties with different growth durations, agronomic characteristics, and climatic tolerances. Table 4 lists varieties planted in 1981. Several new varieties have not reached R2 multiplication. They include Bouaké 198b, BG90-2, IRATl09, IRATll2, IRATl04, and IRATl36. Some of them have begun to spread to farmers' fields within the limit of available seeds. Among those is BG90-2, which was developed by WARDA.

West Africa Rice Development Association, P. O. Box 1019, Monrovia, Liberia.

Table 1. Climatic characteristics of the trial sites on the Ivory Coast.

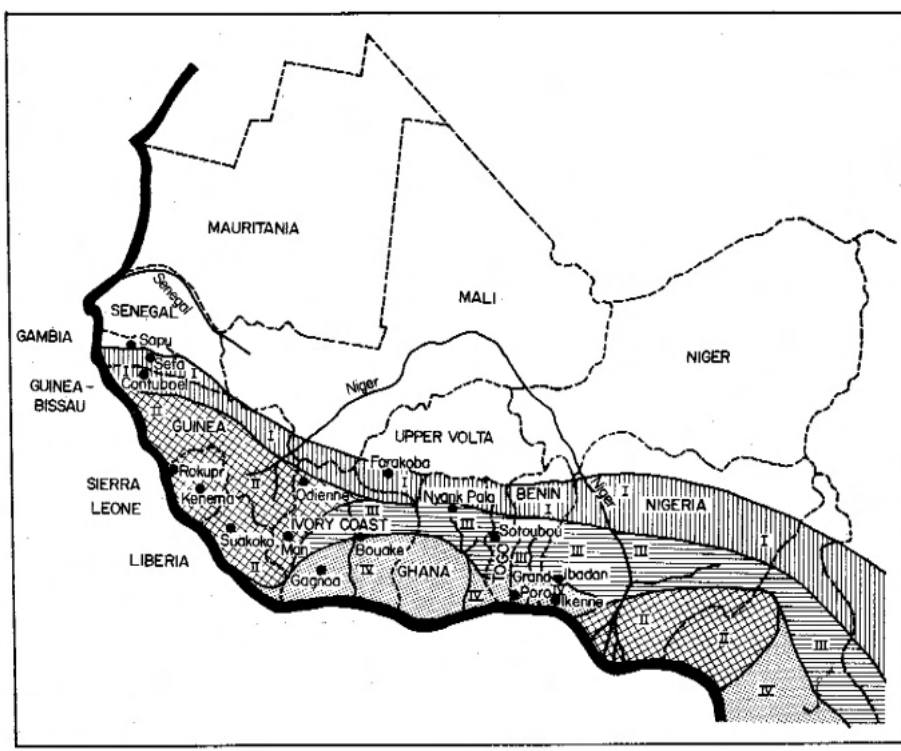
Mo	Man						Gagnoa					
	Evapo-transpiration (mm)	Sunshine hours	Relative humidity (%)	Temp (°C) Max	Temp (°C) Min	Rainfall (mm)	Evapo-transpiration (mm)	Sunshine hours	Relative humidity (%)	Temp (°C) Max	Temp (°C) Min	Rainfall (mm)
J	163	224	71	32.0	16.4	16	117	186	79	31.3	20.5	38
F	150	201	71	33.1	18.9	53	108	176	77	32.6	21.8	73
M	164	200	74	32.4	20.4	110	120	194	80	32.4	21.8	132
A	134	173	79	31.4	20.9	157	128	190	82	33.1	21.9	165
M	116	177	82	30.7	20.9	154	96	177	84	31.1	21.9	175
J	102	127	85	28.1	26.6	204	93	117	87	29.2	21.7	181
J	74	92	87	27.4	20.1	219	71	94	87	28.0	20.9	100
A	83	–	88	27.2	20.2	267	82	81	86	27.9	21.0	78
S	104	125	86	28.6	20.3	313	90	113	86	29.1	21.5	167
O	112	179	85	29.6	20.1	160	102	154	85	30.1	21.8	183
N	106	187	83	29.7	19.3	51	87	171	85	30.8	21.7	108
D	94	192	78	30.7	16.5	20	72	167	84	30.3	20.9	50

Table 2. Soil characteristics of the trial sites on the Ivory Coast.

	Bouake	Man	Odienne	Gagnoa	Korhogo	San-Pedro	Dabou
Latitude	7°40'	7°20'	6°30'	6° 20'	9° 30'	4° 50'	5° 20'
Altitude	375 m	360 m	425 m	190 m	300 m	15 m	10 m
Soil type	ferralitic	ferrallitic	ferrallitic	ferrallitic	hydromorphous on pseudogley alluvium	hydromorphous with gley	peaty
Structure	slightly polyhedral	slightly polyhedral	–	–	-	-	-
Texture	silty-clayey-sandy	clayey-sandy	sandy-clayey silty	silty-clayey-sandy	clayey-sandy	clayey-sandy	peaty
pH	5.5	5.0	5.4	5.2	5.2	5.4	5.3
Chemical Composition	moderately un-saturated	unsaturated	moderately unsaturated	moderately unsaturated	no data	no data	no data
Depth of groundwater table	>1 m	>1 m	>1 m	>1 m	irrigated, complete control	complete control of irrigation	complete control of irrigation
Depth of surface water	rain	rain	rain	rain	irrigated, complete control	complete control of irrigation	complete control of irrigation
Previous harvest	riz + crotalaire	fallow	cotton	maize	irrigated	irrigated	irrigated

Table 3. Upland rice calendar for Ivory Coast.

Zone	Upland pattern	Variety type	Sowing season	Harvest
II	One long, abundant season	Medium-late	Late May	Late Oct
I	One short season	Medium-early	Mid-Jun	Early Oct
III	Two rainy seasons – sowing in the first season, heading in the second	Medium	Early Jun	Mid-Oct
IV	Two rainy seasons – sowing and heading in the first season	Early	Early Apr	Mid-Jul



1. Rainfall zones in West Africa.

Table 4. Rice varieties cultivated in the Ivory Coast in 1981[a] based on seed sales.

Certified seeds	Area (ha)	Potential output (t/ha)	Progression rate	Origin
Early Dourado	1000	3.5	Stable	Brazil
Iguape Cateto	5600	5	Stable	Brazil
Moroberekan	4500	4	Slight decrease	Local c. I. selection
IRAT13	700	6	Strong progression	IRAT C. I. creation
IM16	500	5	Decrease	Guinea
IR5	3800	8	Stable	IRRI
Jaya	3000 (?)	8	Stable	India
Numerous local self-produced varieties	Not known; estimated 200,000-400,000	4	?	

[a] Av output is unknown.

INFLUENCE OF RAINFALL REGIME ON UPLAND RICE PRODUCTION: WATER DEMAND SIMULATION

F. FOREST and J. M. KALMS

In tropical West Africa, fluctuating rainfall often limits upland rice yields, particularly in central Ivory Coast (Gigou 1973). Gravelly soils with low water retention capacity accentuate this effect.

We have described the influence of water demand on upland rice yield during a precise determination of climatic demand, hydrodynamic soil characterization, and in situ interpretation of rice water demand (Kalms et al 1979 1982).

The association of simulated water demand (Forest 1982) with a series of upland rice yields observed from 1967 to 1980 at three fertilizer levels has enabled us to establish response curves for rice yields. These are a function of the intensity of water deficit and the growth period in which the deficit occurs.

This procedure shows that it is possible, with an appropriate modeling tool, to predict the suitability of a site for upland rice cultivation by observing local climate and soil conditions.

SITE DESCRIPTION AND METHODS

Soils

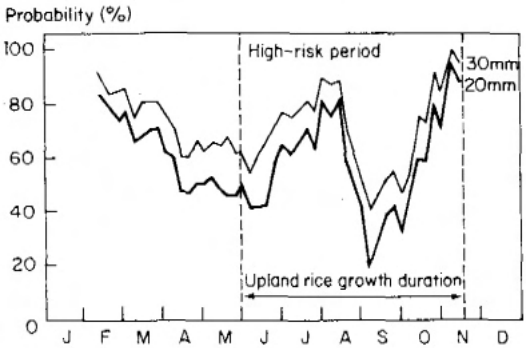
Soils in the central rainfed areas of Ivory Coast are Alfic Ustoxs (sols ferrallitiques faiblement desaturés remaniés) with moderate saturation and plinthites. A hardpan 50 – 80 cm deep prevents deep rooting (Bertrand 1971) for upland rice.

Climate

Bouaké in central Ivory Coast has a highly fluctuating climate. Days regularly vary from dry to moist and sun – ny to hazy.

Rainfall. Bouaké has two distinct rainy seasons. Drought risk is high for upland rice cultivation (Fig. 1), except from 15 August to 15 October, when the chance for drought is less than 20% (Gigou 1973). Farm-

Agroclimatologist, IRAT/GERDAT B. P. 5035, 34032 Montpellier, Cedex, France; and agronomist, IRAT/IDESSA B. P. 635, Bouaké, Ivory Coast, presently at FUDECO, Apt. 7420, Coro, Venezuela.



1. Probability of less than 20-30 mm rainfall for 6 days. Bouaké, Ivory Coast.

ers can cultivate upland rice during the first rainy season, March to June, but they usually cultivate from June to October as at the Bouaké experiment station since 1966. Dry periods dre frequent in July and August when the rice crop is at late tillering and panicle initiation stages.

Evaporation demand. Although originally estimated by Tuc's formula, we evaluated evaporation demand using Penman's equation (Monteny et al 1981). We adapted our formula for Bouaké (Kalms and Monteny 1980) from the generalized formula (Perrier 1977);

$$ETPc = ETo + Eap$$

where ETPc = potential climatic demand,
ETo = radiation term, and
Eap = advection term.

Based on June–October atmospheric conditions, the operational formula considers only the global radiation (RG). The advection term is estimated to remain constant at 20%, thus:

$$ETPc = 1.20\ ETo \quad \text{where } ETo = 8.2 \times 10^{-3} RG$$

from which we determined the simplified relationship

$$ETPc = 9.8 \times 10^{-3} RG$$

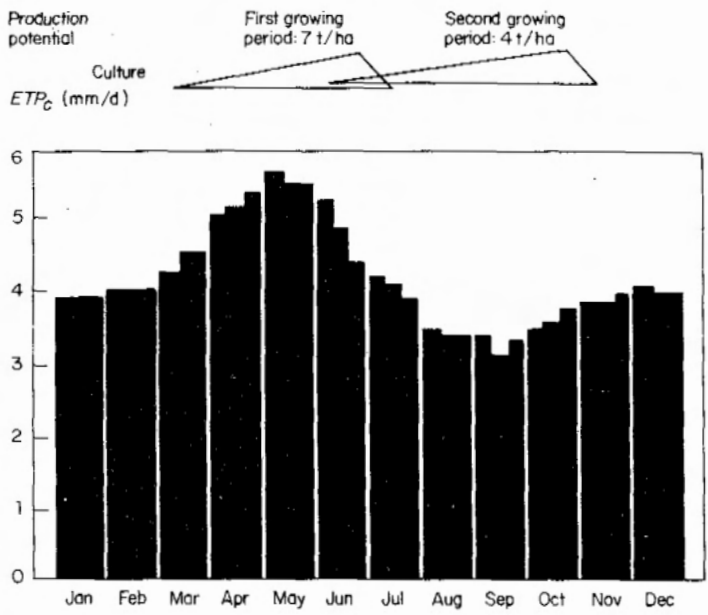
which allows direct estimation of the evaporative demand from global radiation data (Table 1).

The evaporation schedule, expressed in 10-d values (Fig. 2), shows that maximum potential photosynthesis is related to global radiation in March–May when, in the absence of water deficit, high production is possible.

Considering the rainfall risk (Fig. 1) and the short vegetative period for the first crop, the single-crop option gives the best chances for success (Gigou 1973).

Table 1. Mean 10-d values of global radiation at Bouaké (1968-78) during upland rice growing period.

	Global radiation (cal/cm^2 per day)														
	Jun			Jul			Aug			Sep			Oct		
Min	390	323	335	306	282	279	296	281	285	320	336	330	337	305	286
Max	502	472	474	401	427	408	394	370	407	406	446	450	450	494	463
Mean	432	414	391	358	337	336	339	320	341	358	366	387	394	400	409
CV %	14	40	40	30	39	40	32	26	39	28	30	38	34	47	50



2. Evapotranspiration and production of upland rice without water stress at Bouaké.

UPLAND RICE WATER NEEDS

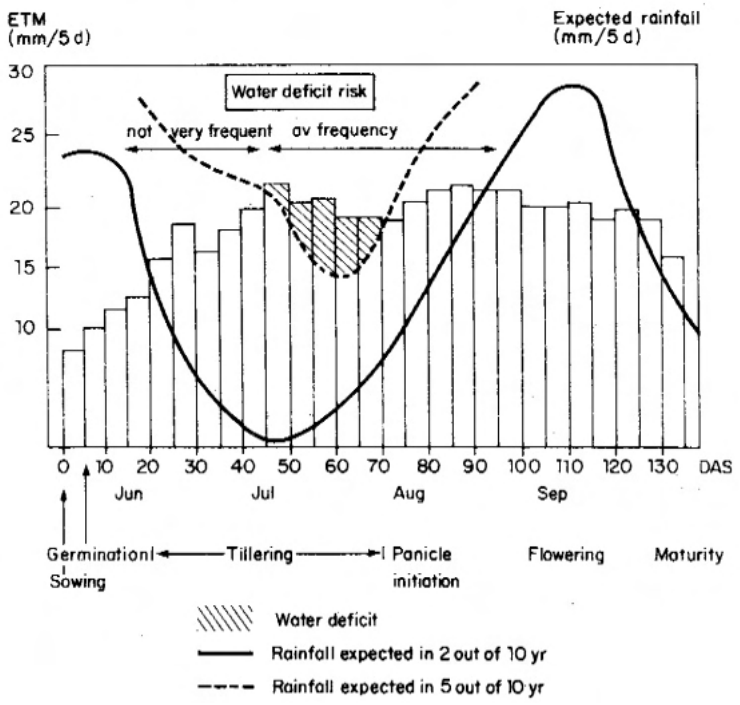
Maximum needs = ETM

Ivory Coast (Kalms 1980) and southern Senegal (Dancette 1979) studies characterized maximum water needs by Kc cultural coefficients corresponding to different states of crop development, in reference to potential climatic evapotranspiration.

$$\underline{ETMi} = \underline{Kc} \times \underline{ETPci} \text{ (period } \underline{i}\text{)}$$

The distribution of water needs (Fig. 3) shows that upland rice has two distinct growth stages with relatively high water requirements: a) during tiller multiplication and field colonization (between 10 July and 1 August), and b) at panicle initiation and heading (15 August-25 September) when water need exceeds 4 mm/d (kc = 1.30).

A comparison of 10-d upland rice water needs (ETMi), with the mean 10-d rainfall expected in 2 out of 10 yr and in 5 out of 10 yr during the second rainy season in Bouaké (Fig. 3) represents estimation of rainfall risk in upland rice cultivation. Soil type, improved cultural techniques, and planting drought-tolerant varieties can moderate this natural handicap.



3. Upland rice ETM and expected rainfall at Bouaké.

Energy and photosynthetic needs of upland rice

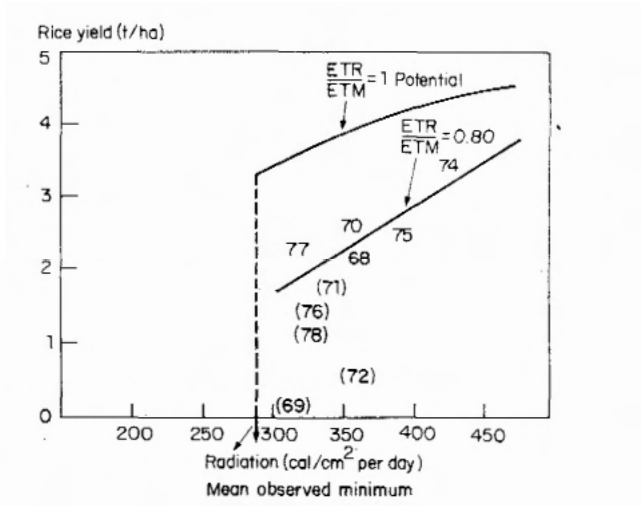
Solar radiation is essential to plant growth and tiller development since maximum yield depends on plant population at the beginning of the reproductive phase (Yoshida 1978). High solar radiation is of primary importance (Fig. 4, Posner 1978). When solar radiation is adequate, yield reduction relates directly to water availability. For this reason, we estimated the maximum yield for second-season rice at Bouaké to be 3.5 t/ha in 1974. An 80 mm supplementary irrigation would have increased yield potential to 5 t/ha (curve $\frac{ETR}{ETM} = 1$).

WATER BEHAVIOR OF GRAVELLY SOILS

Gravelly soils with high moisture permmeabilicy that were saturated with water (Le Buanec 1975) and planted to upland rice from 1966 to 1980 resisted erosion and streaming (Kalms 1977).

A hardened horizon limits soil water supply to upland rice below 50-cm soil depth and allows root development to only about 70-cm depth.

Neutron and tensiometer analyses have allowed precise characterization of the usable water reserve for different soil type depths (Table 2).



4. Effect of global radiation during tillering on upland rice yield. 76 = yield under water stress. The upper curve is Posner's (1978).

Table 2. Usable watcr reserve in gravelly soil.

Depth (cm)	Usable water reserve (mm)
0 - 15	14
16 - 30	11
31 - 45	9
46 - 60	8
61 - 70	5
Total 0-70	47

Low water availability is caused by the combination of two factors: soil whose texture may allow only low water retention, and roots with very low capacity to extract soil water when the potential is 900 millibars or less.

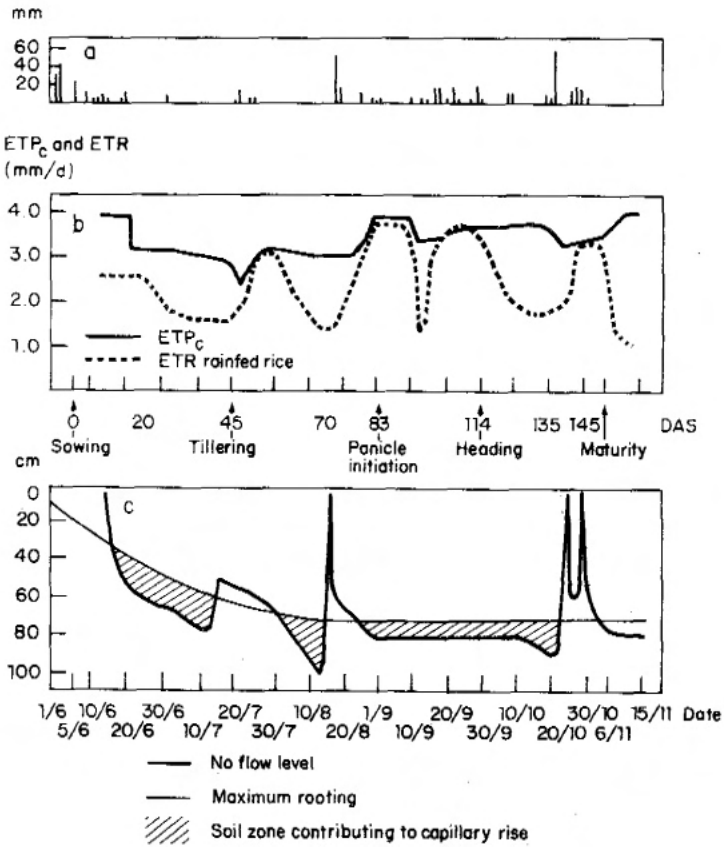
However, upland rice can obtain enough water to survive (ETR = 1 mm/day), because it has weak capillary rise (Fig. 5), and there is frequent morning dew from tillering to panicle initiation stages. We used a Hiltner dew recording machine to determine that 0.2-0.4 mm of dew forms on rice plants each day and reduces the evaporation demand in the morning.

Cultivation conditions

The 1966-80 trial. Agronomic experiments at the IRAT-IDESSA station at Bouaké sought to identify the most effective crop rotation for subsistence farmers as an alternative to traditional shifting agriculture (Kalms and Chabalier 1981).

The trial fields were at the edge of a 350-m elevation plateau. The trial was a 3-yr rotation with 3 levels of intensification. This rotation is similar to cultivation practiced in the Bouaké area of central Ivory Coast (Table 3).

We planted upland rice in 100-m^2 plots and followed procedures used since 1967: tilling in May, applying fertilizers basally, sowing 60 kg seed/ha in rows spaced 30 cm, weeding manually (hoeing with the daba or baoulian hoe), broadcasting nitrogen ferti-



5. a. Rainfall at Bouaké, 1978. b. ETP_c and ETR of upland rice in situ. c. Depth of no-flow level and maximum rooting of rice.

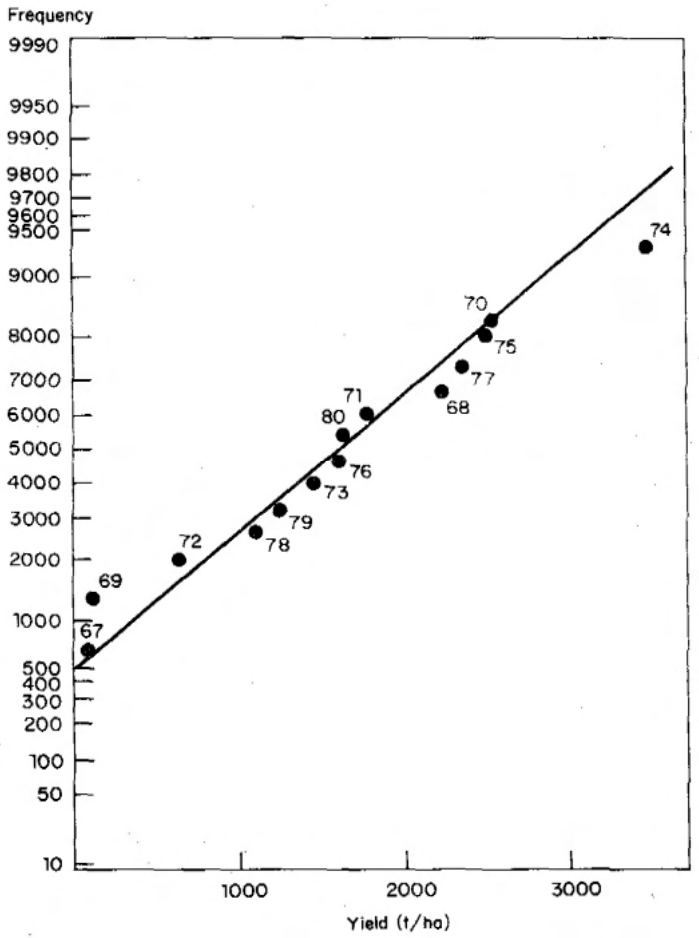
Table 3. Cultivation practices for GII trial at Bouaké.

Plants in rotation:	yam, maize, cotton, upland rice
Fertilization:	Mineral and organic; three levels: without (FO), F1, F2 (F2 = 2 × F1)
Land preparation:	by hand (daba), plowing with animals, plowing with tractor

lizer, and harvesting rice manually. OS6 variety was planted from 1966 to 1972 and Iguape Cateto from 1973 to 1980. Both matured in 135 days.

The following model, considerably simplifies the situation because it only considers the date when 5 d cumulative rainfall at Bouaké is more or less equal to 40 mm, permitting good crop growth.

Yield variability of upland rice. The yield distribution observed for upland rice (level F2) is normal (Fig. 6). Total rainfall during the growth cycle (Kalms and Chabalier 1981) partly caused high yield variability (.8-3.45 t/ha) (Table 4). Sowing date, which was always during the first 10 d of June, does not seem to have had an effect. Rainfall distribution in each phenological stage appeared to determine yield. However, it was impossibls to describe a simple relationship between yield and drought because drought varied in



6. Yield adjustment to HENRY straight line.

Table 4. Rainfall and upland rice yield at Bouaké.

Year	Rainfall (mm)	Useful rainfall[a] mm	Sowing date	Yield (t/ha)
1966	–	–	late sowing (Jul)	not harvested
1967	515	370	25-31 May	0.10
1968	965	475	1-05 Jun	2.20
1969	370	350	6-10 Sun	0.08
1970	725	420	1-05 Jun	2.50
1971	145	475	1-05 Jun	1.76
1972	370	310	1-05 Jun	0.62
1973	528	380	1-05 Jun	1.40
1974	620	460	1-05 Jun	3.45
1975	525	415	6-10 Jun	2.45
1976	410	365	1-05 Jun	1.55
1977	710	400	1-05 Jun	2.32
1978	350	310	1-05 Jun	1.05
1979	821	520	1-05 Jun	1.20
1980	833	600	6-10 Jun	1.55
Mean	606	418	first Jun decade	1.58
S. D.	190	79		0.95

[a] Useful rainfall is the proportion of total rainfall to the useful reserve.

duration, intensity, and frequency during the crop cycle, and affected rice stages differently (Reyniers and Kalms 1976). Water demand simulation can describe the susceptibility of upland rice yield to the rainfall regime.

MODELING UPLAND RICE WATER DEMAND

It is possible to estimate rice crop evapotranspiration using the general equation of water demand (Charoy et al 1978) if some climate, soil, and agronomic data are available (Forest 1982, Table 5).

Climate data

Daily rainfall is the basis for the evapotranspiration simulation model. By using the 36 measured or estimated values of Penman's potential evapotranspiration or class A pan evaporation, one can determine ETP. Either the ETP Penman (K) or class A pan evaporation (K^1) can adjust cultural coefficients evaluated in 10-d periods.

Soil water availability is in millimeters of water depth and is a function of three criteria: maximum depth of soil for rooting, rooting capacity of the crop expressed in depth of the settled soil, and plant water storage capacity between permanent wilting and saturation humidities.

For the GII trial, the pedological constraint is a usable reserve of 50 mm available water at 70-cm soil

Table 5. Estimated ETR consumption of upland rice by a model of the water demand[a] at Bouaké.
Year: 1978
Maximum Usable Reserve: 50 mm Streaming Coefficient : 0.0
Uplandrice

Periods	P	HR	K	ETR	ETM	RES	RU-I	DR	Satis	Defi	Disp	Front
1 Jun	77.1	0.00	0.35	9.6	9.6	40.4	0.0	67.4	1.00	0.0	3.0	50
2 lun	39.6	0.80	0.40	11.0	11.0	39.0	0.0	30.0	1.00	0.0	1.5	50
3 Jun	20.0	0.80	0.45	12.2	12.2	37.8	0.0	9.0	1.00	0.0	0.0	50
4 Jun	5.9	0.68	0.50	13.5	13.4	30.3	0.0	0.0	0.99	0.1	0.0	50
5 Jun	12.1	0.65	0.60	16.5	15.5	27.0	0.0	0.0	0.94	1.0	0.5	50
6 Jun	0.0	0.34	0.70	19.2	13.6	13.4	0.0	0.0	0.71	5.7	0.0	50
1 Jul	8.0	0.23	0.80	16.8	10.7	10.7	0.0	0.0	0.64	6.1	0.0	50
2 Jul	0.0	0.01	0.90	18.9	3.3	7.3	0.0	0.0	0.18	15.6	0.0	50
3 Jul	0.0	0.00	1.00	20.5	2.6	4.7	0.0	0.0	0.13	17.9	0.0	50
4 lul	0.0	0.09	1.10	22.6	4.7	0.0	0.0	0.0	0.21	17.8	0.0	50
5 Jul	19.1	0.38	1.10	20.9	14.8	4.3	0.0	0.0	0.71	6.1	0.5	50
6 Jul	11.7	0.32	1.10	25.1	13.8	2.3	0.0	0.0	0.55	11.3	0.0	50
1 Aug	0.0	0.05	1.10	19.2	2.3	0.0	0.0	0.0	0.12	17.0	0.0	50
2 Aug	0.0	0.00	1.10	19.2	0.0	0.0	0.0	0.0	0.00	19.2	0.0	50
3 Aug	0.0	0.00	1.15	19.0	0.0	0.0	0.0	0.0	0.00	19.0	0.0	50
4 Aug	68.2	1.00	1.25	20.6	5.5	44.5	0.0	18.2	0.27	15.1	2.5	50
5 Aug	0.5	0.50	1.30	21.5	17.0	28.0	0.0	0.0	0.79	4.5	0.0	50
6 Aug	10.6	0.77	1.30	25.7	23.2	15.4	0.0	0.0	0.90	2.5	0.5	50
1 Sep	9.8	0.50	1.30	21.5	17.0	8.2	0.0	0.0	0.79	4.4	0.0	50
2 Sep	0.0	0.16	1.30	21.5	8.2	0.0	0.0	0.0	0.38	13.3	0.0	50
3 Sep	9.2	0.18	1.30	20.1	9.2	0.0	0.0	0.0	0.46	10.9	0.0	50
4 Sep	32.5	0.65	1.30	20.1	17.9	14.6	0.0	0.0	0.89	2.2	1.0	50
5 Sep	18.2	0.66	1.25	20.6	18.3	14.5	0.0	0.0	0.89	2.4	0.5	50
6 Sep	20.5	0.70	1.15	19.0	17.4	17.6	0.0	0.0	0.92	1.6	0.5	50
1 Oct	4.6	0.44	1.15	20.1	15.7	6.6	0.0	0.0	0.78	4.5	0.0	50
2 Oct	12.0	0.37	1.10	19.2	14.2	4.4	0.0	0.0	0.74	5.1	0.0	50
3 Oct	0.0	0.09	0.90	16.2	4.4	0.0	0.0	0.0	0.27	11.8	0.0	50
4 Oct	9.8	0.20	0.80	14.4	9.5	0.3	0.0	0.0	0.66	4.9	0.0	50
5 Oct	51.4	1.00	0.00	0.0	6.2	43.8	0.0	7.7	0.00	0.0	2.0	1
6 Oct	66.7	0.50	0.00	0.0	15.5	34.5	0.0	60.5	0.00	0.0	2.5	1
1 Nov	0.0	0.69	0.00	0.0	3.9	30.6	0.0	0.0	0.00	0.0	0.0	1
Total	833.0	SOMETP	1543.00	525.00	97.0		0.0	339.0		220.0	23.0	

Index of ETR/ETM satisfaction

IDV	FL1	FL2	FL3	MATUR	CYCLE
0.68	0.27	0.63		0.70	0.54

□ Period of water deficit

[a]P = rain, HR = relative humidity, K = cultural coefficient, ETM = water need, ETR = consumption, RES = reserve, RU/I = streaming or irrigation, DR = drainage, Satis = satisfaction of water needs, Defi = water deficit (mm), Disp = number of unworkable days (soil), Front = value (mm) of profile moisture.

depth (see estimated punctual measure at 47 mm) (Table 2).

Agroclimatic situation

Parameters determining cultivation conditions, evapo-ration, and water regime identify every agricultural situation. They are

- the quantity of rain that determines optimum sowing date;
- the number of days between early growth of the main crop and sowing of the second crop;
- delays caused by improper technology; and
- the number of half-days when excessive soil moisture prevents tillage.

The following model is simple because it only considers optimum sowing date, (40 mm or more cumulative rainfall for 5 days at Bouaké).

Agrophysiological information

After developing a tool to determine crop water availability it is interesting to try to link the ETR/ETM water needs with rice yield as determined by water supply from tillering to heading.

This model analyzes the influence of water supply on yield at different crop stages over several years. Agronomists and physiologists can then use the model to develop better cultivation systems to take advantage of rice varieties bred for drought resistance (Reyniers et al 1976).

Three water demand terms are important to breeders and economists:

- water drainage during the first 2 mo after sowing;
- adequate water for ETR/ETM at different crop growth stages; and
- ETM-ETR water deficit, which determines the necessary level of supplemental irrigation.

EXPERIMENTAL RESULTS

Controlled environment experiments have only been on the effect of cultural practices on yield and have not clearly defined the role of fluctuating soil and climate conditions. A simulated water demand model provides soil-climate information for comparison with other yield components.

Analysis of optimum sowing periods

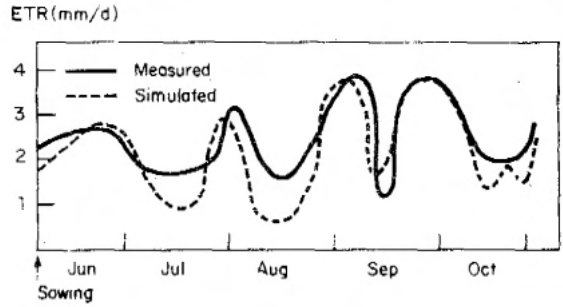
A rainfall frequency analysis can predict the optimum sowing date which is 25-31 May in Bouaké. Planting the crop at that time reduces the effect of drought from late July to mid-August on a medium-duration (125-135 d) variety.

Estimated actual evapotranspiration

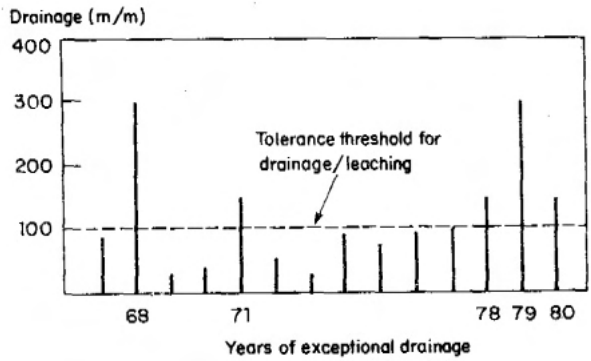
Values of actual evapotranspiration estimated in the model (Fig. 7) compared favorably with those determined by in situ measurement (Fig. 5). The quadratic difference between actual and simulated evapotranspiration for 5 d shows that for the overall cycle the average relative difference is 10.7%.

Leaching

The amount of water that drains beyond the root zone during the first 60 d of cultivation indicates the level of fertilizer leaching (especially N) that can occur. Heavy drainage in 1968 and 1979 (Fig. 8) probably caused a yield decrease of 1 to 2 t/ha. Therefore, we should study physiological relationships of nitrogen fertilizer, nutritional needs of upland rice, and the leaching action in gravelly soil.



7. Comparison between actual evapotranspiration, simulated and measured in situ (1478).



8. Evolution of drainage under cropping for June/July.

Effect of drought and leaching on upland rice yield

Water supply affects upland rice yield three ways at different times during the crop cycle (Table 6.).

If excess water is present during the first 60 d of crop growth (1968, 1971, 1978, 1979, 1980), fertilizer leaching may reduce upland rice yield potential. Even with a well-established crop, a leaching rate more than 2.4 or 100 mm in the first 2 mo of crop growth will seriously limit fertilizer utilization. The minimum water deficit during the crop cycle determines the plants' response to water (Fig. 9a).

When water is the limiting factor, the yield-water supply correlation considers the average rate of water needs of the plant (Pig. 9b). Therefore, upland rice has good drought resistance when no water deficit or excesses disturb the early growing period. It can also survive during water stress (1970-75, 1971, 1977) recovering rapidly with rainfall. However, very low yields observed during drought years (1967, 1969, 1972) show that a regular water supply is necessary to attain good yields. These yields help identify drought tolerance thresholds (Table 7).

Table 6. Rates of satisfaction of water needs, and index of leaching in relation to rice-paddy production at Bouaké.

Year	ETR/ETM (%) at indicated DAS					Index of leaching[a] (1-60 DAS)	Production[b] (t/ha)
	1-50	51-75	76-100	101-135	Cycle		
1974	89	80	88	90	86	1.3	3.4
1970	83	49	93	90	72	0.8	2.5
1975	94	49	70	86	76	1.2	2.4
1977	77	39	90	96	68	1.9	2.3
1968	95	95	94	93	95	3.1	2.2
1971	82	50	75	96	74	2.4	1.8
1976	77	41	68	78	64	0.9	1.6
1980	59	90	96	94	80	2.4	1.6
1973	67	53	89	75	63	0.5	1.4
1979	94	83	43	92	80	3.2	1.2
1978	68	27	63	70	54	2.1	1.1
1972	73	20	61	71	53	1.0	0.6
1967	76	39	82	92	66	1.9	0.1
1969	66	32	72	81	57	0.7	0.07

[a] Index of leaching = $\frac{DR}{RFU}$ (RFU = 40 mm)

[b] Long-duration trial GH IRAT/IDESSA 1966-80. F2 level (Table 4).

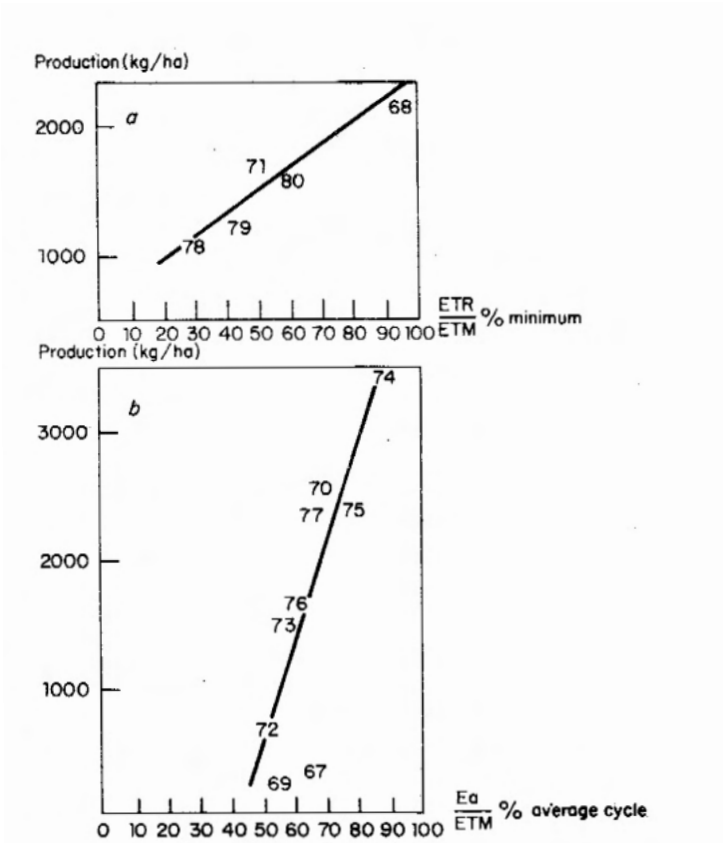
When water resources become available at Bouaké, researchers would view supplementary irrigation with interest. An annual 60 mm (net dose: 40 mm) would stabilize production at 2.5 t/ha. Then the expected average annual production would be 1.0 t/ha, for a 1.67-kg rice paddy gain from a cubic meter of pumped water.

Influence of water deficit and drainage on fertilizer effectiveness and plant vigor

The conjunction of two independent factors determines upland rice production:

1. When combined with decreased radiation at the early growth stage, rainfall excess leaches fertilizer and lowers plant vigor, drought tolerance, and recovery ability. Thus, leaching reduces yields to 2 t/ha during 5 out of 14 yr (Fig. 9a),
2. Satisfying plant water needs is vital during growth when dry and moist periods alternate. If fertilizers are sufficient in such a situation (Fig. 9b), rice can survive and recover. In Bouaké, an important drought occurs in 9 out of 14 yr which makes it a good location to improve drought-resistant varieties. At Bouaké, maximum yield is 5 t/ha, with 100% satisfaction of the crop's water needs and without water excesses during the start of growth.

In agroeconomic terms, Figure 10 justifies the choice of traditional farmers preferring lower yields



9. Influence of drainage and water deficit on upland rice production. a. Production and minimum satisfaction of water needs observed during 25 consecutive days after cultivation begins with water excess: drainage (1-60 DAS) > 100 mm. b. Production and average satisfaction of water needs throughout the cycle after cultivation begins without water excess: drainage (1-60 DAS) < 100 mm.

with full security (F0 to F1) to risk with greater crop intensification (F1 to F2).

CONCLUSION

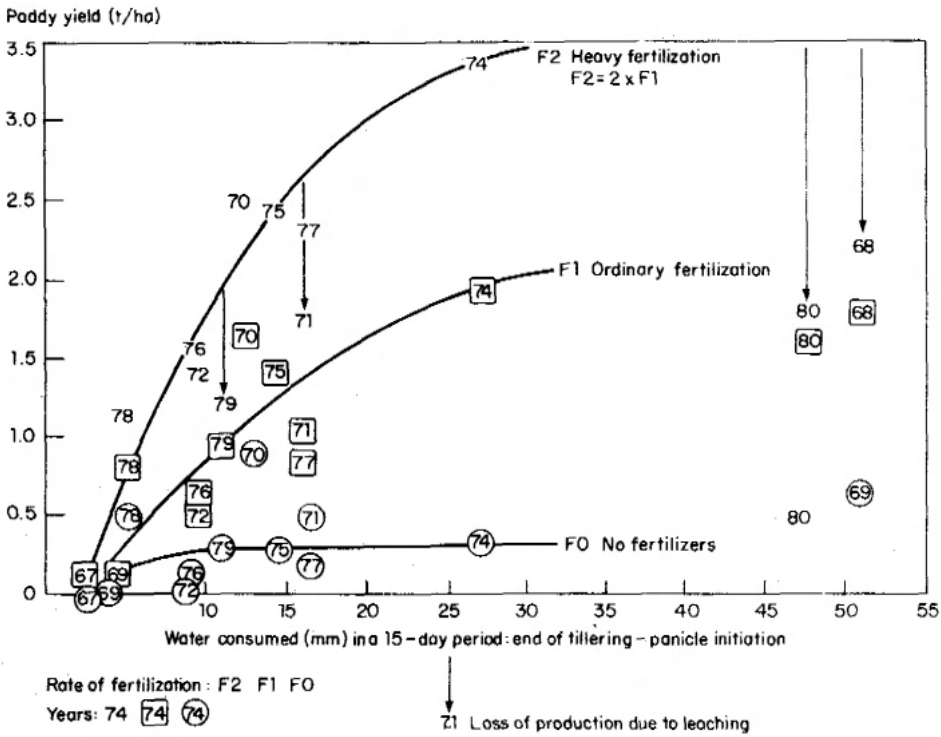
A model and water balance simulation show soil and water regime influences on upland rice production. This method also works for other annual cultures (Dancette and Forest 1981).

By taking into account the plant's environment and the fluctuations of the principal factors determining the environment (rain, evaporation, usable soil reserve), the technique evaluates expectations for upland rice production at different intensity levels.

Table 7. Production objectives and miminum thresholds for satisfaction of water needs.

Production level (t/ha)	ETR/ ETM[a] (%)	Daily av ETR (mm/day)
3	80	3.2
2	40	1.6
1	30	1.2

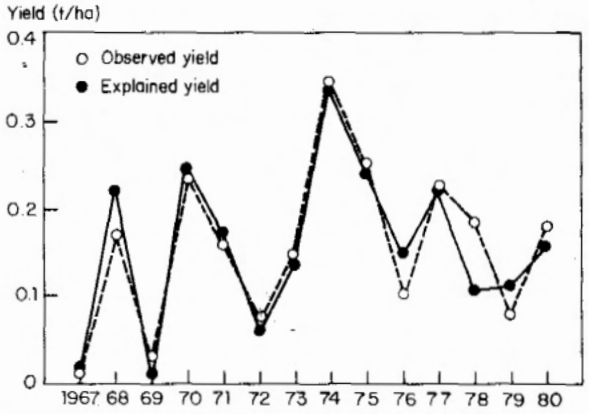
[a] In 25 consecutive d.



10. Upland rice yield under three fertilization levels in relation to simulated actual evapotranspiration.

Because the crop is susceptible to water deficit and excessive drainage, the technique is useful for research to minimize the effect of drought and fertilizer management. Thus, we can evaluate identified water consumption levels (maximum, medium, and minimum) as a measure of a chosen variety's adaptability to a given environment.

The use of water demand model is a scientific approach to explain yields (Fig. 11, Table 8) by identifying and counteracting the major constraints to production.



11. Explaining upland rice yield by modeling the water demand.

Table 8. Explanation of upland rice yield in the Central Region, by multiple regression.

Years of excessive drainage at the beginning of the culture (1-60 DAS)
DR/RU ≥ 2,0
R^2 = 0,83

$$\text{Production} = -505{,}1 + 10.3\left(\frac{ETR}{ETM}\right)_{76}^{100\ DAS} + 17{,}0\left(\frac{ETR}{ETM}\right)_{1}^{130\ DAS}$$

Years without excessive drainage at the beginning of the culture (1-60 DAS)
DR/RU < 2, 0
R^2 = 0, 97

$$\text{Production} = -2451{,}7 - 955{,}1\left(\frac{ETR}{ETM}\right)_{1}^{50} - 906{,}7\left(\frac{ETR}{ETM}\right)_{51}^{75} + 94{,}5\left(\frac{ETR}{ETM}\right)_{76}^{100}$$

$$-699{,}9\left(\frac{ETR}{ETM}\right)_{101}^{130} + 2542{,}1\left(\frac{ETR}{ETM}\right)_{1}^{130} - 313{,}6\frac{DR}{RU}$$

Theoretical potential production: $\frac{ETR}{ETM}$ = throughout the cycle

1. Year with drainage
2. Year without drainage

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ASIAN UPLAND RICE ENVIRONMENTS

D.P.GARRITY

Although upland rice has not been cultivated as long as lowland rice (Chany 1976), it has had a long history as a major form of rice culture in Asia. Most upland rice is produced in permanent unbunded fields and has always been the predominant base crop in shifting cultivation systems throughout tropical Asia.

Production tends to be widely dispersed, which results in a diverse range of climatic conditions, soils, and crop management systems.

The average yield has held at about 1 t/ha during the 1970s (Barker and Herdt 1979). Upland rice technology has lagged mostly because of environmental diversity and few researchers and research stations to pursue work.

A clearer understanding of the range and importance of the dominant upland rice environments would greatly enhance the exchange of genetic materials and management technology.

DEFINITIONS

Upland rice has been defined in various ways in Asia, resulting in confusion among researchers. In the Philippines, upland rice is that grown on soil usually dry on the surface. In Japan, it is bunded, irrigated rice at higher elevations. In India, upland rice is that grown in elevated rainfed bunded fields with undependable water supply. These three cases represent widely differing rice ecosystems.

For this workshop upland rice is that grown in rainfed, naturally well-drained soils, without surface water accumulation, normally without phreatic water supply, and normally not bunded. The most important feature In this definition is that ricelands submerged for a significant part of the growing season are not considered upland rice.

The most comprehensive estimates of upland rice area and geographical distribution in Asia were made by Huke (1982). He defined upland rice as grown in fields

Associate agronomist, International Rice Testing Program, International Rice Research Institute, Los Baños (mail address: P. O. Box 933, Manila), Philippines.

that are pot bunded; are prepared and seeded under dry conditions, and depend on rainfall for moisture. This is the definition traditionally used by IRRI (De Datta 1975a). It is similar to the workshop definition because it excludes bunded ricelands but is slightly broader because it includes some nonbunded ricelands that are subjected to a phreatic water supply or shallow flooding later in the season. However, because these situations are infrequent in Asia, the two definitions may be considered the same.

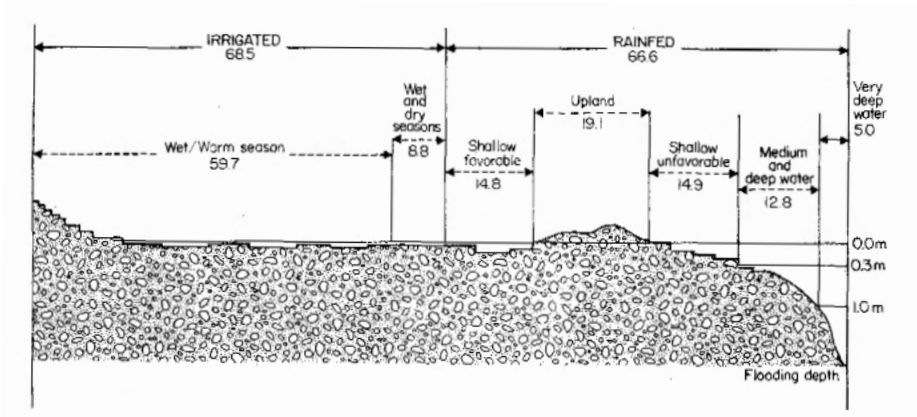
Huke (1982) used dryland for upland. Because upland has been laden with misunderstanding in the Asian context, dryland will be used in the following discussion. Data dicussed correspond to unbunded ricelands as they were defined in his work.

AREA AND DISTRIBUTION

Figure 1 shows the position of dryland rice compared to other major rice cultural systems. About half of the world's 135 million ha of riceland is rainfed, and of this, 19.1 million ha is dryland. This is 14% of the total rice area and 29% of the rainfed area. Dryland rice area is considerably less than shallow rainfed wetland (5-30 cm water depth) but more extensive than medium deep and deep water rice (30-100 cm maximum depth) or very deep water rice (>100 cm maximum depth) areas.

In South and Southeast Asia, dryland rice covers about 11.6 million ha (13%) of the total riceland. South Asia produces about 7.0 million ha while Southeast Asia has 4.6 million ha.

More than half of Asia's dryland rice is in India (6.0 million ha). Indonesia grows dryland rice on more than 1 million ha. Nine of the 14 rice-growing



1. Relative areas of the world's rice land, by water regime. Horizontal extent is approximately proportional to the extent of the classes. No elevation scale. Numbers are million ha.

countries of the region have more than 0.3 million ha of dryland rice. In Laos, dryland rice is more important than all other rice culture systems (Table 1). More detailed estimates of dryland rice area within provinces may be found in Huke (1982). Dependable estimates of dryland rice in China are unavailable, but it may be only about 600,000 ha (1.4%) of the total rice area (Huke 1982).

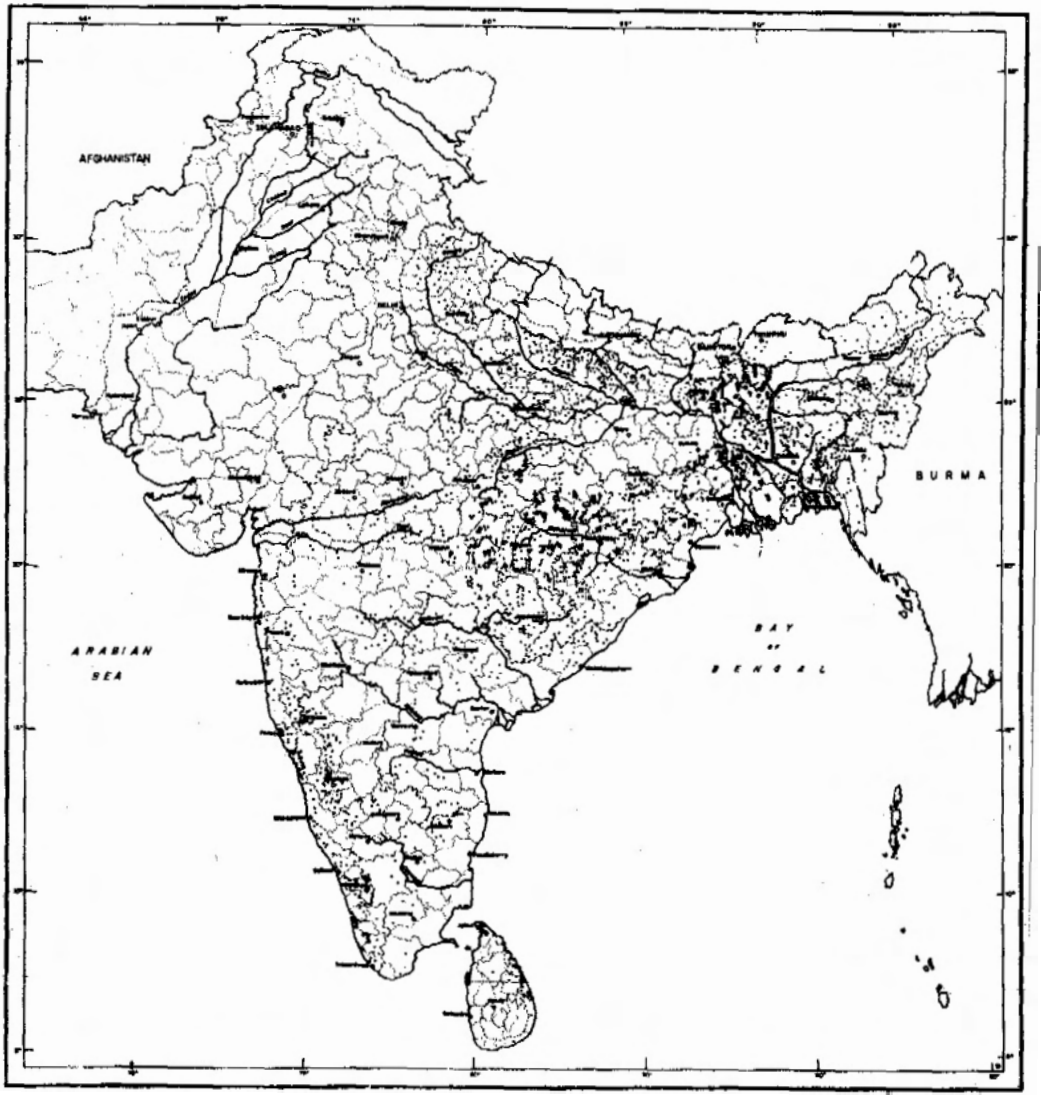
Figure 2 shows that dryland rice in India is concentrated in the eastern and north central states and along the southwestern coast. A large amount of dryland rice is found in Bangladesh, but it is not grown in Pakistan, and is unimportant in Sri Lanka, Nepal, and Bhutan.

Dryland rice is found in northern and southeastern Burma, northern and eastern Thailand, throughout Laos and Kampuchea, and in the highlands of northern and southern Vietnam (Fig. 3). Malaysia has very little dryland rice, mostly in Sarawak on the island of Borneo (Kalimantan). In Indonesia, dryland rice is predominantly in West Java, Sumatra, Sulawesi, and Kalimantan. In the Philippines, most is in southern Luzon and the western half of Mindanao.

Table 1. Estimated rice area in South and Southeast Asia by major culture type and county (Huke 1982).

Country	Area allocated (thousand ha)						Total
	Dryland	Floating (> 100 cm)	Irrigated[a]		Rainfed		
			Wet season	Dry season	Shallow (0-30 cm)	Deep water (30-100 cm)	
South Asia							
India	5,973	2,434	11,134	2,344	12,677	4.470	
Bangladesh	858	1,117	170	987	4,293	2,587	
Pakistan	–	–	1,710	–	–	–	
Sri Lanka	52	–	294	182	210	22	
Nepal	40	53	261	–	678	230	
Bhutan	28	–	–	–	121	40	
Total	6,951	3,604	13,569	3,513	17,979	7,349	52,965
Southeast Asia							
Burma	793	173	780	115	2,291	1,165	
Thailand	961	400	866	320	5,128	1,002	
Viet Nam	407	420	1,326	894	1,549	977	
Kampuchea	499	435	214	–	713	170	
Laos	342	–	67	9	277	–	
Malaysia	91	–	266	220	147	11	
Indonesia	1,134	258	3,274	1,920	1,084	534	
Philippines	415	–	892	622	1,207	379	
Total	4,642	1,686	1,685	4,100	12,396	4,238	34,741
Grand total	11,593	5,290	21,254	7,613	30,375	11,587	87,712
%	13	6	24	9	35	13	

[a] Double-cropped areas are counted twice.

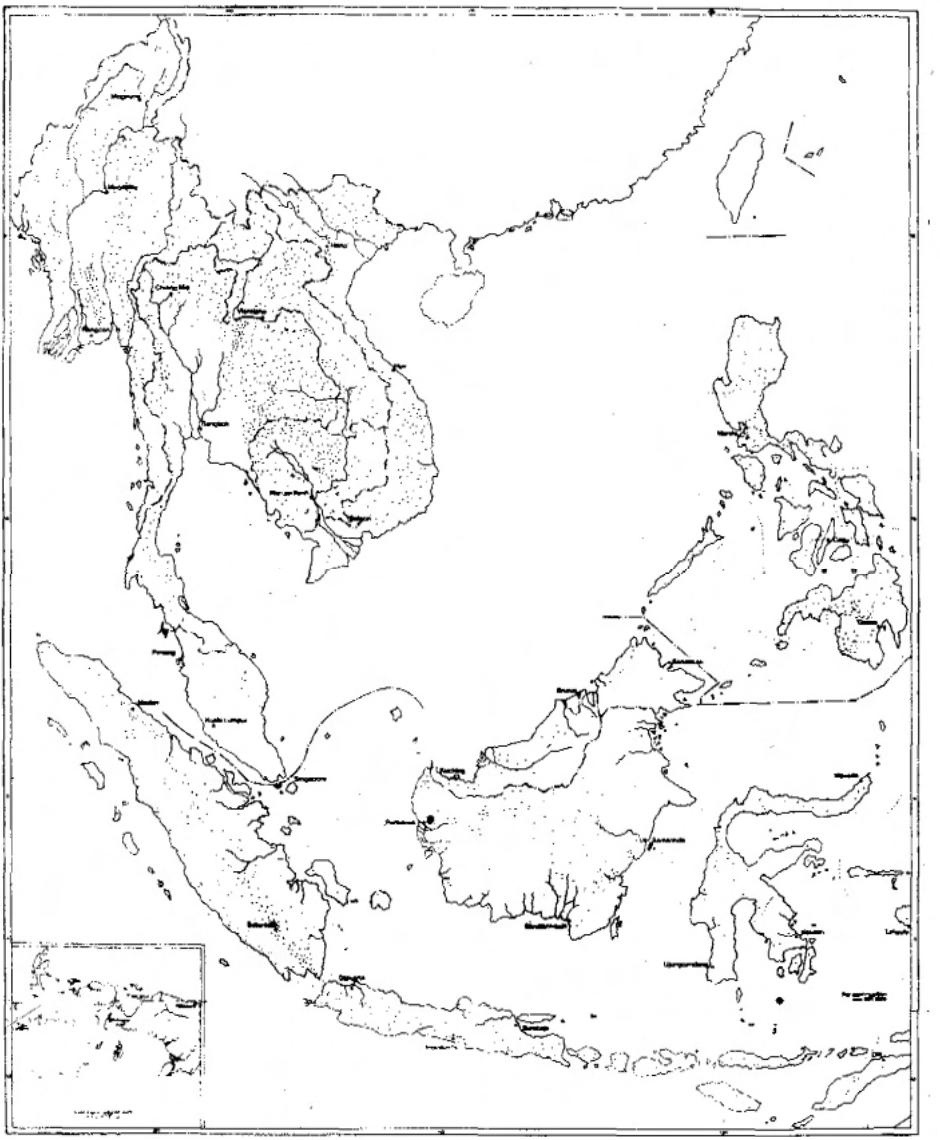


2. Dryland rice distribution in South Asia. Each dot represents 3,000 ha (source: Huke 1982).

Given present yield and area planted, Huke (1982) estimated that dryland rice in Asia may supply about 46.2 million people with 75% of their average daily needs.

DRYLAND RICE ECOSYSTEMS

Climatic and soil conditions are the major physical constraints of dryland rice productivity. Climate, specifically the amount of rainfall and the length and continuity of the humid period, is the dominant factor,



3. Dryland rice distribution in Southeast Asia. Each dot represents 3,000 ha (source: Huke 1982).

although soil fertility and water-holding capacity are also important. Poor soil fertility is frequently a major limitation.

The biological environment is dominated by the degree of rice blast disease (Pyricularia oryzae). Other disease and insect pests are locally Important.

Human environment variations, including technological level of the rice-growing community and its rice quality preferences, also determine characteristics of dryland rice culture.

An ecosystem is a pattern of relationships among the physical, biological, and evolutionary factors in an area (Buddenhagen 1978). Many dryland rice ecosystems could be identified. But genetic improvement has not focused beyond the general concept of dryland because the ecosystems have not been differentiated, a first step in improved targeting of research.

CLASSIFICATION METHODS

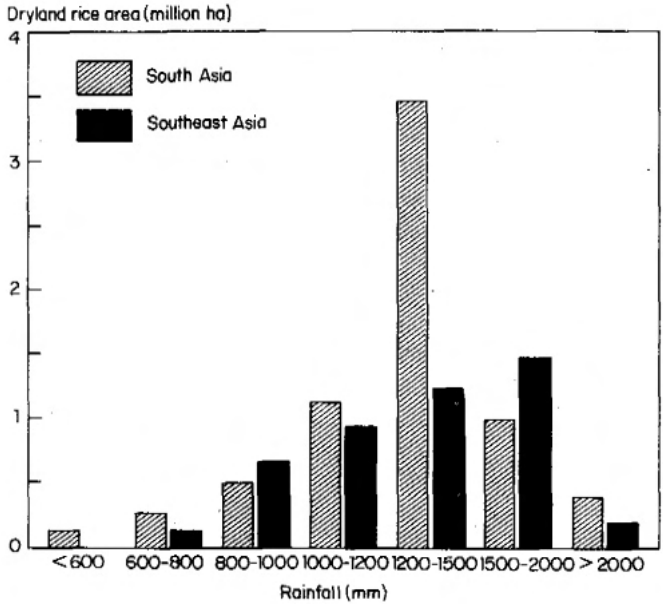
A quantitative dryland rice environmental classification was attempted for South and Southeast Asia by Garrity and Brinkman (1981, unpubl. data) using three sets of maps. Huke's (1982) map of rice area by culture type (1:4,500,000 scale), which used the best available rice area statistics on the district, state, or regional level within each country, was used to locate production sites. Dot placement was based on topographic and soil information. This map's spatial. distribution of rice area is the first step toward the future classification of all rice cultural types.

The second set of maps contains climatic data specifically for the 5-mo growing season in each locality throughout the region (Garrity, 1981, unpubl. data). Literature review and study of Asian rainfall patterns showed that dryland rice is usually planted during the first month of 100 mm rainfall at the onset of the humid period. In areas that are humid year-round, rice is seeded the month after the driest month of the year.

The climatic maps (1:4,500,000 scale) included those showing total rainfall during the 5-mo growing period. Others showed the growing-season length expressed as the number of months in which rainfall exceeded potential evaporation by 20%. Potential evaporation estimates were obtained from Thornthwaite Associates (1963). Research in the Philippines has shown that when precipitation does not exceed potential evaporation by this margin, dryland rice undergoes severe drought stress (Puckridge and O'Toole 1981).

The third set of maps were the FAO-UNESCO soil maps (1:5,000,000 scale) for South Asia (FAO 1977) and Southeast Asia (FAO 1979). These maps used a uniform soil classification system and contain data on the dominant soil mapping units, surface soil textures, and general slope classes. Each unit has certain general chemical and physical characteristics.

The dot map of dryland rice distribution was transferred to transparent acetate sheets and overlaid onto each of the climate and soil map sheets. The values for the climate and soil determinants were recorded for each of the nearly 4000 sites (dots) each site representing 3000 ha of rice area.



4. Distribution of dryland rice area by amount of rainfall during a 5-mo growing period, South and Southeast Asia.

Coded data listed climate and soil variables at each site which the computer grouped into environments which shared the same values for the determinants.

CLIMATE

Southeast Asia is generally characterized by a humid tropical climate. Although the term humid tropics implies excessive moisture, it usually occurs during a limited period of the year (Oldeman and Frere 1982). Even during the period of abundant rainfall, great variability often threatens dryland rice with drought.

Rainfall

Because dryland rice fields are not bunded, and water storage is limited to the meager amount that the crop's inadequate root system can extract from shallow depths, moisture supply is considerably more unreliable than for wetland rice. Among Asian dryland regions, rainfall varies widely during the 5-mo growing period (Fig. 4). Average rainfall ranges from more than 2500 mm in Assam in northeastern India to 600 mm or less in upper Burma and central India. Growing season rainfall ranges between 1200 and 1500 mm for 40% of the area. Southeast Asia has more humid (1500-2000 mm) dryland rice sites than South Asia.

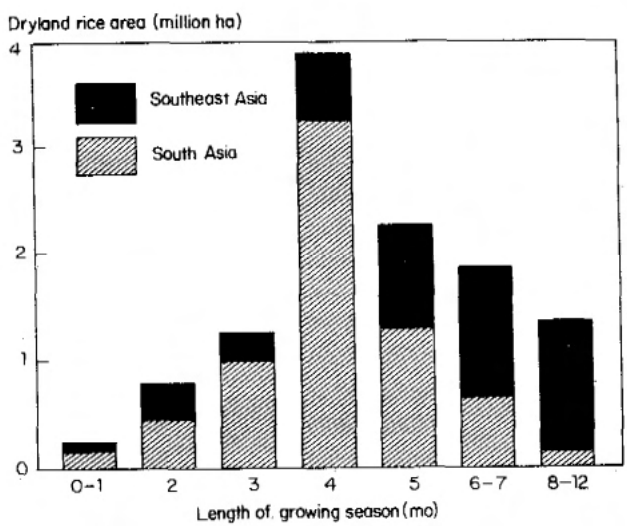
Growing – season length

Agronomists have long considered growing – season length, rather than total rainfall, the primary detetminant of cropping patterns (Oldeman 1975, Garrity et al 1978, Buddenhagen 1978). Data Erom this study reinforce that conclusion.

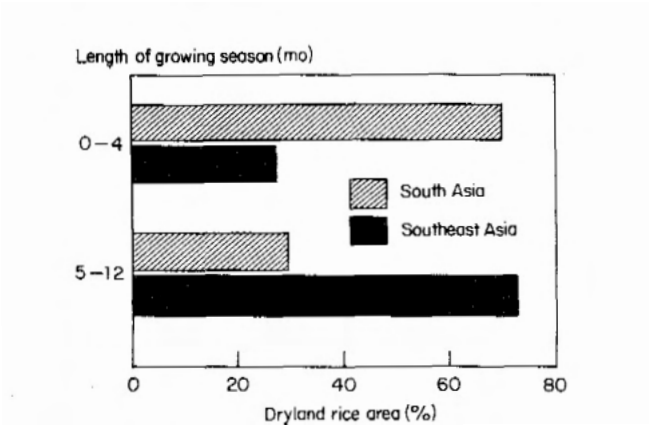
Growing – season lengths vary widely in tropical Asia (Fig. 5, 6). Dryland rice in South Asia is mostly grown in areas with a short rainy period (3 – 4 mo of rainfall in excess of potential evaporation). Extremely short and highly variable growing seasons in eastern Uttar Pradesh, Bihar, and Madhya Pradesh result in very low average yields and frequent crop failures. Only extremely early – maturing varieties are adapted to these areas. Figure 7 shows rainfall patterns for four sites on the Chota Nagpur Plateau. Rainfall is insignificant except for 3 consecutive summer months in which it exceeds 200 mm/mo.

The modal length of the growing season for South Asia is 4 mo (Fig. 5). In Southeast Asia, it is between 5 and 7 mo, with much rice (1.2 million ha) found in areas that are humid year – round.

Figure 6 compares the proportion of short – and long – season dryland rice. Three – quarters of South Asia has a short growing season and three – quarters of South – east Asia has a humid period long enough for even late – duration varieties.



5. Distribution of dryland rice, by length of growing season, in South and Southeast Asia. Growing-season length is the number of months in which rainfall exceeds potential evaporation by a factor of 1.2.



6. Comparison of the proportion of dryland rice grown during relatively short or long growing seasons in South and Southeast Asia.

Table 2 shows the distribution of dryland rice area in South and Southeast Asia by growing-season length. Thailand, India, and Sri Lanka grow the highest proportion of their dryland rice area in short growing-season (1-4 mo). Laos, Malaysia, Indonesia, and the Philippines have long growing seasons (5-12 mo). Even in humid areas, where growing-season length is not a constraint, dryland rice is seeded as early as possible at the onset of the rainy season because of several factors:

- solar radiation and temperature decrease later in the rainy season;
- there is a flush of nitrogen from the mineralization of oryanic N at the very beginning of the rainy season; and
- an early seeded rice crop can be more competitive with weeds.

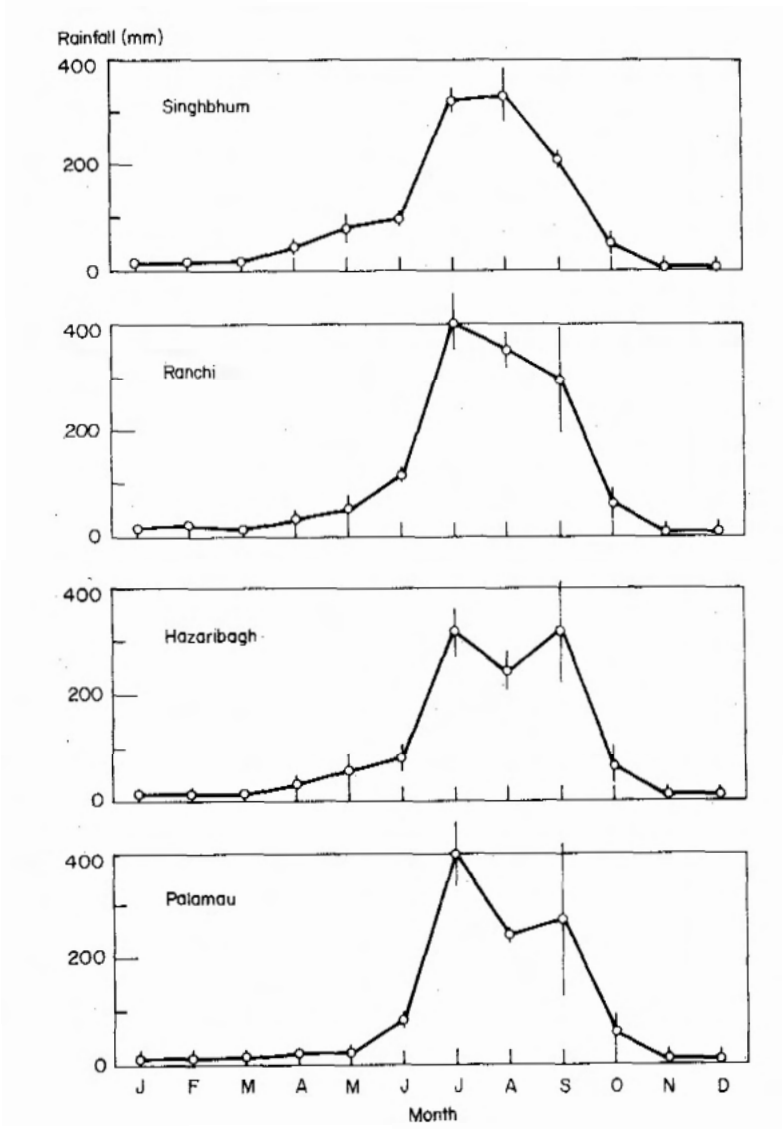
TEMPERATURE

Most dryland rice in Asia is grown at low elevations where temperature during the wet season ranges from 24 to 26°C (De Datta and Vergara 1975). Cold tolerance is important in varietal adaptation at higher elevations in certain parts of India, Burma, Thailand, and Vietnam.

SOILS

Slope

South and Southeast Asia differ sharply in the slope classes upon which the bulk of the dryland rice is grown. About 4 million ha (30%) was mapped on level to



7. Mean monthly rainfall for selected districts of Chota Nagpur for 1974-77 (±SE) (source: Rice Res. Stn., Patna, Bihar).

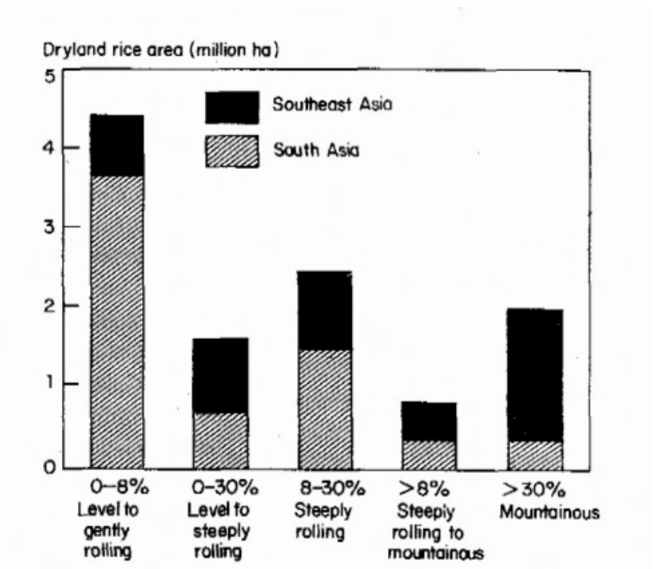
gently rolling terrain (Fig. 8). This includes most dryland rice in India and Bangladesh where relatively little rice is grown on steeply rolling or mountainous terrain.

Dryland rice in Southeast Asia is mostly on slopes exceeding 8%, about 1.5 million ha on mountains where slopes exceed 30%. Soils in these areas are often excessively drained and subject to rapid erosion. Shifting cultlvation is common.

Table 2. Distribution of dryland rice area in South and Southeast Asia by growing-season length.

Country	Area classified (million ha)	Dryland rice area (million ha)[a]						
		Growing-season length (mo)[b]						
		0-1	2	3	4	5	6-7	8-12
South Asia								
India	5.97	0.14	0.45	0.98	3.00	0.77	0.48	0.15
Bangladesh	0.86	–	–	–	0.23	0.48	0.15	–
Sri Lanka	0.05	–	0.01	0.04	–	–	–	–
Nepal	0.04	–	–	–	–	0.02	0.02	–
Bhutan	0.03	–	–	–	–	0.02	0.01	–
Total	6.95	0.14	0.46	1.02	3.23	1.29	0.66	0.15
%	100	2	7	15	46	18	10	2
Southeast Asia								
Burma	0.79	0.00	0.01	0.03	0.08	0.22	0.45	–
Thailand	0.96	0.04	0.29	0.16	0.18	0.20	0.09	–
Vietnam	0.41	–	–	–	0.01	0.24	0.09	0.07
Kampuchea	0.50	–	0.02	0.01	0.27	0.12	0.04	0.04
Laos	0.34	–	0.00	0.03	0.02	0.05	0.15	0.09
Malaysia	0.09	–	–	–	–	–	0.03	0.06
Indonesia	1.14	–	–	0.02	0.07	0.05	0.20	0.80
Philippines	0.41	–	–	–	0.00	0.10	0.16	0.15
Total	4.64	0.04	0.32	0.25	0.63	0.98	1.21	1.21
%	100	1	7	5	14	21	26	26
Grand total	11.59	0.18	0.78	1.27	3.86	2.27	1.87	1.36
%	100	2	7	11	33	19	16	12

[a]A dash indicates zero hectarage. [b]Growing season is the number of months in which rainfall exceeds potential evaporation by 20%.



8. Distribution of dryland rice area, by slope class, in South and Southeast Asia.

Soil texture

Texture of a dryland rice soil influences both fertility and water-holding capacity, which also influences drought stress.

Correlation of dryland rice distribution with soil textural class data on the FAO Soil Map of the World showed that most dryland rice in Asia is on medium-textured soils (sandy loams, loams, and clay loams). They have good to excellent water-holding capacities and favorable physical properties for tillage.

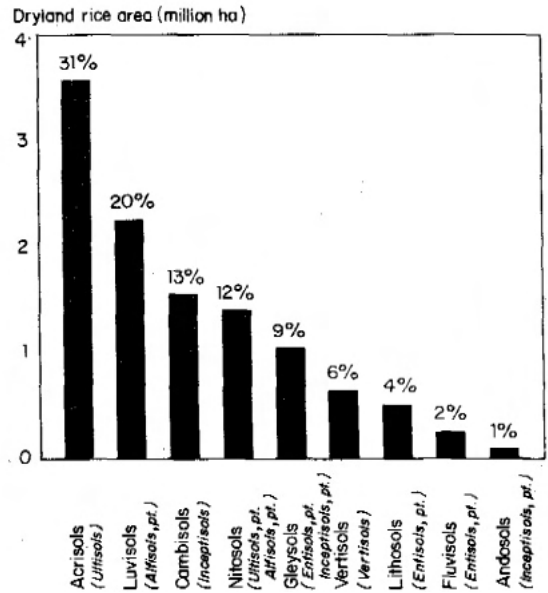
Dryland rice in Southeast Asia is common on fine-textured soils (clays) and uncommon on coarse-textured soils (sands).

Soil groups

In wetland rice, fertility distinctions between soils can often be ignored because of the enhanced availability of macro- and micronutrients in submerged soils. But in dryland rice production, soil fertility is critical (Buddenhagen 1978).

Soil classification units reveal certain chemical characteristics of each soil. By correlating the dryland rice distribution in Asia with the Soil Map of the World, production sites were stratified by soil groups.

Small mapping scale made the assignment of individual sites to specific soil mapping units rather uncertain, but a clear overall pattern of dominant soils



9. Distribution of dryland rice in Asia by soil mapping unit. Soil nomenclature is in correlation wifh the USDA Soil Taxonomy (USDA 1975). pt. indicates that only part of the class is included.

emerged. FAO soil mapping unit nomenclature is used, but a loose correlation with USDA Soil Taxonomy nomenclature is included in Figure 9 and Table 3.

About one-third of dryland rice (3.5 million ha) occurs on Acrisols (Fig. 9). Luvisols (2.3 million ha), Cambisols (1.5 million ha), and Nitosols (1.4 million ha) are the next most important followed by Gleysols (1.0 million ha) and Vertisols (0.6 million ha).

Table 3 shows the five most important soil mapping units in each region. The Orthic Acrisols are most important and limited to Southeast Asia. They are chemically poor, strongly acid and weathered, and low in organic matter. They are most important in Thailand (0.5 million ha), Burma (0.4 million ha), and Indonesia, Vietnam, and Laos (0.3 million ha each) where they produce between one-third and two-thirds of the dryland rice.

The second and third most important soils in Southeast Asia are Ferric and Gleyic Acrisols on which 65% of the region's dryland rice is grown. More than half of the region is classified as Acrisols. These soils demand more research attention because of their law inherent fertility.

Table 3. Dominant soil mapping units for dryland rice in South and Southeast Asia.

Ranking	Soil unit	Dryland rice in the region		Inherent fertility status[a]
		million ha	%	
	South Asia	6.93		
1	Ferric Luvisols (Ustalfs)[b]	1.13	16	7
2	Eutric Cambisols (Eutropepts)	0.89	13	2
3	Chromic Luvisols (Alfisols)	0.75	11	5
4	Eutric Gleysols (Tropaquepts)	0.60	9	5
5	Chromic Vertisols (Vertisols)	0.54	7	3
	Southeast Asia	4.67		
1	Orthic Acrisols (Tropudults)	1.97	42	6
2	Ferric Acrisols (Tropudults)	0.60	13	8
3	Gleyic Acrisols (Aquults)	0.47	10	8
4	Dystric Nitosols (Khodudults)	0.44	9	7
5	Ochric Andosols (Andepts)	0.11	2	4

[a]Rating scale: 1-2 = highly favorable 7-5 = favorable, 6-7 = unfavorable, 8-9 = highly unfavorable. [b]Approximate equivalent in Soil Taxonomy (USDA 1975). Only onc name is listed: many units overlap so that parts of several taxa are equivalent to one unit.

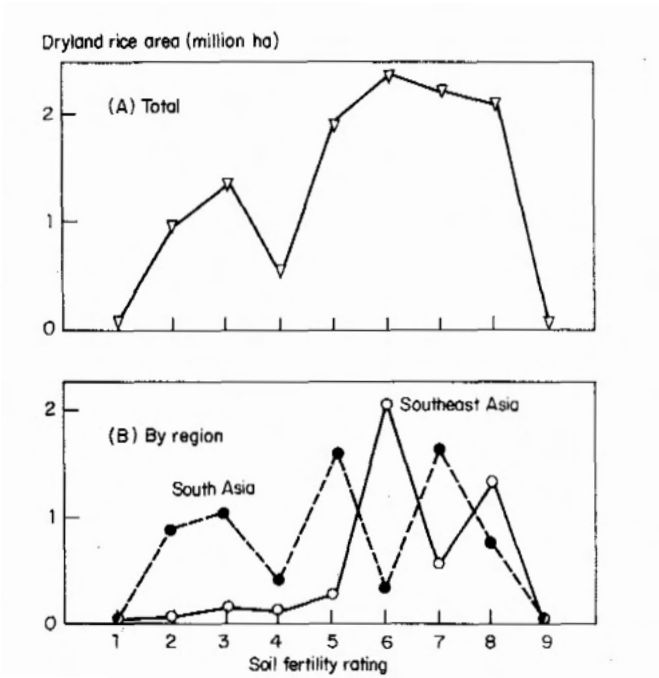
In South Asia, dominant soils are Ferric Luvisols, which also have low inherent fertility, but none is as dominant as Orthic Acrisols in Southeast Asia. Four other major soils have fair to excellent inherent fertility.

Inherent fertility status

Inherent fertility characteristics of the 51 soil units associated with dryland rice were rated on a 1-9 (high to low fertility) scale (Table 4). The fertility scale was formulated from information in the FAO World Soil Map publications (FAO 1977, 1979) and personal observa-

Table 4. he relationship between soil fertility rating and soil unit.

Inherent fertility status rating	Soil mapping unit	
2	Lk Calcic Luvisols	
	Bg Gleyic Cambisols	
	Be Eutric Cambisols	
3	Jc Calcaric Fluvisols	Vp Pellic Vertisols
	Bk Calcic Cambisols	Lv Vertic Luvisols
	Je Eutric Fluvisols	Vc Chromic Vertisols
	Lg Gleyic Luvisols	
	Lo Orthic Luvisols	
	Bv Vertic Cambisols	Tm Mollic Andosols
4	Ne Eutric Nitosols	
	Th Humic Andosols	
	To Ochric Andosols	
5	Ah Humic Acrisols	Gc Calcaric Gleysols
	Bh Humic Cambisols	Lc Chromic Luvisols
	Ge Eutric Gleysols	Tv Vitric Andosols
6	Bd Dystric Cambisols	
	Jd Dystric Fluvisols	
	Nh Humic Nitosols	
	Ao Orthic Acrisols	
7	Gd Dystric Gleysols	
	Bf Ferralic Cambisols	Lf Ferric Luvisols
	Fh Humic Ferralsols	Nd Dystric Nitosols
	Fr Rhodic Ferralsols	Re Eutric Regosols
8	Af Ferric Acrisols	I Lithosols
	Ag Gleyic Acrisols	Ph Humic Podzols
	Gh Humic Gleysols	Rd Dystric Regosols
	Fo Orthic Ferralsols	Qc Cambic Arenosols
	Ap Plinthic Acrisols	Po Ochric Podzols
	Fx Xanthic Ferralsols	Qo Ochric Arenosols
		Qf Ferralic Arenosols
9	Qa Albic Arenosols	
	Od Dystric Histosols	
	Pg Gleyic Podzols	
	Jt Thionic Fluvisols	
	Hh Haplic Phaeozems	



10. Distribution of dryland rice soils by their inherent fertility status rating: A, South and Southeast Asia combined, and E, comparison of the distribution between regions. Rating scale: 1 = highly favorable, 9 = highly unfavorable.

tions concerning acidity, cation exchange capacity, organic matter level, natural NPK status, and the probability Of micronutrient toxicities or deficiencies.

Low-inherent-fertility soils are poorly adapted to dryland rice. Productivity is low; micronutrient imbalances are likely; returns to the use of cash inputs may be poor. Such soils are often relegated to shifting cultivation as the only viable management system.

Figure 10A shows the amount of rice area in various IFS rating classes. The majority (58%) of dryland rice areas were rated between 6 and 9, unfavorable to highly unfavorable. Table 5 shows distribution of dryland rice by inherent fertility status in each country.

In Southeast Asia, an insignificant proportion (only 11%) of dryland rice is on inherently fertile soils compared to 30% in South Asia (Fig. 10, Table 5).

Table 3 shows the inherent fertility status ratings of the dominant soils in South and Southeast Asia. In Southeast Asia, research efforts should be directed to soils with fertility ratings of 6-8, specifically Orthic Acrisols.

Table 5. Distribution of dryland rice by soil inherent fertility status (IFS) for South and Southeast Asia.

Country	Area classified (million ha)		Dryland rice area (million ha)			
			IFS rating			
			1-3	4-5	6-7	8-9
South Asia						
India	5.95		2.06	1.29	1.82	0.78
Bangladesh	0.86		0.03	0.72	0.11	0.00
Sri Lanka	0.05		0.01	0.04	–	–
Nepal	0.04		–	–	0.04	–
Bhutan	0.03		–	–	0.03	–
Total	6.93		2.10	2.05	2.00	0.78
%		100	30	30	29	11
Southeast Asia						
Burma	0.79		–	0.14	0.65	0.00
Thailand	0.96		0.00	0.01	0.54	0.41
Vietnam	0.41		0.01	0.01	0.31	0.08
Kampuchea	0.50		0.02	–	0.11	0.37
Laos	0.34		–	–	0.27	0.07
Malaysia	0.09		–	–	0.09	0.00
Indonesia	1.14		0.11	0.21	0.43	0.39
Philippines	0.41		0.08	0.13	0.19	0.01
Total	4.64		0.22	0.50	2.58	0.34
%		100	5	11	55	29
Grand total	11.58		2.34	2.54	4.58	2.12
%		100	20	22	40	18

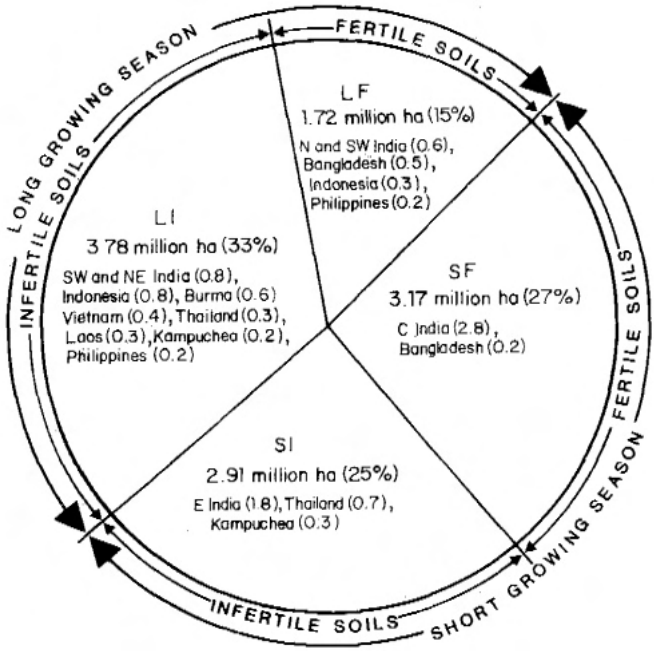
MAJOR DRYLAND RICE ENVIRONMENTS

Asian dryland rice sites were divided into four environmental complexes based on the interaction between climate and soils. Each site was categorized as having a long growing season (5–12 mo) or a short growing season (1–4 mo) and fertile (IFS 1–5) or infertile soils (IFS 6–9) (Fig. 11, Table 6).

Long growing season x Fertile soils (LF)

An environment with a long growing season and fertile soils is favorable for dryland rice. About 15% of total dryland rice in Asia is grown in this environment (Fig. 11). Yields are higher and improved technology, including semidwarf plants, will most likely be developed and adopted in these areas. Cash inputs, such as fertilizer and intensive management, may be cost effective.

Because of the long rainy period, a single crop dryland rice is often grown in sequence with other field crops. Earlier-maturing rices may make multiple cropping promising although rice will be grown only once a year.



11. Proportion of dryland rice in Asia classified into 4 environments. Countries listed have more than 0.2 million ha within the environment.

India (0.6 million ha), Bangladesh (0.5 million ha), Indonesia (0.3 million ha), and the Philippines (0.2 million ha) have significant area in the LF category. In India, dryland rice within LF is found in the northeast, along the Himalayan foothills and the Tarai area near the Nepalese border, and limited areas in southwestern Maharastra and western Karnataka. Most dryland rice in northern Bangladesh is included in LF. In Indonesia, this environment is limited to Java. In the Philippines, LF is found in southern Luzon and west-central Mindanao.

Batangas Province, Philippines, is a sample LF site (Fig. 12). It has a long growing season (precipitation exceeds potential evaporation by 20% for 6 mo) and has Ochric Andosols, volcanic soils with excellent inherent fertility. Fertilizer use on both traditional and improved dryland rice varieties is high (40–100 kg N/ha).

Long growing season x Infertile soils (LI)

The largest proportion (33%) of dryland rice in Asia is in this environment. It is the most important environment in Indonesia (0.8 million ha), Burma (0.6

Table 6. Distribution of dryland rice area in South and Southeast Asia by environmental complex.

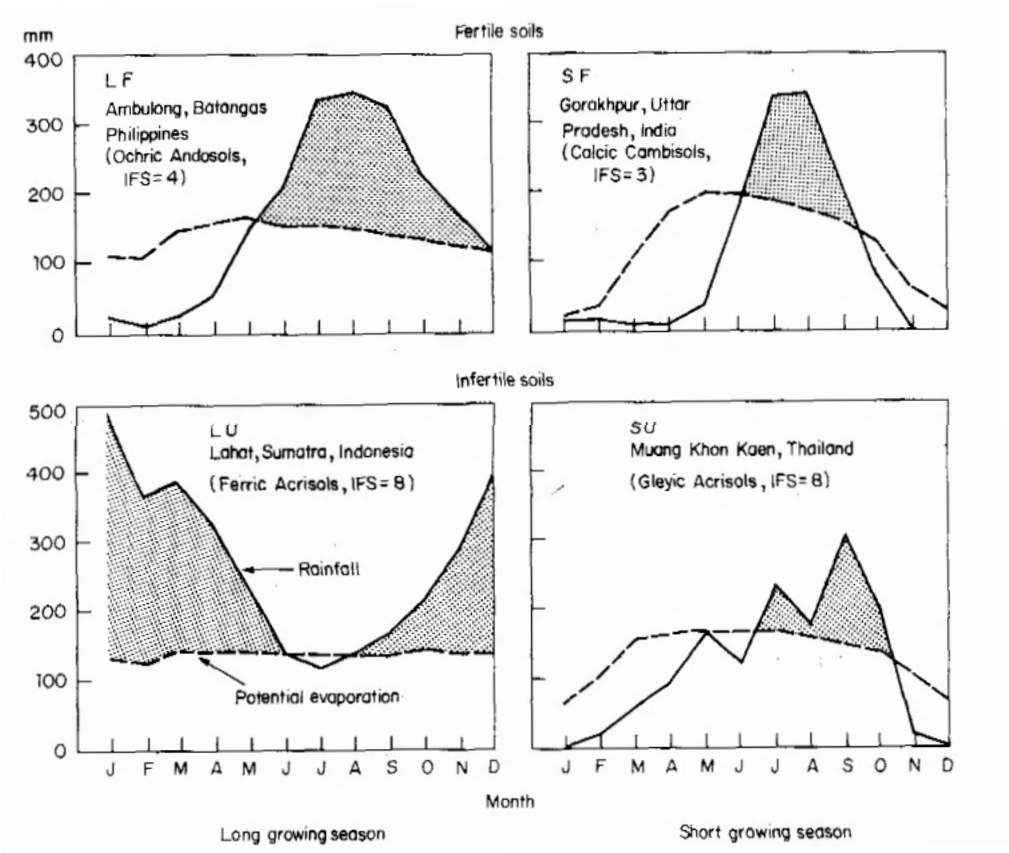
Country	Area classified (million ha)		Dryland rice area (million ha)			
			Long growing season (5-12 mo)		Short growing season (0-4 mo)	
			Fertile soils[a]	Infertile soils[b]	Fertile soils	Infertile soils
South Asia						
India	5.97		0.57	0.84	2.80	1.76
Bangladesh	0.86		0.52	0.11	0.23	–
Sri Lanka	0.05		0.01	–	0.04	–
Nepal	0.04		–	0.04	–	–
Bhutan	0.03		–	0.03	–	–
Total	6.95		1.10	1.02	3.07	1.76
%		100	16	15	44	25
Southeast Asia						
Burma	0.79		0.12	0.55	0.02	0.10
Thailand	0.96		0.00	0.29	0.01	0.66
Vietnam	0.41		0.01	0.39	–	0.01
Kampuchea	0.50		0.01	0.19	0.01	0.29
Laos	0.34		–	0.28	–	0.06
Malaysia	0.09		–	0.09	–	–
Indonesia	1.14		0.26	0.79	0.05	0.04
Philippines	0.41		0.22	0.19	–	–
Total	4.64		0.62	2.77	0.09	1.16
%		100	13	60	2	25
Grand total	11.59		1.72	3.79	3.16	2.92
%		100	15	33	27	25

[a] Inherent fertility status = 1-5. [b] Inherent fertility status = 6-9.

million ha), Vietnam (0.4 million ha), and Laos (0.3 million ha) where it includes 70-95% of the dryland rice. It is an important environment in all the Southeast Asian countries and also includes 0.8 million ha in India.

In these areas, acidic, highly leached soils or shallow soils seriously constrain adaptation and productivity of improved varieties although the rainfall pattern is favorable. Yields can be moderate to high with careful management of soil fertility. Drought stress may be severe in some seasons, particularly on excessively drained soils. The long rainy season usually ensures that the crop has adequate moisture. Later-maturing varieties with drought stress recovery ability are suitable.

Lahat, in Sumatra, Indonesia, is a sample site in this environment. The growing season is 9 mo long (Fig. 12) and dryland rice is often grown with or in sequence with other crops. Major soils are the Ferric (IFS 8) and Orthic Acrisols (IFS 6).



12. Yearly profile of monthly rainfall and potential evaporation for sites representative of each of the four environments of dryland rice in South and Southeast Asia. IFS = inherent fertility status.

Short growing season x Fertile soils (SF)

SF is significant only in South Asia. It is the most important land unit in India, covering 2.8 million ha; Bangladesh has 0.2 million ha, and nearly all of the dryland rice in Sri Lanka (0.05 million ha) is included.

Gorakhpur, Uttar Pradesh, in the broad north central belt of India (Fig. 12) has Calcic Cambisols (IFS rating of 3). An extremely short; growing season makes drought a major constraint. Very early maturity is critical to escape severe reproductive drought stress when the monsoon fades. Drought avoidance characteristics and drought stress recovery are essential adaptations.

Short growing season x Infertile soils (SI)

SI (23% of the area) is marginal for dryland rice. Climate and soils are severe constraints and may prevent significant yield improvement. India grows most rice (1.8 million ha) in this environment but most

dryland rice in Thailand (0.7 million ha) and Kampuchea (0.3 million ha) is also included. Khon Kaen in northeastern Thailand situated on very common Gleyic Acrisols (IFS 8), represents this environment (Fig. 12).

IMPLICATIONS

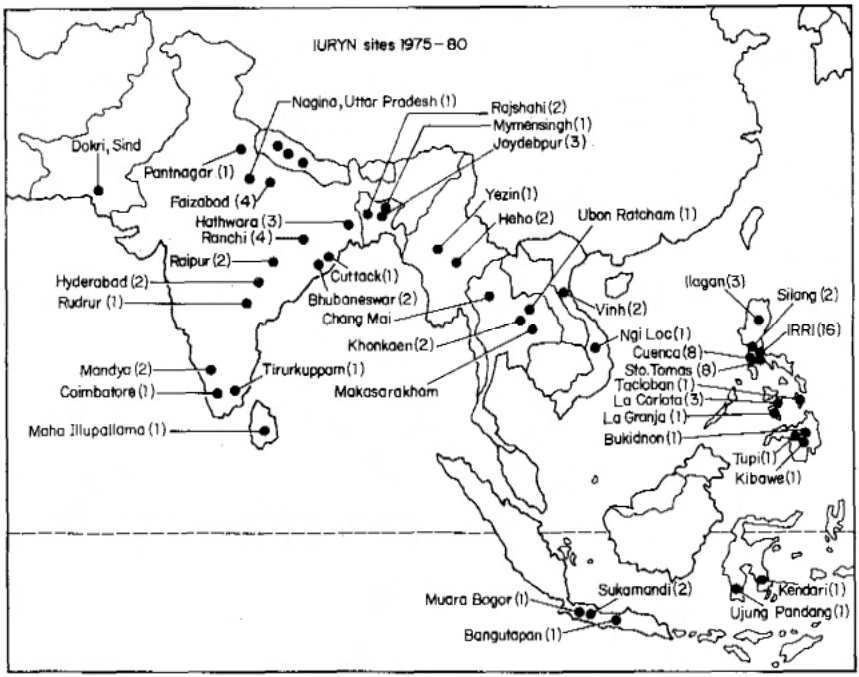
The environments discussed reveal the importance of fitting plant type and maturity characteristics to the respective areas and emphasize the importance of drought resistance and adverse soils tolerance for large proportions of the Asian dryland rice area. Crop management requirements and crop intensification potential vary among the environments.

The classification of dryland rice into four environments may be useful for a broad understanding, but much more specificity is needed for practical application. The work is subject to imprecision at all steps, including placement of dryland rice sites as dots on maps, construction of climate and soils maps, and proper overlay of dot placement maps onto environmental maps. Limits between short and long growing season and fertile and infertile soils are also arbitrary. The classification could be made more specific by 1) increasing the number of classes of growing season and inherent fertility status, and 2) including interactions of the biological system and the socioeconomic system with the physical environment. This might be accomplished by mapping the endemic rice blast areas, for example, and by classifying dryland rice into shifting cultivation sites as opposed to permanent field sites.

More precise classification of dryland rice environments is also needed at the national program level. Scientists can define the rice ecosystems within each country better than a regional classification system. An example of an integrated dryland rice classification for a particular country is that by Garrity et al (1978) for the Philippines. Related papers in this volume (e.g. Oldeman) discuss other ways to improve environmental classifications for dryland rice.

However, even a broad dryland rice classification can identify the crop's dominant target environments. With such information, it is important to characterize present dryland rice research sites and determine the environments they represent.

The International Upland Rice Yield Nursery (IURYN) sites in Asia are shown in Figure 13. Characterizing the climate and soils of the present research sites and understanding where each may fit into an environmental classification may significantly strengthen the ability to interpret and extrapolate dryland rice research.



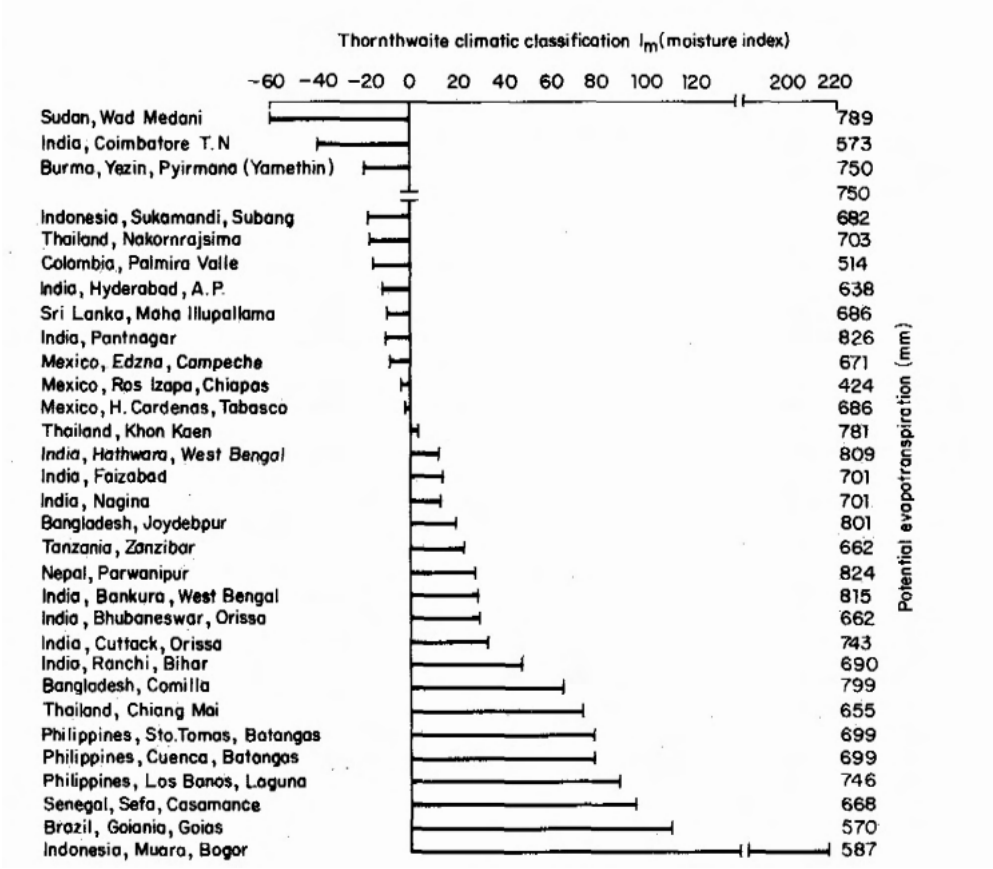
13. Location of the International Upland Rice Yield Nursery (IURYN) sites during its first 6 yr. Numbers in parentheses indicate the number of trials for which data were reported.

As a step in this direction, a climatic classification of the 32 International Upland Rice Observational Nursery sites for 1976 has been prepared (Fig. 14). Although actual site data were unavailable, published long-term climatic data were used (Thornthwaite Associates 1963) as the basis for calculating an average water balance and computing a moisture index (Im). Arid to extremely humid sites were represented.

The most useful research collaboration will develop among workers from different countries or regions who encounter analagous rice ecosystems. With our present knowledge, we may begin to plan more rational collaborative working relationships and to reach some crude level of predictability in the transfer of germplasm and agronomic research.

ACKNOWLEDGMENT

The support of Dr. Robert Brinkman in many aspects of this work is gratefully acknowledged.



14. Climatic classification of the 32 International Upland Rice Observational Nursery sites for 1976. Values are for rice-growing months only (IRRI 1979).

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PATTERNS OF WATER SUPPLY IN UPLAND RICE IN BOUAKE, IVORY COAST

J. M. KALMS and J. IMBERNON

Studies at the Institut des Savanes (IDESSA) station, Bouaké, Ivory Coast, have used several methods to determine avenues of water transfer to upland rice in cultivated soils.

Methods include in situ measurement of humidity (neutron probe), hydraulic head (tensiometers), and root penetration depth. With the no transfer level method, one can precisely estimate the actual evapotranspiration of upland rice for deficit periods. The drainage flow method, which requires hydrodynamic characterization of the soil, helps evaluate water extraction from soil layers in the root zone. It clearly shows the effect of soil type on water transfer. Because of the ferralitic soil variability in the plots, only genetically remote rice types show varietal differences.

Since 1973, the Tropical Agricultural Research Institute (IRAT) research in central Ivory Coast has concentrated on environmental factors that influence upland rice production, especially patterns of water supply within test plots (Reyniers et al 1976, Kalms 1979, Kalms et al 1979, 1982). Researchers tried to determine the hydrodynamic properties of plateau soils and observe water flow in cultivated areas. Earlier methods (Hillel 1972, Vachaud et al 1978) enabled them to identify the water supply patterns. With the use of water balance sheets and root profiles, two varieties showed distinct differences during water deficits.

By determining the no transfer level with tensiometers during rice growth and considering the soil hydrodynamic characteristics, one can better estimate actual evapotranspiration (ETR).

These methods also differentiated water use in different types of Ivory Coast upland rice. Hydrodynamic characteristics determined the amount of water two cultivars extracted from the root penetration area of the soil, but because of varying soil characteristics, a methodological study was done in plots.

Agronomist, IRAT/IDESSA/DCV, B. P. 635 Bouaké, Ivory Coast (presently at FUDECO Apts. 7420, Coco, Venezuela; and hydrologist, IRAT/DRD 6. P. 5035 34032, Montpellier, France.

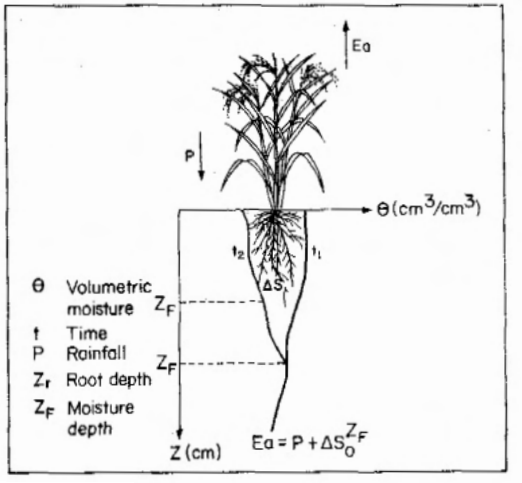
THEORETICAL AND EXPERIMENTAL TOOLS

Evaluation of water flow under cultivation using in situ measurements

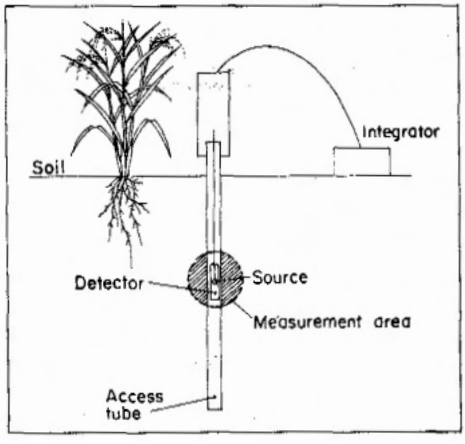
Three approaches can quantify water flow in the non-saturated zone.

The overall balance sheet. The law of conservation of water mass in the soil assumes that with zero loss in depth (Zf) the crop consumption (Ea) is equal to the variation of the water supply in the 0-Zf soil layer (Fig. 1). A neutron probe measures the volume of humidity (Fig. 2).

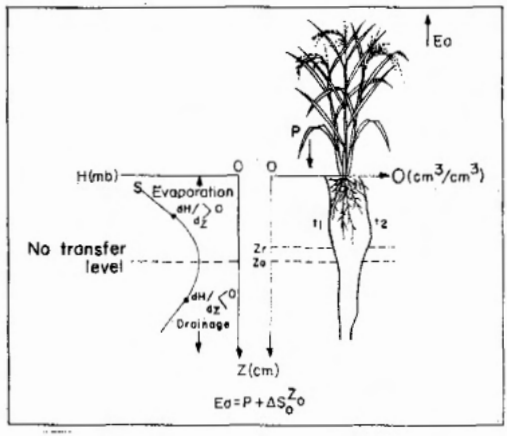
The no transfer level. This marks the boundary between two soil profile zones, one contributing to evaporation, the other to drainage. Ea is calculated by the variation of the water supply in the upper zone



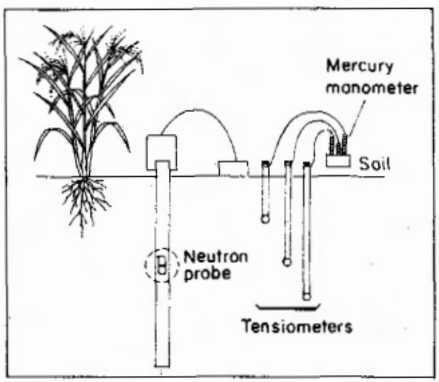
1. Water supply in the soil layer.



2. Moisture measurement using a neutron probe.



3. The no-transfer level method for estimating Ea.



4. Measurement of hydraulic head profiles by tensiometer and moisture profile by neutron probe.

(Fig. 3). Tensiometers at different depths measure the hydraulic head profile for determining the no transfer level that estimates the water supply (Fig. 4).

Darcy's law. This transfer equation quantifies the flow of water (outflow per surface unit in mm/day) using the rating with the aid of a conductive term K and a gradient of hydraulic potential:

$$q = -K(\theta) \cdot \frac{dH}{dH}$$

By using volumetric moisture q, the hydraulic head H, and previous knowledge of the relationship between hydraulic conductivity K and moisture q (see next section), one can estimate the flows

- in depth, outside of the rooting zone (This

quantifies losses by drainage or capillary remounting and estimates Ea by variation of water supply.); and

- within the root zone to evaluate the rate of root extraction per soil layer.(Fig. 5).

Hydrodynamic characterization

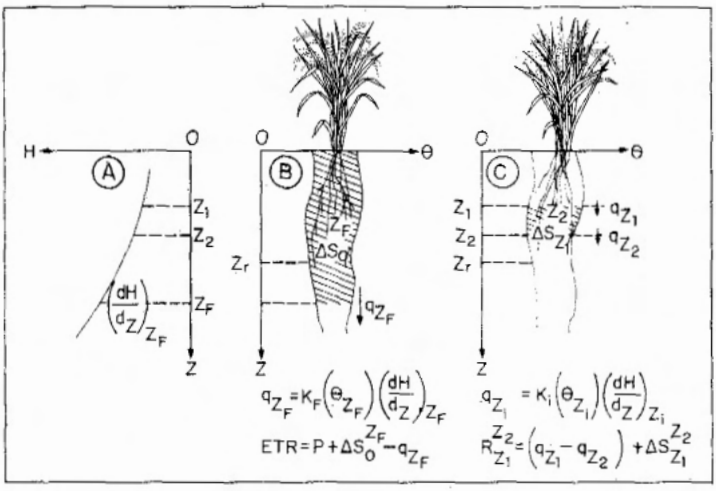
Hydrodynamic characterization determines, at a given depth, the linkage of hydraulic conductivity K and the soil water pressure h (h = H + Z) with the volumetric moisture q, by the method of internal drainage (Hillel et al 1972). The experimental design allows:

- infiltration at a constant head aided by a double ring and a Mariotte vase (Hamon 1980, Imbernon 1981), and
- a follow-upon moisture redistribution and hydraulic heads using neutron probes and tensiometers (Fig. 6).

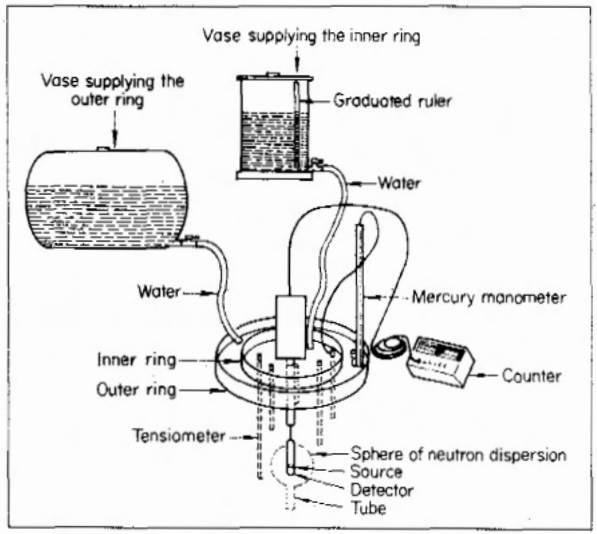
STUDY OF ACTUAL CONSUMPTION

Earlier works tried to establish the effect of water management on upland and irrigated rice growth (Reyniers et al 1976). First, the overall balance sheet followed the dynamics of water. However, difficulties in interpreting results necessitated tensiometric measurements, the no transfer level method (Kalms 1979), and the in-depthflow method (Kalm et al 1979).

We investigated the advantages and the limits of the different approaches.



5. Application of Darcy's law to the calculation of in-depth and root-zone flows.



6. Experimental setup for hydrodynamic characterization of the soil.

Overall balance sheet method

The aim of this study was to compare the growth and production of Moroberekan, a traditional upland rice variety, and of IR5, bred for intensive irrigated rice cultivation, under different water supply conditions: one optimum (ETM), the other slightly deficient during tillering and booting.

Field trials did not show a significant difference in moisture consumption between the two varieties during deficit periods. But in the 0-17 cm surface layer, IR5 mobilized soil water better than Moroberekan did (Table 1).

The estimates of ETM and Ea were only approximate because we did not consider in-depth drainage and we were unable to calculate the difference between drainage and evaporation.

Method of no transfer level (Kalms 1979)

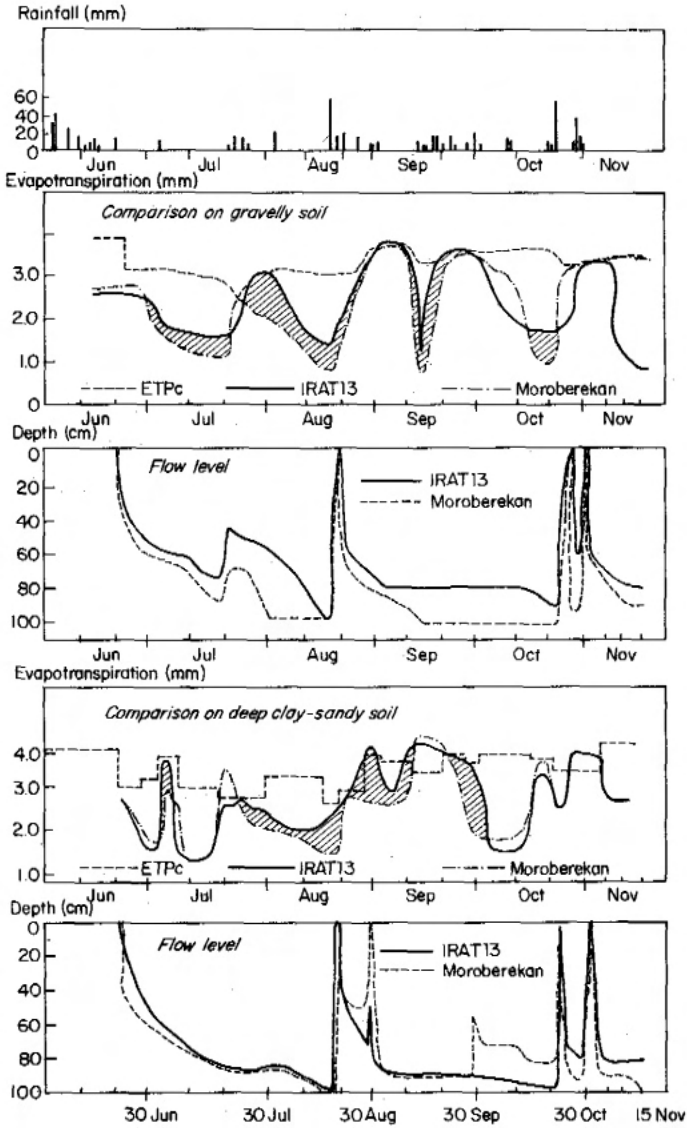
During a very dry year (1978), we used the <u>no transfer level</u> to calculate Ea for

- o two varieties of upland rice: IRATl3 and Moraberekan, and
- o two soil types: gravelly, with a low water storage capacity (60 mm); and clay-sandy, with a high water storage capacity (120 mm).

Figure 7 indicates differences in behavior. In the soil with low water storage capacity, Moroberekan used the soil water from an average of 20 cm deeper than

Table 1. Comparison of average volumetric moisture during the period 65 to 120 days after sowing.

Variety	Moisture (%) at given depth	
	0-7 cm	7-17cm
IR5	12.4	14.2
Moroberekan	16.5	16.3



7. Evolution of Ea and of the no-transfer level under upland rice in Bouake in 1978.

IRAT13, but the two varieties did not significantly differ in Ea.

In the soil with high water storage capacity, the two varieties exploited the water at the same depth during the whole cycle. In contrast, the Ea of IRAT13 during drought periods (between panicle initiation and heading) was 15 – 20% greater than that of Moroberekan. Moroberekan showed signs of necrosis, absent in IRAT13.

This method gives reliable results for clear – cut periods of water deficit. But it is inapplicable during humid periods when the no transfer level is between the surface of the soil and the root zone Zr.

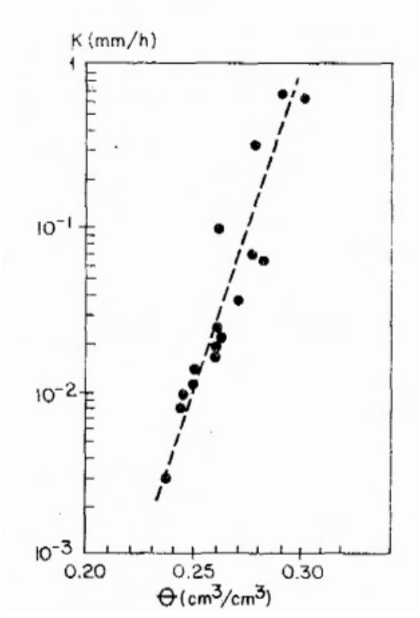
In the latter case, using the method will result in a systematic underestimation of Ea. At this level, the method can also overestimate Ea because it does not consider loss by drainage.

To use the method for humid phases, one must know the in – depth flow below the root zone.

In – depth flow method

By applying Darcy's law, one can estimate drainage flow beneath the root zone regardless of moisture con – ditions, but one must know the hydraulic conductivity K (q) (Fig. 8) and the gradient of hydraulic poten – tial H.

For example (Kalms et al 1981), on the same type Of clay – sandy soil, the calculated drainage below the



8. Relation between hydraulic conductivity (*K*) and soil volumetric moisture (q) at 87 cm deep.

rooting zone (Z = 87 cm) for upland rice varieties IRAT13 and Iguape Cateto was about 2 mm (Fig. 9). But for the same period (17-30 Nov), the total water supply was 54 mm.

Three replications per variety were done during the humid season to determine any differences in water supply and total drainage (Table 2) a

This table shows that

- the uncertainty about the drainage is of the same size as its estimate, and
- the total drainage is of the same size as the uncertainty about supply variation.

Considering the uncertainty about the estimate of supply variation, total drainage can be omitted. That leads to the simplification:

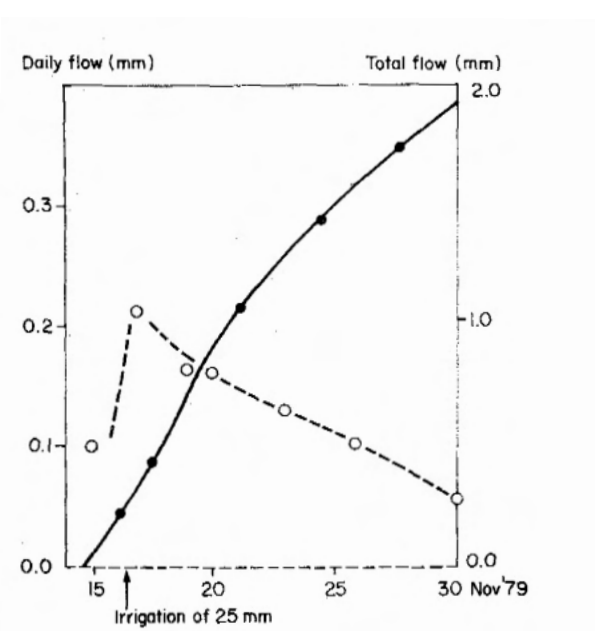
$$\underline{Ea} = \Delta S_{0}^{87\ cm}$$

IN-DEPTH STUDY OF WATER SUPPLY PATTERNS

These are site-specific results from only one experiment and this cannot be extrapolated to the entire field without a more methodological study.

Consumption within the plot (Kalms et al 1981, 1982)

An in-depth plat study showed that the slight difference in Ea between the two varieties was due to soil variability. The varietal effect was uncertain.



9. Daily and total drainage flow under 2 upland rices.

Table 2. Total drainage and water supply variation in two upland rices.

Variety	Water supply variation (mm)	Drainage (mm) 17-13 Nov
IRAT13	27.9 ± 2.0	2.5 ± 2.0
Iguape Cateto	28.4 ± 2.0	1.4 ± 0.5

The standard deviation for the moisture levels was 0.03 cm^3/cm^3, and that for water supply was 20 mm. But because the supply values are not spatially independent (high auto correlation), the spatial standard deviation of their variation is lower (8 mm).

In actual practice, measurements of water supply variation on the two varieties would significantly differ with a 95% probability if they differed by more than 16 mm. But that did not happen in this experiment.

Rates of water extraction by roots from soil layers

Lack of knowledge about water transfer within the root zone has limited the previously described methods. Until now, we have been unable to objectively compare two varieties by their amount of water extraction (R) from soil layers.

R is calculated from the equation of mass conservation in a given soil section (see Fig. 5). Besides the estimation of water supply variation, it rquires calculation of interlayer flow by the Darcy equation.

Two experiments compared root extraction profiles among IRAT13, Iguape Cateto, and Moroberekan in a clay-sandy soil.

Although no significant Ea differences appeared among the varieties, water profiles of root extraction during a prolonged drought showed these tendencies:

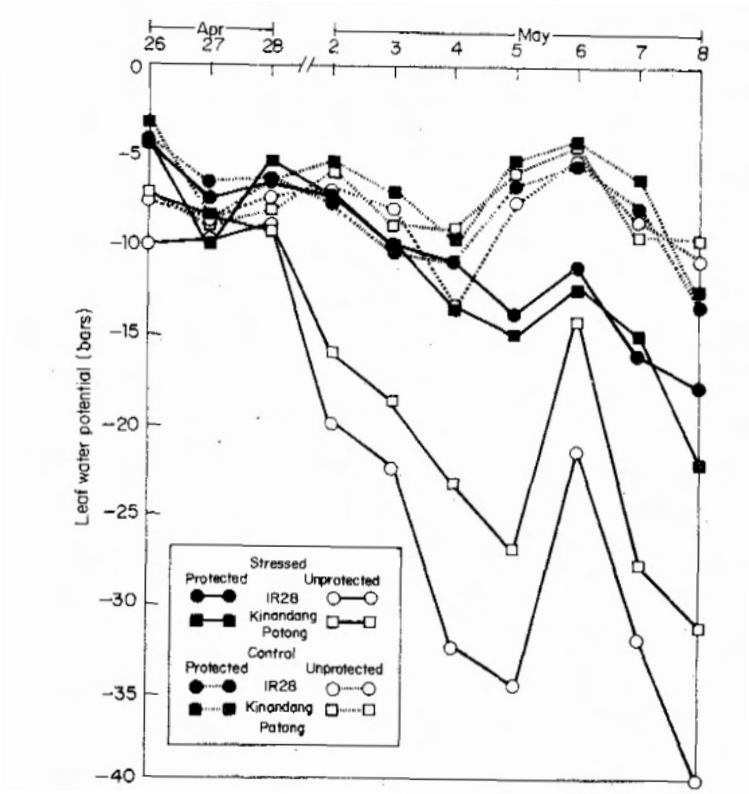
- Moroberekan exploits soil water more deeply than IRAT13 (Fig. 10), but IRAT13 uses available water in the upper 30 cm better.
- Differences in extraction rates between IRAT13 and Iguape Cateto were slight and insignificant (Fig. 11).

Possible explanations for the results are:

- the morphological root differences between IRAT-13 and Moroberekan including rooting depth, spread, and density; and
- the genetic proximity of IRAT13 and Iguape Cateto.

The Darcy equation method using root water extraction also shows these results:

- Interlayer transfers during drought lasting at least 10 days are lower than 10% of the water supply variation in a specific soil section.

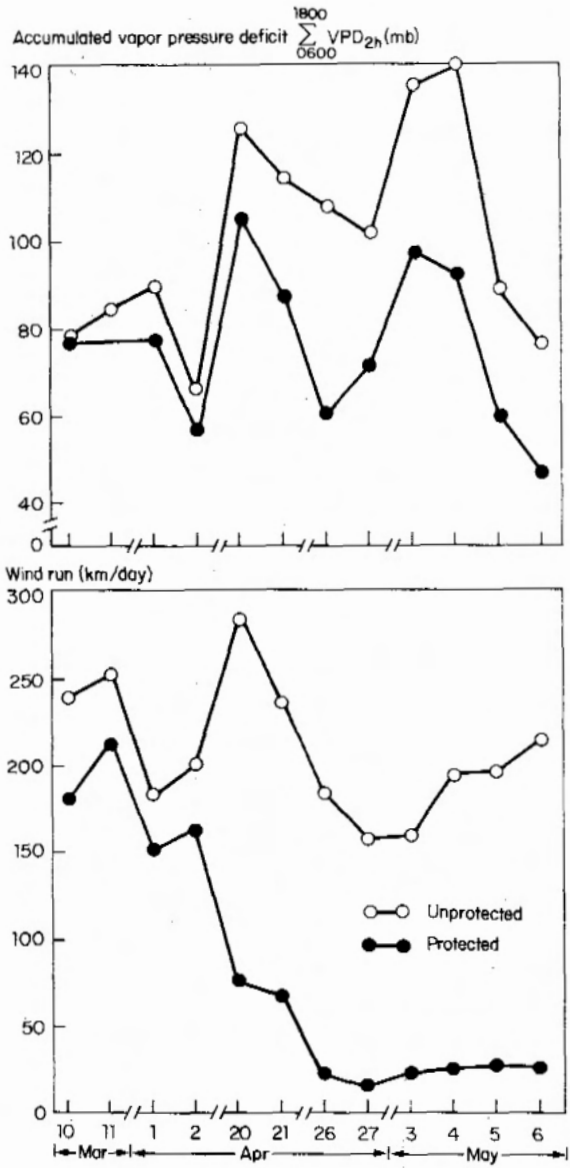


4. Average daily leaf water potential $\left[\frac{\psi max + \psi min}{2}\right]$ response of 2 rice varieties (lowland hybrid IR28 and Philippine upland variety Kinandang Patong) in an open upland field (unprotected) and on the leeward side of a maize wind barrier (protected). The control was irrigated; the stress treatment was not irrigated from 19 April to 8 May 1977. IRRI upland farm, 1977.

Thus soil modification to increase water retention in the root zone and changing the crop's aerial environment to decrease turbulence and evaporative demand may result in better plant water status and increased growth and yield.

Seeding date has a practical bearing on whether drought stress will damage the crop. Upland rice farmers throughout Asia consistently seed as early as possible at the onset of the monsoon rains (Garrity, 1984; this volume). In areas with a limited unimodal rainy season they may even seed before the first rains occur since seeds are viable even after one month in the soil (Malabuyoc et al, unpubl. data).

Early seeding increases the probability of drought stress during crop establishment and early vegetative stages because these stages occur during the dry to wet transition period. Poor stand establishment frequently results, requiring reseeding. However, delayed planting



5. Changes in the rice crop microclimate attributable to intercropping with maize at selected dates during the growing season. Rice was seeded on 2 Feb and maize was seeded on 9 Feb 1977. IRRI 1977.

later than 1 mo after the onset of the rains substantially reduces yields (Jana and De Datta 1971; De Datta et al 1974; Malabuyoc et al, unpubl. data). This results from more frequent drought stress during the reproductive stage, lower mineralized soil nitrogen,

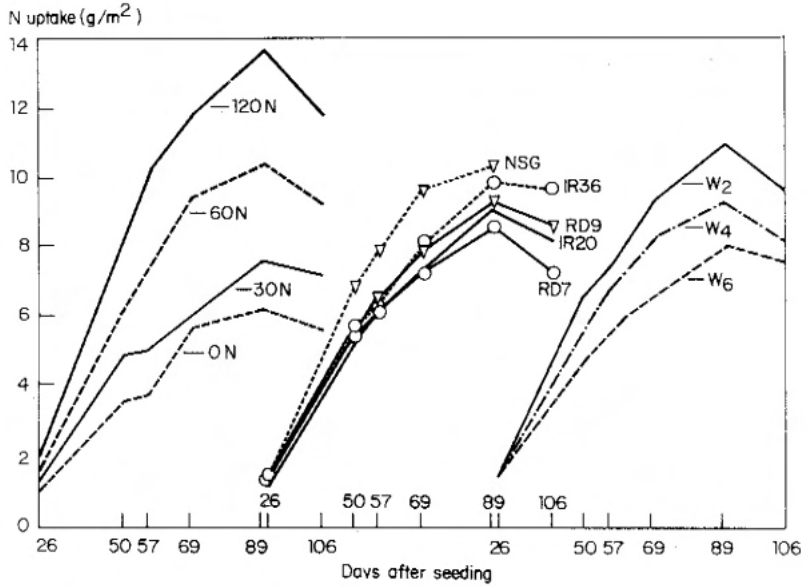
and lower solar radiation during the postflowering period. Early seeding consistently yielded the most productive crops, confirming what upland rice farmers know from experience. The benefits of early seeding versus seeding after rains begin apparently depend on the number of months of adequate rainfall.

The frequency and intensity of drought strongly affect optimum plant density of cereal crops in a rainfed environment. Lower densities, by allowing more soil volume (i.e., a larger water storage reservoir) per plant, frequently result in a higher harvest index and higher grain yield when drought is a major threat. However, they reduce yield potential under favorable circumstances. A comparative study of the seed rate and plant density literature is needed to understand density X environment interactions for upland rice,

Water deficits which decrease soil water uptake are associated with decreased nutrient uptake in several dryland crop species (Begg and Turner 1976, Verasan and Phillips 1978). There are few reports which compare the nutrient uptake of upland rice subjected to different levels of soil or plant water deficiency. Enyi (1962, 1965) reported contrasting results on nutrient uptake between flooded and aerobic soil treatments and between upland and swamp adapted varieties. Jana and De Datta (1971) measured soil moisture levels of rice grown with various nitrogen levels. Their observations established the interaction of soil water and nitrogen supply on upland rice yield. Aragon and De Datta (1982) found an interaction between soil and plant water potential and rate of applied nitrogen in determining dry matter production and grain yield of upland rice. Their results showed variations among the four cultivars and warrant further research in breeding for improved up land rice varieties.

In a similar experiment, Amnart (1981) used the line source sprinkler irrigation technique to measure crop nitrogen and water uptake as affected by nitrogen application rate, variety, and water applied. Figure 6 illustrates the interactions between those factors on nitrogen uptake.

Knowledge of the interactions between soil water and nitrogen uptake will affect fertilizer recommendations. Both Aragon and De Datta (1982) and Amnart (1981) show differences between traditional varieties' and modern semidwarf cultivars' response to water and nitrogen. A high nitrogen application rate in a severely drought-stressed environment resulted in lower leaf water potentials (i.e., more severe internal water stress) than were observed with less or no nitrogen. This reduced grain yields. Nitrogen response was significant only up to 60 kg N/ha with even mild drought stress. The drought damaged traditional varieties least but their nitrogen response was not significant.



6. Cumulative nitrogen uptake of 5 rice cultivars (NSG = Nam Sagui 19 [Thailand], RD9 and RD7 [Thailand], and IR36 and IR20 [Philippines] 1 as influenced by nitrogen fertilizer application rates (kg/ha) and applied water: W_2 = irrigation at 1.2 times class A pan evaporation (E_p), W_4 = 0.8 Ep, and W_6 = 0.4 E_p. Uptake rates for each nitrogen application level are mean values for all variety and irrigation levels. Similarly varietal uptake is the mean for all nitrogen and irrigation levels, and nitrogen uptake by irrigation level is the mean for all nitrogen rates and varieties.

Nitrogen fertilizer efficiency is poorly understood particularly when nitroyen interacts with water deficits. Quantitative estimates of nitrogen loss from fertilizer broadcast in upland rice (the universal method) are not available. Surface placement or incorporation, which is currently practical only at planting time, is a practice farmers are reluctant to undertake because of drought uncertainty. If we want to improve upland rice yields, we have to combine varietal characteristics, such as deep root systems to exploit soil water, with fertilizer practices (timing and placement) to assure nitrogen uptake. Perhaps more importantly we will have to efficiently use that nitrogen in growth and production of economic yields. These goals will require close cooperation between breeders and agronomists and increased appreciation of water and nutrient flow in the SPAC of upland rice.

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VARIETAL IMPROVEMENT

VARIETAL IMPROVEMENT IN UPLAND RICE AT THE INTERNATIONAL INSTITUTE OF TROPICAL AGRICULTURE

K. ALLURI, A. O. ABIFARIN, K. ZAN, and M. S. ALAM

Rice genetic research at the International Institute of Tropical Agriculture (IITA) seeks to develop superior varieties adapted to free-draining uplands, near-saturated valley bottoms (hydromorphic), and irrigated or shallow flooded (swamp) ecologies. Solutions are sought to important African upland rice problems such as drought stress, blast (Bl), glume discoloration (Gld), leaf scald (LSc), sheath rot (ShR), and brown spot (BS) diseases, and stem borers (SB).

IITA is working to combine specific adaptational attributes of local African varieties and grain yield potential of more productive genotypes. The research process involves organized multilocational testing of germplasm, introduced varieties, and breeding materials, from early generations through fixed lines. Scientists will identify new rice varieties with high yield potential and quality for the major ecological zones with high production potential for rice.

To maximize researchers' efforts and to rapidly identify and utilize diverse rice germplasm, IITA participates in multilocational trials conducted by the International Rice Testing Program (IRTP) coordinated at the International Rice Research Institute (IRRI), the West Africa Rice Development Association (WARDA), and the Institut de Recberches Ayronomiques Tropicales et des Cultures Vivrieres (IRAT).

BREEDING OBJECTIVES

The major objective of IITA dryland rice varietal improvement programs is increased grain production (Abifarin et al 1972). To achieve this objective, agronomic, socioeconomic, physical, and biological factors and grain quality characters demanded by local consumers must be understood and planned for.

The specific objective of upland rice improvemeat at IITA is to identify or develop superior rice varieties with

1. high, stable grain yield;
2. improved plant type,
3. resistance to major African upland stresses such as drought, diseases (Bl, Gld, LSc, ShR,

International Institute of Tropical Agriculture, Ibadan, Nigeria.

BS), insects (stem borers), and nutritional deficiencies or toxicities;

4. a range of maturity suited to different rainfall and cropping patterns; and
5. locally acceptable grain quality.

Traditional African varieties and several similar introduced cultivars are generally well adapted to major upland stresses such as drought, Bl, and panicle diseases with some exceptions. Virmani et al (1977) observed that on upland-rainfed farms in Liberia, none of the introduced varieties were superior to LAC23, a selection made from local sativa populations. However, in Liberia and Nigeria, several unadapted introductions had grain yield potential superior to that of local varieties in experimental plots (IITA 1977, 1978, 1979, 1980). Introduced varieties often have been susceptible to panicle diseases, Bl, or drought.

Interestingly, some selections from crosses of African and introduced varieties have been superior. These results show that testing large segregating breeding populations is more useful than concentrating on a limited number of fixed lines. Comparisons of fixed lines from IRRI with progenies of the same cross selected from the F_2 in Africa have confirmed the advantages of in situ selection beginning with early segregating populations.

The major strategy is to combine the specific adaptational attributes of upland varieties with grain yield potential of more productive genotypes. Scientists will also develop intermediate-statured varieties which phenotypically and genotypically resemble both the land races but have superior lodging resistance and tilleriny ability.

A second goal is to further improve these semi-improved varieties by accumulating their favorable traits into more productive, short-statured varieties which resemble the improved semidwarfs but will be adapted to uplands.

MUTLTILOCATION RESEARCH

Multilocation test sites have been carefully chosen to represent the major upland stresses. In Ibadan, Nigeria, varieties are tested on a derived savanna for drought and Bl. In Ikenne, which has higher rainfall than Ibadan but has drought because of a bimodal rain pattern, varieties are evaluated for resistance to LSc and panicle diseases, Onne does not have drought, but varieties are tested for Bl, LSc, Gld, and grain filling problems. In Zaria, a savanna area, rices are evaluated for drought tolerance early and late in the growing season. In addition, through the collaboration and participation of national programs, it has been

possible to exchange and evaluate rice varieties in several African countries. The multilocational breeding program is particularly important for upland rice improvement because of the extreme variability of upland stresses. Collaboration ensures that test material is of a wide genetic base and therefore increases the probability of identifying superior genotypes. Appropriate selections from each site are evaluated at several other sites to confirm their performance.

MAJOR APPROACHES TO GENETIC IMPROVEMENT

Yield stability and potential

The African varieties OS6, LAC23, and ROK3 have relatively high yields and stable performance on peasant farms (Virmani et al 1977). Without severe upland stresses, however, several improved cultivars outyielded the local varieties (IITA 1979, 1980, 1981). IITA has worked to attain the yield stability of adapted germplasm; at the same time, raising yield potential by simple, three-way, and multiple crosses in the hybridization program to accumulate desirable genes for adaptation and productivity.

Efforts are being made to obtain vigorous, intermediate and short-statured varieties that yield higher and adapt to upland stresses. They may require improved cultural management and will probably be best suited to favored uplands.

Early vigor

For direct-seeded upland rice, early seedling vigor is extremely important for successful competition with weeds, a major production constraint. Early vigor may also reflect tillering ability in semidwarf rices. Quick shading of the ground, rapid increase in plant height, and moderate tillering ability, appear to be important in smothering weeds.

Lodging resistance

Upland rice varieties in Africa are traditionally tall, have low to inoderate tillering ability, long, droopy leaves, and large, well-exserted panicles (Alluri 1975, Chang and Vergara 1975, Chang et al 1972). Because their major disadvantage is their tendency to lodge under improved management practices, particularly high N, a major objective of varietal improvement is to develop lodging-resistant cultivars.

Plant type selection

The proper plant type for upland rice has been controversial. A major goal of the IITA breeding program has been to develop a plant type for African upland rice

Table 1. Performance of high-yield-potential rice cultivars at different sites in Nigeria, 1978 (Alluri et al 1982b).

Variety [a]	Grain yield [b] (t/ha)			
	Lowland Ibadan	Upland		
		Onne	Ikenne	Ibadan[c]
BG66-1	6.7	0.8	3.1	0.0
C4–63	7.2	N.T.	0.8	0.3
LET1996	6.9	0.7	2.6	0.2
IR8	6.7	0.8	3.6	0.0
IR1416-131-5	6.6	0.6	N.T.	1.2
IR1529-430-3	6.9	1.2	3.2	0.0
IR2035-120-3	8.2	1.7	4.4	0.4
IR2035-244-3-2-2	7.2	0.7	3.3	0.3
IR2061-228-3-9	6.9	0.9	1.7	0.3
IR2071-586-5-6-3	5.7	N.T.	2.4	0.8
IR2071-588-3	6.0	0.8	2.3	1.4
PMI 6624-257-1	7.0	1.5	2.5	0.0
RP4-14	7.2	1.2	2.4	0.0
RPW6.17	6.9	N.T.	3.1	0.0
TOx 514-16-101-1-1	7.7	N.T.	4.6	1.1
BG90-2 (check)	7.9	1.2	2.4	0.0
OS6 (check)	N.T.	1.1	2.4	0.9
S.e.	0.2	0.1	0.2	
C. V.	12.6	31.2	29.7	

[a] OS6 is tall; all others are improved semidwarfs. [b] N.T. = not tested. [c] The low yield at Ibadan was due to severe blast incidence.

Table 2. Grain weight, root dry weight, and root thickness of 4 varieties with different plant types in 3 ecologies.[a]

Variety	Grain yield (t/ha)			1,000-grain weight (g)		
	P	H	U	P	H	U
68-83	2.9	2.3	2.4	37.3	38.8	39.1
ITA116	3.7	4.4	2.6	32.6	35.1	33.8
ITA119	3.7	4.4	2.9	31.5	32.9	29.8
IR1416-131-5	4.1	5.4	1.2	27.1	26.9	17.7

Variety	Root dry weight (g)			Root thickness [b]		
	P	H	U	P	H	U
68-83	48	80	65	5	9	6
ITA116	61	12	76	7	8	6
ITA119	48	68	91	7	8	7
IR1416-131-5	107	134	112	5	5	3

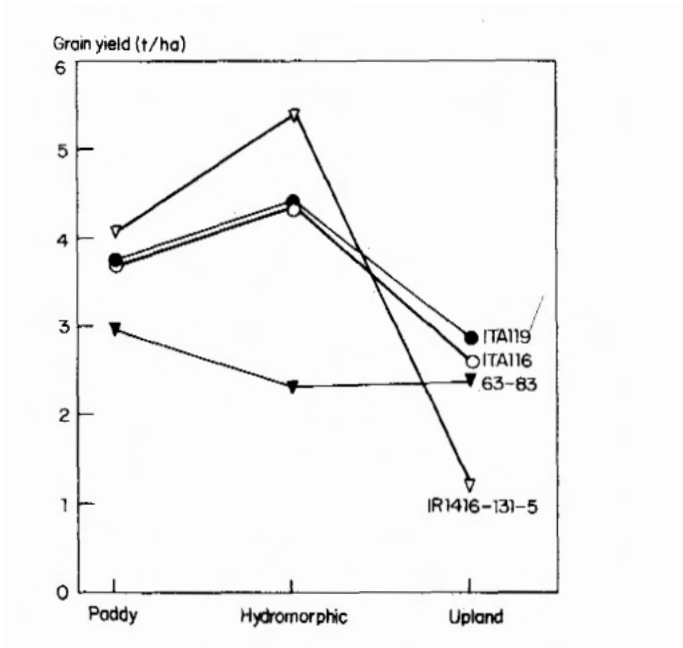
[a] P = paddy, H = hydromorphic, U = upland. [b] Score on 0-9 scale, where 0 = most roots thinner than 2 mm and 9 = most roots thicker than 2 mm.

areas. Evaluation of several high yielding semidwarf rice varieties developed for lowlands showed that most failed to meet their high yield potential in uplands (Table 1). However, IITA'S observations (Alluri et al 1979, IITA 1980) show the upland performance of semi-dwarfs was variety-specific and not a reflection of plant type.

Traditional African upland varieties have deeper, thicker roots than those in lowlands. Deep-rooted varieties usually have a larger proportion of thicker roots than shallow-rooted types. When compared with upland rice root dry weight and thickness (Table 2), grain yield data (Fig. 1) suggested no relationship to root dry weight but showed that thicker roots increase yield. IR1416-131-5 had nearly twice the root weight of other varieties, but most roots were thin and its upland grain yield was lowest (Alluri et al 1981a; IITA 1981; Yamaguchi, unpubl. data).

Root strength tests by Miyasaka (1969) indicate some correlation between pulling strength and root thickness. Recently, IRRI researchers (IRRI 1981, Chang et al unpubl. data) confirmed that the mean diameter of roots among 35 varieties was significantly correlated with field drought tolerance scores.

Alluri (1979) showed that heavy tillering exhibited by typical lowland irrigated semidwarf rices is detrimental in drought-stressed uplands. Studies at IITA (Alluri et al 1981a; IITA 1981; Yamaguchi, unpubl.



1. Grain yield of 4 rice varieties in 3 ecologies.

data) indicated that a combination of moderate tillering (150-200 panicles/m^2) with moderate panicle weight (2.5-3.0 g) produced 4-6 t/ha upland grain yield. These are substantially different tillering and panicle characters from those for typical improved irrigated semidwarf rice.

For example, an upland semidwarf differs from IR1416-131-5 by its lower tillering ability, higher 1000-grain weight, lower root volume, and thicker roots. The upland semidwarf ITA119 has droopy lower leaves, which improves weed competition, and erect upper leaves for efficient use of solar radiation. Multilocation tests in Nigeria (IITA 1981) indicated the superiority of this variety in uplands. Other evaluations show that ITA119 maintained high leaf water potential under draught (IITA 1981).

Ekanayake (1982) reported that root length is positively associated with root thickness, but observed no dominance in the expression of root thickness. He suggested that the relatively high additive genetic variance for root thickness might be a good basis for recurrent selection. Adja (1981) observed high heritability of root thickness and suggested that the selection could be effective at F3.

Considering the advantages of short-statured varieties with thick and deep roots for upland cultivation, attempts have been made to select, for these traits at seedling stage (Alluri et al 1981a). The results of a cross of IR43 and Iguape Cateto, a tall upland variety, show that the fit of seedling stage selection and adult plant root thickness in short-statured plants was as high as 95%. The correlation coefficients between plant height and root thickness were inconsistent. Therefore, the linear regression equation between plant height ($\underline{y}$) and root type ($\underline{x}$) for all the F2 plants ($\underline{Y} = 0.318\ \underline{x} + 147.7$ and $\underline{R} = 0.025$) at maturity was not significant. This indicated that plant height and root type are independent characters, making it possible to select for short height and thick roots at seedling stage (IITA 1981).

Because of the relatively low level of cultural practices used in Africa and the magnitude of the shift in management practices needed to promote short-statured varieties, IITA is simultaneously selecting for intermediate stature for low to moderate management levels and short stature for relatively high management.

Breeding for drought resistance

Rice has low levels of drought tolerance compared to other cereals. No single selection criterion or screening methodology has been found adequate in drought tolerance breeding. The various mechanisms for drought resistance -- drought escape, avoidance, tolerance, and

recovery -- are generally associated with different genotypes.

The drought escape mechanism is the ability to complete the essential growth cycle during the period of adequate moisture. The common escape mechanism is earliness, and breeding cultivars with a suitable growth duration for the regional rainfall pattern effectively selects for productivity (Abifarin and Okereke 1974, Alluri and Vergara 1975).

Drought avoidance is a plant adaptation mechanism that prevents excessive water loss. Plants have thick, deep roots. They absorb more moisture from the soil and conserve it by rolling leaves, stopping active growth, growing thick cuticles, etc. The value of thick, deep root systems for drought tolerance has been documented by rice researchers (O'Toole and Chang 1979, Alluri et al 1981a). The importance of panicle weight and other characteristics for drought tolerance is emphasized by a correlation matrix between selected plant parameters of 36 varieties under 4 drought treatments (Table 3). To facilitate field screening, routinely fixed breeding lines are evaluated in the dry season in a toposequence transect where soil moisture gradient is 2 – 40% with periodic sprinkler irrigation (Alluri et al 1978). The drought line along the transect was determined by the drought symptoms of standard varieties planted after every 10 – 20 test varieties. If test varieties are superior, they are selected and subjected to detailed physiological parameters to confirm drought tolerance.

Glume discoloration

Gld leading to dirty panicles commonly occurs in African uplands afid is a major problem with most high – yield – potential semidwarfs developed for the lowlands. Ngala (1980) and IITA (1980, 1981) reported that the predominant fungi associated with Gld in Nigeria are Sarocladium sp., followed by Curvularia sp.,

Table 3. Correlation matrix between selected plant patmeters of 36 varieties under 4 drought treatments. (Alluri et al 1981a),

Plant parameter	Mean value	Plant height	Panicle exsertion	Panicle no.	Grain weight	1,000-grain weight	Weight per panicle
Plant height (cm)	107	1.0					
Plant exsertion (cm)	3.9	.45*	1.0				
Plant no./hill	9.2	.01	.00	1.0			
Grain weight (g/hill)	14.5	.46*	.28*	.30*	1.0		
1,000-grain weight (g)	13.8	.46*	.21*	.28*	.98*	1.0	
Weight per panicle (g)	2.0	.45*	.29*	.11	.86*	.87*	1.0
Harvest index (%)	30.5	.26	.10	.07	.49*	.48*	.44*

*Significant at 1% level.

Acrocylindrium sp., Fusarium sp. Pyricularia sp., and Nigrospora sp.

The incidence of dirty panicles is severe in high rainfall regions where soils are low in pH and CEC and usually have nutritional imbalances. Grain-sucking bugs are also associated with dirty panicle incidence in Sierra Leone (Agyen-Sampong and Fannah 1980).

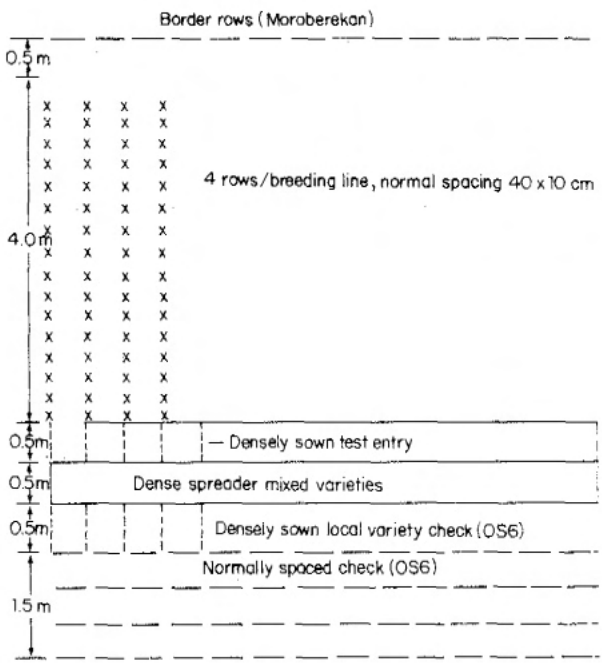
Recent studies (Yamaguchi, unpubl. data) suggest that dirty panicles can affect grain filling and, in severe instances, considerably reduce milling recovery. Results show that the severity of dirty panicle incidence varied with plant density and variety.

Although the importance of various factors leading to dirty panicles has not been clarified, observations at IITA show that land races and their selected progenies have less Gld incidence. They generally have well-exserted, clean panicles with good grain filling under moderate drought.

Breeding for blast resistance

Bl disease caused by Pyricularia oryzae Cav. is one of the most important rice diseases and a major limitation to improving upland rice production in Africa, particularly under drought conditions (IITA 1979).

Most Bl resistance breeding has been based on vertical resistance genes from different sources. How-



2. Field layout for horizontal blast resistance screening of breeding lines under upland conditions.

ever, IITA strategy has been based on horizontal resistance, which is not strain specific and should not break down quickly (Buddenhagen 1979, IITA 1979).

Traditional upland rice varieties in Africa have a good level of horizontal resistance. The method (Bidaux 1978, IITA 1979) and the design (IITA 1980) for selecting for horizontal Bl resistance (Fig. 2) attempt to simulate a gradient in the disease buildup with time and distance from the inoculum source (Buddenhagen 1979). The level of horizontal resistance is determined by measuring the amount of Bl at different distances from the inoculum at different times and calculating the rate of disease increase in either of those terms. The superiority of the selections is based on their ability to slow disease development when virulent races of the pathogen are present (IITA 1979).

Many varieties and advanced breeding lines from IITA (Table 4, 8) have shown moderate to high levels of Bl resistance (IITA 1979, 1980, 1981; Alluri et al 1981b; Buddenhagen, unpubl. data).

Breeding for insect resistance

Insect pests are a major constraint to upland rice production in Africa. Quantitative figures on crop loss caused by insect pests are not widely available. Breniere (1969) estimated that insects cause 25% yield loss in African upland rice.

More than 80 insect species attack rice in Africa (Jerath 1965), but the major upland rice pests are stem borers (SB), stalk-eyed fly, termite, and grain-sucking bugs. Insects can be controlled by several methods, but planting resistant varieties is one of the most effective. Resistant varieties are an inexpensive insect control method and are compatible with other control methods. The only cost to the farmer is for seeds of the improved varieties. Major effort at IITA has been made to screen available germplasm for SB resistance.

Breeding for varietal resistance to rice insect pests was initiated at IITA in 1973. Varietal resistance to upland rice insects African striped borer *Chilo zacconius*, African white borer *Maliarpha separatella*, African pink borer *Sesamia calamistis*, and stalk-eyed fly *Diopsis thoracica* has been studied. Screening for all but the white borer was done in the screenhouse and the field. Screening for white borer was done in the field in endemic areas. From 1973 to 1977, 4,120 varieties or lines were screened against the 4 insect species and 38 varieties were identified as resistant or moderately resistant (Table 5). Sources of resistance to insect pests are given in Table 6. A breeding program has begun which uses resistant donors to develop varieties resistant to insect pests (Table 7).

Successful breeding for insect resistance depends on the development of suitable screening techniques. A

Table 4. Characteristics of some superior IITA upland rice varieties.

Variety	Cross	Grain yield[a] (t/ha)	Plant height (±·10 cm)	Days to maturity (±·10 days)	Resistance[b] to		Grain characteristics
					Blast	Drought	
ITA116	63-83/IR773	5.2	140	115	R	MR	Long, bold, translucent
ITA117	13a-18-3-1-3/TOx 7	5.5	110	110	R	R	Medium-long, translucent
ITA118	TOx 74-2-5-1/63-83	5.3	120	110	R	MR	Long, bold, with specks of abdominal white
ITA141	LAC23/(TOx 7, LET 1444)	6.1	135	120	R	R	Long, slender, translucent
ITA162	Moroberekan/ (ROK1, TOx 7)	6.2	130	120	R	MR	Medium-long, bold, trace white specks
ITA225	63-83 (ROK 1, Dourado Precose, Se 363G)	5.0	115	120	R	MR	Medium-long, bold, abdominal white (highly resistant to shattering)
ITA235	OS6 mutant/OS6	5.5	115	115	R	MR	Medium-long, translucent

[a]Grain yield under experimental conditions. [b] R = resistant, MR = moderately resistant, S = susceptible.

Table 5. Varieties or lines tested against major insect pests of upland rice.

Insect	Varieties tested (no.)	Varieties identified as resistant (no.)	Condition of test
African pink borer	800	6	Field and screenhouse
African white borer	2000	5	Field
African striped borer	600	10	Field and screenhouse
Stalk-eyed fly	720	17	Field and screenhouse
Total	4120	38	

Table 6. Sources of resistance to insect pests of African upland rice (IITA 1974a,b; 1975, 1976, 1977).

African striped borer	
Taichung 16	TOS2513
PR403	Ratna
ITA6-20-1-Bpl	Malagkit
IR503-1-91-3-2-1	Sung Song
PR325	SML 81B
H8	
African white borer	
ITA6-4-2	
IR1168-76 [a]	
IR1561-38-6-5 [a]	
IT47-7-2 [a]	
TKM6 [a]	
African pink borer	
W1263	INJ171
Taichung 16	INJ146
SMLB1B	Sikasso
Stalk-eyed fly	
IR579-160	ITA6-22-22Bp-1
Tx52-24	E. L. Gorpher
IR523-1-218	IR1561-38-6-5
Iguape Cateto	Huang-Sengoo
Leuang 28-1-64	Td10A
DNJ171	Magoti
Ctg 680	C5565
IR589-53-2	Saconodo Brazil
ITA6-16-7-Bp-3	

[a]Moderately resistant.

Suitable screening technique to determined stalk-eyed fly resistance has been developed (Alam,unpubl.data) and a systematic screening project for resistant varieties was started inmarch 1982. Five hundred germplasm breeding lines have screened and nine varities identified as promising. Promising material selected from mass screening test will be evaluated further for confirmation.

Table 7. Sources of resistance used for different insect pests.

Insect	Donors used
Striped borer	Taichung 16, Ratna, and PR403
Pink borer	Sikasso and Taichung 16
White borer	TKM6
Stalk-eyed fly	Iguape Cateto and G. L. Gorpher

Breeding for nutritional deficiencies or toxicities

Scientists have depended on natural incidence of common nutritional problems such as Fe deficiency, Al toxicity, and others in various test sites to systematically select for superior genotypes.

Kang et al (1977) showed that Fe deficiency is a problem of upland rice. Many IITA lines have good levels of tolerance for Fe deficiency, and some upland lines have performed well in high-Al acid soil (pH 4.5) at David, Chiriqui Province in Panama (Table 8) (trip report by J. C. O'Toole; IRRI 1981).

Growth duration

West Africa has three rainfall zones. The north has monomodal rainfall; the south central zone, bimodal; and the southeast and southwest, forming a continuum with the northern zone, has a pseudobimodal pattern (Lawson 1980). Varietal selection for growth duration for uplands must be based on regional rainfall pattern. Early-maturing varieties are suited to areas with monomodal rainfall. In areas with bimodal rainfall, dura--tion and distribution of rainfall during any period will support a rice crop. In areas with long rainy periods, such as the pseudobimodal areas, medium- to long-growth duration (130-150 d) varieties are best (Alluri and Vergara 1975). Variations in appropriate growth duration suggest the need to develop varieties with wide range of maturity to suit rainfall distribution patterns.

Table 8. Promising upland vaxieties in 1981 International Upland Rice Observational Nursery, Panama (J. C. O'Toole, pers. comm.).

David, Chiriqui Province [a]	Rio Hato[b]
ITA116	IR52
ITA117	IR6115-1-1-1
ITA118	IR9782-111-2-1-2
ITA225	ITA117
ITA235	ITA118
IRATl3	ITA225
IAC47	ITA235
Azucena	

[a]Acid soil (pH 4.5) with high aluminum. [b]Rainfall 1,000 mm; selections for drought, blast, and phenotypic acceptability.

Grain quality

In most urban areas in Africa (where the demand for rice is increasing most rapidly), medium to long translucent grains with intermediate amylose (22-26%) content are preferred. IITA gives priority to material with those characteristics and has released several improved varieties with those qualities (IITA 1979).

ACHIEVEMENTS IN GENETIC IMPROVEMENT

Improved upland rice varieties (Table 4) developed at IITA resist major upland stresses such as drought, Bl, and Gld. They mature in 90-120 d and are generally selected for nonchalky grain character. They have lodging resistance superior to that of traditional varieties, respond to better crop management, and have shown promising results in several WARDA and IRTP tests.

Preliminary results from 104 entries of the 1981 IRTP International Upland Rice Observational Nursery (IURON) conducted in 19 locations in 5 countries showed that several IITA varieties have superior drought recovery ability, herbicide reaction, and phenotypic acceptability. Other entries were from Asia, Africa, Latin America, and IRRI.

Of the entries, only five -- IR3794-9-2-3 from IRRI, and ITA235, ITA164, ITA175, and ITA183 -- had good drought tolerance, drought recovery, and phenotypic acceptability.

ITA116, ITA117, ITA118, ITA141, ITA235, and TOx 475, a sister line of ITA118, were included in the 1982 minikit trials (Alluri and Sarkarung 1982) conducted in farmer fields throughout Nigeria by the National Accelerated Food Production Project. All of these varieties except ITA117 have intermediate stature.

In the 1981 WARDA coordinated trials, several IITA varieties were outstanding. In the moist zone, ITA117 yielded an average 3.0 t/ha at 16 moist upland locations. IRAT yielded highest (3.3 t/ha) in this zone. ITA117 has medium-long, translucent grains and produced clean panicles even under the generally severe incidence of Gld (IITA, unpubl. data)

Among the 174 varieties from various breeding programs tested in 4 locations in the WARDA Initial Evaluation Trials, ITA233, ITA234, and ITA235 had the least or no grain sterility among the good yielders.

Nominations for 1982 IURON trials included three IITA TOx lines selected by the Central Agricultural Research Institute (CARI) at Liberia, and 12 ITA lines selected in Nigeria. Several IITA varieties also were evaluated in the 1982 WARDA Coordinated Variety and Initial Evaluation Trials.

FUTURE EMPHASIS

Upland rice is the major rice growing ecology in Africa. West Africa has more than 1.4 million ha of upland rice -- 65% of total rice area. Millions of small farmers will depend on upland rice production in the foreseeable future, therefore, any yield improvement will have substantial impact on total regional rice production. Unfortunately, inadequate research emphasis is being placed on upland rice work despite the depth and diversity of upland rice production problems. There are too few scientists working on upland rice in Africa and throughout the world. An increased number of researchers and research programs are needed.

To improve this situation, IITA will emphasize the following research in future varietal improvement programs.

Drought

Various drought resistance mechanisms will be investigated and appropriate screening methodologies for root thickness and length will be developed.

Diseases and insect pests

New and old screening methods will be improved for the use of interested scientists. Scientists will work to incorporate resistance to LSc, ShR, and SB, which are becoming increasingly important, in upland varieties.

Farming systems

Cultivars for specific upland farming systems in Africa will be developed,

Collaborations

Realizing the complexity of upland rice problems and the difficulty of any organization working in isolation to solve them, emphasis will be placed on close collaboration with national and international organizations within and outside Africa. Close cooperation with WARDA, IRRI, IDESSA-IRAT, National Cereals Research Institute, and other national and international organizations will be strengthened and new cooperative projects established.

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VARIETAL IMPROVEMENT OF UPLAND RICE IN SOUTHEAST ASIA AND AT INTERNATIONAL RICE RESEARCH INSTITUTE

T. CHANG, T. MASAJO, B. SOMRITH, nad B. H. SIWI

ECONOMIC IMPORTANCE

About 4.64 million ha, 13% of the total rice area in Southeast Asia is planted to upland rice. Upland rice in this region is characterized by dry soil preparation, direct seeding, and an absence of levees. Because much of it is grown on sloping land, it is also called hill rice.

Upland rice yields are generally low, averaging less than 1 t/ha. Most upland rice growers are subsistence farmers whose diet is supplemented with other cereals (mainly maize), legumes, and vegetables. Although their total daily caloric intake is slightly below national averages, they enjoy balanced nutrition because of the diverse diet.

The three Southeast Asian countries discussed in this paper are Indonesia, the Philippines, and Thailand. Upland rice is planted on 1,134,000 ha in Indonesia, 415,000 ha in the Philippines, and 961 000 ha in Thailand. Mean national yields are between 0.5 and 1.5 t/ha. Favorable areas bordering irrigated lands or with hydromorphic conditions where some high-yielding semidwarfs perform well have slightly higher yields. Yields in most upland areas vary significantly from season to season, and frequently suffer from water deficit. In some areas, blast (Bl) disease is a chronic yield constraint. In many regions, highly acidic soils are deficient in N and P or contain excessive Al and Mn.

Upland rice breeding is a relatively recent project in Southeast Asian countries and at IRRI, but research is increasing because subsistence farmers in upland areas constitute a major segment of the neglected sector. This paper reviews the situation during the last two decades.

PRINCIPAL BREEDING OBJECTIVES

Principal breeding objectives of the upland rice breeders of Southeast Asia and IRRI follow:

International Rice Research Institute, Los Baños, Laguna, Philippines.

1. Upgrade yield potential by developing an intermediate-stature, moderate tillering plant type to replace tall, weak-strawed traditional varieties. Target yields are 2 t/ha for unfavored areas and 4 t/ha for favored areas. For unfavored areas, the plants should be moderately tall with moderately long, droopy leaves to compete with weeds. Semidwarfs IR43 and IR45 may fulfill most of the requirements for highly favored areas.
2. Retain resistance or tolerance mechanisms related to related to yield stability: drought resistance (avoidance), Bl resistance, and recovery ability after water stress is relieved, which is generally poor in traditional upland varieties.
3. Develop a range of maturities to suit various ecologic niches. Weak photoperiod sensitivity may be required for some areas, as in northeast Thailand.
4. Retain preferred agronomic characteristics (long, well-exserted panicles; high panicle fertility; nonshattering spikelets) and grain quality (low to intermediate amylose content, intermediate gelatinization temperature, and soft gel consistency). Specific grain size and shape are less rigidly preferred.
5. Incorporate high levels of pest resistance from improved materials (mainly semidwarfs) or outstanding donors to: Bl, sheath blight (Shb), brown spot (BS), stem borers (SB), whitebacked planthopper (WBPH), leaffolders (LF), root-knot nematodes, and others.
6. Retain or incorporate tolerance for adverse soil factors: P deficiency, Al and Mn toxicity in acid soils, salinity, and Fe and Zn deficiency in alkaline soils.

Other location-specific requirements are cool temperature tolerance for high altitudes, seedling resistance to uprooting in the cross-harrowing weeding technique, and glutinous (waxy) endosperm. Aromatic grain is preferred in some areas (Chang et al 1982).

BREEDING PROGRESS

Indonesia

Until the mid-1970s, upland breeding efforts in Indonesia consisted largely of purification and selection among local varieties and evaluation of foreign introductions. Seratus Malam and Genjah Lampung were two popular varieties selected from farmers' plantings in Lampung, Sumatra. Pulut Nangka and Leter were pureline selections. Kartuna and Bicol (BPI-76-1) were

introduced from the Philippines, but BPI-76-1 neck blast (NBl) susceptibility has been a handicap.

Through hybridization and selection by Central Research Institute for Agriculture (CRIA) breeders, three upland varieties better adapted to the more favored areas were developed. Gata (from Sigadis/Syntha), Gati (from Sigadis/Basmati), and Gemar (Jerak/PB8). Breeders in Gadjah Mada University at Yogyakarta have crossed Genjah Mataram with Genjah Raci and bred drought-resistant Gama 87.

Philippines

Mass selection and comparison of farmers' varieties early in the century identified Pinulot, Kinandang Puti, and Apostol which later became major Philippine varieties. The Philippine Seed Board and its cooperative testing program were established in the early 1950s. After extensive testing, Palawan, Azucena, and Dinalaga were recommended as pureline upland selections (Cada and Escuro 1972).

Hybridization in the 1960s led to the release of Milpal 4, HBDA-2, BPI-I-48 (MI-48), and Azmil 26. Breeding at the University of the Philippines at Los Baños in the 1970s produced C22, UPL Ri-3, UPL Ri-5, and UPL Ri-7 which have intermediate height, moderate tillering ability, and good grain quality. OS-4 is a UPL Ri-7 parent. About this time, the Bureau of Plant Industry bred BPI Ri-6, a short-statured variety.

These varieties sometimes suffered from NBl. Although their drought recovery ability is generally excellent, they have intermediate type root systems. Yield potential is about 4 t/ha.

Thailand

Breeding efforts from the early 1950s to the mid-1970s were limited to collecting farmers' varieties, purification, and evaluation. Through multiple-station testing, two nonglutinous varieties, Goo Muang Luang and Dawk Payom, were recommended for southern Thailand. Their yield potential is slightly under 2 t/ha. One glutinous variety, Sew Mae Jan, is recommended for northern Thailand. Its top yield is 2.8 t/ha. All three are traditional varieties.

Recent crosses have been made at the Thailand Rice Division and Kasetsart University and are at different stages of evaluation in the north and northeast.

International Rice Research Institute

Upland breeding activities at IRRI were preceded by intensive studies of shoot and root characteristics of upland varieties that make plants more drought re-

sistant than lowland varieties. During the studies, correlations between deep-and-thick roots and drought avoidance, between leaf rolling and unrolling plasticity and favorable water status in plant tissues, and between recovery ability and vegetative growth vigor were unraveled (Chang et al 1972). A mass screening technique for both the vegetative and reproductive phases was developed in 1973 (Chang et al 1974, IRRI 1974, Loresto and Chang 1981). However, the nature of tissue tolerance for desiccation and factors associated with reproductive stage resistance to water deficit remain to be fully elucidated.

More than 4,000 crosses have been made at IRRI for local testing and selection and for international collaborative activities. Most involved one pest-resistant semidwarf in order to incorporate characteristics selected in IRRI's Genetic Evaluation and Utilization (GEU) Program.

The following are constraints in the breeding process:

1. lack of donors with drought resistance at reproductive stage,
2. genetic barriers to obtaining desirable progenies in upland/semidwarf crosses,
3. negative correlation between drought escape and avoidance mechanisms and recovery ability,
4. Philippine test sites are not representative of drought-prone production areas with low soil fertility, and
5. lack of adequately equipped and staffed experiment stations in cooperating countries.

Despite these handicaps, IRRI breeders have made substantial progress:

1. Breeding materials that combine high levels of drought resistance and a moderate level of recovery ability have been generated (Table 1).
2. A yield potential of 4 t/ha for favored areas has been attained.
3. several components of pest resistance and desired grain quality have been incorporated.
4. Improved materials have been categorized by their adaptiveness to favored, unfavored, or all upland environments through multisite testing (Table 2).
5. Some new upland varieties also can be used for drought-prone shallow rainfed-wetland culture.
6. More than 100 crosses involving IRRI's improved germplasm and traditional varieties from collaborating national or regional centers have been provided to centers for selection under local conditions.

IRRI also is cooperating with upland rice breeding centers in Brazil and India and with the International

Table 1. Promising IR breeding lines that have performed well in various screening nurseries.

Breeding line	Test site	Type of experiment	Reputed superior features
IR1750-F_5B-5	East India	IURON '77	High yield potential
(E425/IR22)	Ecuador, Peru	VIRAL-S '77	High yield potential; early
IR1746 lines	Chiang Mai, Thailand	IURON '77	Drought resistance, high pheno-
(OS4/IR8)	Faizabad, U. P., India		typic acceptability
IR1754-F_5B-22	Philippines	Screening nursery for	Tolerance for Mn/Al toxicity;
(E425/IR8)		adverse soils	drought resistance
IR3839-1	Rajshahi, Bangladesh	IURYN '77, '79	High yield potential
(Pelita I-2/IRl529-680-3//	Philippines	Philippine Seed Board	High yield potential
IR442-2-58/RN21)		1980, 1981	
	Latin America	VIRAL-S 1980 WS	High yield potential
	(favorable upland areas)		
IR3880-13	Ranchi, Bihar	IURYN '79 WS	High yield potential
(IR841-67/C22//Pelita I-2/	Philippines	Philippine Seed Board	High yield potential
IR1541-76)		1976 WS, 1977 WS	
IR5178-1-14	Philippines	Philippine Seed Board '78	Blast resistance
(IR1746-194-1/IR1487-372)	Nangina, India	IURYN '79	Drought resistance
	Joydebpur, Bangladesh	IURYN '79	High yield
IR5931-110-1-1	Nigeria	IURYN '80, '81 WS	High yield, blast resistance
(MRC172-9/IR1544-340//	Chiang Mai, Thailand	IURYN '80, '81 WS	High yield, blast resistance, early,
IR4520-76-90)			good recovery ability
IR6115-1-1-1	Philippines	Philippine Seed Board 1978	Blast resistance
(IR1529-680-3/Moroberekan)	Philippines (IRRI)	Screening for adverse soils	Good on low-pH upland soils
	Philippines (IRRI)	Screening for insect resistance	Resistance to BPH biotype 1
	Thailand and Southeast Asia	IURYN '80, '81	High yield
	Huimanguillo, Mexico	VIRAL-S '80	High yield
IR7844-12-2-2	Vinh, Vietnam	IURON '81	High phenotypic acceptability,
(IR1721-11-8/63-83//MRC172-9)			good recovery ability
IR10110-23-1	Khon Kaen	IURON '81	Drought resistance, high pheno-
(IR1754-F_5B-23/IR3179-25//			typic acceptability
BPI-76*9/Dawn)			
IR12979-24-1	Philippines, Khon Kaen	IURON '81	Drought resistance, high pheno-
(IR3179-25/K. Patong//	Ranchi, Nawagam,		typic acceptability
IR26///IR879-314-2)	Hawalbagh		

Table 2. Performance of promising IR lines in upland trials during 4 yr at 3 locations, 1977-80 wet seasons.

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

Institute of Tropical Agriculture (IITA) and the West Africa Rice Development Association (WARDA) in Africa (Chang et al 1982).

FUTURE ENDEAVORS

Directions for future breeding efforts

Intensive breeding programs in Brazil and several other national centers, as well as at the International Rice Agriculture in the Tropics (IRAT), IITA, Centro Internacional Agricultura Tropical (CIAT), and International Rice Research Institute (IRRI), have demonstrated that yield potential can be readily raised to 2 t/ha in uhfavored upland areas and 4 t/ha in favored areas and that high yield stability could be attained by combining drought resistance with recovery ability after water stress is over. However, most recently bred germplasm lacks disease and insect resistance, adverse soils tolerance, and grain quality.

Because few full-time upland rice breeders are found in tropical Asia, it is imperative for breeders to exchange and share breeding materials for a fuller utilization.

The IRRI germplasm bank, which conserves more than 60,000 accessions, offers a wealth of genetic resources for most desired traits. Moreover, IRRI varieties and lines selected from wetland nurseries have high levels of resistance to some diseases and insects. Breeding materials from national programs can supplement other desired traits. IRTP provides a channel to intraregion and interregion exchange and testing. It is to be hoped that better methods of selecting materials for inclusion in the nurseries will be developed, and that nurseries will be better targeted for upland environments.

Breeding methodology must be tailored to suit breeding objectives. Wide crosses are necessary to combine many desired traits, and multiparent crosses have proved useful in IRRI's program. Bulk selection during early generations may prove to be more useful than pedigree selection. Backcrossing may be expedient to improve an adapted genotype. Population improvement techniques could be used to fully exploit useful genes in diverse populations. Extensive multisite and multiseason testing may provide information on both broad and specific adaptiveness and yield stability (Chang et al 1982).

Related future research

Drought resistance at reproductive stage needs to be elucidated to develop effective selection criteria for drought-prone areas. Root systems need to be investigated under a soil-water continuum. Adverse soils tol-

erance could be studied under tissue culture at seedling stage. Studies on major diseases and insects should be augmented.

Manpower and station development are two areas which must be strengthened to support expanded breeding programs. Upland rice breeders will benefit from broad-spectrum training by learning to fully utilize available information and techniques from studies in agronomy, crop physiology, water science, and soil science. Interdisciplinary and interinstitutional collaboration hold the key to future progress in upland rice improvement.

Research center strengthening

The national centers of Southeast Asia and IRRI should strengthen their upland research activities by

1. expanding the generation and cooperative testing of improved germplasm;
2. developing additional selection criteria to enhance the effectiveness of evaluation efforts, especially the physiological components;
3. using more effective and innovative approaches in breeding -- population improvement, composites, backcrossing;
4. training workers; and
5. developing upland rice experiment stations in major upland rice production areas.

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VARIETAL IMPROVEMENT OF UPLAND RICE AT THE SAVANNA INSTITUTE

K. GOLI

The importance of rice in the Ivory Coast's economy has grown rapidly because of the development of urban centers, state social institutions, and semipublic and private major agricultural cash crop schemes using a great amount of labor.

Rice research activities in the Ivory Coast have constantly evolved to increase rice production as a local food source as well as a cash crop.

To satisfy consumer needs, the cereals program integrates the results obtained by agronomy, plant improvement, crop protection, and seed research, and offers development companies a number of promising, stable varieties that can withstand different conditions and yet have acceptable cooking qualities.

IMPORTANCE OF RICE TO THE NATIONAL ECONOMY

Self-sufficiency in food supply is one of the main priorities of the National Campaign for the Independence of the Ivory Coast. To satisfy domestic rice needs, the Ministry of Planning estimated the necessary production (Table 1). But during the last few years, the actual production has not kept up with the needs and even shows a regular decrease.

In the Ivory Coast, rice is the only food of plant origin that needs massive importation and is the agricultural product having the largest and surest market.

Table 1. Necessary and actual rice production and amount of imported rice for the Ivory Coast.

Year	Production (t)		
	Actual	Imported	Neccssary
1960	160,000	35,000	
1970	316,000	78,800	400,000
1975	496,000		615,000
1980	420,000	300,000	800,000
I985			1,030,000

Head, Plant Breeding Division, IDESSA/DCV Communication, B. P. 635, Bouake, Ivory Coast.

Rice production objectives

The national policy for food self-sufficiency in rice production aims to:

- move farmers toward modern production methods,
- use extension service methods,
- identify and develop regional potentials and structure the territory by promoting a small number of national centers,
- achieve these production objectives from 1981 to to 1985 through
  1. either at least 125,000 ha of an irrigated rice crop with 4 t/ha,
  2. or 165,000 to 250,000 ha of upland rice with 2 or 3 t/ha.

At this rate, the national rice production would be 830,000 to 1,250,000 t, which would satisfy national needs.

Strategies

To put rice production on par with other local food crops, we need

- progressive cultivating methods for farmers;
- selected seeds for high stable yield, disease tolerance, drought and insect resistance, and good agronomic and taste qualities;
- preservation methods for fragile, perishable foodstuffs such as yam, banana, and cassava, to fill the gap left by rice and to avoid mass importation;
- prices that will encourage the producer. We can achieve this by incorporating rice into the general stabilization system of the CSSPPA by controlling private acquisitions and producing rice under contract with the state retaining ownership of the plants and equipment; and
- a sensible and progressive organization of existing farm structures guaranteeing unity of the family. This would mean regrouping state activities:
  1. improving rural environment without breaking up the family unit: technical training, use of appropriate mechanical means for soil preparation activities;
  2. establishing cooperatives with efficient management units to manage agricultural guarantee funds and interest rebate funds; and
  3. initiating industrial agriculture for farmers with a very high level of technical know-how and adequate means for practicing not a monoculture, limited to rice, but mixed farming (maize, rice, yam) with livestock. The hect-

arage and machinery may sometimes call for private capital.

INTEGRATION OF THE CEREALS PROGRAM AND RICE CULTIVATION DEVELOPMENT

Three periods mark the history of rice research activities in the Ivory Coast. Research was almost entirely agronomical from 1954 to 1966, at which time the Ivory coast Government entrusted it to the Institute of Tropical Agronomic Research and Local Food Cultivation (IRAT), following previous work done by the Center for Agronomic Research (CRA). From 1966 to 1974, research work became progressively multidisciplinary and in 1971, the Ministry of Scientific Research was established. Starting in 1972, rice research activities were on a multidisciplinary basis with well-defined objectives in a cereals program within IRAT. Later the Department of Local Food Crops at the Savannah Institute created in 1976 coordinated it.

At that time, the Ivory Coast Government introduced an aquatic rice program, integrated into the other rice programs.

IMPROVEMENT OF UPLAND RICE VARIETIES

Upland rice will continue to have a major place in achieving self-sufficiency in rice. It represents 87%- of cultivated areas and 62% of the total rice production.

A multidisciplinary team working on varietal improvement has achieved these results:

- On the scientific level, they are working on
  1. drought resistance,
  2. resistance to insects (stem borers) and diseases (rice blast),
  3. the study of variability of African rices to safeguard and catalog African rice resources, and
  4. creating new varieties to improve production and seed conservation.
- On the development level
  1. Drought-resistant varieties should enable us to extend upland rice cultivation to places where the rainfall quantity previously did not allow it.
  2. Using poorly explored plant resources (*glaberrima* complex) will help upgrade specific resistance and hardiness characteristics.
  3. Obtaining new varieties with high stable yields good taste qualities, low-susceptibility to pests, and likely to appeal to development companies.

Upland rice drought resistance

The Department of Local Food Crops of the Savannah Institute is working to identify resistance genes and define characteristics (rooting capacity, resistance to transpiration, ability of carbonaceous reserves to migrate from the stem toward the grains during drought) whose combination would give drought tolerance. The Institute also wants to perfect screening methods for overall resistance and determine the physiological stage of greatest drought susceptibility.

We tested a method of quantitative characterization of the root activity profile measured by the absorption of phosphorus 32 (32p). Tested on several varieties, the method produces results sufficiently correlated with the mass root profile to make it useful in selection.

New varleties, IRAT 104 109... tested for their overall drought tolerance, have shown they are superior to IRAT13 whenever drought occurs at the booting stage. However, IRAT 13 is still the most tolerant at the grain-filling stage. We are crossing numerous high-yielding varieties with IRAT 13 to transfer this tolerance at the grain-fllling stage.

Rice blast resistance

We are basing the breeding strategy on use of horizontal resistance to Pyricularia oryzae and on stability of horizontal resistance in space and time.

An improvement in the breeding design for horizontal resistance enables us to detect varietal resistance mixed with horizontal resistance and gives better quality of the disseminated product.

A study of F_2 progeny suggests the possibility of early choice of parents for horizontal resistance.

Research on parents and varietal creation

In looking for parents, we study four characteristics ranked by farmers: yielding ability, yield stability, agronomic qualities, and technological qualities. In creating new varieties we want

- to obtain genetic material for testing in diverse ecosystems,
- to modify the technique for breeding, and
- to perfect new techniques of breeding and studying progeny: hybridization using male sterility, and natural outcrossing or outcrossing chemically induced through male sterility.

Studying the variability of African rices for breeding purposes should enable us to

- introduce new characteristics for rice improvement,
- create new varieties of O. glaberrima,

- create varieties by interspecific crosses with O. sativa,
- understand mechanisms of barriers to sterility in species related to the Oryza genus,
- understand sterility in interspecific hybrids,
- transfer the allogamy observed in O. longistaminata to annual autogamous Oryzae, and
- create varieties with better adaptation to the West African environment.

We identified a range of varieties with different abilities for development agencies to choose from.

- Some are old varieties such as early Dourado, Moroberekan, and Iguape Cateto.
- One improved variety, IRAT 13, is a clear improvement with a yield greater than that of old varieties in present cropping systems with minimum input.
- Modern varieties IRAT 104, 109, 112, 132, and 136 produced higher yields than improved varieties. Instead of 2-3.5 t/ha, we get 4.5 t/ha if they are correctly managed.
- A set of parents (5-7 groups) of various geographical origins enables us to study various crosses which combine complementary genetic characters while taking into account different yield strategies ending with the same product.
- We collected more than 10,000 samples of varieties from Asia and America and traditional varieties of sativa and African Oryzae from 12 African countries. They constitute a very rich gene bank for future genetic improvement.
- We identified varieties for dietetic and medical use in the Ivory Coast pharmacopoeia.
- We discovered the tolerance of O. glaberrima for poor soil, weeds, nematodes, and certain insects.

Screening and study of varieties under upland conditions

We screen varieties both in the ecosystems of the Ivory Coast and in those Of international trial networks. We seek material with the following characteristics for dissemination to farmers:

- short- or medium duration,
- high yield potential,
- drought resistance,
- blast resistance,
- resistance to shattering, and
- good technological, commercial, nutritional, and cooking qualities.

Varietal resistance to pests

Varietal resistance studies involve research on

- chemical control,
- biological control, introduced only in 1979, and
- protection of stored foodstuffs.

The plan is to

- identify pest-resistant or tolerant varieties;
- screen varieties currently used or being disseminated, new lines created in the Ivory Coast, and recently introduced material for resistance to known pests;
- prepare an index, mass breed, and release arthropods (parasites and predators);
- use entomopathogens and
- study insecticides' impact on insect-eaters.

We identified parasites of insects that attack rice (Table 2).

Production and seed control for upland rice

We plan to

- obtain sufficient quantity and quality of foundation seeds (G0, Gl, G2) necessary to produce foundation seeds (G3) and certified seeds (R_1, R_2);
- define technological characteristics of varieties being disseminated;
- obtain, by field control, production of quality foundation and certified (R_1, R_2) seeds; and

Table 2. Parasites of rice insect pests.

Name	Stage	Parasites
Stem borers		
Diacrisia scorlillia	Egg-laying	*Telenomus thestor* Nixon
Scirpophaga	Egg-laying	*Telenomus* sp. gr. *Benefactor* Nixon
Maliarpha separatella	Egg-laying	*Telenomus* sp. gr. *Lemoleae* Nixon
Sesamia caaomistis	Larva	*Apanteles sesamiae*
Sesamia calamistis	Nymph	*Pediobus fervus* Cameron
Marasmia trapezalis	Larva	*Bracon* sp.
Maliarpha separatella	Larva	*Bracon* sp., *Bracon antennatus* (Granger), *Rhaconotus niger* Szepl.
Pachydiplosis oryzae	Larva	*Plastygaster oryzae* Cameron
Stingers		
Aspavia spp.	Egg-laying	*Trissaleus atys.* Nixon
Plant eaters		
Parnara sp.	Egg-laying	*Telenomus narolus* Nixon
Epilachna similis	Egg-laying	*Oencyrtus* sp.

- adapt methods of control to local conditions of production.

This operation also applies to aquatic rice. We have greatly improved the quality of seeds furnished to the farmer by using better control techniques in the field and laboratory. Varietal purity went from 937% in 1972 to 993% since 1975 in 500 – gsamples.

We release more than 3,500 t of rice seeds every year for all types of cultivation, thus guaranteeing seed quality.

CONCLUSION

To satisfy domestic rice demands, the Ivory Coast es – tablished a rice program within the Cereals Program included in the national policy for self – sufficiency in food Supply.

To attain the objectives on the scientific and development levels, numerous strategies were set into action to stop the tremendous currency drain of the last few decades.

Although many problems remain, accomplishments at every level of the rice program have had an impact on development, as measured by the number of varieties having a stable high yield, great adaptability, insect and disease resistance, and techniques for developers to increase upland rice production.

UPLAND RICE BREEDING AT IRAT AND IDESSA

M. JACQUOT and K. GOLI

Because of frequently uncertain yields, upland rice cultivation has not always received the attention it deserves. In the early sixties, however, IRAT chose to devote an important portion of its activities to upland rice by establishing a multidisciplinary research team which cooperates closely with scientists of IDESSA (Institut des Savanes of the Ivory Coast).

THE RESEARCH STRUCTURE

IRAT maintains three basic research groups which coordinate their activities with other research centers in France, French Guyana, and Guadeloupe. Scientists use laboratory and field research to study rice androgenesis, gynogenesis, isozyme electrophoresis, O. longistaminata allogamy and transfer to O. sativa, drought resistance factors, rice blast intcractions, and resistance to rice pests. In addition, IRAT conducts service activities such as germplasm maintenance and conservation, analytical studies, documentation, and training. This involves 15 scientists, including 10 in training courses.

National cooperation

Several IRAT scientists also cooperate with national research teams. This cooperation may be applied, such as varietal evaluation and seed production (Togo, Cameroon, Madagascar), or basic in fields such as entomology and plant pathology (Senegal, Upper Volta). Other research encompasses both basic and applied areas, with a multidisciplinary team as in Ivory Coast and Brazil. In West Africa, an intercountry network evaluates different rice varieties. For example, researchers studied varieties, such as IRAT10, IRAT13, and IRAT112, on a broad basis to evaluate their adaptability. Strong links exist among IRAT, ORSTOM, universities, and "Societe de Developpement" for scientific and technical support.

Head of the Upland Rice Program at IRAT and head of the Plant Breeding Division at IDESSA/ DCV Communication.

International cooperation

Intense international cooperation with IITA and WARDA in West Africa permits the exchange of varieties and segregating lines. Scientists exchange information and seeds with IRRI and an IRAT scientist studies rice enzyme polymorphism there. Finally, IRAT collaborates with IAEA on studies of root development in relation to drought resistance.

THE RESEARCH PROGRAM

The breeding objectives are high yield potential, yield stability, adaptation to different cropping systems, and better grain quality.

Varietal characterization

Varietal characterization will establish a better classification of upland rices within the O. sativa species, improve the crossing efficiency, and permit a better understanding of O. sativa and O. glaberrima varieties and their sorting into homogeneous groups. Analysis based on morphophysiological and electrophoretical characters and crossing behavior promotes research efficiency in use of new crosses. For a short-term improvement program, japonicas are preferable to the indicas because many upland rices belong to that group. Indica/japonica crosses are suitable for longer term programs. For rainfed lowland rices, intragroup crosses are preferable.

Disease tolerance or resistance

Blast is most important. Its polygenic resistance coming from the japonica (wide sense) group is durable. Researchers are conducting similar studies with the indica group.

Drought tolerance or resistance

Although drought tolerance is very complex, many trials in West Africa show that IRAT13, IRAT104, and IRAT144 give high and stable yields.

Haploidy

Scientists have used haploidy to rapidly obtain fixed lines from anthers or ovaries cultured on special media and obtained diploids with colchicine treatment after green plant regeneration. Studies initiated in 1974 gave some new double haploids (IRAT156....) in 1980.

Allogamy

In one method to obtain hybrid seeds (F_1), researchers increase parental fitness for spontaneous allo-

gamy, using crosses between O. sativa and O. longistaminata, a wild allogamous species.

Seed production

Because multiplication, control, and organization of seed production are important, scientists have adapted methods from developed countries for use in developing areas. In the Ivory Coast, IRAT and IDESSA actively contribute to the in-country seed production, establishing field and laboratory control rules and seed quality standards.

CONCLUSION

Through these programs, we have obtained progenies with earliness, lodging and blast resistance, drought tolerance, high yield potential, and adaptability, and thus have increased basic knowledge. Simultaneously, scientists studied cropping systems and obtained yields of 2.5-3.5 t/ha depending on pedoclimatic environment and cultivation intensity.

We expect further progress with better drought tolerance, higher productivity, and insect and virus tolerance. We will also exploit japonica (wide sense) variability for rainfed lowland rice improvement.

THE CIAT STRATEGY TO IMPROVE UPLAND RICE IN LATIN AMERICA

C. P. MARTINEZ

Rice is grown in Latin America under various cropping systems, each with distinct production constraints. About 8.2 million hectares in Latin America are planted to rice; however, vast regions of the rest of the continent have favorable topography, adequate temperatures, and sufficient moisture for possible rice growth (Sanchez and Salinas 1981).

Upland rice occupies 72% of the total rice area in Latin America. Although most is found in Brazil, it is also important elsewhere. In Central America alone, 87% of total production is upland rice, and in Bolivia, all rice is upland. Upland culture occupies significant areas in Venezuela, Colombia, and Ecuador. Peru wants to increase rice production by emphasizing uplands. Some Latin American governments believe that one way to rapidly increase food production is to increase upland rice. Mexico recently shifted from irriyated to upland production in the humid southeast. All of this interest requires more appropriate technology development and improved varieties suited to diverse growing conditions.

Table 1. Soils and moisture variability in some Latin American upland areas (Viral-S 1979).

Country	Region	Soil		Total growing-season rainfall (mm)
		Texture	pH	
Bolivia	Portachuelo	Clay	6.6	827
Brazil	Campinas	Sandy clay	5.5	1100
Colombia	La Libertad	Clay loam	4.5	1659
Costa Rica	Cañas	Clay loam	6.4	1231
Guatemala	Jutiapa	Clay	5.4	861
Honduras	Guaymas	Clay loam	6.5	–[a]
Mexico	Chiapas	Sandy	4.1	842
Mexico	Huimanguillo	Clay	5.6	1322
Panama	Tocumen	Clay loam	6.5	803
Peru	Yurimaguas	–[a]	6.0	701
Salvador	San Francisco Gotera	Clay	5.5	1540
Venezuela	Araure	Clay	6.5	–[a]

[a] Data not available.

Rice breeder, CIAT Rice Program, A. A. 67-13, Cali, Colombia.

This paper discusses CIAT's strategy to improve upland rice varieties in Latin America to meet the growing demand.

ECOLOGY OF RICE PRODUCTION IN LATIN AMERICA

Upland rice is grown within a broad continuum of ecosystems with productivity ranging from extremely low to very high (Laing et al 1984, Martinez 1984). There are great differences in soil types, fertility, and topography and great variability in total rainfall and rain distribution (Table 1). In some upland areas such as central Brazil and Penonome in Panama, rice production is risky because of low total rainfall. Farmers are aware of this and are moving toward more favorable areas (Table 2).

Average rice yield in Latin America is 1.9 t/ha. It is 3.9 t/ha in irrigated fields and 1.2 t/ha in uplands (Table 3). Upland yields vary from 3.8 t/ha in El Salvador to 1.1 t/ha in Brazil. Differences in rainfall quantity and distribution are main reasons for the large yield differences. Other reasons include soil quality and agroenvironmental factors (Posada 1982). Most upland yields have remained stagnant or declined over the past 10 yedrs (CIAT 1979). According to CIAT estimates, the average yield increase in the favored upland sector will be about 0.5 t/ha within the next 5 years, an increase of 20%. Countries will begin to adopt high-yielding rice varieties in 1985 (CIAT 1981).

Upland varieties in Latin America are listed elsewhere (Laing et al 1984).

RESEARCH STRATEGY

CIAT's long-range plan describes the rice program's objectives, strategies, and accomplishments (CIA'T

Table 2. Predicted upland rice production in Latin America, 1981.[a]

Country	Increase or decrease in	
	Favored areas	Unfavored areas
Bolivia	Modest increase	None
Brazil	Large increase	Gradual and small decrease
Colombia	Large increase	Gradual decrease
Costa Rica	Small increase	None
Mexico	Large increase	Modest decrease
Panama	Modest increase	Small increase
Paraguay	Small increase	Gradual decrease
Nicaragua	Modest increase	None

[a]Based on discussions with representatives from various countries at a workshop in Goiania, Goias, Brazil, 1981.

Table 3. Production areas, and rice yield in Latin America, 1979-80.[a]

Country	Area planted (thousand ha)			Total grain production (thousand t)			Yield (t/ha)		
	Lowland (irrigated)	Upland (nonirrigated)	Total	Lowland (irrigated)	Upland (nonirrigated)	Total	Lowland (irrigated)	Upland (nonirrigated)	Av
Argentina	100.0	–	100.0	300.0	–	300.0	3.0	–	3.0
Belize	4.0	2.5	6.5	10.0	6.0	16.0	2.5	2.4	2.5
Bolivia	–	54.1	54.1	–	92.7	92.7	–	1.7	1.7
Brazil	780.0	5451.0	6231.0	3000.0	5921.0	8921.0	3.8	1.1	1.4
Chile	40.8	–	40.8	95.4	–	95.4	2.3	–	2.3
Colombia	327.6	95.0	422.6	1638.0	152.0	1790.0	5.0	1.6	4.2
Costa Rica	1.5	80.0	81.5	7.5	208.4	215.9	5.0	2.6	2.6
Cuba[b]	151.0	–	151.0	450.0	–	450.0	3.0	–	3.0
Dominican Republic[b]	98.8	–	98.8	299.8	–	299.8	3.0	–	3.0
Ecuador	66.1	68.8	134.9	269.7	110.8	380.5	4.1	1.6	2.8
El Salvador	3.3	11.5	14.8	13.8	43.7	57.5	4.2	3.8	3.9
Guatemala	–	11.5	11.5	–	24.3	24.3	–	2.1	2.1
Guyana[b]	86.4	35.2	121.6	259.2	52.8	312.0	3.0	1.5	2.6
Haiti	31.5	10.6	42.1	169.9	30.4	200.3	5.4	2.9	4.8
Honduras	1.2	18.0	19.2	3.6	32.4	36.0	3.0	1.8	1.9
Jamaica	1.5	–	1.5	4.2	–	4.2	2.8	–	2.8
Mexico	73.5	58.5	132.0	311.0	145.2	456.2	4.2	2.5	3.5
Nicaragua	23.0	19.0	42.0	79.1	28.9	108.0	3.4	1.5	2.6
Panama	1.5	97.0	98.5	5.3	155.6	160.9	3.5	1.6	1.6
Paraguay[b]	20.7	11.1	3 1.8	43.4	14.8	58.2	2.1	1.3	1.8
Peru	72.0	28.2	100.2	360.0	48.0	408.0	5.0	1.7	4.1
Surinam	35.2	–	35.7	150.0	–	150.0	4.2	–	4.2
Uruguay	62.0	–	62.0	310.0	–	310.0	5.0	–	5.0
Venezuela	125.0	106.4	231.4	500.0	260.0	760.0	4.0	2.4	3.3
Total	2107.1	6158.4	8265.5	8279.9	7327.0	15,606.9	3.9	1.2	1.9

[a] A dash indicates that no rice is grown. [b] Harvest data 1977, 1978. Source: report of the fourth conference of IRTP for Latin America, 10-14 Aug 1981.

1981). The rice program will concentrate on the region's more favored upland rice environments.

According to Posada (1982), generation and diffusion of rice varieties in each country are highly correlated with national program strength. The research strategies pursued by the CIAT rice program will thus depend upon national program capability to conduct adaptive or innovative research. Countries with limited trained personnel will only be able to evaluate materials in late selection stage, while countries with strong research programs will be able to select early generation materials.

Three major problems will inhibit increased rice production (CIAT 1979). They are:

- agronomic factors water availability, land preparation, seeding methods, weed control, and fertilization;
- lack of high-yielding varieties with stable resistance to rice blast and tolerance for soil and water stresses; and
- pathogens and pests that are not as widespread as blast but can cause losses in specific areas: *Rynchoaporium* (leaf scald), *Helminthosporium* (brown leaf spot), grain discoloration, hoja blanca virus disease, and planthopper *Sogatodes oryzicola.*

Other problems result from environmental stresses. Plant types developed for irrigated conditions are not necessarily suitable for favored upland culture. Moreover, upland rice is often cultivated on marginal soils, which have low pH and high levels of aluminum and manganese. The low water-holding capacity of these soils in the root zone creates severe drought stress, even during short dry periods. All these stresses make the rice plant less tolerant to pest and disease attacks.

Breeding objectives for highly and moderately favored upland conditions are similar to those for irrigated rice:

- vigorous dwarf-intermediate plant types;
- lodging resistance;
- maturity of 110 to 130 days;
- durable blast resistance, either through gene pyramiding or crossing with the slow blast type;
- tolerance for other foliage or panicle pathogens (*Rhynchosporium, Helminthosporium, Thanatephorus*);
- resistance to *Sogatodes oryzicola* and hoja blanca virus disease;
- tolerance for upland soil stresses (deficiencies, toxicities, drought); and
- long, heavy grain (26-30g/1,000), clear endosperm and intermediate amylose content and gelatinization temperature.

CIAT is also working on an important production system that has excellent rainfall and strongly acid, infertile soils. This environment is found in the vast savanna regions of Colombia and Venezuela and in the jungle areas of Peru and northern Brazil. Existing varieties are tall land races that tolerate low level aluminum toxicity, phosphorus deficiency, and fungal diseases.

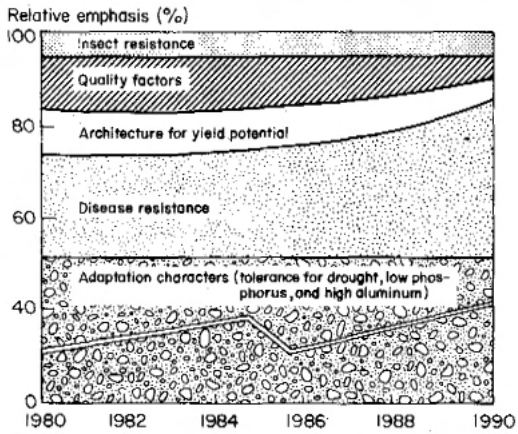
Breeding objectives for this environment are:

- vigorous intermediate plant type,
- lodging resistance,
- maturity of 110 to 130 days,
- moderate yielding ability of 2 to 4 t/ha,
- durable blast resistance,
- tolerance for other foliar or panicle pathogens (Rynchosporium, Helminthosporium, Thanatephorus),
- resistance to Sogatodes oryzicola and hoja blanca virus disease
- tolerance for aluminum toxicity,
- thick and deep roots, and
- long, heavy grain (26-30 g/l,000), clear endosperm, and intermediate amylose content and gelatinization temperature.

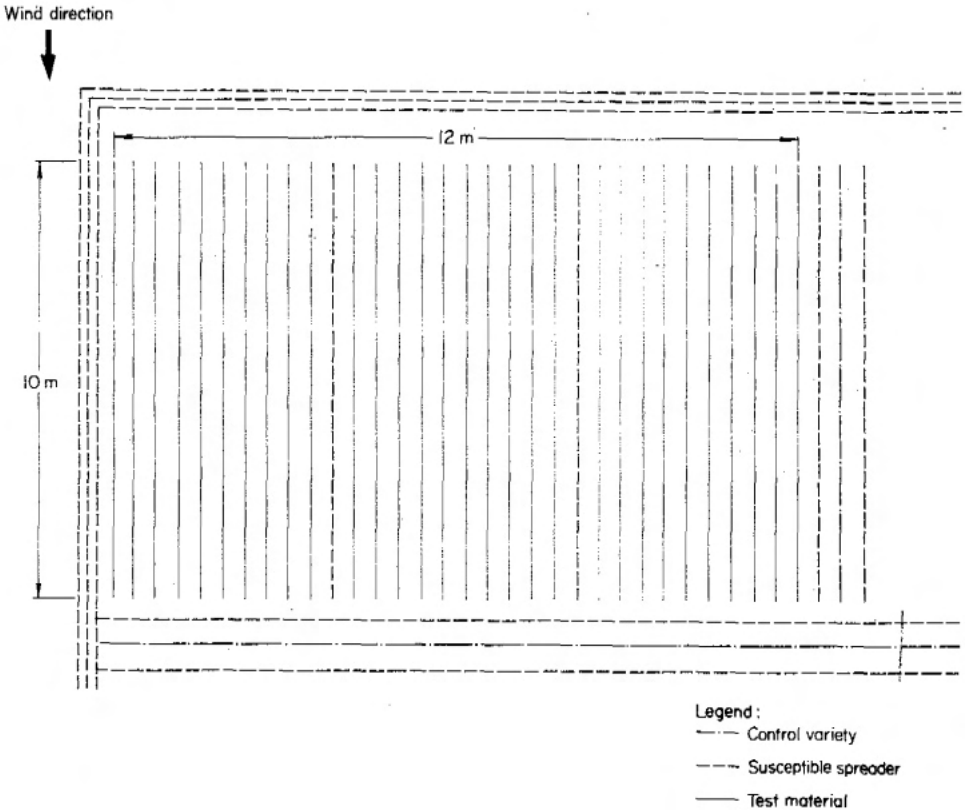
Figure 1 shows the projected breeding emphasis for upland varietal improvement in the 1980s.

Breeding procedures

Because favored / upland rice objectives in Latin America are similar to those of the irrigated program, parents for crosses are carefully selected from desirable lowland varieties and crossed with American,



1. Emphasis by rice program on varietal improvement for upland rice in the 1980s.



2. Proposed planting scheme for upland rice fungus disease research in Latin America.

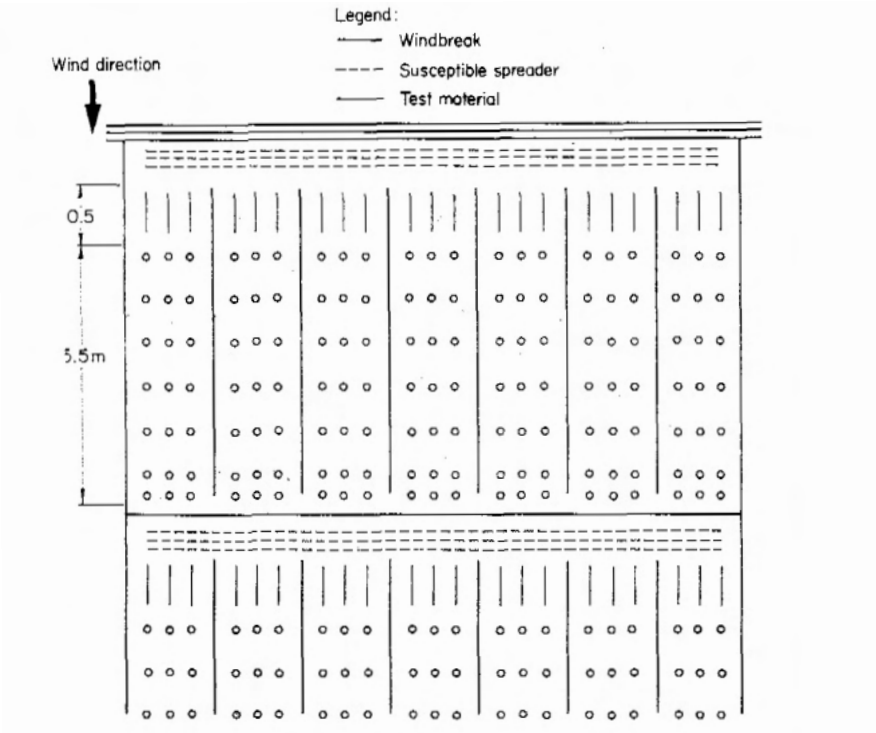
African, and Asian upland varieties. Routine breeding procedures include high volume crossing, emphasis on topcrosses, large F_2 populations, modified bulk selection from F_2 through F_5 stages, and pedigree selection from the F_2 onward.

To expose populations to upland soil stress, favored upland rice breeding is conducted on moderately fertile, alluvial upland soils, without supplemental irrigation. Appropriate planting designs (Fig. 2, 3) induce fungal disease pressures on segregating materials and advanced lines.

Figure 4 shows a proposed scheme for upland rice research in Latin America outlining CIAT collaboration with IRRI, IITA, WARDA, and national programs.

Germplasm sources

To improve breeding and preserve specific characters, scientists are collecting and preserving traditional and improved breeding materials from upland ecosystems in Latin America and Africa. Our germplasm bank now has about 640 entries from IRRI, IITA, IRAT, and national programs such as EMBRAPA and those of Costa Rica, Panama, Bolivia, Peru, Colombia, and Ecuador.



3. Field layout to evaluate resistance of advanced lines of upland rice to rice blast in the field.

Preliminary evaluation

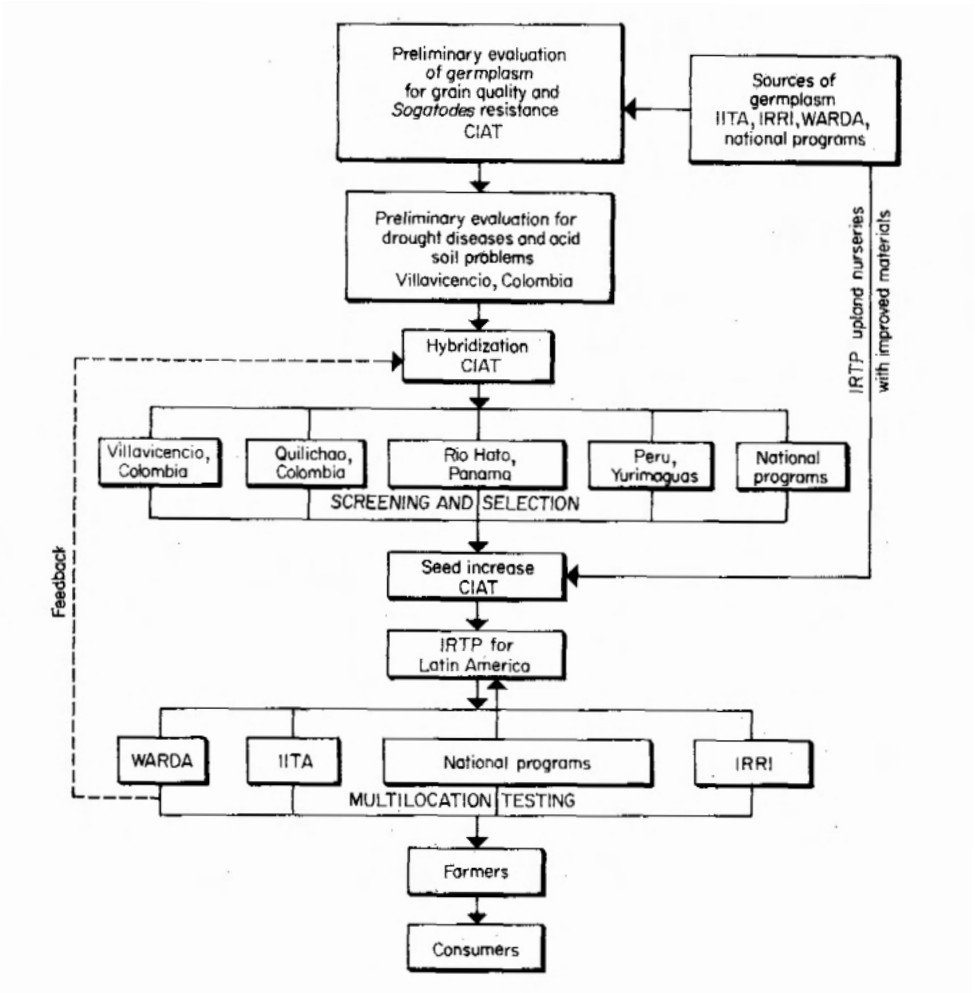
CIAT evaluates grain quality and Sogatodes resistance, and Villavicencio, Colombia, tests disease resistance and soil problems. Because upland materials from other regions are susceptible to Sogatodes and hoja blanca virus and have undesirable grain quality, preliminary screening is essential for breeding purposes.

Hybridization

Parent selection is based on the performance of materials in upland fields. TJpland varieties from IITA and IRAT are donors of drought tolerance and blast resistance while genes for Sogatodes and hoja blanca virus resistance must come from irrigated materials. Some varieties from Surinam bridge both upland and lowland varieties.

Screening and selection

CIAT grows the F_1 generation. But before evaluation and selection, the F_2 onward grows in upland conditions in four different sites. To select material for favored upland environments with two crops a year, scientists use alluvial soils in Villavicencio, Colom-



4. Proposed scheme for collaborative upland rice research in Latin America.

bia. To select materials for highly infertile, acid soils, an Oxisol in Villavicencio is the test site. Selections made there in August – September can be sent to Yurimaguas, Peru, for planting and evaluation in November – March and brought back to La Libertad, Colombia, for another evaluation. This cycle goes on for several generations. Another site for selection and evaluation is Penonome, Panama.

Some lines from this project should be useful in northern Brazil, the vast savannas of Colombia and Venezuela, and some acid areas in Bolivia and Peru. IDIAP (Panama) and CLAT have a cooperative project to use a Rio Hato selection site for moderate and less-favored environments in Central America where with supplementary irrigation, they can harvest two crops a year. National programs in Costa Rica and Guatemala can

handle early segregating materials and are receiving some F_2 populations.

Selections showing high promise will go to the International Rice Testing Program (IRTP) for evaluation throughout Latin America. The IRRI representative at CIA'T will help the CIAT upland breeder select the most appropriate materials for the IRTP.

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RICE PRODUCTION AND RESEARCH IN THE IVORY COAST

C. POISSON

Rice is one of the most important food crops in the Ivory Coast. It is the staple crop in the western region and ranks just after yam as the main source of nourishment for the rest of the country.

Total production is about 420,000 t of rough rice for 355,000 ha, or an average 1.2 t/ha.

Rice is mostly upland, grown alone or with other crops, or rainfed, with or without water control on about 20,000 ha of lowlands or flood-prone plains.

In forest zones, during the first years after clearing, rice is an itinerant or pioneer crop in the first rainy season -- March to July. Farmers often plant rice with maize, cassava, plantain bananas, or young plantations of cacao or coffee trees. Production level is low. After 2 years, weeds thrive and rice yield decreases. Erosion increases, especially in the mountainous zones, forcing farmers to abandon their yearly cultivation.

Nevertheless, in certain regions where land is scarce, farmers who are more receptive to innovation, practice fixed, more intensive agriculture.

In the savannah zones, farmers grow upland rice from May-June to October in rotation with yams, cotton,. or maize. Drought duriny the vegetative cycle, weeds, and fungus diseases are the main constraints.

The production level varies among regions and farming systems. In the north and east, farmers plant manually with animals; in central Ivory Coast, they use small motorized machines to plant cotton. In the northwest flood-prone plains they use large machines to cultivate rice.

Production is insufficient to meet food demands of a population with continually increasing domestic consumption. With rapid urbanization and changing eating habits, rice consumption doubled in 10 yr. White rice imports reached 262,000 t in 1981, and cost US$5 billion.

Research to increase rice production is essential and the creation of a multidisciplinary research team in Bouake demonstrates Ivory Coast's intent to increase yields.

IRAT/IDESSA B. P. 635, Bouake, Ivory Coast.

Our breeding research seeks to develop varieties with yield stability that are adapted to different rice growing environments. To increase yield stability, we screen our plant material simultaneously for resistance to several insect biotypes to develop resistance to stronger and more selection pressures in space, rather than in time. We use these screening methods at various sites in Ivory Coast and other West African countries.

We crossed 100 or more parents from our collection of 1,100 strains. We first crossed West African groups to shorter plants but did not succeed.

We then tried sources farther away.

- Crosses between West African and Taiwan, China (japonica) varieties produced successful varieties such as IRAT10. But certain parents used to limit height also introduced some unwanted characters such as open lemma and palea which favor insect attacks. We returned the results of those crosses for more breeding to correct this deficiency.
- Crosses between West African and Laotian varieties were from genetically close material. It was easy to obtain medium-straw-length progenies, but most progeny retained the high shattering level of the Laotian parent. We returned the progeny to improve some of the deficiencies.

We are correcting the excessive shattering of IRAT109 by crossing it with R54, from Zaire. We are improving the useful tillering of IRAT112 by crossing it with Iguape Cateto from Brazil.

We are also using certain aquatic types in our upland crossing program. The progeny variability is important, but the number of promising progenies remains very low. We isolated intermediate size plants with long panicles and they were productive, especially in the cross H105/R67 where we improved very low F_2 fertility in the following generations. We could use these varieties as they are or as eventually recrossed, in flooded rice-growing areas where most current cultivars are susceptible to rice blast. Likewise, research for new, utilizable breeding traits led us to further exploit Oryza genetic variability.

To safeguard endangered genetic material, we collected, catalogued, and analyzed more than 2,000 African samples of O. sativa, O. glaberrima, the annual wild O. breviligulata, and the perennial wild species O. longistaminata.

Even if these varieties have major deficiencies such as lodging susceptibility and shattering, they might be used to transfer hardiness, and tolerance for weeds, nematodes, or some toxicities. These interspecific crosses presently have sterility problems in their progeng which we can correct by backcrossing.

Exploiting hybrid vigor by transferring the allogamy of O. longistaminata to an autogamous species is also a research aim.

Besides hybridization, we are exploring mutagenesis by physical means to modify limiting traits in profitable varieties. We developed IRAT13 from a West African variety using this technology.

To make selections more rapidly, we use in vitro culture in Montpellier laboratories. The haplomethod by androgenesis or gynogenesis applied to certain crosses has allowed us to produce varieties such as IRAT156, IRAT157, and IRAT160.

Following development, all our varieties undergo multilocation testing at regional stations in Gagnoa, Man, Odienne, and Ferkessedougon. Later we test them in development company networks before entering them in the international networks of WARDA, IITA, and IRRI.

Our regional breeding system, complemented by this experimentation network, enables us to create adaptable varieties or those such as IRAT144 which maintain good yield even at low intensification.

Work to develop disease resistance has emphasized horizontal rice blast resistance, which is more stable over time. We screen different rices simultaneously in different environments using a DITER design. In the DITER design, lines are planted back to back with an infesting strip of susceptible varieties and check plants of different resistance levels. We use this design as early as F_2 to quickly identify crosses with good resistance.

We evaluate those crosses in the laboratory to determine if the resistance is monogenic or polygenic. In the evaluation, we plant the F_2 in a tub and spray it with spores to inoculate it with blast disease. Plants are then placed in a greenhouse for 2 days at 100% humidity and results are recorded 1 wk later.

Because chemicals are not economical, we are emphasizing varietal resistance to insect control. Field studies show that rice varieties with large diameter stems have higher insect infestation rate but are more tolerant than susceptible varieties with thin stems at lower infestation rates.

Presently we are experimenting in greenhouses with artiflcial infestation. We are also investigating biological methods to limit insect attacks on rice and rearing parasites of harmful insects and will introduce them in rice fields.

We are studying global drought resistance in the field. The most reliable indicator of drought resistance is grain yield obtained after stress at particular vegetative stages. TRAT13, for example, performs well, especially when stress occurs during the grain-filling stage. To obtain a high drought tolerance, we foresee the combination of different tolerance

factors such as

- rooting capacity (screened by absorption of p32),
- transpiration resistance, and
- aptitude for migration of carbon reserves from stems to grains during drought.

We are also studying techniques to reduce water demand. They include different planting methods to achieve dense plant canopies and planting techniques to increase soil permeability and porosity while reducing water loss by streaming or draining.

Supplementary irrigation can increase yield in regions with short dry seasons. Pumps powered by biogas from harvest residue fermentation are possible irrigation aids.

Besides competing with rice, weeds also use water. Weed flora was characterized by recording weed invasion, comparing infestation in different regions, and evaluating plot age after clearing, planting cycles, and rice intensification level. Herbicide trials for effectiveness and selectivity helped us identify satisfactory oxadiazon dosages.

CONCLUSION

Our multidisciplinary approach to rice growing problems in Ivory Coast has enabled us to propose some technical solutions that integrate many agronomic and cultural factors and recognize socioeconomic restrictions. We obtained data from real-environment studies and farmer-level field tests to isolate causes of poor communication of research results to farmers.

If the proposed innovations respond to Ivory Coast's concern about improving rice production and are compatible with the present system, then the research will have been important.

UPLAND RICE IMPROVEMENT AT EMBRAPA, BRAZIL

E. P. SANT'ANA

Rice is an important crop in Brazil, covering a cultivated area of 5.4 million ha and yielding 7.6 million t. It is the basic energy food for Brazilians who consume an annual 45 kg rice/person (IBGE 1980).

Although farmers grow rice in all parts of Brazil, the most important regions are the west central, southeast, and southern areas, which give 78% of production.

Brazilians cultivate rice using four different systems:

System I - lowland rice under controlled irrigation,
System II - lowland rice without controlled irrigation,
System III - lowland rice without irrigation (varzea), and
System IV - upland rice totally dependent on rainfall for water requirement.

Upland rice is the most important and covers about 77% of the total cultivated area, about 4.2 million ha, and yields 4.4 million t.

Brazil has different climatic and soil conditions for upland rice. Although those regions have not been clearly defined, climatic data show regions where upland rice suffers from water deficits during the rainy season. Because it is a risky crop to grow, farmers use poor technology and harvest low yields. These regions are unfavorable for upland rice cultivation.

Most System IV areas are in south central Brazil and include the southern states of Goias, Mato Grosso do Sul, São Paulo, and Parana and, which contribute about 53% of upland rice production (Table 1). However, farmer and extension agent information and preliminary climatic analysis show that some upland areas in the north central region have good rain distribution during the wet season. The strongly reduced probability of drought will encourage farmers to use more technology. Best rice yields may come from these areas considered more favorable for upland rice cultivation.

Rice breeder, CNPAF/EMBRAPA - C. P. 179 - 74000 Goiania, Goias, Brazil.

Table 1. Rice area (A, in ha) and production (P, in t) per cultivation system, 1978-79 (IBGE).

State		Upland (IV)	Lowland (I)	Lowland (Varzea) (III)	Others (I, II, III, IV)	Total
Goias	A	927,000	–	–	–	931,110
	P	1,140,210	–	–	–	1,155,080
Maranhão	A	853,779	–	–	–	853,779
	P	1,070,190	–	–	–	1,070,190
M. Grosso	A	741,130	–	–	–	741,130
	P	975,476	–	–	–	975,476
M. Gerais	A	371,836	77,528	60,000	–	509,364
	P	178,070	181,340	300,000	–	659,370
M. Grosso S.	A	584,719	–	–	–	584,719
	P	457,131	–	–	–	457,131
S. Paulo	A	300,400	–	–	–	300,400
	P	307,800	–	–	–	307,800
Parana	A	323,916	–	–	–	323,916
	P	286,676	–	–	–	286,676
R. G. Sul	A	31,500	493,500	–	–	525,000
	P	13,400	1,661,600	–	–	1,675,000
Sta. Catarina	A	75,877	80,197	–	–	156,074
	P	20,323	239,471	–	–	259,794
Others	A				514,430	514,430
	P				745,391	745,391
Total	A	4,210,157 (77.4%)	655,335 (12.0%)	60,000 (1.1%)	514,430 (9.5%)	5,439,922 (100%)
	P	4,449,276 (58.6%)	2,097,281 (27.6%)	300,000 (4.0%)	745,391 (9.8%)	7,591,948 (100%)

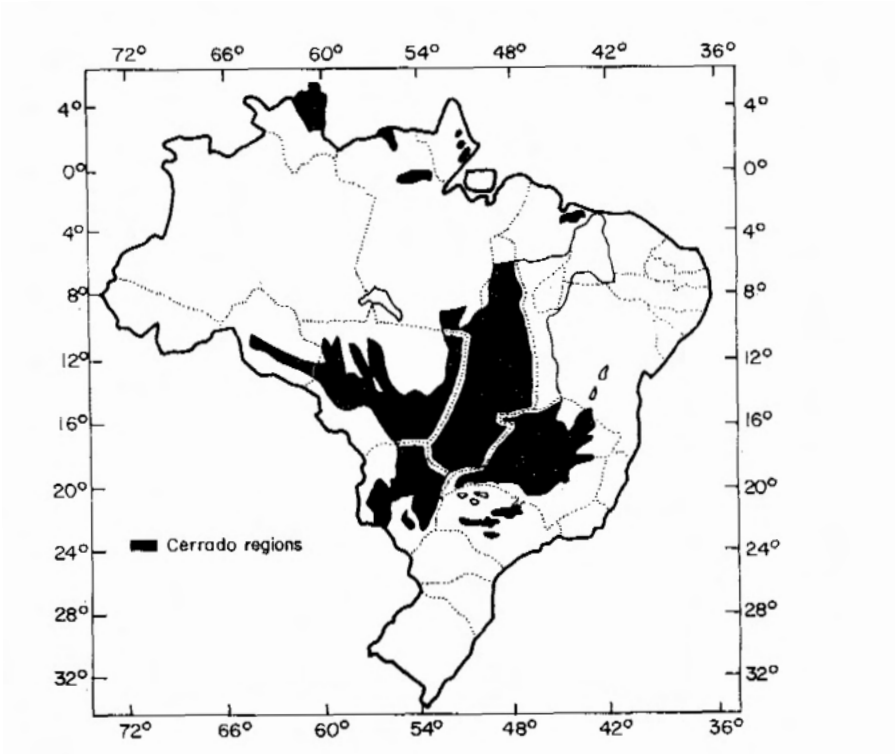
CHARACTERISTICS OF UNFAVORED AREAS

More than 60% of upland rice production in Brazil comes from low-yielding unfavored areas. The most important constraints are water deficits, diseases, and low fertility or toxic soil.

In unfavored areas, farmers plant rice in deep cerrado soils (Fig. 1). They have high permeability, low water retention capacity, and low organic matter. They also have low fertility, phosphorus deficiency, and aluminum toxicity (Table 2). Soil water deficits are frequent and occur during all stages of rice growth. Drought may vary from a few days to more than 3 wk, causing a marked yield decrease or even total crop Loss.

Besides causing soil and plant water deficits, drought also favors blast, which significantly reduces yield.

The law phosphorus content and high aluminum toxicity of cerrado soils prevent the normal rice plant development. Short tillers and inadequate root systems make the plant more sensitive to soil water deficits (Fageria and Zimmermann 1979, Fageria and Barbosa Filho 1980).



1. Distribution of cerrado soils in Brazil.

Table 2. Soil property means for each type cerrado vegetation[a] (Lopes and Cox 1977).

Soil property[b]	Campo limpo (64)+	Campo cerrado (148)+	Cerrado (245)+	Cerrado (45)+
pH (H_2O)	4.87	4.94	5.00	5.14
Organic matter (%)	2.21	2.33	2.35	2.32
Exch. Ca (meq/100 ml)	0.20	0.33	0.45	0.69
Exch. Mg (meq/100 ml)	0.06	0.13	0.21	0.38
Exch. K (meq/100 ml)	0.08	0.10	0.11	0.13
Exch. Al (meq/100 ml)	0.74	0.63	0.66	0.61
Eff. CEC (meq/100 ml)	1.08	1.19	1.43	1.81
Al saturation (%)	66	58	54	44
Extr. P (ppm)	0.5	0.5	0.9	2.1
Extr. Zn (ppm)	0.58	0.61	0.66	0.67
Extr. Cu (ppm)	0.60	0.79	0.94	1.32
Extr. Mn (ppm)	5.4	10.3	15.9	22.9
Extr. Fe (ppm)	35.7	33.9	33.0	27.1
Clay (%)	33	36	34	32
Silt (%)	20	16	15	16
Sand (%)	46	48	51	53

[a]Figures in parentheses are number of samples analyzed. [b]Exchangeable Al, Ca, and Mg were extracted with 1 NKC 1. P, K, Zn, Cu, Mn, and Fe were extracted with 0.05 + 0.025 H_2SO_4. These soils are deficient in Ca, Mg, P, and Zn. They are acidic in reaction, organic matter and CEC level are low, and Fe and Al saturation is high.

CHARACTERISTICS OF FAVORED AREAS

Although intensive studies of rice cultivation in favored areas are not available, preliminary yield trials at different favored sites show that grain yield is higher than in other areas. Yields can be more than 4 t/ha, and in large areas yield is 2.5 – 3 t/ha. This may be due to good rain distribution during the growth period. The temperature is also higher than in the unfavored areas and blast is not an important disease.

Currently, favored upland areas have less rice production than unfavored areas, but they are becoming an important rice production region because of increasing numbers of big farms and better yield stability.

BREEDING UPLAND RICE FOR UNFAVORED AREAS

The main objective of the upland rice breeding program for unfavored areas is yield stabilization. In the last 25 years upland rice yields decreased as rice expanded onto less fertile cerrado soils and farmers used the more fertile soils for crops such as soybean and maize. Besides soil problems, drought is the main cause of production changes. Additional problems are the strong relationships between drought and blast and drought and insect (the Lesser cornstalk borer, Elasmopalpus Lignosellus Zeler) attack.

New varieties for unfavored areas should be:

- drought tolerant,
- blast resistant,
- tolerant of low soil phosphorus and high aluminum toxicity, and
- insect resistant.

Drought tolerance

Rice varieties actually grown by Brazilian farmers have good drought tolerance. However, experiments show that this characteristic could be increased by modifying plant morphology. Increased root length and reduced leaf size allowed traditional varieties experiencing drought to show yield increases. Growth duration is also important. Short-duration varieties will escape flowering during the drought period. By using such varieties, farmers can choose the most convenient time for sowing during any month of the rainy season, even after the most important drought period between January and February. We are also selecting medium-duration varieties for farmers using supplementary irrigation.

Blast resistance

Blast is the most important disease affecting upland rice in unfavored areas. Experimental results show that

blast control may increase upland rice yield about 40%.

EMBRAPA is attacking the blast problem by:

- diversifying resistant varieties with vertical resistance genes from different sources,
- developing multilines from these sources,
- developing varieties with many genes for vertical resistance, and
- breeding for horizontal resistance.

Tolerance for soil phosphorus deficiency

Phosphorus is the most important nutrient for upland rice in cerrado soils. It favors root development, which helps rice tolerate drought. With low phosphorus levels and high fertilizer prices, farmers use a minimum and consequently have poor yields.

In breeding upland rice for phosphorus deficient-soils we are

- screening for tolerance to low phosphorus content in the soil (We evaluated more than 200 varieties and found some with good tolerance to the low phosphorus content.);
- doing basic studies on tolerance to phosphorus deficiency; and
- incorporating low phosphorus tolerance into upland rice varieties.

Tolerance for high aluminum toxicity

Aluminum toxicity is another important factor that decreases yield in cerrado soils. It affects the normal root development and interferes in important biochemical reactions including absorption, transport, and use of nutrients such as phosphorus, calcium, and magnesium. It limits root absorption of nutrients and water essential for upland rice. To deal with aluminum toxicity, we are:

- screening for tolerance. (Research using a nutrient solution showed that high aluminum concentration markedly reduced plant weight and height and root length. Based on the results, we classified the varieties into high, medium, and low aluminum toxicity tolerance.);
- doing basic studies on the nature of aluminum tolerance in rice. (Data analysis of plant height, root length, weight of aerial part of the plant, and dry root weight showed that aluminum tolerance was quantitative.); and
- incorporating aluminum toxicity tolerance in upland varieties.

Insect resistance

Many insects attack upland rice but the most important in Brazil is the lesser cornstalk borer *Elasmopalpus lignosellus* Zeler. Infestation accompanies drought,

mainly at the seedling stage. Selected tolerant plants from severely attacked varieties were 60% more tolerant than the original population.

BREEDING UPLAND RICE FOR FAVORED AREAS

Although most upland rice research has been on unfavored areas, preliminary experimental results show that rice varieties for favored conditions need different characteristics from those for unfavored areas. Favored areas with more and better rainfall distribution and higher temperatores encourage rice growth. Varieties currently grown in favored uplands are more than 1.5 m high and lodge easily.

Without a drought period during harvest time, farmers often must harvest in the rain, which causes serious grain quality problems.

Varieties developed for favored regions should yield higher with better technology, and have lodging resistance; resistance to diseases, mainly leaf scald (*Rynchosporium oryzae*) and brown spot (*Helminthosporium oryzae*); seed dormancy; adequate growth duration; and drought tolerance.

Grain yield capacity and lodging resistance

Varieties currently grown in favored areas are tall with large leaves. With good technology, they lodge, which decreases yield and grain quality.

Physiological disturbance causes large leaves when well-developed plants shade each other.

Because there is little drought risk in the favored areas, we encourage farmers to use more technology and we need better varieties to support that. In the upland rice breeding program for favored areas, we select plants that have erect leaves and are no more than 1.2 m high.

Disease resistance

Leaf scald is the prevalent disease in favored areas in Para and Amazonas and is increasing in Maranhao. We have not found varieties resistant to leaf scald, perhaps because a good screening method does not exist.

Although brown spot leaf lesions do not significantly reduce yield, even under epidemic conditions, the grain infection causes substantial yield reduction. We have identified brown spot resistant varieties and used thein to incorporate resistance in new material for favored uplands.

Seed dormancy

In favored uplands, farmers frequently must harvest rice in the rain, which decreases grain quality. Heavy

rain and wind may also cause lodging before harvest. Some seed dormancy is necessary to avoid this problem.

Adequate growth duration

Suitable growth duration is important in breeding for favored areas. Small farmers usually prefer long-duration varieties harvested at the end of the wet season because they have no way to dry the rice after harvest. Large scale farmers, however, prefer short- to medium-duration varieties because they have dryers and can harvest even on rainy days.

Drought tolerance

Although long drought periods in favored areas are extremely improbable, short periods (1 wk or less) may occur and severely damage rice on sandy soils. If drought occurs at early growth stages, before roots are well developed, plants can die. Drought during flowering stage may decrease yield. Thus, some drought tolerance is necessary for varieties developed for favored uplands.

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CROPPING SYSTEMS

SOIL EROSION AND CONTROL METHODS FOR UPLAND RICE CROPPING SYSTEMS: SOME WEST AFRICAN EXAMPLES

J. L. CHOPART

Upland rice is planted in large areas of West Africa, but is limited to zones with specific, favorable climatic condltions. Because upland rice is susceptible to drought and relatively tolerant of low radiation, it is generally cultivated in high rainfall zones: forest regions or tree-covered savannahs in Guinea, Sierra Leone, Liberia, Ivory Coast, and Nigeria. Upland rice also tolerates low temperatures better than other tropical crops and often is the food crop in mountainous zones with humid climates (Fouta Djalon range and the Nimba mountains).

Although upland rice is mainly cropped in countries with more than 1,000 mm annual rainfall, its water needs are similar to those of other rice crops: 500 to 700 mm, depending on plant cycle and climatic demand (Dancette 1979, Kalms 1980).

Excess water drains away and can cause soil erosion in hilly, tropical soils where upland rice is usually grown. However, early studies in Guinea on soils with slopes greater than 15% showed that simple control methods such as strip cultivation with partitioned, contour ditches and high plant population effectively limit erosion of upland rice soils. Other erosion control experiments have been conducted in Senegal, Ivory Coast, and Nigeria.

Using those results, this paper discusses the risks and methods of controlling water-induced erosion of upland rice soils.

RISKS OF EROSION IN WEST AFRICAN UPLAND RICE ZONES

Mechanisms of water erosion

Many studies of water-induced erosion have been conducted, particularly in the United States, where Wischmeier and Smith (1960) developed the following equation to evaluate, or predict, land losses by erosion:

$$\underline{A} = \underline{R} \times \underline{SL} \times \underline{K} \times \underline{C} \times \underline{P}$$

where $\underline{A}$ = t/ha of land carried away by erosion, $\underline{R}$ = rainfall factor (t/ha), $\underline{SL}$ = topographical index linked

IRAT/IDESSA B. P. 635, Bouake, Ivory Coast.

to the slope, K = soil erodibility, C = index of soil protection by plant cover and crop management as related to plant cover establishment, and P = effectiveness index of erosion-control practices used. Each parameter has a value between 0 and 1.

Although this equation does not integrate all erasion factors, it does consider major effects and their relation to the quantity of eroded soil.

Values of different coefficients in the Wischmeier-Smith equation have been tested in different West African regions (Bertrand 1967; Charreau 1969; Roose 1973, 1977, Lal 1976) and found to perform well.

The equation in West Africa

Methods for evaluating the equation's coefficients were described by Wischmeier and Smith (1960) and Roose (1973). In the following section these coefficients are calculated from erosion measured on various normalized, experimental plots equipped with a device that collected erosion water and measured the weight of eroded soil.

Rainfall erosion index (R). Roosts (1973) established a relationship between the average annual R (RUSA), measured using the method described by Wischmeier, and the average annual height of rainwater (H) in West Africa.

$$\frac{R}{H} : 0.5 \pm 0.05$$

This equation was used to develop an outline of the distribution of the rain erosion factor index in Ivory Coast (Roose 1973), Upper Volta (Roose et al 1974), and West Africa (Roose 1977).

In the West African humid tropical zone, R is greater than 600 and can reach 2,000 in the coastal fringe between Conakry and Monrovia. These values are larger than the 50 to 650 range observed in the US (Wischrneier 1962), in northern Europe (10 to 60 in the Netherlands) (Bergsma 1978), and even in the Mediterranean zone (50 to 350) (Masson and Kalms 1971).

Topographical index (G). Slope (inclination, length, and shape of the land) plays an important role in runoff and erosion when the soil is bare or sparsely covered. Wischmeier and Smith (1960) described the relationship between slope, length of slope, and erosion as:

$$SL = \frac{L}{100} (0.76 \pm 0.53\ S + 0.076\ S^2)$$

where L = length of slope and S = % incline of slope. The influence of incline can be expressed in a similar exponential function (Hudson 1973).

On bare, sandy soil in Ivory Coast, Roose (1973) found similar results, but noted that slope measurements vary annually. Roose (1975) and Lal (1976) found

Table 1. Values of the index *K* of soil resistance to erosion in several soils of West Africa.

Location	Type of soil	*K*	Source
Sefa (Senegal)	Ferruginous	0.04-0.17	Charreau 1969
Bouaké (Ivory Coast)	Ferrallitic	0.02-0.05	Bertrand 1967
		0.05-0.22	Kalms 1977
Adiopodoume (Ivory Coast)	Ferrallitic, sandy	0.07-0.17	Roose 1973
Agonkamey (Benin)	Ferrallitic	0.03-0.11	Roose 1973

that the influence of SI can be decreased on cultivated or straw-mulch covered soil. Lal (1976) reported that slope length is variable and depends on the shape of the slope.

Therefore, it seems that the topographical factor is a weakness of Wischmeier and Smith's equation for predicting erosion, because knowing the actual influence of the slope is essential to predict erosion. Complementary studies, based on the Wischmeier equation, should be done in West Africa.

The soil factor (K). Contrary to widespread opinion, studies in West Africa show that tropical soils with predominantly kaolinitic clay resist water erosion because K index is between 0.02 and 0.2 (Table 1).

Plant cover and crop management (C). The soil plant cover reduces the kinetic energy of raindrops that reach the soil after falling from the leaves. In the Wischmeier equation, C is the ratio between the erosion measured on a cultivated plot at different levels of cropping intensity and on a base plot that has been shallowly plowed along the line of the slope.

Under forest vegetation, the C factor is low (0.001) (Roose 1973). On cultivated soil, the amount of protection provided by vegetation depends on the crop. Studies in Ivory Coast (Bertrand 1967, Roose 1973) and Senegal (Charreau and Nicou 1971) showed that upland rice provides better average soil coverage throughout the crop cycle than maize, peanut, and millet (Table 2, 3). However, the greatest variability in land loss has been observed for upland rice (Table 3). Erosion variability seems to be linked to a greater interannual

Table 2. Influence of plant cover on erosion. Evaluation of average annual values of the *C* factor on peanut and upland rice in Bouaké, Ivory Coast (Bertrand 1967).

Crop	Rainfall erosion index during culture	Average value of *C* factor
Peanuts	222	0.4
Upland rice (long cycle)	345	0.1

Table 3. Influence of plant cover on erosion in Sefa, Senegal (Charreau, according to results published by Charreau and Nicou 1971).

Crop	Replications (no.)	Average value of *C* factor	Erosion (t/ha)	
			Minimum	Maximum
Upland rice	17	0.26	0.2	18.4
Maize	17	0.36	1.8	26.7
Millet	4	0.37	5.0	12.6
Peanuts	32	0.37	2.3	20.8
Protected forest	11	0.05	0.02	0.2
Burnt forest	13	0.13	0.02	0.8
Bare soil	11	3	6.5	54.5

irregularity in the vegetative development of upland rice.

At Bouaké, Ivory Coast, erosion is most severe during the first 20 days of upland rice growth. After 20 days the plants form a closed canopy that limits erosion (Table 4).

Effectiveness of erosion control practices factor (P). Heavy antierosion techniques such as embankments, which are expensive to construct and maintain, appear to be ill-adapted to West African conditions, uneconomical, and not always effective for upland rice cultivation (Roose 1977a,b). Rice cultivation on contour lines between strips of fallow soil seems to be a more effective erosion control method (Roose and Bertrand 1971, Le Buanec 1972). Partitioned, contoured ditches also provide effective control. These erosion control techniques have a P coefficient value between 0.1 and 0.3 (Roose 1977a,b).

The analysis shows upland rice in West Africa usually is cultivated on soils that resist erosion, and that the plant cover provided by upland rice culture protects the soil effectively after one month's growth.

In other countries, upland rice is grown where rainfall erosion index is high during the first month of rice growth when soil is poorly covered. Erosion potential is greater on soils with poor plant cover or steep slope. On soils that are even slightly sloped, erosion potential should be recognized, especially during the first weeks of rice cultivation.

Table 4. Erosion at the beginning of an upland rice cycle in Bouaké, Ivory Coast. Three-year average, 1960, 1962, 1964 (Bertrand 1967).

Time [a]	Rainfall (mm)	Erosion (t/ha)
From sowing to 20 DS	192	1.57
From 20 DS to harvest	592	0.06

[a] DS = days after sowing.

EROSION CONTROL IN UPLAND RICE CULTIVATION

Soil losses to erosion can be reduced by modifying the values of one or several coefficients of the Wischmeier equation.

Decreasing rainfall erosion index

Rainfall erosion index is a nonmodifiable climatic parameter, but R can be decreased by cultivating crops under a light tree cover. The light tree canopy could be natural (incomplete clearing), which is often true for traditional upland rice cultivation in forest areas, or a cover of cultivated trees. Unfortunately, there is limited information available to calculate how effectively this cultural practice reduces the impact of raindrops falling on the soil surface.

R varies during the year (Table 5, 6) and can be one of the criteria for choosing the optimal sowing date to redace erosion during early growth stages. For example, in Sefa, Casamance, where R is lower in June, at the start of the rainy season, it is wise to plant early to reduce the effect of hard rains of July.

At Bouaké, R is lower than at Sefa, particularly during July and August (Table 6). The best time to plant to lessen erosion hazard is at the end of June. However, other conditions favor planting earlier in June, when R is slightly greater but within reasonable limits.

Limiting slope

In tropical zones, cultivation of any crop on highly sloped and even medium sloped (5-10%) soils creates erosion potential if soil remains bare at any time. It is better to leave such lands fallow as permanent grassland, or to plant shrubs but this is not always possible. Modifying slope by constructing large installations is not practical for food crops in most West African countries. However, leaving grassy blocking strips perpendicular to the slope may decrease the effect of slope on erosion and be economically effective (Roose and Bertrand 1971, Le Buanec 1972).

Table 5. Monthly values of rainfall erosion index (*R*) at Sefa (southern Senegal) between 1964 and 1968 (Charreau and Nicou 1971).

Month	R
Jun	136
Jul	180
Aug	159
Sep	206
Oct	71

Table 6. Monthly values of rainfall erosion index in 2 Ivory Coast locations: Bouaké (center) and Man (west). Frequency study over 11 years between 1971 and 1981 (Chopart-Kesse).

		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Rainfall									
50% probability (1 out of 2 yr)	Bouaké	78	124	153	131	87	103	174	144
	Man	69	87	102	128	137	236	228	118
Maximum observed between 1971 and 1981	Bouaké	283	233	239	348	263	206	299	161
	Man	217	178	280	327	308	343	501	202
R (usa)									
50% probability (1 out of 2 yr)	Bouaké	39	66	41	45	15	21	62	52
	Man	47	69	59	70	85	143	157	53
Maximum observed between 1971 and 1981	Bouaké	162	197	104	189	119	81	154	119
	Man	113	202	400	324	292	258	478	169

Decreasing soil erodibility

Resistance of soils to erosion depends primarily on basic soil composition, which is difficult to modify, but changes can be made to increase erosion resistance. Enriching the organic matter content of soil generally improves soil structure and stability, and proper soil management can substantially reduce erosion potential.

Tillage practices have diverse effects, some favorable, others unfavorable, on soil erosion in temperate (Henin et al 1969) and tropical areas (Charreau and Nicou 1971). In some soils, tillage decreases soil cohesion (Charreau and Nicou 1971) and increases detachability of soil structural elements.

In other soils, tillage brings coarse particles to the surface and thus improves erosion resistance. At Bouake, for example, the K coefficient of gravelly ferrallitic soil kept bare during 4 years ranges from 0.05 to 0.08 on soil plowed annually, and from 0.18 to 0.22 on nonplowed soil (Kalms 1977). Tillage also improves the root systems of plants in poorly structured soil, which also can limit erosion. In Senegal, tillage substantially improves upland rice root systems (Chopart and Nicou 1976, Chopart 1980). Root networks increase soil cohesion through meshing. By increasing porosity, tillage also can temporarily improve water percolation into the soil (Charreau and Nicou 1971).

The overall effect of tillage on erosion resistance of soil planted to upland rice is difficult to pinpoint because tillage effect varies with soil characteristics, slope, tillage tools used, quality of tilling, etc. However, experience shows it is better to keep most clods at the soil surface and to avoid using too many tillage tools and working under conditions that are too moist. Covering soil with a permanent layer of straw, which is a biological rather than a mechanical method, may improve or maintain the struc-

ture of certain soils (Lal 1976). Lal (1981) observed that improving soil erosion resistance is the key to maintaining low levels of erosion damage on highly sloped soils.

Increasing plant canopy

The degree and speed of soil coverage by a plant canopy are important determinants of erosion level. Upland rice has a canopy that enables it, under average cropping conditions, to resist erosion better than many annual crops. Any practice that helps the upland rice canopy cover bare soil more rapidly will improve erosion control.

High sowing density. Similar upland rice yields can be harvested at different plant populations. Where erosion can cause more damage than water stress, planting density should be increased to the maximum level that will not reduce yield.

Mixed cropping. Sowing upland rice with another crop maintains vegetative cover during the first phase of the rice crop. Mixed cropping is practiced by traditional manual cultivators in certain regions of West Africa. There are numerous complex problems to solve, but research should be designed to adapt mixed cropping to mechanized aariculture.

Agricultural intensification. Intensification of upland rice cultivation, such as the utilization of bred seeds, fertilizer, increased tillage, and pesticides, generally increases plant canopy.

Soil and crop management

Soil and crop management substantially affects, positively or negatively, erosion potential in areas with high R.

Among the principal soil and crop management practices that influence erosion are tillage, straw mulching, sowing practices, and weed control.

Overall cultivator interest in erosion control practices depends on farmers' production objectives, environmental conditions and constraints (of which erosion hazard is only one), inputs, and constraints to changing management practices. All factors are highly variable in West Africa, not only from one country or one natural region to another, but even between farmers.

There are few studies of the effect of crop management on erosion in West Africa, especially in upland rice cultivation. The only research is that by IRAT and ORSTOM in Senegal and Ivory Coast. Extrapolation to upland rice culture of results obtained for other crops should be done prudently.

Soil preparation. Research in Senegal shows that upland rice tillage in sandy clay soils with a slight slope noticeably reduced erosion (Table 7). Tillage

Table 7. Effect of tillage on erosion (t/ha) on bare soil in Sefa, southern Senegal (Charreau 1969).

	Erosion[a] (t/ha)
Shallow (5 cm) land preparation	27
Plowing to 15-20 cm depth	16

[a] Rainfall in 750 mm.

improved water percolation, encouraged better root settlement (Nicou et al 1970, Chopart and Nicou 1976, Chopart 1980) and vegetative development, and better soil coverage (Table 8).

In the forest zones of lower Ivory Coast, on bare, sandy soil with 2-3% slope, manual tillage 15 to 20 cm deep with a hoe lessens erosion for about one month, after which the effect disappears, soil hardens, and erosion level increases (Roose 1977a,b).

In central Ivory Coast, Kalms (1977) obtained different results with moldboard plowing on gravelly soil with 3 to 4% slope (Table 9). Plowing improved water percolation and brought to the surface coarse soil particles that helped reduce erosion. In Bouake, the effect of tilling on vegetation and yield is variable (Kalms in Chopart et al 1981), depending on variety planted and physical soil characteristics. Average erosion is low without tillage, if correct germination can be obtained by sowing hills by hand. In mechanized cultivation, chisel tillage can sometimes advantageously replace plowing (Gremillet 1979).

In Nigeria, the only information on the effect of tillage was obtained on a land planted with maize (Lal 1976, Table 10). Results contrasted with those obtained on cultivated soil in Senegal and in Ivory Coast. Erosion losses after tillage were greater than losses with no tillage. Erosion losses were still relatively low on soil that was tilled and cropped with maize and distinctly lower than on bare soil.

Straw mulching. The comparative effects of tillage and straw mulching or minimum tillage on upland rice have been studied in southern Senegal on slightly sloping ferrallitic soil. The research design did not

Table 8. Effect of plowing on upland rice yield in Senegal, 1969-80 (Chopart 1981 a,b).

	Tillage without burying or organic matter	Tillage with burying of organic matter
Number of results	29	10
Yield of control (kg/ha)	2360	1364
Yield with tillage (kg/ha)	2329	2779
Difference (%)	+ 71%	+104%

Table 9. Effect of soil preparation on development of erosion at Bouaké, central Ivory Coast. Bare soil maintained (Kalms 1977).

Year	Rainfall		Erosion (t/ha per yr)			
	mm/yr	Rusa	Control	Plowing	Shallow disking	Plowing + disking
1971	1345	523	–	11.5	12.9	14.9
1972	965	329	17.9	19.7	25.0	11.0
1973	959	352	41.1	17.6	48.6	9.3
1974	1121	464	51.9	12.2	43.8	11.2

Table 10. Effect of tillage on erosion under maize cultivation in Ibadan, Nigeria (Lal 1976).

Slope (%)	Erosion (t/ha)		
	Bare soil	Maize cropping	
		Tillage	No tillage
1	4.0	1.0	0.4
5	32.1	2.7	1.5
10	45.5	5.8	5.1

allow for calculations of soil losses to erosion, but erosion losses appeared negligible. Yields were greater after tillage (Table 11). In years with adequate rainfall for upland rice, straw mulching had no effect on rice yield, but weed infestation was considerably greater after minimum tillage with straw mulching than on tilled soil alone (Chopart 1981a,b).

In Bouaké, Kalms has compared different agronomical effects (other than erosion) of tillage and minimum tillage with or without straw mulching. Mulching with the residue of the preceding year's harvest (cotton) did not affect upland rice yield (Chopart et al 1981).

The effect of straw mulching has been studied at IITA in Ibadan, Nigeria. For maize crops, mulching helped keep erosion losses low, even on bare soils with 15% slope (Lal 1976). Mulching was not tested on upland rice.

Table 11. Comparative effects of plowing and minimum tillage with straw-mulching on yield (kg/ha) of u-pland rice at Sefa, southern Senegal (Chopart 1981a, b).

Tillage practice	Yield (kg/ha)
Plowing [a]	3014
Minimum tillage + straw mulch [b]	1446

[a]Plowing with an ox-driven plow, burying of cornstalk. [b]Straw-mulching with cornstalk.

Sowing practices. Random sowing seems to provide more rapid vegetative coverage of the soil than row sowing, particularly if interrow spacing is greater than 30 cm.

Weed control. Weeds compete with annual crops for moisture, nutritive elements, and light energy. But from the erosion control point of view, leaving a weed cover at the beginning of the crop cycle can be beneficial. Research in Ivory Coast (Merlier 1976) and Ghana (Carson 1975) indicated the upland rice crop was most susceptible to weed competition between 6 and 8 weeks after sowing. Leaving an upland rice culture weedy during the first month of vegetation did not decrease final yield (Merlier 1976). Perhaps the first weeding should be delayed 2 or 3 weeks after germination in areas where erosion hazards are high.

SUMMARY

If conditions are similar, erosion of areas planted to upland rice is generally less than that for other crops, such as maize, millet, and peanuts, because the plant covers the soil well 2 months after planting.

In some upland rice areas in West Africa, however, rainfall intensity is high to very high, and causes substantial erosion damage, regardless of crop culture.

Where erosion potential is substantial, the following agronomic practices may reduce erosion damage:

- weedy strips following contour lines;
- semideep plow or chisel tillage (15-20 cm) perpendicular to the slope;
- no tillage and protection of the soil with a permanent straw mulch;
- sowing when rainfall causes minimum erosion;
- high density sowing;
- mixed cropping; and/or
- utilizing agronomic practices that encourage rapid crop growth and vegetative soil coverage.

The farmer's choice of a cropping system in upland rice cultivation should also consider the overall effect of erosion control practices on production, crop economics, and constraints.

For example, despite its effectiveness as an erosion control technique, mulching can cause practical problems detrimental to upland rice cultivation:

- scarcity of straw in animal breeding regions;
- sowing difficulties -- no simple, efficient sowing machine to plant rice in straw-mulched soil exists; and
- weeding difficulty.

Straw mulching can be used for traditional, manual cultivation in certain situations, but cannot presently

be used in all upland rice production areas in West Africa. Research in Ivory Coast (the IDESSA-GERDAT station at Bouaké) is trying to develop cropping systems for direct sowing of upland rice on straw-mulched soil, with intermediate or conventional mechanization.

To be accepted by farmers, a cropping system that minimizes erosion should be effective, coherent, relatively easy to adopt, and profitable. Its adaptation should result from an analysis of the local physical environment, the systems currently used by the farmers, farmer econolnic resources, and constraints to adoption.

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REVIEW OF SOIL FERTILITY MANAGEMENT AND CROPPING SYSTEMS FOR WETLAND RICE PRODUCTION IN WEST AFRICA

B. T. KANG and A. S. R. JUO

In the humid region of West Africa, many farmers grow upland rice in the traditional bush fallow system. They alternate 1 or 2 years of cropping with several years of bush fallow to regenerate soil fertility and suppress weeds. During the cropping period, farmers clear the land and burn the vegetation to obtain a clean seedbed. They often lightly till the soil with a hoe and then broadcast or dibble rice seeds.

In the traditional system, upland rice is often grown with other crops, such as pearl millet, maize, cassava, yam and pigeonpea. Rice yield is generally very low (600 – 800kg/ha) because of inadequate nutrient supply, low planting density, poor weed control, and pest and disease incidence (Chabrolin 1977, Buddenhagen and Persley 1978, IITA 1979b, IRAT 1980).

Research on upland rice during the past decade emphasized varietal improvement rather than fitting rice into cropping systems with better soil management practices. This paper discusses the potential and limitations of West African soils in upland rice production.

SOIL ENVIRONMENT FOR UPLAND RICE PRODUCTION

West African soils with low activity clays (LAC) predominate and are a major congtraint for upland rice cultivation. Those soils have low effective cation exchange capacity (CEC) and low available nutrient and water-holding capacities. Rice grown on such soils under well-drained conditions is often subject to periodic drought stress and inadequate nutrient supply (Alluri et al 1979, Kalms 1979). Properties of some commonly occurring ALfisols, Ultisols, and Oxisols in West Africa are given in Table 1.

Upland rice is grown mostly on kaolinitic and coarse-textured Ultisols and Oxisols in the humid and perhumid regions (Kang and Juo 1981, Lawson et al 1979). High rainfall and good soil permeability make nutrient leaching a major constraint for shallow rooting crops such as rice. In some instances, soil acidity, low silica solubility, and low potassium

International Institute of Tropical Agriculture, Ibadan, Nigeria.

Table 1. Properties of selected well-drained soils with *low activity clays* in West Africa.[a]

Depth (cm)	Particle size of fine earth (%)		Gravel (whole soils) (%)	pH (H_2O)	Effective cation exchange capacity (meq/100 g)	Base saturation (%)	Bulk density of fine earth[b] (g/cm^3)
	Sand	Clay					
			Alfisol from banded gneiss, Ibadan, Nigeria				
0-12	70	15	5	6.2	10.8	99	1.32
20-42	57	34	54	6.0	4.8	99	1.49
			Ultisol from coastal sediments, Onne, Nigeria				
0-15	67	18	0	4.3	2.9	35	1.32
30-45	67	28	0	4.3	2.5	24	1.39
			Ultisol from granitic gneiss, Suakoko, Liberia				
0-13	76	18	30	4.5	2.2	55	n.d.
20-53	72	20	47	4.1	1.8	35	n.d.
			Oxisol from clayey alluvium, Kpuabu, Sierra Leone				
0-6	37	41	0	4.5	3.8	25	n.d.
21-60	31	49	0	5.0	1.6	25	n.d.

[a] Sources of data: Nigeria and Liberia – IITA soil data bank; Sierra Leone – R. T. Odell et al (1974). Univ. Illinois Agric. Exp. Bull. 748, and Njala Univ. College Bull. 4. [b] n.d. = no data available.

reserve my also increase disease and limit growth and yield.

Under continuous cultivation, the kaolinitic but high-base status Alfisols and Inceptisols in the sub-humid or the wet-dry climatic region are prone to erosion, soil acidification, and drought. If the crop has poor ground coverage, particularly during the early growth stage, severe soil erosion and runoff can occur (Roose 1977).

In newly cleared Alfisols from secondary forest fallow, with pH value above 6 and base saturation

Table 2. Changes in soil properties (0-15 cm) of a kaolinitic Alfisol at Ibadan after 4 years of continuous upland rice cultivation (2 crops/yr).

Property	Under secondary forest	Under continuous upland rice for 4 yr
PH (H_2O)	6.2	4.6
Organic C (%)	1.72	1.04
Exchangeable cations (meg/100 g)		
Ca	3.60	0.92
Mg	1.12	0.24
(Al+H)	0.20	1.20
Effective cation exchange capacity (meq/100 g)	5.36	2.54
Base saturation (%)	96	53
Bulk density (g/cm^3)	1.12	1.38

greater than 90%, soil acidification can occur rapidly within a few years of continuous cropping of cereals even with moderate chemical applications (IITA 1979a). In an experiment at IITA (Table 2), soil acidification resulted in a large loss of exchangeable Ca and Mg by leaching and a twofold reduction of effective CEC.

Thus, research on upland rice cultivation on these marginal soils should stronyly emphasize development of cropping systems and soil management practices that will minimize soil degradation and increase nutrient and water use efficiency. Crop residue conservation and tillage systems are among the important soil management practices that require further research.

NUTRIENT AND WATER MANAGEMENT

In the traditional system, newly cleared and burned soils usually contain adequate and balanced nutrients for one or two cycles of low-intensity cropping. However, soil nutrients may become inadequate for high-intensity cropping, particularly after a short period of fallow. N application has produced large yield increases (Table 3) on newly cleared land (Mahapatra and Jalloh 1979, WARDA 1982).

Continuously cropped land may need application of N, P, K, and S, but N is the most limiting nutrient in both the humid and subhumid regions (Mahapatra and Jalloh 1979, Sesse and Braun 1971, WARDA 1982).

Water transports soluble N and other nutrient ions from the soil to the root surface through both mass flow and diffusion (Barber 1962, Liao and Bartholomew 1974, Bolton 1981). Nutrient and water availability are interdependent. For shallow rooting crops such as rice in LAC soils, a balanced and timely nutrient supply will help the crop use the available soil moisture more efficiently. On the other hand, soil management practices that can improve soil water storage will also increase crop efficiency in N utilization. Much re-

Table 3. Effect of N application on grain yield of 2 upland rices after bush fallow at Suakoko, Liberia (WARDA 1982).

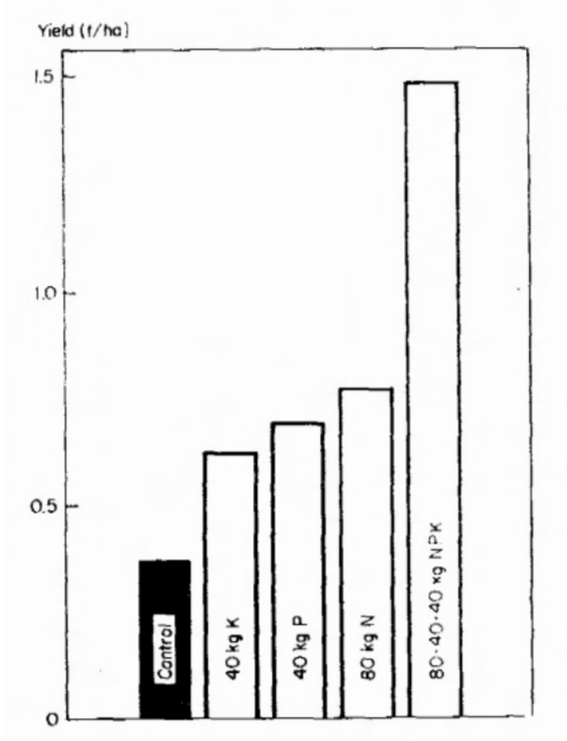
N rate (kg N/ha)	Grain yield (t/ha)			
	4418		LAC23	
	1980[a]	1981	1980[a]	1981
0	1.02	0.99	1.65	0.79
20	2.8	1.26	2.50	1.13
40	3.57	1.45	3.08	1.28
Mean	2.46	1.23	2.41	1.07
LSD .05	0.21	0.0	0.21	0.08

[a] Newly cleared.

search is needed to increase water use efficiency by upland rice through balanced nutrient supply in the wet-dry tropics where drought stress is a major growth-limiting factor (Kalms 1979).

In the high rainfall regions, leaching of nitrate in the highly permeable Ultisols and Oxisols is a major problem. Arora and Juo (1982) reported that splitting N application (90 kg N/ha) from 1 to 3 applications reduced leaching losses from 53 to 28% of applied N. It also increased upland rice yield from 1.6 t to 2.5 t/ha at IITA's high rainfall substation at Onne. They also observed that liming the Ultisol at the rate of 1 t of $CaCO_3$ equivalent per hectare increased N leaching, but had no effect on rice yield.

Mahapatra and Jalloh (1979) reported that three split N applications gave the best upland rice grain yield in Sierra Leone. They found small and insignificant differences in effectiveness among N sources -- urea supergranules, sulfur-coated urea, and other compound sources. Also, in the highly leached soils such as the lateritic Ultisol in Sierra Leone, a balanced nutrient application was essential for better crop growth and yield (Fig. 1).



1. Grain yield of variety LAC23 as affected by N, P, and K applications at Rokupr, Sierra Leone (IITA 1977).

Table 4. Effect of external P concentrations on yield of 4 pluvial rices on Alfisols (J. Kiazolu and B. T. Kang, unpubl. data),

External P concn. (ppm)	Rice yield (t/ha)			
	OS6	ITA116	ITA117	ITA122
0.003 (control	3.65	3.50	2.35	2.93
0.03	3.63	4.23	3.13	3.65
0.06	3.65	4.23	3.00	3.33
0.12	3.83	4.08	3.13	3.33
LSD .05	0.47			

Because of the coarse texture and the kaolinitic mineralogy, the P fixation capacity of the regional soils is low (Juo and Fox 1977, Pichot and Roche 1972). In the kaolinitic Alfisols and Ultisols, moderate P requirement of 20 to 40 kg/ha initially is sufficient to sustain crop yield (Kang and Osiname 1979, Mahapatra and Jalloh 1979). Because of P's high residual effect, the Alfisols require a decreasing amount in subsequent cropping (Kang and Osiname 1979). Recent studies by Kiazolu and Kang (unpubl. data) showed some varietal differences in P response. The short and intermediate-statured upland rice varieties showed greater response to P application than the tall variety OS6 (Table 4).

Published data on upland rice response to K application in West Africa are scarce. It is expected, however, that K deficiency may be a problem on highly leached soils under continuous cropping, particularly sandy sedimentary soils which are low in K reserve.

Experimental data on other cereal crops give strong evidence that adequate K nutrition may increase plant tolerance for drought (Skogley 1976), Mengel and Braunschweig 1972). When K supply was adequate, plants responded almost immediately to water stress by reducing transpiration; but those with moderate or severe K deficiency were unable to do so. Beringer and Trolldenier (1978) pointed out that K^+ ion facilitates water uptake by roots and at the same time reduces transpiration loss. There is, however, no published data relating K nutrition and water use efficiency for upland rice. Future research should investigate this.

Among the secondary nutrients and micronutrients, S deficiency can be a problem in the wet-dry region (Osiname and Kang 1975). Zinc deficiency is also common on sandy-textured soils in the subhumid area such as that on which upland rice is grown in the Atebubu district of central Ghana. After intensive burning of vegetation, severe Fe deficiency in upland rice is observed in Fe-rich Alfisols (Kang et al 1976). The problem may become more frequent and pronounced with continuous cropping, particularly during drought stress and early growth.

VIABLE CROPPING SYSTEMS

Because upland rice is widely grown in intercropping systems in the humid and wet-dry regions, research on soil and crop management should be high priority.

Results from a few agronomic trials demonstrated that improved cultural practices gave large yield increases (Alluri et al 1979, IITA 1977, WARDA 1982). There have been only a few short-term trials on mixed cropping systems and results from such experiments are often inconclusive.

Results from a 3-year experiment at Rokupr, however, showed that combinations of rice + pearl millet, rice + cassava, and rice + tree-type pigeonpea at a 3:1 ratio are promising for total yield and monetary return (Mahapatra et al 1979). At Onne, Nigeria, upland rice was successfully intercropped with plantain without decreasing plantain yield (G.F. Wilson, pers. comm.).

In Asian rice production, prunings of tree legumes are frequently used as a N source. In Southeast Asia, recent research has used Leucaena prunings for upland rice (Vergara 1982). To develop more stable low-input cropping systems, southern Nigerian scientists studied alley-cropping upland rice with Leucaena on an Alfisol at Ikenne. In this system the established Leucaena hedges are periodically pruned and the prunings applied as mulch to the rice crop grown in the alleys. Alley-cropped rice grew better than monocropped rice. This system may be an alternative to the traditional bush fallow for more stable upland rice production in tropical Africa. Future research should give stronger emphasis to intercropping with economic tree or shrub species to minimize soil fertility decline due to erosion and acidification.

Is continuous monocropping of upland rice a feasible production system in the tropics? McIntosh et al (1981) obtained sustained rice yield in a mixed-crop system on a fine-textured Ultisol in south Sumatra, Indonesia, with fertilizer inputs. Seguy et al (1970) showed that with proper tillage, it was possible to obtain rice yields of more than 5 t/ha with 5 successive croppings in western Cameroon. Yield of continuous upland rice on a fine-textured Ultisol at Yurimaguas, Peru, however, sharply declined after three croppings with NPK and lime application (NSCU 1976). The yield decline was attributed to nutrient imbalance and secondary and micronutrient deficiencies. Similar results were observed in short-term experiments on coarse-textured Ultisols at Suakoko (WARDA 1982) and at Rokupr (Mahapatra and Jalloh 1979). Rice yields declined sharply in the second year of cropping even with high dosages of N application (Table 3).

These data indicate that soil condition and nutrient level management are key factors in continuous

cropping. For that reason, mixed and alley cropping are probably better systems for small farmers.

SUMMARY AND CONCLUSIONS

Upland rice is widely grown in intercrop systems on well-drained ultisols and Alfisols with LAC in the humid and wet-dry regions of West Africa. These soils are characterized by low effective CEC, low nutrient and water-holding capacities, and kaolinite mineralogy. Continuous upland rice cultivation on them resulted in rapid decline of yield possibly because of loss of soil fertility soil erosion, and soil acidification.

Future research should give high priority to developing viable cropping systems and balanced nutrient programs to improve crop water use efficiency in the wet-dry tropics. Research to minimize leaching loss of nitrogen and intercrop rice with economic trees and shrubs is important to increase upland rice production in the high rainfall regions.

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ASIAN UPLAND RICE CROPPING SYSTEMS

J. L. McINTOSH, Z. HARAHAP, and B. H. SIWI

We may not appreciate potential upland rice development because we do not understand its culture and role in the farming system. This workshop will make a major contribution if we can characterize upland rice culture so that we can plan variety improvement and management practices. The Technical Advisory Committee Subcommittee Report on Upland Rice illustrates the confusing situation.

> "There are approximately 19 million hectares of land used to grow upland rice in Asia, and another 20 million hectares which conform to the definition in some years. Of the 19 million hectares, about half is bunded but subject only to occasional periods when the land is flooded."

By this definition, the upland rice hectarage in Asia could vary from 9.5 million to 39 million from one year to the next. In this paper, however, upland rice means rice that is direct seeded and intentionally grown under aerobic soil conditions. Because of time and experience limitations, we will focus on small farms (1–5 ha) in tropical Southeast Asia.

SHIFTING CULTIVATION

Shifting cultivation opens land for cultivation, uses it until crop production is unprofitable, and then abandons the land. Crop removal, erosion, oxidation, and leaching subtract from soil quality. Shifting cultivation is common wherever open lands exist and soils are fragile because of fertility or landscape problems. The lands may be tribal, government, or even private.

Where land pressure is not intense and land is flat and relatively productive, this farming is stable and sustainable. But with increasing population, farmers plant steep, erodable lands and the time intervals between crop lessens. Such land pressure in the upper watersheds causes deforestation, erosion, and diminish–

Cropping systems agronomist, Cooperative CRIFC/IRRI Program in Indonesia; rice breeder; and head, Bogor Research Institute for Food Crops.

ing subterranean and river water flow. Annual burning makes the situation worse, resulting in vast areas of Imperata cylindrica grasslands (or other hardy grasses) and deforested hills. If farming systems include large ruminants, the problems are compounded.

Land clearing and preparation

Farmers clear land by cutting vegetation in dry season. Clear-cutting is common. Near the end of dry season, they burn the vegetation. Farmers may or may not cultivate the land depending on soil condition. If they are cutting heavy forest, they usually do not need to cultivate. If they are clearing Imperata, they remove rhizomes, cultivate the land, and repeat the process.

Common cropping patterns

Even with local variations, a general cropping pattern characterizes shifting cultivation for food crops in humid tropical Asia. The maize + upland rice ≠ cassava cropping pattern[1] diagrammed in Figure 1 is common in Indonesia. Upland rice + maize is especially common and any variations are from different maize populations. Cassava interplanting depends on local food preferences and market availability. In cooler subtropics, cassava may not grow well and farmers may omit it or substitute other crops adapted to cooler climates.

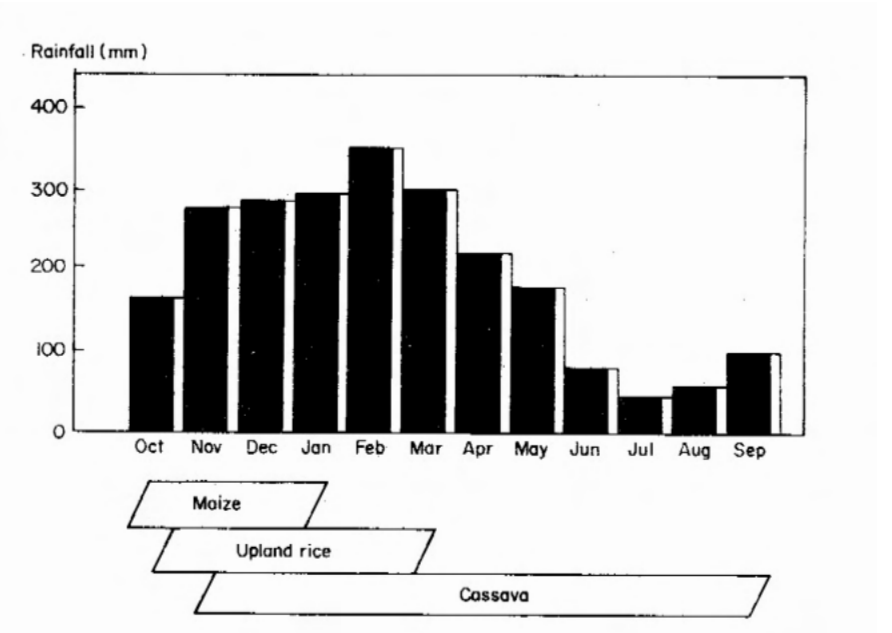
Cropping pattern management

Farmers randomly plant upland rice and maize soon after rainy season begins. Cassava follows 30 days later. The cropping pattern usually includes random plantings of miscellaneous legumes, amaranthus, chilies, and eggplant.

The rice varieties are usually local, rather tall (120-150cm), and require more than 150 days to mature. The maize varieties are local flints, early maturing (79-90 days), and short-statured (150-200 cm). The local cassava varieties have moderate branching, low hydrocyanic acid, and high dry matter content. Farmers harvest cassava 6-10 months after planting.

Maize and cassava populations depend on local food habits and needs. Where there are other food sources, the cassava area would be very small. Usually, farmers do not use fertilizers or pesticides. Other crops ap-

[1] common pattern symbols are the following: + between two crops means planted about the same time and possible harvest is about the same time; ≠ between two crops means relay planting of second crop into first crops later in the season; - between two crops means the second crop follows the first in a sequence.



1. Monthly rainfall distribution and year-around cropping pattern commonly used on Red-Yellow Podzolic soils in Indonesia.

pear randomly and depend on seed availability. Farmers emphasize legumes and leafy vegetables (string bean, cowpea, amaranthus, sweet potato, etc.).

SEDENTARY AGRICULTURE

Areas where upland agriculture is stable and settlements flourish appear to have good soil, accessibility, and a favorable human environment. Here there are two categories of cropping patterns with upland rice and other food crops.

Temporary food crops production

Where food crop production is temporary, farmers continually use land for agricultural purposes, but grow food crops for only 3-4 years. These serve as nurse crops to establish perennial crops such as coconut, oil palm, rubber, and spices. They also are valuable food and income sources before the perennial crop harvest. When perennial crops are old and unproductive, farmers repeat the process. With a stable economy, farmers have enough land to continually produce food and perennial crops.

Land clearing and preparation, and common cropping patterns and their management are the same as in shifting cultivation. However, farmers reduce the amount of cassava planted to a level necessary for subsistence. The land area opened at any one time rarely exceeds 1 ha.

Sustained food crops production

The most intensive, stable, and sustainable upland food cropping occurs where there are fertile soils and good markets. Upland rice cropping patterns fall into several categories according to existing field conditions. The following three are common in Indonesia, Philippines, Thailand, and Bangladesh.

Stable -- higher elevations. The more stable areas usually occur at higher elevations (200-1000 m) and involve vegetable crops production. In these systems, upland rice is important as a source of high quality rice and also for soil management. It is an excellent cover crop to prevent erosion and to produce straw mulch.

In stable areas, many soils are derived from volcanic debris. They are immature and difficult to puddle for lowland rice cultivation. Their physical properties facilitate cultivation (even while extremely wet), bedding, internal drainage, and aeration to produce many specialty crops. The vegetable crops use fertilizers, especially phosphates. Traditionally, crop residues and farmyard manure provide the main sources of nitrogen.

The cropping systems in these areas are usually stable and sustainable. As population grows, however, farmers expand into less favorable steep land and shallow soil. The result is less stable and sustainable agriculture. The most common cropping patterns involving upland rice include maize + upland rice - sweet potato + maize, maize + upland rice ≠ cassava, maize + upland rice - maize + peanut, and maize + upland rice - vegetable (white potato, tomato, etc.).

Cropping patterns in the stable systems receive high management with much hand labor. Farmers plant crops in rows to accommodate intercropping and use manure to maintain soil fertility. Many soils are Andosols with high phosphorus fixing capacities. Farmers minimize the problem by using stable manure and crop residues, particularly rice straw.

Maize varieties are usually early maturing (75-90 days) and downy mildew resistant. Local or improved rice varieties are from the national programs. In Indonesia, neck blast is a serious problem that prevents intensive use of any variety for more than 2 consecutive years.

Stable -- lower elevations. At lower elevations on more mature soils with less rainfall, there are also stable food crop areas. Farmers have not used these lands intensively and animals play a major role in the farming systems, providing power and cash income. Recently, these areas have become more important because of fertilizer availability. These upland soils are usually very responsive to phosphorus and nitrogen fertilizer applications. In tropical regions of Indo-

nesia, Thailand, and the Philippines, the common cropping patterns may be: maize + upland rice - maize, upland rice - vegetable, maize + upland rice - maize + peanut, maize - upland rice + maize, and maize + upland rice - sweet potato + maize.

These patterns (minus cassava) are common in plantations of perennial crops such as coconut and rubber. As traditional barriers between food and perennial crops are eliminated, this practice will expand.

In the cooler regions of Bangladesh the common patterns may include: upland rice - wheat or barley, upland rice - white potato, and upland rice - wheat or barley + chickpea.

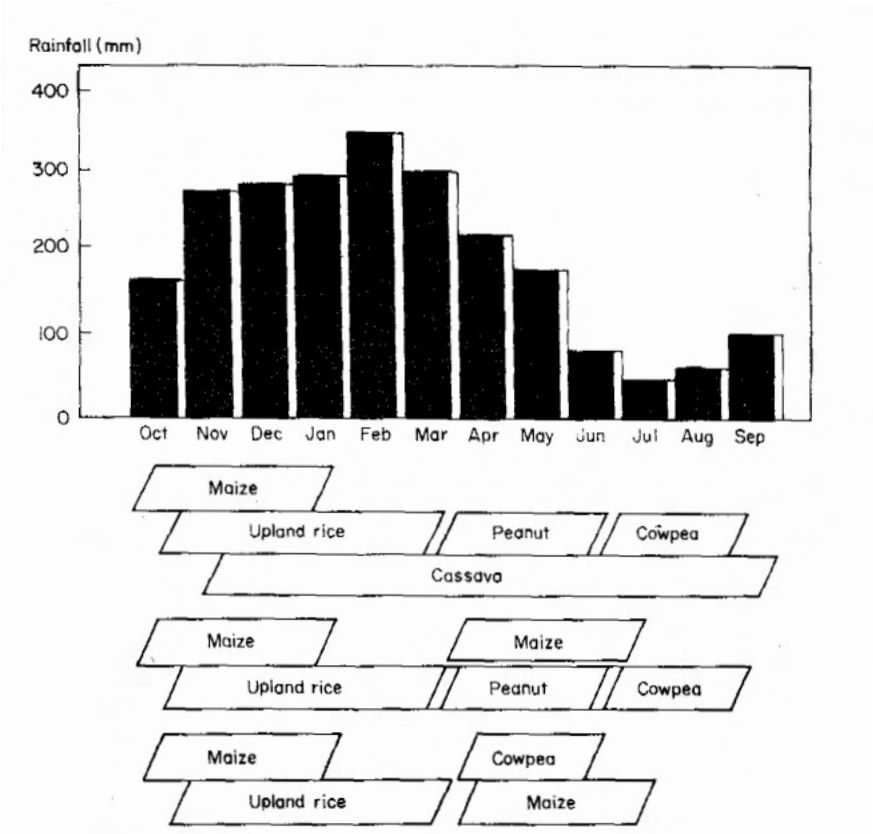
Landholdings at lower elevations are larger and farmers use animal and tractor power sources. Consequently, plantings are systematic and in rows, with fewer crops planted at once. In sustained crop production, soil fertility maintenance and erosion control are major problems.

Quantity of production is more important, particularly for maize, but downy mildew and neck blast are still constraints. For upland rice, drought tolerance is an important factor, particularly in the Philippines and Thailand. Blast resistance and tolerance for acid Soils are important in Indonesia.

Potentially stable -- lower elevations. At lower elevations with potentially stable production, soils are highly weathered from shifting cultivation and have become low-grade secondary forests or infested with *Imperata cycindrica*. With proper management and use of inorganic fertilizers, however, they can be productive. They can support sustained agriculture, but viability depends on integrated mixed farming systems. Large areas in Indonesia and other parts of Southeast Asia have these characteristics. Their initial development depends on availability of suitable varieties of food crops and infrastructure.

In Indonesia, Malaysia, and southern Philippines, rainfall is sufficient for upland rice and maize during the rainy season. Major constraints are low pH (aluminum toxicity) and infertile soil. Although large areas are suitable for development (15 million ha in Indonesia), these areas are not in statistical data as ricelands but as grasslands or secondary forest lands.

We need to develop suitable technology for cropping and farming systems components. This is a major objective of rainfed farming systems research in Indonesia. Presently, suitable cropping systems for the areas have been developed although upland rice varieties and management practices are not completely reliable. The most common cropping patterns (Fig. 2) in humid tropical areas are: maize + upland rice ≠ cas-



2. Typical rainfall pattern of Indonesian upland crop areas and adapted cropping patterns.

sava + peanut - cowpea, maize + upland rice - maize + peanut - cowpea, and maize + upland rice - maize.

In drier regions with shorter rainy seasons, sesame may replace or supplement maize in the pattern and pigeonpea may replace cassava. If so, the whole pattern grows in alleys between rows of leguminous tree crops such as Leucaena leucocephala.

The choice of cropping patterns and land use intensity depends mostly on marketing. In Indonesia we try to discourage intensive monoculture of either cassava or maize because erosion and soil fertility loss are rapid. But long-term research using the mixed cropping patterns in Figure 2 shows that the monoculture patterns are stable. The key management factor involves using fertilizers and returning crop residues to the fields. Intercropping rice and legumes with maize and cassava helps preserve the soil.

It is important to find varieties adapted to soil and climatic conditions. We simply do not have adapted and improved varieties of upland rice and legumes suitable for potentially stable lower elevations. Neck

blast is the major problem for upland rice and acid soil tolerance is the major constraint for legumes. Management practices, such as systematic rotation of varieties and soil fertility management, can minimize these problems.

On a long-term basis, food crop production is not likely to be a stable and sustainable kind of agriculture. The competition from irrigated areas with better water and soil conditions is too great. But subsistence food production and minor sales will remain a high priority in mixed farming systems.

CROPPING SYSTEMS AND UPLAND RICE IN LATIN AMERICA

C. P. MARTINEZ

Latin America represents only 5.1% of the world's total rice area and 3.7% of total rice production. However, rice is becoming a very important staple in the Latin American diet as per capita consumption increases as a result of production increases (Posada 1982). Today 72% of production is upland rice, but in 1978, upland rice was only 49% of the total. Latin American upland rice is increasing in importance; in contrast, upland rice production in Asia is minor (CIAT 1979). Upland rice constitutes >150% of national production in Bolivia, Costa Rica, Guatemala, Honduras, Panama, and El Salvador.

Latin American farmers in various ecosystems with distinct soil types, climatic conditions, and production constraints grow rice in different cropping systems. This paper discusses the distinct upland cropping systems found throughout Latin America, excluding Brazil.

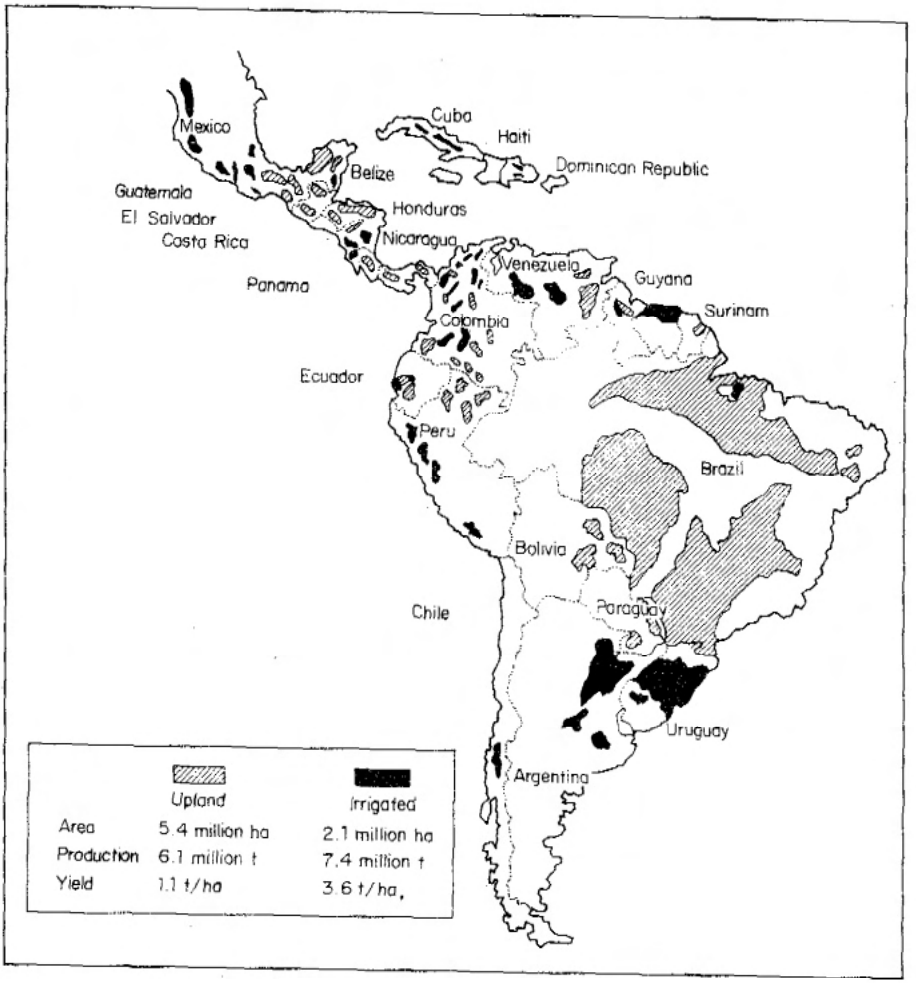
PRODUCTION SYSTEMS AND CONSTRAINTS

Definitions of upland rice and production systems in Latin America are given elsewhere (Laing et al 1984).

Latin American rice is grown on medium to large farms, with diverse production systems, ranging from intensive irrigated to extensive upland. Average yields vary markedly. Rainfall patterns, irrigation cost, soil types, topography, and availability of infrastructure determine the type of production systems (CIAT 1982).

Latin American rice production is often divided, misleadingly, into two main systems: irrigated and upland (Fig. 1). The upland area by production system and country is presented in Table 1. Table 1 indicates that most countries have a mix of farming systems, perhaps because it provides more stable total production. Hectarage and yield in 1979-80 are in Table 2. Upland rice covered 6.0 million ha, about 73% of the area, with most (3.2 million ha) in the unfavored areas of Brazil.

Rice breeder, CIAT Rice Program, A. A. 67-13, Cali, Colombia.



1. Distribution of rice in Latin America, 1978.

CIAT work with agroecosystem analysis has begun to identify and describe Latin American rice production areas, but little information is available. It is incorrect to view upland rice in Latin America as a uniform farming system in which cropping practices and yield constraints are similar; however, some constraints overlap (Fig. 2). Upland rice comprises a broad continuum of ecosystems with extremely low (cerrados in Brazil) to high productivity (Eastern Plains, Colombia). It is difficult to subdivide them further into subsystems, but the following classification analyzes each ecosystem for yield constraints, potential productivity, breeding objectives, priorities, and economic profitability (Jennings et al 1981).

Table 1. Area planted in different rice production systems in Latin America, 1979-80[a] (Posada and Nores 1982).

Country	Area (thousand ha)						Tota1 area (hundred ha)	Total area planted with improved varieties[b] (%)
	Irrigated	Rainfed lowland	Highly favored upland	Moderately favored upland	Un-favored upland	Traditional manual upland		
Brazil	779	125	623	810	3178	716	6231	8
Mexico	73	0	11	26	16	7	133	55
Tropical South America								
Bolivia	0	1	2	14	0	38	55	3
Colombia	308	0	21	0	0	93	422	70
Ecuador	51	20	10	23	0	0	104	32
Paraguay[c]	21	0	0	11	0	0	32	6
Peru	72	12	0	11	0	5	100	47
Venezuela	125	9	0	97	0	0	231	87
Central America								
Costa Rica	2	0	42	35	0	3	82	96
El Salvador	4	0	0	10	0	0	14	94
Guatemala	0	1	5	3	2	1	12	60
Honduras	1	2	1	2	1	12	19	86
Nicaragua	22	0	5	0	0	0	27	77
Panama	2	5	8	20	10	54	99	53
Caribbean								
Guyanat[c]	86	0	0	35	0	0	121	20
Cuba	151	0	0	0	0	0	151	100
Dominican Republic	99	5	0	0	0	0	104	34
Haiti	38	3	2	2	10	3	43	30
Jamaica	1	0	0	0	0	0	1	50
Surinam	34	0	0	0	0	2	36	100
Belize	3	0	1	0	0	2	6	50
Temperate South America								
Argentina	100	0	0	0	0	0	100	12
Chile	41	0	0	0	0	0	41	0
Uruguay	62	0	0	0	0	0	62	0
Total Latin America	2075 (25)	183 (2)	731 (9)	1099 (13)	3217 (39)	936 (12)	8226 (100)	

[a]Unofficial CIAT preliminary estimates based on information from qualified sources. [b]Dwarf varieties only; mostly CIAT and CIAT-derived materials (CIAT 1979, 1982). [c]1977-78 harvest (CIAT 1982). [d]Values in parentheses are percentages.

Latin America has six rice production system (Table 2): irrigated, rainfed lowland, highly favored upland, moderately favored upland, unfavored upland, and traditional manual upland (CIAT 1982). In this paper we are concerned with the upland production systems. Case studies will describe the cropping system, cultllral practices, and yield constraints in the highly favored upland (Eastern Plains, Colombia), moderately favored upland (Guanacaste Province, Costa Rica), and traditional manual upland (Yurimaguas, Peru).

Table 2. Summary of area and yield in major Latin American rice production systems, 1978.

System	Area		Average yield (t/ha)	Production	
	million ha	%		million t	%
Irrigated	1.9 [a]	0.23	3.5	6.6	0.46
Rainfed lowland	0.6 [b]	0.07	2.5	1.6	0.11
Upland					
Favored (highly and moderately)	1.3 [c]	0.16	2.0	2.5	0.17
Less favored	3.4 [d]	0.42	1.0 [d]	3.3	0.23
Manual	0.9	0.12	0.6	0.5	0.03
Total	8.1	1.00	1.9	14.5	1.00

[a] IRTP, report of the third conference, CIAT-IRRI, May 1979. [b] Dominican Republic, Haiti FAO production yearbook; Ecuador 20,000 ha, pozas system, Programa Nacional de Pesquisa-Arroz Brazil 520,000 ha, Varzeas, EMBRAPA, and Centro Nacional de Pesquisa-arroz Feijao, several issues of annual reports. [c] Mexico, Costa Rica, Guatemala, Venezuela, Colombia, Ecuador, Peru, FAO production yearbook; Brazil, 1 million ha noncerrados upland rice. [d] Estimated as residual.

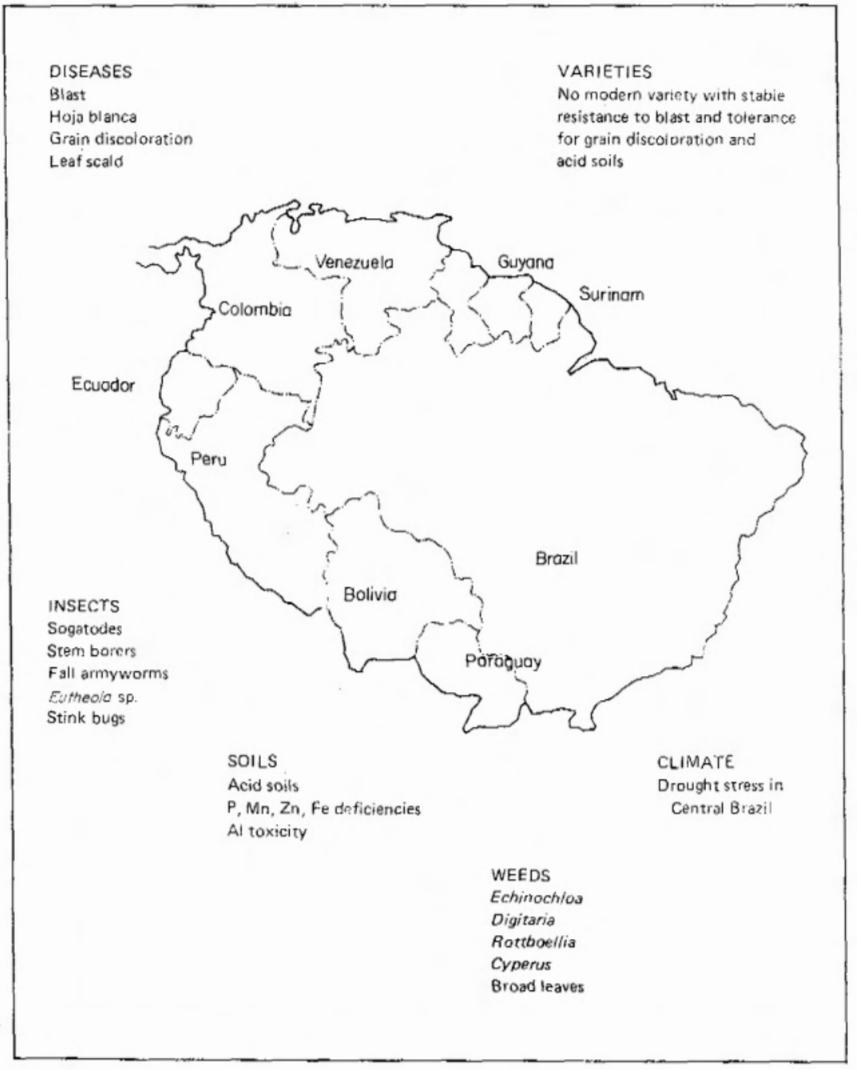
CROPPING SYSTEMS: CULTURAL PRACTICES AND YIELD CONSTRAINTS

Highly favored upland rice

The savanna foothills near Villavicencio in the Eastern Plains of Colombia, which represent the mechanized cropping system in the highly favored areas, is 400–450 m above sea level. In the alluvial soils of the rivers Ariari, Negro, and Guateguia, about 40,000 ha are planted to rice. Table 3 shows the soil analysis. Soils vary in physical and chenical characteristics, but all have good water–holding capacity (Sanchez and Owen 198la). Most rice is concentrated on the deeper clay–loam soils with a pH of 4.9–6.0 and medium fertility level. The most pronounced nutritional problems are nitrogen and zinc deficiencies.

The rainy season usually starts mid–March and ends mid–November. Total rainrall averages 2,789 mm (12 yr data); usually there are no marked dry periods during the rainy season. Table 4 shows monthly average data for rainfall, temperature, and relative humidity.

Before rainy season begins, farmers plow under sorghum, maize, or cotton stubble with a disk plow. They then harrow two or three times, depending on soil and weather conditions, with an offset disk harrow. They broadcast dry seed with a tractor and a portable seed spreader at the rate of 150–180kg/ha. Often, rain at planting time either is too much or too little, resultiny in problems in seed germination, fertilizer application, and weed control. Short dry spells 20–40d after seed germination provoke severe leaf blast Bl attacks an a high percentage of susceptible varieties.



2. Constraints to upland rice production in South America.

With the last harrowing farmers broadcast and incorporate either 10-30-10 or 14-14-14 kg NPK/ha. The total amount depends on soil analysis. Table 5 shows fertilizer recommendations for these soils.

Nitrogen fertilization is very important in this ecosystem because environmental conditions are very conducive to Bl epidemics. Recommendations are

- no more than 30 kg N/ha for susceptible varieties without chemical control of Bl;
- up to 60 kg N/ha for susceptible varieties with good chemical control; and
- up to 70 kg N/ha for resistant varieties.

Table 3. Soil analysis of three alluvial sites in Eastern Plains of Colombia (Sanchez and Owen 1981).

Site	pH	O.M. (%)	P (ppm)	Elements (meq/100 g soil)					CEC	Base saturation (%)
				Al	Ca	Mg	K	Na		
Ariari	5.8	5.0	16	0.3	9.9	1.6	0.71	0.8	13.31	98.1
Negro	4.9	3.8	22	1.8	4.4	1.5	0.24	0.12	8.06	17.7
Guatequia	6.0	1.7	21	-	2.0	0.3	0.28	0.14	2.72	100.0

Table 4. Climatic data of the Eastern Plains of Colombia. ICA, La Libertad Experiment Station, Villavicencio.

Month	Average rainfall[a] (mm)	Average temp[b] (C°)	Average relative humidity[b] (%)
Jan	26.9	26.8	68.5
Feb	42.3	28.0	65.5
Mar	167.0	26.9	72.2
Apr	318.4	25.4	81.2
May	438.3	24.8	83.2
Jun	369.6	24.0	85.0
Jul	328.9	23.9	82.5
Aug	274.3	24.2	82.8
Sep	254.0	24.9	81.5
Oct	304.9	25.0	81.5
Nov	186.1	24.3	81.0
Dec	78.7	25.6	78.0
Total	2789.4		

[a]12 yr data. [b]4 yr data.

Table 5. Some recommendations for P and K fertilization of upland rice alluvial soils of the Eastern Plains of Colombia (Sanchez and Owen 1981b).

Phosphorus		Potassium	
P in soil (ppm, Bray II)	Recommended dosage of P (kg/ha)	K in soil (meq/100 g)	Recommended dosage of K (kg/ha)
<10	44	<0.10	62
10-15	22-33	0.10-0.15	42-62
16-30	11-22	0.16-0.30	21-42
>30	0-11	>0.30	0-21

It is better to split applications of N (urea) at 30, 50, and 70 d after germination.

Grassy weeds are a serious problem across the region. The most important are Ischaemum rugosum, Echinochloa colona, Cyperus diffusus, Rottboellla exaltata, Digitaria sanguinalis, Tripogranda red rice, Cenchrus

Table 6. Effect of herbicide applications on CICA-8 yields in upland fields, Villavicencio, Colombia, 1980 (Vargas and Jaramillo 1980).

Treatment	Dosage (kg ai/ha)	Time of application (d after germination)	Yield (t/ha)	Comparative yield (%)
Thiobencarb/propanil	4.0/2.0	13	7.02	296
Propanil + piperofos/ Dimethametrin	3.0+0.8	13	5.92	249
Propanil + bifenox	3.0+1.3	13	5.41	227
Propanil + butachlor	3.0+2.4	13	7.00	293
Propani/phenothil	2.2/2.2	13/21	6.83	280
Bifenox	2.5	Preemergence	7.16	302
Propanil + 2-4-D BE	4.0+0.12	13	6.70	282
Control	0	0	2.37	100

echinatus, Ipomoea sp., Chenopodium sp., Cynodon dactylon, Amaranthus dubius, Portulaca oleracea, Cyperus ferax, and Fimbrystilis annua (Vargas and Jaramillo 1980, Fedearroz 1982). To control weeds, farmers use airplanes or spray booms to apply single or split herbicide applications 12-15 d after seed gemination when weeds are at the 2- to 4-leaf stage. Common treatments include a) propanil (360 g/liter) at 7.6-9.5 liters of commercial product/ha, and b) propanil (480 g/liter) at 7.6 liters of commercial product/ha. In some cases, farmers use a mixture of propanil and a preemergence herbicide when weed infestation is high. Examples include propanil + thiobencarb (8 + 10 liters/ha) and propanil + butachlor (8 + 4 liters/ha). The effect of herbicide applications on CICA-8 upland yields is in Table 6.

Sogatodes oryzicola, Eutheola sp. and Hydrellia sp. are the most important insect pests. Spodoptera frugiperda, Panoquina sp., Rupela albinella, Elasmopalpus lignosellus, Blissus leucopterus, Tibraca sp., and Mormidea ypsilon are less important (Fedearroz 1982). Several predators and parasites are effective in checking insect damage (Jimenez 1979). The most important ones include Polistes canadiensis, Polybia sp., Colomegilla maculata, Doldina bicarinata, Calosoma granulatum, Trichogramma fasciatum, and Telenomus sp.

Insecticides most commonly used are monacrotophos (1 liter/ha), methyl parathion (1 liter/ha), trichlorfon (1 liter/ha), carbofuran (1.5 liters/ha), diazinon (1 liter/ha), phosphamidon (1 liter/ha), and sevin 80 (2 g/ha) (Fedearroz 1982).

Hoja blanca virus disease and Bl (Pyricularia oryzae) are the most important diseases, but grain discoloration (or dirty panicles) is also becoming a serious problem. Leaf scald (Rhynchosporium oryzae) (LSc) and brown spot (Helminthosporium oryzae) (BS) are common, and stem rot (Leptosphaeria salvinii) and sheath blight

(Thanatephorus cucumeris) are also found. Nematodes (Aphelenchoides besseyi and Meloidogyne sp.) have been reported in some areas (Villarraga 1979). The following fungicides are regularly used for leaf Bl and NB1 (3-4 applications): edifenphos (1 liter/ha), kasugamycin (1-1.5 liters/ha), blasticidin-S (1.2 liters/ha), IBP (1.5 liters/ha), and tricyclazone (300 g/ha). Propineb (2 kg/ha), triphenyltin hydroxide (2 kg/ha), and benomyl (300 g/ha) are recommended for LSc (Fedearroz 1982).

Although heavy rains at harvest cause some problems, farmers harvest their fields by combine and transport the rice in sacks to commercial mills for drying and processing.

Dwarf rice varieties such as CICA-8 and Metica 1 are planted in this area. Farm yields average about 4.5 t/ha, but some farmers get about 5.5 t/ha. These extremely high yields are the result of fertile soils and excellent rainfall distribution. The yields are about equal to those of irrigated rice sown on acid, infertile soils which predominate. Production costs for CICA-9 are about US$900/ha. Because production costs for upland rice are about $300 lower than for irrigated rice, the upland sector is expanding rapidly. Large areas of unused alluvial soils are available for future upland rice cultivation. Continued growth will depend on the development of varieties resistant to Bl, the most serious biologlcal constraint to productivity.

Moderately favored upland rice

Guanacaste Province in Costa Rica illustrates the predominant mechanized cropping system in Central America (Gonzales and Murillo 1981). The climate has a rainy season beginning in May and lasting 6 mo with the remaining 6 mo extremely dry. Yearly rainfall averages 1,800 mm, with the greatest amount falling in June, September, and October. Total rainfall is extremely variable over years and areas and causes major yield variances. Furthermore, all years have a pronounced low-rainfall period of about 3 wk which occurs between mid-June and mid-August when rice is in the active tillering stage. This results in drought stress and Bl and other foliar diseases which complicate weed control. Some farmers prepare land during this dry period and plant when rains begin, running the risk of rains stopping before growing season ends. Others prepare land at the onset of the rainy season when they plow under volunteer rice and weeds with a disk plow. They harrow 2 or 3 times, depending on soil and weather conditions, with an offset disk harrow. During the last harrowing, they attach a board to the back of the harrow to level the surface.

To establish the crop, farmers direct seed, either by broadcasting or drilling seed at a row spacing of 34

(occasionally 17) cm. Usually they drill (90%) and plant at 80–100 kg seed/ha. They either broadcast manually or with a tractor or airplane using 130–140 kg seed/ha. Often there is too much or too little rain at planting time, which causes problems in seed germination and interferes with fertilizer application and weed control.

Soils are not uniform in physical and chemical characteristics. Most rice is concentrated on the deeper alluvial clay–loam soils with a pH of 5.5–7.0. The sandier soils are not planted to upland rice because their low water–holding capacity results in drought stress, increased fungal disease, and loss of native fertility in heavy rainfall areas. Most pronounced nutrient problems are nitrogen and phosphorus deficiencies (P particularly on Vertisols). Deficiencies of K, Zn, Mn, and Fe are common but less widespread.

According to soil analysis, 26 kg P/ha and 33 kg K/ha are applied at planting time. Nitrogen at 75–90 kg/ha is used in three split applications: at planting, at medium–tillering, and at primordia initiation. In Some cases, 10–15 kg $ZnSO_4$/ha and 10-15 kg Mn are used to prevent zinc or manganese deficiencies.

Grassy weeds are a serious problem across the region. The most important are *Echinochloa colona*, *Leptochloa filiformis*, *Rottboellia exaltata*, *Cynodon dactylon*, *Cyperus rotundus*, red rice, *Ischaemum rugosum*, *Eleusine indica*, and *Stenotaphrum secundatum*. Among the broadleaves are *Amaranthus spinosus*, *Commelina diffusa*, *Cucumis melo*, *Crotalaria striata*, *Mimosa pudica*, and *Portulaca oleracea*. Farmers control weeds with one or split applications. For example, one application of 4.8–5.4 kg ai of propanil is at 15–20 d after germination when weeds are at the 2– to 4–leaf stage. In the split–application system, 2.7 kg ai of propanil is used when weeds are at the 2–leaf stage. The same treatment is repeated later. Some farmers use airplanes or spray booms and combine propanil and a preemergence herbicide such as 1 kg ai of pendimethalin + 3.5 kg ai of propanil.

Spodoptera frugiperda, *Eutheola sp.*, *Elasmopalpus lignosellus*, *Rupela albinella*, *Blissus leucopterus*, *Mormidea* sp., and *Sogatodes oryzicola* are the most important insect pests in this system. When applied, the insecticides are bufencarb (1 liter/ha), monocrotophos (750 cc to 1 liter/ha), methomyl (5 liters/ha), chlorpyrifos (1 liter/ha), and carbaryl (1.5 kg/ha).

Bl is the most important disease, but LSc, BS, eye spot (*Drecshlera gigantea*), and sheath rot (*Acrocylindrium oryzae*) are also common. Edifenphos (1-5 liters/ha) kasugamycin (1.5 liters/ha), IBP (1.5 liters/ha), and tricyclazone (0.2 kg/ha) are used to control NBl in epidemic years.

Farmers harvest by combine and transport rice to commercial mills for drying and processing. Throughout Central. America, this moderately favored upland system has dwarf rice varieties including CR1113, CR201, CR-5272, CICA-7, CICA-8, Tikal 2, Eloni, ICTA Virginia, and ICTA Tempisque. There are also small areas of moderately tall varieties from the United States.

Farm yields average about 2 t/ha. With better than average rainfall distribution or in more favored areas, yield may be 5 t/ha. With less than average precipitation, yields decline to 1 or 2 t/ha.

Subsistence upland rice

Subsistence or traditional manual upland production takes place in Mexico, Central America, and all of the tropical countries of South America. In some areas (Central America, except Panama), it has negligible importance; in others it makes a modest contribution to local production. Only in Bolivia and the Amazon Basin (Colombia, Ecuador, Peru, and Brazil) does it achieve more importance than other production systems.

Subsistence upland rice production is found only at the agricultural frontier in areas of tropical rain forest. It involves felling and burning forest during the dry season. Farmers plant rice in hills spaced about 50 cm apart, dropping several seeds into holes opened with a pointed stick. Soils vary from extremely acid and infertile (Choco in Colombia and the Amazon Basin) to fertile (Bolivia). Ash from the burn is the only source of added nutrients. Rainfall in rain forest environments is abundant and well distributed.

The system produces 1 crop a yr for 1 or 2 yr. Farmers shift to a new piece of forest to begin the process again. With low human pressure on the land, farmers rotate back to previously planted patches about every 20 yr. More recently, they reduced the cycle to 8-10 yr. Hand weeding with machetes control broadleaf weeds which may become a problem in the second year of planting.

All labor is by hand. Farmers never plow the land or apply purchased inputs. Improved seed is not available and farmers plant unimproved native types -- tall, leafy, low-tilleriny, of medium maturity. Their distinguishing feature is large panicles, an essential trait because harvest is panicle by panicle. Panicles dry when placed individually on tree trunks or hung in bunches. The difficulty of drying threshed seed in the rain forest prevents harvest by cutting plants and threshing by beating.

Each farm family manages about 1 ha each season. After harvesting, farmers may raise a cash crop of maize or tomato at the end of the rainy season. The rice harvest averages about 1 t/ha and is stored as panicles and threshed and consumed as required. Fami-

lies rarely market it but do retain seeds for the following season. Rice consumption by producer-families is high because rice is one of the few staples they can safely store.

Insects and diseases are minor because of varietal tolerance acquired through years of farmer selection and because of wide spacing, low density, and lack of applied fertilizer.

Apart from the low yields, farm problems are not readily apparent but the system is extremely difficult to improve. Partial mechanization of small holdings is out of the question. Simple farm technology for rice drying is not available. If it were, farmers theoretically could plant shorter, high-tillering varieties at closer spacing and harvest and thresh plants. Modern varieties at closer spacing, however, would elevate minor pathogens and pests to serious problems. For these reasons, coupled with the system's minor contribution to total rice production, CIAT does not plan to do any research on subsistence upland rice systems.

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PERFECTING FARMING SYSTEMS MODELS FOR UPLAND RICE MANUAL CULTIVATION

L. SEGUY

Maranhao is one of nine states in northeastern Brazil. It has an area of 325,000 km^2 and is a transition state between the Amazon region in the northwest and the subarid northeast.

Maranhao grows about a million ha, or 1,100,000-1,500,000 t of rice a year. Small farmers, who are often without land or purchasing power, use an itinerant upland system on cleared land with poor productivity.

In 1976, after Maranhao sent a request to GERDAT, members of an exploratory mission proposed a project to the state's agronomic research department to rapidly increase small farmers' rice production.

In 1978, the French Cooperation and the Maranhao State government decided to cooperate on the project. A special convention between EMAPA and IRAT allowed the assignment of French researchers L. Seguy and S. Bouzinac to São Luis.

The objective for this team and Brazilian researchers was to improve fixed cropping systems for upland rice.

Researchers, extension officers, and farmers worked together to get the most from traditional cropping practices and yet preserve local eating habits.

Cocais region, an important rice producing area with an increasing land constraint, was the site of the first IRAT project.

We concentrated efforts on

- the station at Bacabal, 240 km south of Sao Luis, from 1978 to 1981; and
- farmers and villages divided among four sites in 1980 and two villages in 1981.

This paper summarizes the essential points of work done from 1979 to 1981:

- the beginning situation including physical environment, social environment, and inputs;
- objectives and description of more attractive cropping systems proposed by researchers, extension officers, and farmers;

EMAPA, Rua Henriques Léal 149 Centro, Caixa Postal 170-65000 Sao Luiz, Maranhao, Bresil.

- the definition and strategy to transfer these systems to the actual environment: and
- the results.

Interested readers may obtain more detailed information by consulting reports available at EMAPA or at IRAT.

INITIAL SITUATION

Physical environment

The basic geomorphological unit of the region is the half orange shaped hill with steep slopes, often exceeding 6%, very favorable to erosion.

The soils are ferruginous tropical clay-sand, tending to be hydromorphic at the ridge summits and sandier at the bottom of the slope; they are phosphorus deficient with reduced accessibility for machines during rainy seasons (Fig. 1).

Rainfall average (15 yr) is 1,621 mm over a 6-mo period from mid-December to early June, with the maximum in March and April. Rainfall deficits were important in 1979, 1980, and 1981. The relative humidity is above 80% during the rainy season, even during dry periods and the average temperature is about 20°C with a maximum of 33°C.

Human environment

An extreme inequality of property division characterizes Brazilian rice cultivation. Most farmers do not own their land but grow about 90% of total production on less than 10-ha farms.

In the Cocais region, farm lands are distributed into these groups:

Area (ha)	No	%	Total area (ha)	%
5	40,888	83	65,171	7.8
5-10	2,045	4	13,523	1.6
10-50	3,460	7	83,014	10.0
50-100	1,319	2.6	85,839	10.4
100-200	805	1.6	105,088	12.7
200-500	483	1.9	136,804	16.5
500-1,000	144	0.3	95,608	11.5
1,000-2,000	56	0.1	76,323	9.2
2,000	38	0.1	165,028	19.9
	49,238		826,398	

Rice cultivation in the microregion of Cocais

Cocais rice production, about 185,000 t in 1980 is 12.5% of Maranhao's total production.

- Principal physicochcmical characteristics of soils (IRAT+EMAPA)
- Essential constraints to development

Bottom of the catena	Slope	Ridge summit
↓	↓	↓
Mechanized central nucleus ½	Satellites: - Plant breeding - Entomology - Fertilization (½) - Tillage Mechanized central nucleus (½)	Manual central nucleus satellites: - Fertilization (½) - Herbicide
Slope bottom soils 10% of area (hydromorphic soils) Physicochemical characteristics Sandy texture PHE = 5.0 S = 24 meq/ 100 g S/T = 60 C (%) = 0.9 N (%) = 0.6 P (caroline) = 2 ppm Y (olsen) = 7.6 P (saunders) = 22 P (Bray no. 2) = 2.4 P total = 100 L value = 3.4 Gachon index = 0.1 Gachon fixing power = 69	Slope soils - 60% (Ferruginous Tropical leached) Physicochemical characteristics Sandy to sandy-clay texture 12 to 15% clay PHE = 5.5 S = 5-7 meq/100 g S/T = 91 C (%) = 0.8% N (%) = 0.5% P (caroline) = 5 ppm P (olsen) = 18 P (saunders) = 47 P (Bray no. 2) = 11 P total = 100 L value = 17 Cachon index = 4 Gachon fixing power = 12	Ridge summit soils 10% of area (hydromorphic lateritic soils) Physicochemical characteristics Clay-sandy texture (23-28% clay) PHE = 6.0 S = 10-13 meq/l00 g S/T = 75% C (%) = 1.35 N (%) = 0.93 P (Caroline) = 8 ppm P (olsen) = 8.8 P (saunders) = 30 P (Bray no. 2) = 2.4 P total = 160 L value = 13 Gachon index = 1.8 Gachon fixing power = 96
Constraints - Poor soils - High hydromorphy - Weeds	Constraints - Steep slopes (6-10%) - Very high level of erosion (necessity of erosion control practices) - Limited machine access in rainy season - Weeds	Constraints - High level of hydromorphy - Limited accessibility for machines during rainy Season - Weeds

1. Localization anticipated for experiments in the soil catena.

Ninety percent of this production comes from small non-owner farmers who work on family farms of less than 10 ha. Seventy percent of their production comes from associated crops. Production increased 80% between 1970 and 1980 by increasing cultivated area. The yield remained about 1,500 kg/ha.

Farmers clear the wild shrub vegetation, mainly babassu palm tree Orbignya martiano, burn the land, and cultivate for only 1 yr. The land then returns to a shrubby fallow for 5 to 10 years.

Rice is cultivated manually and planted with other crops, usually maize, sometimes a little cassava and cowpea as secondary crops for rice and maize.

Farmers do agricultural work from September to June. During clearing, they conserve a tree formation of 100-150 babassu palm trees/ha. They sow maize first in rows 4-5 m apart, then sow 7-10 rice seeds in hills spaced about 40 cm in all directions. Between the

stalks of standing maize and rice, they dibble cowpea and mulch everything with straw.

Interviews with numerous farm workers showed the following number of work days/laborer/ha for different operations:

• clearing	13.6
• fencing	18.5
• cleaning before sowing	0 to 50 (depending on sowing date in relation to first rainfall).
• rice + maize sowing	7.0
• first weeding	16.2
• second weeding	24.7
• rice + maize manual harvesting	20.0
• cowpea relay sowing	5.0
• mowing rice straw	6.0
• cowpea harvesting	4.6
• rice + maize threshing	6.0
• cowpea threshing	3.4

Farmers never till the soil or use fertilizers or herbicides. Available labor is very low and credit is accessible only to property-owners. Surrounding structures and the input supply are extremely limited.

Possibilities for improvement. Improvement objectives were to

- increase farming system productivity and define farm models for different users depending on land capital, and labor availability;
- encourage the small farmer to move from subsistence to commercial agriculture; and
- preserve the physical environment for long-term fertility.

Cropping and farming systems to test. Systems in the first stage aim to improve manual agriculture while reducing expenditures for inputs.

Researchers extension agents, and farmers wanted to improve these items;

- herbicide use, to relieve labor shortage and increase yields;
- fertilizer use, improved varieties, and ways of mixing crops to increase productivity of cropping systems and of middle- and long-term labor; and
- crop rotations, pure or mixed, to encourage farmers to continuously cultivate the same land.

Strategy for studying and disseminating new cropping systems. At the conceptual level, the strategy has three parts (Fig. 2):

- choice of the study zone. The Cocais microregion is homogeneous in natural and socioeconomic environment.

I. Identification of physical and socioeconomic environment			Traditional farming systems (= initial agro-socio-economic situation) (role of permanent control samples)
II. Creation Research Multidisciplinary participation (researchers, extension officers, farmers)			Definition of more attractive cropping systems (individual and national interests)
	at station	Comparison of systems on large plots (central nucleus. actual areas) (= agrotechical + economic evaluation)	Topical studies (on satellites) (= perfecting cropping systems. fertilization, varietal breeding)
			Definition of more attractive cropping systems (first evaluation)
			Training of extension men
	in farming environment		Study of these systems in controlled actual environment (second evaluation)
III. Extension			Farming systems Improved by diffusion of all techniques elaborated in the region

2. Process of creation-diffusion of cropping and farming systems.

- multidisciplinary participation in the creation and diffusion of farming systems. Researchers, extension agents, and farmers participate in the experimental procedure by
  1. working together to plan the research, using the knowledge, objectives, constraints, and motivations of each;
  2. carrying out the experiment in part by farmers using their traditional practices; and
  3. applying the results to the environment with researchers training extension agents.
- to reduce the difference between experiment station results and the field situation, farmers perform agricultural work in the station on full-size experimental plots (central nucleus and satellites).

Four complementary research units comprise the design to perfect proposed cropping systems.

1. A central nucleus unit concentrates on full-scale agrotechnical studies and compares the traditional and the new, more attractive systems in which rice is the pivot of the rotations. This allows the first economic evaluation.

Table 1. Cropping systems analyzed at the central nucleus.

Cropping systems	Number[a]
Control[b]: traditional system, mixed cropping rice + maize + cowpea	1
Rice monocrop: rice - rice	2
Cereal rotation: rice - maize	3
maize - rice	4
Legume-cereal rotations: rice - peanut	5
peanut - rice	6
Tuber-cereal rotation: rice - cassava	7
cassava - rice	8
Combined rotation: peanut - rice - maize - cassava	9
Mixed cropping "systematized" by research (rice + maize + cowpea + cassava)	10

[a]Actually 7 systems, with 3 represented twice in the same year: rice - maize, maize - rice. [b] Shifting in peasant environment but fixed at the central nucleus, this traditional system is also reproduced in its itinerant form in the same region, near the nucleus. This treatment will serve as reference.

At the Bacabal Experiment Station, the central nucleus compares 10 cropping systems (Table 1), each of which receives 8 levels of cropping intensity (Table 2), chosen depending on identified agronomic constraints.

The elementary plot of the nucleus is 250 m^2 and total area is 2 ha/year.

2. A backup satellite unit deals with problems revealed by the central nucleus. These satellites carry nut topical studies on each cropping system: varieties, fertilization, pesticides.
3. An actualization area unit tests the most economically interesting farming systems in larger areas (0.5 ha). The areas are used for demonstration, seed multiplication, and study of new problems that might occur but escape analysis in the nucleus-satellite design.
4. Anti-erosion belts preserve the physical environment (long-term fertility maintenance) and increase the farmer's net profit/ha while diversifying his production. Perennial crops planted on these belts include banana, passion-

Table 2. Cropping intensity levels applied to each cropping system.

Variety	Practices	Key[a]
Traditional	Zero	(0) T
	Only herbicide	(H) T
	Only fertilizer	(A) T
	Herbicide + fertilizer	(A + H) T
Improved	Zero	(0) M
	Only herbicide	(H) M
	Only fertilizer	(A) M
	Herbicide + fertilizer	(A + H) M

[a] T = traditional, M = modern, H = herbicide, A = fertilizer.

flower, sugarcane, pepper plant, pineapple, and citrus.

As soon as researchers judge certain techniques or technical packages as more motivating than the traditional system, they apply them to actual farms.

- First, researchers perform a few tests on farmers' fields to evaluate the technique and its degree of acceptability by farmers.
- In the second phase, if the response is positive, extension agents promote the systems accepted by the farmers. This pre-extension phase is carried out on several farms in a restricted number of villages, chosen as representative sites of the region. It also serves for training extension agents who will later use these technological packages.

Analysis of results

Researchers evaluate and interpret the results of agroeconomic studies at the central nucleus level to identify the most attractive practices for the farmers, considering these factors:

- labor utilization;
- increase of the gross added value/ha, or gross product productive consumptions (called black balance in several of the tables that follow); and
- increase of the workday return.

After evaluation, we combine these technical packages to simulate technical models before proposing them to the farmer. We evaluate the designs

- on the nucleus, satellite, and area of actualization levels with multivaried analysis of agronomic results and economic data,
- on the satellite level with statistical analysis to study efficiency of inputs and their combinations that bring the most stable return through crops, cultivars, rotations, fertilizers, and pesticides;
- on the level of applications in the actual environment by manual treatment, and data processing (automated budget).

EXPERIMENT STATION RESULTS

Research activities on satellites

Breeding for cropping systems.

- Rice. Researchers and producers hoped for a plant of average height (1.20 m), heavy and not very numerous panicles to facilitate harvesting, high productivity, resistant to rice blast and torrential rains, and with glabrous leaves and grains.

Researchers selected six varieties from 1979 to 1981 and three from 1979 to 1980 (IRAT20, IRAT79, and IRAT101) as best meeting these criteria although the latter two are pilose.

In 1981 scientists chose three new glabrous varieties: IREM190, IRAT112, and IREM194 with the latter two having excellent grain quality.

These varieties greatly outyield local cultivars as much in the first year after clearing as in the various rotations, close to 5 t/ha at best. This advantage is even greater in a particularly dry year such as 1981 (Table 3).

- Maize. Researchers chose several cultivars whose composites (BR5026, BR105, and CMS28) showed they were at least as productive as the local variety Central Mex. In 1980, on a plot previously planted to rice, maize yielded 1.9 t/ha without fertilizer and 5.6 t/ha with fertilizer. In 1981, with less than 400 mm of useful rainfall, the composite CMS28 exceeded 5.5 t/ha with fertilizer.
- Cassava. Scientists selected three local varieties: Carga de Burro, Rebenta Burro, and Naja Boi. The average yields obtained for an 11-mo cropping cycle were 25 t/ha without fertilizer and 30 t/ha with fertilizer.

Fertilization of cropping systems. For mineral fertilization for cropping systems, researchers base experiments on NPK perennial factorial trials and complementary response curve trials. When crops did not respond to an element, it was returned to the soil by burning the straw.

- Rice. All along the toposequence either on new clearings or in rotation, rice grown alone responds significantly to NP treatment.

Considering agronomic interpretation, the following formulas are recommended:

  - 60 kg N + 40 kg P_2O_5/ha after maize, rice, or cassava
  - 20 kg N/ha + 40 kg P_2O_5/ha legume

Peanut is the best crop to precede rice. After other preceding crops, rice yields drop especially in the second year without fertilizer S.

- Other crops. Maize is very sensitive to fertilization and responds significantly to NP on cleared land as well as in rotation with rice. The recommendation is 80 kg N + 80 kg P_2O_5/ha.

On cleared land and rotated with rice, cassava responds only slightly to fertilization.

Table 3. Rice yields in various rotations in pure cropping, on satellites from 1979 to 1981 (arithmetical averages).

Variety	Fertilizer	Rice yield (t/ha)								
		After clearing[a] 1979	After rice		After maize		After peanut[b]		After cassava	
			1980	1981[c]	1980	1981[c]	1980	1981[c]	1980	1981[c]
IRAT10	With	1.9	2.8	2.2	2.1	1.5	2.4	1.7	2.0	2.6
	Without	4.0	4.9	3.3	4.2	2.4	4.5	2.6	4.9	4.3
IRAT79	With	1.9	2.6	1.6	2.0	0.7	2.6	1.6	1.8	2.6
	Without	3.5	4.4	2.8	4.2	1.5	4.4	2.3	4.5	3.8
IRAT101	With	2.1	2.6	d	2.5	d	2.8	d	1.8	d
	Without	3.7	5.2		4.5		4.6		4.8	
IREM16B	With	d	d	1.9	d	1.7	d	2.1	d	2.6
(IRAT190)	Without			3.9		3.1		3.2		4.7
IREM247	With	d	d	1.9	d	1.6	d	2.1	d	2.4
(IRAT195)	Without			3.8		2.7		3.1		4.0
IRAT112	With	d	d	2.0	d	1.8	d	2.0	d	2.3
	Without			3.6		2.9		3.5		4.1
Cana Roxa	With	2.0	2.5	0.4	2.3	0	2.6	0.9	1.9	1.8
(local check)	Without	2.8	3.9	0.8	4.0	0.5	4.0	1.0	3.8	1.5
Useful rainfall (mm)		750	860	440	860	407	860	377	860	555

[a]Av of different rotations with rice in the first year. [b]Av of rotations peanut-rice and combined. [c]Severe drought in 1981. [d]Variety was not tested.

Cowpea cropping, in the second and third years after rice without fertilization, maintains the same yield as rice and maize.

Chemical weed control. Local weeds are

1. Cyperaceae, such as Fimbristylis annua, and Cyperus luzulae;
2. graminaceous plants of which the most harmful are Panicum fasciculatum, Paspalum conjugatum, Digitaria sanguinalis, Eleusine indica, and Echinochloa colona;
3. dicotyledons, the most competitive among which are Melampodium divaricatum, siaea linifolia, and various Sida (acuta, rhombifolia).

- Rice and mixed crops. The herbicide oxadiazon, applied preemergence at 1 kg ai/ha in crop rotation, is very effective during 30 d and shows no toxicity. Nevertheless, its current price is prohibitive and the product bifenox can replace it at a dose of 12 liters of the commercial product per hectare. Bifenox is also two times less expensive (1981).
- Maize. The mixture atrazine + simazine at 2 kg ai/ha and cyazine at 15 kg ai/ha gives very good results. It is recommended in severe cases of weed invasion in maize.
- Peanuts. This crop is more competitive against weeds and a herbicide is unnecessary. If needed, oxadiazon at 0.7 kg ai/ha can be applied before the shooting stage.
- Cassava. Cassava yields in rotation with rice depend on the amount of weed invasion during the first month of cultivation. For 2 mo of effectiveness, we recommend 2.5 kg/ha of fluometuron or 1.5 kg ai/ha of Diuron before the shooting stage.

Agroeconomic studies on the central nucleus

We identified the most attractive cropping systems and proposed production systems using several calculation methods. To compare revenues from one crop to another and especially from one farming year to the next, one must calculate with a stable monetary unit.

Assuming this, input costs (seeds, herbicides, fertilizer) have gone up between 1977 and 1980, a 95% increase for certain herbicides and 126% average for tertilizer. In 1981, the trend reversed with herbicides and seeds costing an average 20% less than in 1980. The fertilizer + herbicides + seed treatment was less expensive.

In the same period, between 1979 and 1980, prices paid to producers went down by about 30% for rice and maize, stayed about the same for cowpea, and tripled for cassava after the creation of a new market in the region. In 1981 farmers received 46% more for rice

than in 1980, 66% more for maize, and 120% more for cowpea, but 16% less for cassava.

Most attractive cropping system proposals. Table 4 provides the agroeconornic data for a cropping system proposal that was most attractive compared to traditional systems.

The results led to these conclusions:

- In the third cropping year, weeding becomes the first factor that limits continuous cultivation. Fertilization and herbicide use are indispensable to maintain lucrative yields. Proposals without herbicides are eliminated because they are much more constraining than the shifting cropping system.
- Systematized mixed cropping (rice + maize + cowpea + cassava) is the most stable with time, based on net balance/ha and workday return using fertilizer, herbicides, and improved cultivars. By using the mixed cropping system, net balance per hectare and workday return improved about 200% compared with shifting cultivation control. This system also corresponds to the small farmer's food needs.
- Rice - cassava - rice and cassava - rice - cassava rotations were the most attractive after mixed crops with or without fertilizer. Because of a great demand for cassava in 1980 and 1981, producers received triple the usual price.
- Besides spectacular improvements in net balance/, ha and in workday return, the mixed cropping system eases the cropping calendar compared to the shifting control and gives farmess greater working capacity. In this respect, certain systems using herbicide alone, even though inferior to the control in net balance, are very attractive in workday return.

Farming systems for small farmers. Starting with the most attractive cropping systems, the researchers sought the best combinations in the annual rotation.

Manual treatment of data and automatized budgeting were used.

The most appropriate models for farmers must

- be compatible with labor availability (about 1.5 workers) for the cropping calendar;
- minimally upset the farmer's technical habits and preserve family consumption. Thus, there will always be some dependence on mixed cropping;
- allow for the fact that the farmer usually does not own the land. Therefore, models without or with little input would be best for the shifting farmer; and
- promote the most lucrative crops: cassava and associated crops.

Table 4. Cropping system proposals for farmer use after 3 yr of testing (1979-81).[a]

Attractive alternative[b]	Yield (t/ha)			Operational costs gross monetary product			Workday valorization (Cr)			Net value/ha (Cr)			Work days/man per ha			Weeding time in days/man per ha		
	1979	1980	1981	1979	1980	1981	1979	1980	1981	1979	1980	1981	1979	1980	1981	1979	1980	1981
CAT (h) m				14.5	32.3	39.3	500	492	430	52,094	38,425	25,843	104	78	60	3.0	5.2	11.0
R-	1.57	1.93	1.32															
M-	0.52	0.66	0.43															
V-	0.30	0.21	0															
CAS (h) t				13.1	27.4	27.5	644	477	584	60,305	48,120	43,834	109	101	75	13.0	10.4	0.9
R-	2.20	1.94	1.95															
M-	0.36	0.27	0.24															
V-	0.05	0.11	0															
Ma-	2.96	3.42	1.03															
CAS (h) m				9.8	27.2	23.0	698	519	760	82,478	48,870	66,572	118	94	74	9.3	1.1	7.3
R-	2.03	2.25	1.95															
M-	0.66	0.36	0.28															
V-	0.18	0.17	0															
Ma-	6.49	2.31	2.83															
R Ma R (h) t	2.22	16.23	1.63	12.8	9.7	31.4	561	1,742	619	44,306	87,138	29,123	79	60	47	0.5	5.2	6.0
R Ma R (h) m	2.41	23.95	1.54	11.7	6.6	33.3	590	1,957	532	49,023	33,084	26,627	83	68	60	7.3	5.2	8.0
Ma R Ma	26.29	1.85	26.25	18.1	37.6	5.0	566	307	1977	43,036	21,548	124,546	76	70	63	16.7	12.2	13.1
(h) t				18.2	40.6	25.8	690	507	964	97,361	72,269	91,691	141	121	96	10.4	8.5	8.4
R-	3.18	4.22	3.63															
M-	0.44	0.55	0.51															
V-	0.25	0.30	0															
Ma-	6.95	3.08	3.90															
R Ma R (a+h) t	3.32	22.10	1.92	22.6	34.7	57.4	690	1,085	359	54,717	85,762	21,281	96	79	59	8.5	8.7	12.4
R Ma R (a+h) m	3.90	24.00	2.98	21.7	32.0	37.0	654	1,427	738	70,042	97,067	48,715	107	68	66	8.4	20.8	10.1
RRR (a+h) m	3.90	6.00	2.56	21.7	39.6	42.9	654	528	527	70,042	67,096	37,977	107	127	72	8.4	6.1	3.5
Farmer's itinerant control[c]				9.0	20.0	8.4	289	221	330	36,608	27,729	43,570	123	126	132	40.9	37.8	41.4
R-	1.33	1.51	1.77															
M-	0.34	0.24	0.11															
V-	0.08	0.08	0															

[a]In 1982, US$1 = Cr 144.44. [b]CAT = traditional mixed cropping (rice + maize), CAS = systematized mixed cropping (rice + maize + cowpea + cassava), R = rice, Ma = cassava, M = maize, V = cowpea, h = herbicide, t = traditional variety, m = improved variety, a =mineral fertilizer, (a+h) = with fertilizer and herbicide. [c]This control is, is in fact, outside of the central nucleus, planted on a unit of similar environment and on which a truly itinerant cultivation is practiced.

Four farming system models adaptable to different types of farmers were simulated and compared to the traditional model (Table 5).

These new farming system improvements might be important at different levels.

One may consider work constraints and overall production.

1. Farmers could raise their working capacity from about 1 ha/worker for the control to 1.33 ha/worker using models based on rice, cassava, and associated crops with herbicides.
2. Cleaning activities before sowing, sowing, and most importantly, manual harvesting limit working capacity in these farming systems.
3. Overall production for 3 yr from crop rotation is more diversified and on the average, is 2-4 times greater than that of the control.
4. As Table 5 shows, model 4 (mixed crops alone with fertilizer, herbicide, and improved varieties) produced in 3/yr 63% more rice, 96% more maize, and 74% more cowpea than the control. It also produced 13,926 kg of cassava.

On the level of net revenues/ha and the workday returns, most of the new models enable farmers to double both the net revenue per hectare and the workday return as compared to profit from shifting cultivation. Net revenues for 3 yr are 2-5 times the minimum daily wage of the area for shifting cultivation.

The most stable models in production and profit are those which use maximum mixed cropping (model 4).

Farmers will choose models depending on credit and labor availability and whether or not they own the land.

Models for shifting cultivation farmers are

1. Model 7 (2.0 ha): minimum input, rice + cassava alternated + mixed cropping
2. Model 1 (1.5 ha): maximum input an mixed cropping, rice and cassava

Models for owners who can easily use inputs, especially fertilizer, are

1. Model 2 (1.5 ha): maximum input, rice and mixed cropping
2. Model 4 (1.75 ha): maximum input on mixed cropping

Agroeconomic studies in actual fields

Field studies confirmed the central nucleus results.

By having farmers do the field tests, the design had negligible differences between measurements on 50 m^2 plots (central nucleus) and those on 5,000 m^2. Thus, there can be good correlation between experiment station results and those in the actual environment.

Table 5. Farm models recommended for small farmers (with 1.5 ha/farm); agoeconomic evaluation based on 1979, 1980, and 1981 data.

Rotation[b]	Input	Area (ha)	Cumulated production (t/ha)				Cumulated output (Cr/ha)	Cumulated balances (Cr/ha)	Cumulated workdays (d × man × ha)	Av weekday return (Cr/ha)
			Rice	Maize	Cassava	Cowpea				
Model 7 0.5 ha CAT (a + h) M reversed 0.5 ha CAS (0) M 1.0 ha R Ma (h)	Low	2.0	11.82	1.54	33.81	0.43	75,286	389,485	581	663
Model 1 1.0 ha R Ma (h) M 0.25 ha CAS (a + h) Mcm 0.25 ha CAS (a + h) Mcc	Low	1.5	9.47	3.75	30.91	0.27	74,557	345,748	479	914
Model 2 0.5 ha CAT (a + h) M reversed 0.5 ha RR (a + h) M 0.25 ha CAS (a + h) Mcm 0.25 ha CAS (a + h) Mcc	High	1.50	16.61	1.51	6.96	0.52	130,599	329,693	500	672
Model 4 0.75 ha CAT (a + h) M reversed 0.50 ha CAS (a + h) Mcm 0.50 ha CAS (a + h) Mcc	High	1.75	18.58	2.64	13.93	0.92	158,682	422,130	610	715
Model 8 Control (shifting cultivation)	Very low	1.50	6.93	1.11	–	0.23	22,575	160,360	520	280

[a]Cr144.44 = US$1 in 1982. [b]Mcm = modern medium-duration variety (IRAT101), Mcc = modern short-duration variety (IRAT10). For the other acronyms, see footnote [b] of Table 4.

For farmers in continuous cultivation, 3 consecutive cropping yr are feasible if they use herbicides, fertilizer, and improved varieties.

Mixed cropping, reversing the succession of crops the same year on the same plot (cowpea - rice + maize), showed a new possibility for using labor and for buffering climatic variations.

Agroeconomic studies on erosion control belts

Erosion control belts use perennial plants and crop diversification, and bring supplementary income. Tested crops included banana, sugarcane, passionflower, and pineapple.

On a 2-ha farm, time devoted to erosion control belts amounts to about 60 d in 3 yr. The net revenue from the sale of products during the same period amounted to about $443.10 (64,000 Cr), an average workday return of $6.92 (1,000 Cr).

ACTUAL ENVIRONMENT RESULTS (1981)

The cropping systems tests were concentrated in 2 villages, one in the north (Brejinho) with 18 farmer cooperators, the other in the south (Firmino) with 11 farmer cooperators.

This sample allowed integration of the agroeconomic and social variability in Cocais. Each farmer cultivated 1.5 ha: in that area, he used 2,500 m^2 for each cropping system described in Table 6.

Yields

Very scant rainfall in February, April and May influenced production. Cropping cycles received about 500 mm in Brejinho and 440 mm in Firmino.

This weather eliminated the cassava and cowpea crops in Firmino. In Brejinho, the cowpea crop as a catch crop after rice was possible only after short- and medium-cycle varieties IRAT10 and IRAT101.

Rice. The effect of drought depended on the sowing and maturing dates of varieties; however, IRAT10 and IRAT101 generally were more tolerant than traditional varieties (Table 7).

Rice in mixed cropping and in pure culture averaged 1.7 t/ha in both villages with the traditional cultivar and practices. Average rice yields in Maranhao are 1.5 t/ha.

At the regional level, mixed cropping without fertilizer shows IRAT10 is equal to the traditional cultivar and IRAT101 is clearly superior with a 49% yield increase. With fertilizer, the trend is similar, with a yield increase of +28% for IRAT101.

Table 6. Cropping systems tested by 29 farmers in their fields in 1981.

	Culture		Rice varieties			Herbicide and fertilizer [c]		
No.	Systematized mixed cropping [a]	Rice as sole crop	Traditional [b]	IRAT10	IRAT101	Without	Herbicide alone	Herbicide with fertilizer
1 a	+		+			+	+	
b	+		+					+
2 a	+			+				
b	+			+				+
3 a	+				+		+	
b				+			+	
4 a		+	+					+
b		+	+				+	
5 a		+		+				+
b		+		+				+
6 a		+			+		+	
b		+			+			+

[a] Rice + maize + cassava + cowpea in succession. [b] Cana Roxa at Brejinho, Branco at Firmino. [c] Herbicide: oxadiazon at 1 kg ai/ha. Fertilizer: 60-35-60 kg NPK/ha.

Table 7. Average yields of rice in cropping systems tested in the actual environment in 1981.[a]

Site[b]	Average yield (t/ha)											
	Mixed cropping						Rice as sole crop					
	Traditional variety		IRAT10		IRAT101		Traditional variety		IRAT10		IRAT101	
	No A or H	A+H	H	A+H	H	A+H	No A or H	A+H	H	A+H	H	A+H
Brejinho (18)												
Land preparation with animals (9)	1.40	2.24	2.14	3.23	2.78	4.00	0.91	1.40	2.45	3.36	2.92	5.52
No tillage (9)	2.25	2.96	2.02	3.01	2.47	3.46	2.40	2.72	3.10	4.50	2.72	3.72
Firmino												
No tillage (11)	1.49	2.50	1.41	2.15	2.50	2.90	1.53	2.06	1.54	2.33	2.76	3.17
Brejinho and Firmino (29)	1.70	2.56	1.83	2.74	2.60	3.34	1.71	2.17	2.26	2.74	2.81	4.00
Regional index	100	152	106	150	149	195	99	127	132	160	164	232

[a]A = fertilizer, H = herbicide. [b]Figures in parentheses indicate number of farmers.

Yields from IRAT101 under severe drought are remarkable:

-- without fertilizer in mixed cropping 2.6 t/ha
-- with fertilizer in mixed cropping 3.3 t/ha
-- without fertilizer in pure cropping 2.8 t/ha
-- with fertilizer in pure cropping 4.0 t/ha

In certain favorable soils (Vertisols in lowland, and highly manured soils), IRAT101 exceeded 7 t/ha.

IRAT10 is more acceptable to small farmers than IRAT101 because of the high pilosity of the latter variety.

Maize. Results for average regional maize yields were

- a 36% increase with fertilizer and mixed cropping with a traditional rice variety
- a 38% increase with fertilizer and intercropped with either IRAT10 or IRAT101.

The maize area in the traditional cropping system is double that in the mixed cropping system (IRAT10 and IRAT101), in which cassava replaced maize in half of the area.

This explains the advantage of maize planted with the traditional cultivar (Table 8).

Cowpea. Because of the early drought, we did not sow cowpea at Firmino nor Brejinho after the traditional rice cultivar which had an intermediate cycle (130 d).

Short-cycle (90 d) IRAT10 allows the best cowpea yield in each cropping by freeing the land early when there is still a good water supply (Table 8).

Table 8. Average yields of maize, cowpea, and cassava in mixed cropping systerms tested in the actual environment in 1981.

Crop[a]	Average yield (t/ha) of crops mixed with					
	Traditional variety		IRAT10		IRAT101	
	No A or H	A+H	H	A+H	H	A+B
			Brejinho			
Maize	0.20	0.40	0.15	0.25	0.18	0.31
Cowpea	–	–	0.46	0.62	0.27	0.35
Cassava	–	–	2.88	3.34	2.09	2.29
			Firmino			
Maize	0.37	0.50	0.31	0.50	0.30	0.45
			Brejinho and Firmino			
Maize	0.29	0.45	0.22	0.36	0.23	0.38
Cowpea	–	–	0.46	0.62	0.27	0.35
Cassava	–	–	2.88	3.34	2.09	2.29

[a] Maize was Central Mex cultivar (av of 13 farmers at Brejinho and 11 at Firmino). Cowpea cultivar was Pitiuba (13 farmers at Brejinho). Cowpea could not be sown at either site after the traditional rice variety. Cassava cultivar was Najazinha, planted only with improved cultivars IRAT10 and IRAT101, and eliminated at Firmino (10 farmers at Brejinho).

Cassava. After a severe drought, cassava was eliminated at Firmino. At Brejinho, in mixed cropping, cassava yielded highest with short-cycle IRAT10 because competition for water and mineral elements was lowest. The traditional system for mixed cropping does not include cassava.

Economic data

Balances/ha and workday return. Mixed cropping is clearly more lucrative and utilizes the workday better than pure cropping systems (Table 9).

In pure cropping, IRAT10 and IRAT101 are superior to the local variety in both net balance per hectare and workday return.

In pure cropping with and without fertilizer, IRAT101 is the best.

In mixed cropping systems in a dry year, IRAT10 gives the best balance values and workday returns.

Use of fertilizer in a dry year for mixed and pure crops with IRAT10 and IRAT101 is economical. But fertilizer is not economical for pure or mixed cropping systems with the local cultivar.

Working times. Mixed cropping systems always have more constraints than pure ones. The mixed cropping system with IRAT10 needs more working days but is more productive on an overall basis (rice + maize + cassava).

Most of the proposals involve working days equivalent to those of the control despite a much larger production from herbicide use.

Harvest time is still the most difficult period for all cropping systems using fertilizer and herbicides to guarantee high production. We can reduce this constraint by using varieties with different cycles to stretch out harvesting as in the farming models at the station (Table 5).

COMPARISON OF AVERAGE AGROECONOMIC RESULTS AT ACTUAL SITES AND EXPERIMENT STATIONS

Comparison of the common practices at the actual sites and during the third year of rotation in the experiment station shows good increases in rice yields (IRAT10), net balance per hectare, and workday return. The exception was the balance and workday return for mixed cropping in model 4 (Table 5). They were more favorable at the actual environment because of their cowpea production which was eliminated in the station by drought. The workday return for the mixed cropping control was more favorable at the actual site because of a lightened cropping calendar, not counting the time for fence building (Table 10).

Table 9. Average economic data (balance/ha, workday return, number of workdays in constant Cr) in cropping systems tested in the actual environment in 1981.[a]

	Av economic data (Cr)											
	Mixed cropping						Pure cropping					
	Traditional variety		IRAT10		IRAT101		Traditional variety		IRAT10		IRAT101	
	No A or H	A+H	H	A+H	H	A+H	H	A+H	H	A+H	H	A+H
Brejinho (18 farmers)												
Balance	51,981	48,742	101,114	126,032	86,816	105,229	34,217	29,889	55,019	77,306	59,088	76,106
VJT	713	703	1,160	1,198	1,015	1,000	580	476	829	934	983	1,038
NJT	73	69	87	105	85	105	59	62	66	82	60	73
Firmino (11 farmers)												
Balance	44,451	46,705	29,895	37,445	57,254	55,024	26,404	25,039	26,603	32,049	58,560	53,749
VJT	517	599	495	535	82	659	443	403	448	433	757	583
NJT	86	78	60	70	78	83	59	62	59	74	77	92
Brejinho + Firmino												
Balance	48,668	47,927	73,246	92,812	73,809	83,988	31,021	27,888	43,179	59,203	58,868	66,648
VJT	626	662	900	1,019	891	856	524	445	670	734	889	845
NJT	77	72	81	91	83	98	59	62	64	80	66	79
Regional indices, Brejinho + Firmino												
Balance	100	98	150	190	151	172	63	57	88	121	120	136
VJT	100	105	143	162	142	136	83	71	107	117	142	134
NJT	100	93	105	135	107	127	76	80	83	103	85	102

[a] In 1982, Cr 144.44 = US$1. A = fertilizer, H = herbicide, VJT = workday return, NJT = no. of workdays (man × days × ha).

Table 10. Comparison of average agroeconomic results obtained in actual environment.

Proposals common at actual environ-ment-station[a]	Site	Yield (t/ha) of associated crops				Balance/ha[b] (Cr)	Workday balance	No. of workdays
		Rice	Maize	Cowpea	Cassava			
CAT (0) (shifting control)	Station	1.77	0.11	0	0	43,570	330	132
	Actual environment	1.71	0.29	0	0	48,668	626	17
CAS (h)[c]	Station	1.85	0.28	0	2.88	55,572	750	74
	Actual environment	1.81	0.31	0.46	2.88	73,246	900	81
CAS (a+h)[c]	Station	3.63	0.51	0	3.99	91,591	954	96
	Actual environment	2.74	0.36	0.62	3.34	92,812	1,019	91

[a]For expianation of symbols, see footnote[b] of Table 4. [b]In 1982 Cr 144.44 = US$1. [c]Rice variety was IRAT10.

CONCLUSIONS

This integrated research leads to the following conclusions:

- It is possible to develop farmer production systems that are attractive and simple and preserve local food habits and traditional cropping systems.
- Farmers can produce steady yields on the same field for at least 3 yr by using crop rotation and efficient soil erosion control.
- It is possible to define terms for annual rural credit for small farmers and improve regional agricultural structure for production by:
  1. farm structures for regional agrarian reform,
  2. providing inputs (seeds, fertilizer, herbicides),
  3. marketing.
- By using a methodological integrated experimental procedure, one can:
  1. perfect potential farming systems and rapidly transfer them to the actual environment with the active participation of the farmers using their techniques and power of decision at the experiment station; and
  2. do advance training of extension agents on how to apply suggested improvements.

UPLAND RICE PRODUCTION SYSTEMS FOR SMALL FARMERS IN NORTHEASTERN BRAZIL

L. SEGUY and EMAPA RESEARCH OFFICERS

TRADITIONAL UPLAND RICE CROPPING SYSTEMS IN NORTH AND NORTHEASTERN BRAZIL

Farmers in Brazil grow upland rice on about 5.5 million ha, 4.4 million of which are rainfed. For decades, the north and northeastern regions have used different cropping systems depending on farm size.

Farmers with large farms generally sow upland rice as a cash crop on newly cleared and burned forest land. After harvest, they plant the land to perennial forage grasses for pasture.

Rice farmers who do not own the land use a different rice cropping system. After forest clearing and burning, they intercrop rice with maize followed by cowpea the same year. After harvesting the second crop, the land is fallow for 7-10 years to permit natural forest regrowth. During the fallow, farmers move to another area where they repeat the process. Because of increasing population in the last decade, land available for this shifting cultivation has decreased drastically.

In Maranhao, farmers produce 90% of rice on farms of less than 10 ha. Crop production systems for permanent land utilization had to be developed. From 1978 to 1981 a research project was carried out to:

- increase cropping system productivity through hand cultivation using existing land, capital, and labor;
- begin a trend from shifting and subsistence cultivation to fixed and cash crop cultivation; and
- safeguard the environment for long-term productivity.

The main stages of the work were:

- a survey of the physical environment, production factors, and constraints from technical and socioeconomic points of view;
- identification of steps for developing more attractive cropping systems with participation of research officers, extension agents, and farmers; and

EMAPA, Rua Henriques Léal 149 Centro, Caixa Postal 170-65000 Sao Luiz, Maranhao, Bresil.

- development of a strategy to transfer those systems into the actual agro-socioeconomic environment.

INITIAL SITUATION

In Maranhao, the tropical ferrous soils erode after tillage and lack phosphorus. Average rainfall is 1,621 mm, distributed over 6 mo. Traditional hand cropping systems, based on associated crops, last from September to June.

Farmers grow about 100-150 Babacus palm trees Orbygnia martiano per hectare of cultivated land and farming operations take 125 labor days/ha.

After discussion with research officers, extension people, and farmers, researchers decided to test technical improvements in varieties, herbicides, fertilizers, crop associations, and pure or associated crop rotations.

METHODOLOGY AND STRATEGY

In research at the experiment station, local farmers did the field work using their own tools and traditional cultural practices.

RESULTS

After 4 years of experiment station research (1978-81) and 2 years (1980-81) of farm application, we propose these more attractive cropping systems that allow at least 3 years of stable agriculture. New associative cropping systems (i.e. , rice + maize + cassava followed by cowpea) rotated every year give more stable financial and labor profits with use of new varieties, herbicides, and fertilizers.

Compared to traditional shifting cultivation, the new systems double output, net profit per hectare, and labor income per day. They are also better adjusted to the small farmer's food requirements.

Rotations such as rice - cassava - rice and cassava - rice - cassava, with and without fertilizers, are the most attractive.

Several models have simulated different input levels, credit, and labor availability (Table 1). Compared to the traditional system, possible improvements are:

- Traditional farming has about 1 ha/worker, increasing to 1.33 when using herbicides. When fertilizer and herbicide use increases production, necessary harvest time exceeds the capabilities of hand harvesting (an example of feedback). Farmers can solve this by planting three varieties of different maturity dates.

Table 1. Agroeconomical comparison of traditional and improved cropping systems on a 3-year basis.

Improved models	Cumulated production (t/ha)				Production costs ($)	Return ($)	Labor-days	Mean return per day ($)
	Rice	Maize	Cowpea	Cassava				
Low inputs model (2 ha) - 0.5 ha with herbicide and fertilizer - 0.5 ha without input - 1.0 ha with herbicide	11.8	1.5	0.42	33.8	502	2596	581	4.5
High inputs model (1.75 ha) - 1.75 ha associative cultures with herbicides and fertilizers and new varieties	18.5	2.6	0.91	13.9	1057	2814	610	4.7
Traditional cropping system (1.5 ha)	6.9	1.1	0.23	NIL	150	1069	520	1.8

- With fertilizers and herbicides, the new cropping system produces twice as much as the traditional one.
- In all models, net profit per hectare and labor day was about twice that of shifting cultivation.
- Net cumulated income for 3 years can reach more than $2,330 for models for 1.5 to 2.0 ha compared to $1,060 for the shifting system (1.5 ha). Profit for labor varied between $4 and $6, 2 or 3 times the lowest official salary in the area.
- Anti-erosive dikes planted with perennial crops such as banana, passion fruit, pineapple, and pepper allow efficient diversity in production. They represent an important means for stabilizing the cropped area and generating additional income.

CONCLUSIONS

This work leads to some important conclusions:

- It is possible to rapidly popularize cropping systems that are attractive, simple to use, and conserve local food habits and traditional cultural practices.
- It is possible to cultivate the same land for at least 3 years with a stable yield if farmers adopt crop rotation and efficient erosion control.
- It is possible to define annual credit conditions for small farmers and to improve regional agricultural and extension structures. Those are bases for regional agrarian reform and networks for marketing, and for seed, fertilizer, and herbicide distribution.
- Methodologically, this integrated experimental approach permits researchers to develop cropping systems that are attractive and easily transferable to the actual environment. This important feature is made possible by allowing farmers to use their own techniques and decision making power at the experimental level.
- Farmer involvement permits the simultaneous early training of extension workers for ready adoption and application of the proposed improvements.

INTERNATIONAL AND REGIONAL COOPERATION

AN INTERNATIONAL NETWORK FOR RICE TESTING AND EVALUATION

D.V. SESHU

A worldwide network to test and evaluate rice varieties and breeding lines became a reality in 1975 through a grant from the United Nations Development Programme (UNDP). This network, the International Rice Testing Program (IRTP), is coordinated by the International Rice Research Institute (IRRI) at Los Baños, Philippines. The program represents more than 800 rice scientists at more than 300 rice research stations in more than 70 countries on 5 continents working to improve rice varieties. Simultaneous with the beginning of IRTP IRRI began its policy of not naming varieties. Thus, IRTP became the mechanism for testing and disseminating national and IRRI's breeding materials.

The objectives of IRTP are to

- provide rice scientists around the world access to varietal diversity;
- provide a facility to test given genotypes under a wide range of agroclimatic conditions within a single season;
- identify donor varieties for major biological, soil, and climatic stresses;
- determine genotype – environment interaction;
- identify genetic variation in major insects and diseases (biotypes, races, etc.) based on variety reactions in different locations;
- identify varieties faster for diverse situations by simultaneous scientific efforts in different countries;
- promote continued interaction and cooperation among international scientists involved in rice varietal improvement; and
- serve as an information center on the interaction of varietal characteristics within diverse rice growing environments.

ORGANIZATION

From the beginning, the program recognized the need to involve the world's rice scientists in planning and evaluation. An ad hoc committee of program leaders from

Coordinator, International Rice Testing Program, IRRI, Los Baños, Philippines.

the large Asian rice producing countries met in early 1975 to develop an overall program strategy. There continue to be opportunities for cooperators to help plan and revise the program during monitoring tours, the annual International Rice Research Conference, regional and subject matter workshops, and the advisory group meetings. During field visits and national workshop participation, IRRI scientists discuss with national program scientists ways to improve and implement the testing program. Correspondence and questionnaires provide additional opportunities for involvement from national programs.

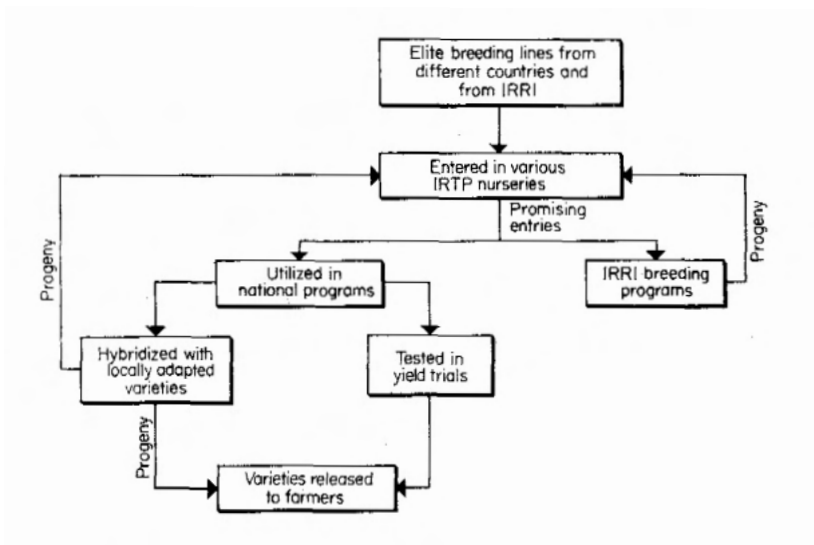
The testing program collaborates with IITA and WARDA in Africa and with CIAT in Latin America. In both areas, IRRI liaison scientists help implement the collaborative testing program and compose special regional. nurseries using appropriate materials.

Figure 1 shows the flow chart for test material and Figure 2 the nursery distribution to different regions. Scientists do more than 70% of the nursery testing in South and Southeast Asia.

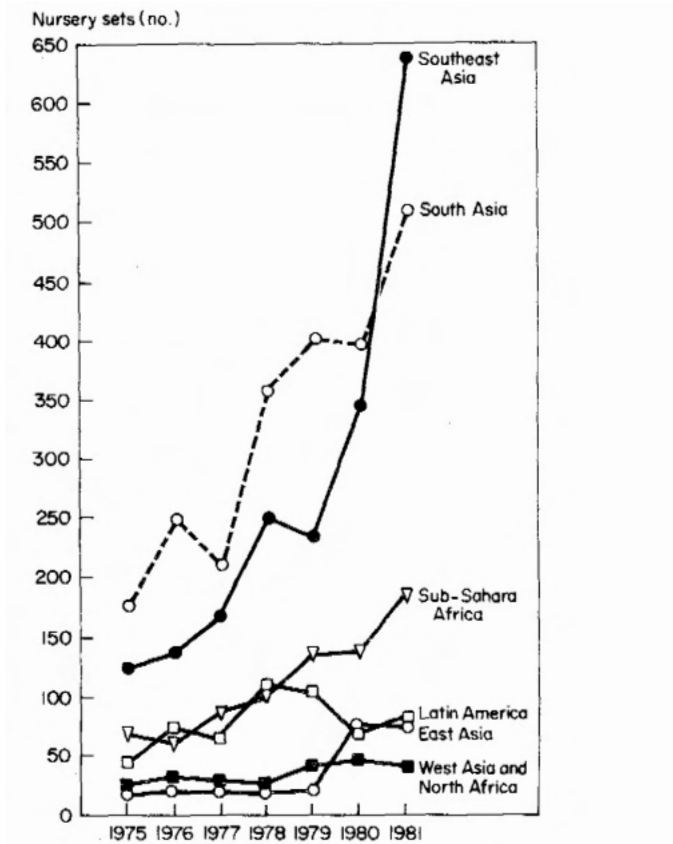
NURSERIES

Based on needs and suggestions of cooperating scientists, researchers periodically modify the types of nurseries. Broadly, there are two groups:

- for different rice cultural types, and
- for different stresses.



1. IRTP nursery testing flow chart.



2. Distribution of IRTP nurseries in various rice-growing regions of the world.

Table 1 lists different nursery types. National programs contribute about 60% of the total entries in different nurseries; 35% are from IRRI's GEU program and 5% from the germplasm bank.

Composition

Various nurseries each year include worthy repetitions from corresponding nurseries of the preceding year, entries from other nurseries where relevant, and new entries from breeding programs of different countries. Scientists decide on repetitions from previous nurseries based on:

- available data from the preceding year's tests,
- advance information from cooperators about promising entries before actual data return, and
- monitoring tour notes.

To ensure timely availability of seed in required quantities, IRRI multiplies the seeds of new entries one season in advance. Requests are made for entries

Table 1. IRTP nurseries.

		Nursery		Nursery
A. Rice culture			B. Stress	
Irrigated			Diseases	
• Tropical	Yield	- Very early (IRYN-VE) Early (IRYN-E) Medium (IRYN-M) Late (IRYN-L)	• Blast	IRBN
			• Sheath blight	IRSHBN
			• Tungro	IRTN
	Observational:	- General (IRON)	Insects	
			• Brown planthopper	IRBPHN
• Temperate	Observational:	- Arid (IRARON) Cord (IRCTN)	• Gall midge	IRGMN
			• Stem borer	IRSBN
Rainfad			Physical	
• Upland	Yield	- IURYN	• Cold	IRCTN
	Observational:	- IURON	Chemical (Soil)	
• Lowland			• Salinity	
- shallow	Yield	- IRLRYN	• Alkalinity	
	Observational:	- IRLRON	• Acid sulfate	
- medium	Observational:	- Medium deep set Tidal swamp set	• Peat soils	
			• Iron toxicity	
			• Acid upland	
• Deep water	Observational:	- Deepwater and floating rice set		

nominated by individual breeders and for promising ones observed in monitoring tours.

Entries originating from national programs increased from 30% to more than 60%. The number of cooperating scientists and countries also increased significantly.

Data collection, processing, and reporting

Because IRTP nurseries are of different types and objectives, data are specific to each nursery. Cooperators record relevant data in fieldbooks enclosed in the seedbox.

The fieldbooks have three sections:

- general instructions about the nursery,
- general information pertaining to the trial and test site, and
- experimental data recording sheets.

The computer generates the data sheets and prints an appropriate list of entries and column headings for notes relevant to the nursery. Sections 2 and 3 have three copies each: for the experimenter, the national rice coordinator, and IRTP headquarters.

Rice researchers in national programs cooperated to develop a standard reporting system that became a booklet, Standard Evaluation System for Rice (SES). In this system, a numerical 0-9 scale expresses several agronomic traits and reactions to various stresses. The SES provides a common language for scientists and greatly facilitates data computerization. Researchers revise the booklet periodically depending on experiences of scientists participating in the testing program.

The IRTP data system involves several steps:

- data collection and return by cooperating scientists;
- data editing by IRTP scientists at IRRI;
- computer validation of data on various traits;
- clarifications from reporting scientists and addition of corrections;
- computer data analysis and printout of results;
- report preparation; and
- data retrieval.

Because rice grows in diverse geographical and ecological conditions, planting seasons differ and data return from nurseries throughout a 12- to 14-month period. Because of this, each nursery must prepare a preliminary and a final report. Researchers write preliminary reports, including data from wet season plantings in Asia, for discussion at the annual International Rice Research Conference in April.

Final detailed reports of individual nurseries come 6 mo after publication of preliminary reports. Each nursery also publishes a separate annual report on

highlights of results. The preliminary, final, and highlight reports receive wide distribution to help national program scientists use the information to plan their local research projects.

The 60% data return is satisfactory. Although the nursery reports are adequately informative, it is often necessary to retrieve specific data about certain regions or situations. With all data from IRTP nurseries being computerized and stored, we expect an increased use of the data retrieval system. Table 2 lists promising entries from various IRTP nurseries (1975–81).

Data utilization

With the international rice testing network, more useful information is becoming available from tests around the world. Multilocation analysis is providing research leads for appropriate follow-up in varietal improvement programs. Individual trials identify varieties for higher local yields and stress tolerance.

A questionnaire included in the fieldbooks systematically monitors national scientists' use of the best performing nursery entries for hybridization or further testing in local, state, or national yield trials. Several countries released varieties for farmer use (Table 3). At IRRI, researchers continuously use promising entries from IRTP nurseries in hybridization programs.

Excellent examples of research leads are the existence and patterns of biotype variation and strains of major rice insects and pathogens. Other useful information includes specific environmental interactions with varietal types or growth stages.

Upland rice nurseries

Among nurseries organized by the IRTP and coordinated by IRRI are two designed to test and evaluate rice varieties in upland conditions. The International Upland Rice Yield Nursery (IURYN) began in 1974 and the International Upland Rice Observational Nursery (IURON) in 1975. Entries include improved and traditional varieties with different plant stature and growth duration. Forty-five locations in Asia, Africa, and Latin America have participated in the nurseries. The test sites differ widely in the amount and distribution of rainfall and in soil characteristics, Nurseries usually have been located in favorable upland areas. In Africa, IITA and WARDA collaborate with the testing program and CIAT works with the program in Latin America.

At present, the countries participating in IURYN are:

- Asia: Philippines, China, Burma, India, Thailand, Bangladesh, Vietnam, Nepal, Sri Lanka.

Table 2. Promising entries from IRTP nurseries 1975-81.

Nursery	Promising entries
Irrigated yield	
IRYN-VE (Very Early)	• IR9729-67-3, IR19746-28-2-2, BG367-7, IR19743-25-2-2
IRYN-E (Early)	• IR36, IR50, IR52, IR1561-228, IR9828-91-2, MRC603-303; IET4094, MTU3419, B541b-Pn-58 B1991b-Pn-43
IRYN-M (Medium)	• BG90-2, Biplab, Jaya, BR4, BR51-282-8, IR42, IR46, IR48, IR54, RP825-24-7, IR4422-983, IR13540-56-3, BG400-1
IRYN-L (Late)	• IET5656, RP1064-14-2-2, CR1002, CR1009, IR4625-132-1-2
Rainfed upland	• IR43, IR45, IR36, IET1444, IR3839-1, IR5931-110-1, IR9669 Sel., MRC172-9, B733c-167-3, B541b-Kn-19, UPLRi-5, BG35-2
Rainfed lowland	• IR46, IR4819-77-3-2, IR4829-89-2 IR14632-2-3, IR8192-166-2, IR13646-55-1,IR10781-75-3, IR13146-45-2, BR51-282-8, Mahsuri, CR1009, C168
Deepwater	
Deepwater	• *50-100cm:* RD19, BKN6986-108-3, BKN6986-167, BKN7022-6-4, BR118-3B-17, Chenab 64-117, CN539, ARC5955 *Above 100 cm.* FRRS43/3, Chamara, Saran Krahan, Habiganj Aman I, Beguamon 349, Madhukar, SPR7233-1-24, SPR7292-151-2
Diseases	
IRBN (blast)	• Tetep, Tadukan, Carreon, Ta-poo-cho-z, IR3259-5-160-3, IR5533-PP854-1, IR1416-128-5-8, IR1905-PP11-294-61, IR4547-2-1-2, IR9660-00948-1
IRSHBN (sheath blight)	• Suduwee, Remadja, H4, BR2-29-2-1-3, RD967-11 (IET4699), IR4422-98-3-6
IRTN (tungro virus)	• ARC11554, ARC10342, ARC13804, Pankhari 203, Gam Pai 30-12-15, Habiganj DW8, Utri Merah, Utri Rajapan, BKNBR1031-7-54, IR8608-298-3-1
Insects	
IRBPHN (brown planthopper)	• PTB33, Suduru Samba, Sinna Sivappu, Kuruhondarawala, IR13427-45-2, IR17496-2-25-1
IRGMN (gall midge)	• W1263, RPW6-17, BKNBR1008-21, BG404-1, OB677
IRSBN (stemborer)	• IR1820-52-2, IR4227-28-3-2, CNT72464-2-1, RP6-1699-25-4, TKM6, W1263
Chemical strews	
IRSATON	• *Salinity:* Pokkali, Nona Bokra, DA29, IR2053-436-1-2, IR36, Damodar, Patnai 23, Getu, CSR1, CSR2, CSR3, IR1529-430-3, IR4515-4-1-15 *Alkalinity:* Getu, CSR1, CSR2, CSR3, IR2053-436-1-2, IR4-11, IR1820-210-2, IR11418-19-2-3
Physical stress	
IRCTN (cold)	• China 1039, Eiko, IR1846-284-1-1, IR3941-45, IR3941-25-1, K84, IR4997-P1p6-9B (HPU2151), RP Kn-2, Stg 6511071, K28-13-Bk-1-3-1-1, K31-163-3, JC99, K39-96 -1-1-2, Shin-ei, Fuzi 102, Jodo, Stejaree 45, Tatsumi mochi, Leng Kwang
Drought	• Aus 8, Aus 61, Dular, IR442-2-58, IR5, IR3880-29, Ctg 1516, Salum-pikit, DJ29, IAC25, BG35-2, Surjamukhi, IR7777-7-1, IR2035-349-2, MI-48, ARC11775, ARC10372, IRAT10, IRAT110

Table 3. IRTP entries named in different countries.

Region, country	Designation	Origin	Name given
Southeast Asia			
Burma	BG90-2	Sri Lanka	Sintheni
	BKN6986-108-3	Thai/IRRI	Yenet-1
	BKN6986-167	Thai/IRRI	Yenet-2
	BR51-91-6	Bangladesh	Sintheingi
	C22	Philippines	Yar-1
	IR34	IRRI	Sinshwethne
	IR751-592	IRRI	Shwe-Thwe-Lay
	KN96	Indonesia	Yar-2
Indonesia	IR26	IRRI	IR26
	IR28	IRRI	IR28
	IR30	IRRI	IR30
	IR32	IRRI	IR32
	IR34	IRRI	IR34
	IR36	IRRI	IR36
	IR38	IRRI	IR38
	IR2307-747	IRRI	Semeru
Philippines	Kn-1b–361-1-8-6-10	Indonesia	RP Kn-2
Vietnam	IR2071-625-1	IRRI	NH 3A
	Jaya	India	
	Pelita I-1	Indonesia	
	Biplab	Bangladesh	
	IR2307-247-2-2-3	IRRI	Nong nghiep 6A
	IR2823-309-5-6	IRRI	Nong nghiep 28
	IR2707-115-3	IRRI	Nong nghiep 38
South Asia			
Bangladesh	IR2061-214-3-8-2	IRRI	BR6
	IR2053-57-3-1	IRRI	BR7
India	BR51-46-C1[a]	Bangladesh	–
	IR30[a]	IRRI	IR30
	IR34[a]	IRRI	IR34
	IR36	IRRI	IR36
	Intan[a]	Philippines	Intan
Nepal	BG90-2	Sri Lanka	Janaki
	IET2935	India	Durga
	IR2061-628-1-6-4-3	IRRI	Lagami
	IR2071-134-6-4	IRRI	Sabitri
Latin America			
Belize	Cica 8	CIAT/ICA	Cica 8
Bolivia	IR1529–430-3	IRRI	Saavedra V5
Cuba	IR1529–430-3	IRRI	IR1529
Guatemala	Cica 8	CIAT/ICA	ICTA Virginia
Honduras	Cica 8	CIAT/ICA	Cica 8
Panama	Cica 8	CIAT/ICA	Cica 8
Paraguay	Cica 8	CIAT/ICA	Adelaide 1
Africa			
Ivory Coast	Jaya	India	–
	IR2058-78-1-3-2-3	IRRI	–
Mali	IET2855	India	–
	IR269-26-3-3-3	IRRI	–
	IR1529-680-3	IRRI	
	Jaya	India	
Niger	IR1529-680-3	IRRI	
Senegal	Jaya	India	
Sierra Leone	Cica 4//IR665/Tetep	CIAT	ROK 11
	Cica 4//IR665/Tetep	CIAT	ROK 12
Sudan	IR2053-206-1-3-6	IRRI	–
Upper Volta	IR1529-680-3	IRRI	–
	Vijaya	India	–

[a]Named in certain states.

- Africa: Ivory Coast, Nigeria, Cameroon, Tanzania, Sudan, Liberia.
- Latin America: Panama, Costa Rica, Brazil, Mexico.

RICE IMPROVEMENT MONITORING PROGRAM

Monitoring programs have been a key component of the IRTP. The tours involve scientists from various countries traveling together to look at IRTP nurseries and other research activities. These tours have helped improve the quality of the IRTP trials and given incentive to cooperating scientists by involving them in regional and international programs. The monitoring tours are combined with regional workshops, and IRTP publishes and distributes reports of both to relevant scientists and administrators.

FUTURE PLANS

In the future, IRTP plans to:

- continue to organize appropriate target-environment and stress nurseries shown by the needs and recommendations of cooperating countries,
- organize regional nurseries,
- study rice-weather relationships,
- increase follow-up of IRTP results in breeding strategies,
- effectively use hot spots for different stresses in screening observational nurseries,
- continue monitoring pathotype-biotype variation in relation to major diseases and insects,
- increase communication, publication, and diversification of reports to meet the needs of different regions and rice cultures, and
- continue promoting interaction among rice scientists through monitoring tours, working group meetings, and workshops.

APPENDIX

WORKSHOP RECOMMENDATIONS

On 4-8 October 1982 the sponsors IDESSA, IRAT, IRRI, and the cosponsors ADRAO (WARDA), IITA, CIAT, of the International Upland Rice Workshop held at Bouaké, and participants invited from many countries examined different effects Of upland rice research conducted in Africa, Latin America, and Asia.

Objectives of the meeting were to

1. assess existing knowledge of upland rice and progress in upland rice improvement;
2. review research on upland rice, with emphasis on upland rice environments and the limitations they impose on improvements in yield; and
3. develop appropriate collaborative programs to accelerate progress in upland rice production.

Upland rice was defined as rice grown in rainfed, naturally well-drained soils, witbout surface water accumulation, normally without phreatic water supply, and normally not bunded.

After five working sessions where scientific papers were presented and discussed, the participants formed working groups to draft the following recommendations.

Varietal Improvement

General recommendations

1. The importance of upland rice and the need for the intensification of research is confirmed.
2. Recommendations made at the previous meetings in Brazil, IRRI, WARDA, and Montpellier are confirmed.
3. The important role of national, regional, and international institutions as individuals and cooperators is recognized.
4. Upland rice research should be carried out with regional specificity in mind.

Specific recommendations

1. Increase germplasm. New collections of germplasm materials should be started. Indonesia and other Asian national programs wish to participate more

actively in exchange of genetic materials. Segregating materials should be distributed from the F_2 generation. Institutions should continue to exchange plant materials, but more detailed observations of materials provided should be made, and care should be taken to diversify genetic systems controlling plant height. Germplasm observations should be reinforced by more detailed agronomic evaluation and studies to determine genetic organization.

2. Resolve the problems of stable resistance to blast in the indica group.
3. Strengthen research on biochemical resistance factors.
4. Strengthen research on the resistance to other stresses (diseases, insects, soil problems, etc.).
5. Increase the use of O. glaberrima and traditional O. sativa cultivars.
6. Strengthen research methodologies on multiple crosses, haploid methods, and hybrid varieties.
7. Improve understanding of the relationship between varietal behavior and different environments, Environments should be classified, so that lowest possible variety-environment interactions can be determined.
8. Varieties must be tested in environments and cropping systems where they will be grown.
9. Grain quality should be considered important.
10. The list of varieties recommended by various institutions (national, regional, or international) should include genetic origin. IRRI was requested to prepare and distribute this information for all existing recommended varieties, and for new varieties as they become available.
11. More lowland varieties that are also adapted to upland conditions should be selected.
12. Varieties adapted to regions with altitudes greater than 800 m should be selected.

Cultural practices, soil management, and cropping systems

1. More effort should be directed at identifying agronomic and socioeconomic shortcomings of present production systems that can be readily improved for higher productivity in the shortest time possible.
2. Various research centers should help in developing technology necessary to modernize upland rice production.
3. Major constraints, listed by priority, to tropical upland rice production are
   a. soil management (including fallow and residue management, and soil and water conservation and management),

b. weed control,
c. better nutrient management and amelioration of toxicity problems,
d. plant establishment and mechanization, and
e. multiple cropping (mixed and sequential cropping).

4. A global network on upland rice-based cropping systems should be established to help solve the primary constraints to developing a viable production system. Coordination and leadership responsibility should be developed in subsequent discussions among the international, regional, and national institutions, and TAC and CGIAR.

Environmental characterization

1. Regions with monthly rainfall >200 mm and regions with <100 mm should be delineated.
2. Detailed studies of rainfall probability, dry spell incidence during the growing season, and rainfall intensity are needed.
3. Agroclimatic zones should be defined by solar radiation and temperature to identify potential upland rice production areas.
4. Upland soils should be characterized and delineated with specific emphasis on water holding capacity, acidity, and inherent soil fertility.
5. Upland rice areas in Africa and Latin America should be mapped, and the map of Asian uplands should continue to be improved.
6. Terminologies such as favorable and unfavorable (used to describe upland rice production areas) should be quantified.
7. Water balance studies, integrated with soil and climate, that are needed to characterize upland rice environments should be carried out. Water balance models should be validated by actual monitoring at several sites on each continent.
8. Coordinated upland rice experiments should be supplemented by real time, weather, and soil data.
9. Collaborative upland rice-weather experiments should be established.
10. Farming systems that result from the interaction of the physical and socioeconomic environment should be characterized.
11. Working groups should be established to discuss and execute these objectives.

Control of diseases and pests

Diseases

Principal upland rice diseases are blast (*Pyricularia Oryzae*), helminthosporium (*Drechslera Oryzae*), leaf

scald (Rhynchosporium oryzae), fungi that caused dirty panicles, seed blight (Rhizoctonia), and sheath rot (Acrocylindrium oryzae).

1. Recommendations of previous meetings printed in Research on upland rice -- existing collaborative agreements edited by IRRI were approved.
2. The need for better collaboration between plant breeders and plant pathologists was emphasized. The collaborative program must be adapted to present strategies for using either vertical or horizontal resistance for all upland rice diseases.
3. Methodology used in trials such as the International Rice Blast Nursery should be reviewed in relation to their scientific objectives.
4. Collaborative research on horizontal resistance must be maintained; however, this type of trial is experimental and not yet ready to be distributed to many collaborators. Trials must be conducted by a small number of scientists with a particular interest in horizontal blast resistance. It is hoped that IRRI will coordinate this trial.
5. At least one center for maintenance of different races of Pyricularia oryzae should be established. Its primary role should be the analysis of vertical resistance or rice varieties to different races of blast and analysis of the stability of resistance and the aggressivity of races. IRAT was encouraged to accept this role. The international collaborative role of the center can be established by a committee composed of all interested research organizations. The working group assumes that funds may be made available through the Consultative Group for International Agricultural Research or European Economic Community, World Bank, United Nations Development Programme, or others.
6. Experiments should be conducted to determine magnitude of yield losses caused by other upland rice diseases.
7. Basic research to define the relationship between host and parasite must be conducted.
8. Upland rice disease trials conducted by IRRI through the IRTP must be maintained. WARDA should continue to organize these trials in West Africa.
9. Bacterial blight research should be increased in West Africa. Bacterial blight has been found in Cameroons and Upper Volta.
10. Although little mention has been made of yield decline which occurs in upland rice under continuing cultivation, it is hoped that research can be undertaken to analyze the role of fungi, nematodes, and arthropods in this decline.
11. IRRI should continue its present efforts to identify chemicals that are effective against major upland diseases. WARDA and IITA also screen pesti-

cides to detect effective formulations for countries in Africa with similar ecosystems. CIAT should establish rates and application for pesticides in Latin America. However, because this method is expensive, the cost-benefit ratio should be considered, and it should he the sole resposibility of national programs to recommend chemical disease control measures.

Insect pests

Stem borers, termites, ladybird beetles, armyworms, and leaf murin beetle are major upland rice pests in Africa. In Asia rice mealybug, snout weevil, rice bug, ants, termites, and crickets are important pests. Important insect pests in Latin America are planthopper (*Sogatodes oryzicola*), stink bugs, and spittlebugs.

1. It was noted that little scientific research on insect pests of upland rice in all the three continents has been conducted. The present and potential danger of insect pests as major constraints to upland rice production were recognized.
2. Scientific research on insect pests must receive greater attention and should be an essential component of upland rice improvement programs.
3. Because basic information is lacking in many countries the following research areas were identified for the immediate attention of national and international institutions: surveillance and monitoring of insect pests of upland rice, study of population dynamics and natural enemies in upland rice environments, and crop loss assessments and economic thresholds and control measures. Cheap, safe, and easy to adopt control strategies that enable introduced varieties to achieve their yield potential should be developed.
4. The working group noted that the use of host plant resistance coupled with cultural measures is the most feasible insect control method.
5. varietal resistance screening tests require intertional collaborative work. Although upland rice insect pests differ for the three continents, they could broadly classified into groups such as stem borers, plant suckers, defoliators, and soil insects. There is need to obtain nurseries for the various groups: upland rice materials with a wide genetic base for local testing.

Nematodes

Nematodes of rice may be more important than presently realized. *Aphelenchoides*, *Hirschmanniella*, *Meloidogyne*, *Pratylenchus*, and *Heterodera* may contribute significantly to yield declines in most rice producing areas.

1. It would be highly desirable for international organizations working with rice to increase nematode research facilities or sign agreements with organizations that have existing facilities.
2. Nematology should be included in training sessions wherever possible in order to identify nematode problems and find appropriate solutions.

Birds and rodents

Bird and rodent control methods should be developed and existing collaborative research between OLLALAV, West Africa Rice Development Association, Comite Interetats de Lutte Contre la Secheresse au Sahel, and Office de la Recherche Scientifique et Technique Outre-Mer in this area should be strengthened.

Training

1. There is an urgent need to strengthen existing upland rice training programs.
2. Training for farmers and junior extension officers must be conducted by national programs.
3. Training programs for intermediate or junior researchers and senior extension officers must be conducted by national and regional organizations and by the international organizations located in upland areas.
4. Training programs at a high scientific level (Masters, Ph D) should be conducted by international and national institutes such as IRRI, IITA, GERDAT, and at African, Asian, European, and American universities.
5. The three kinds of training programs must be focused on cropping systems based on upland rice.
6. After graduating from a training program, trainees must be employed by suitable national organizations to contribute to rice research production and development.
7. Governments must develop incentives to strengthen and stabilize the national rice research staff.
8. Donors should be sought to fund training programs at national research organizations working on upland rice.
9. IRRI's proposal to establish an upland rice course at IRRI to train the trainers and develop a training methodology was recognized.
10. ADRAO was congratulated for its courses in rice production and production factors.

The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of 13 nonprofit international research and training centers supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 50 donor countries, international and regional organizations, and private foundations.

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FOREWORD

In Africa and Latin America, most rice is grown in upland culture similar to other cereals. In Asia, although rice is predominantly produced in wetland conditions and flooded for most of the growth period, 11 million hectares of upland rice are grown. This hectarage, and the 2 million hectares in Africa and 6 million hectares in Latin America total 19 million hectares or about 12% of the world's rice area. Upland rice yields are low, they account for only 5% of world production. Even so, upland rice is important because for upland rice growers, mostly subsistence farmers, among the poorest of the poor, and with few alternate sources of food, rice constitutes a significant part of their diet.

In the last 15 years, lowland rice yields have improved substantially while those of upland rice have remained about the same. Less research has been done on upland rice which has more diverse production problems although not necessarily more difficult ones. Therefore, The Technical Advisory Committee (TAC) to the Consultative Group for International Agricultural Research (CGIAR) asked the international centers concerned with rice to report on their upland rice activities and to develop a strategy to improve upland rice throughout the world. IRRI was asked to coordinate these activities.

To review the present state of knowledge and current research activities, each of the centers involved produced a base line paper on upland rice production in their continent. The report for Africa was prepared by the International Institute of Tropical Agriculture (IITA); Asia, by the International Rice Research Institute (IRRI); Latin America, by the Centro Internacional de Agricultura Tropical (CIAT); West Africa, by the West Africa Rice Development Association (WARDA); and Brazil, by Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA).

The information contained in this volume can provide a factual. background on which to base future research and development programs. The papers give a comprehensive account of current upland rice research conducted by national research organizations and by regional and international centers.

The conference recommendations will help plan future research to advance upland rice production.

M. S. Swaminathan
Director General
International Rice Research Institute

Los Baños, Philippines

BASE PAPERS

UPLAND RICE IN AFRICA

IITA

Africa accounted for only 3.4% of the world's rice area, 2.1% of rice production, and 16.5% of world rice imports in 1980 (Table 1, App. 1, 2). Increased demand for rice as a staple food in Africa reflects a dietary shift from traditional foods (especially roots and tubers), urbanization, and recent socioeconomic trends. Demand for rice will continue to rise and methods of increasing production in proportion to demand are essential to avert serious economic imbalance of payments in developing nations in Africa. Despite the current and widening gap between rice supply and demand, rice production potential in Africa is good, but depends upon soils, climate and water resources, and a relevant research and development program that concentrates on key problems and is supported by interdisciplinary research.

Major rice producers in Africa south of the Sahara Desert are Malagasy, Guinea, Sierra Leone, Zaire, Nigeria, Tanzania, Ivory Coast, and Liberia. Of these countries, Malagasy has about one-thirdof the area and production. Potential for increasing production is good in Kenya, Angola, Cameroon, Mozambique, and Zambia.

DEFINITION OF UPLAND RICE AREAS

At their meeting in Washington, D. C., on 30 October 1979, representatives of the International Rice Re-

Table 1. Area, production, and imports of rice in Africa.

	1961-65	1969-71	1975	1980	1981
Area (thousand ha)					
Africa	3,097	4,010	4,215	4,815	4,817
World	124,112	130,673	142,668	143,362	143,812
Production (thousand t)					
Africa	5,425	7,336	7,729	8,117	8,168
World	253,013	311,536	359,693	396,115	408,055
	1965	*1970*	*1976*	*1980*	
Imports (thousand t)					
Africa	783	801	1,019	1,863	
World	7,790	8,990	9,235	11,276	

search Institute (IRRI), International Institute of Tropical Agriculture (IITA), West Africa Rice Development Association (WARDA), and Centro Internacional de Agricultura Tropical (CIAT) defined upland rice production systems as systems where:

a) there is no control or addition of water beyond rainfall or changes in the water table,
b) soil water level is not normally above the soil surface except during occasional flooding;
c) topography is flat or undulating and bunding may or may not be present; and
d) other upland crops can be grown during the main rice production season.

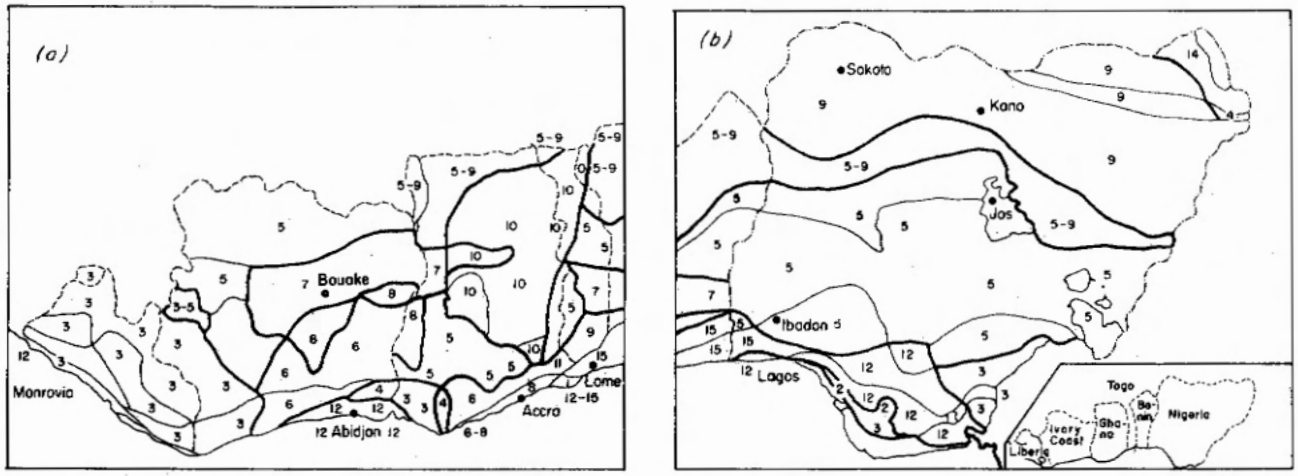
Rice culture systems were discussed at the IITA conference on rice in Africa in March 1977 (Buddenhagen and Persley 1978). During the conference, a distinction was made between dryland rice grown on freely drained soils and hydromorphic rice grown on soils where the water table may rise near the surface during growing season.

In the past, both types were classified as upland rice. Although precise statistics on dryland and hydromorphic rice production systems are difficult to obt in, reasonable estimates available for West Africa (TAC Quinquennial Review Mission on WARDA 1979) confirm that the dryland upland rice production system is the dominant rice system in West Africa (Table 2).

A classification of ecological regions where rice is grown in West Africa was attempted by Papadakis (1965). Major soil and climatic characteristics of each region were evaluated for rice cultivation potential. Climatic zonation in West Africa is relatively simple because isohyets are parallel to latitudes (Fig. 1). In Central and East Africa sharp differences in altitude cause a complex mosaic of climatic zones within smaller areas. In most of East Africa upland rice cultivation in freely drained soils is limited by low rainfall and is less important than hydromorphic and swamp rice systems. This is particulariy true of the major rice producing countries of this region -- Malagasy, Zaire, and Tanzania, but does not imply that upland rice culture cannot be extended to many areas in East Africa, espe-

Table 2. Rice production systems in West Africa.

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



1. Rice ecosystems in West Africa. 1. Mangrove swamps. Flooding regulation, drainage, or irrigation works are usually necessary; possible danger of sulfuric acid formation. Humid climate makes rice harvesting difficult. 2. Fresh water coastal swamps. Flooding regulation, drainage, or irrigation works are usually necessary. Some difficulty in rice harvesting. 3. Forest belt with soils poor in bases and often concretionary. This is the rice-cassava belt. Yams are not grown and upland rice is sown as the first crop on fallow land. Phosphorus and other mineral deficiencies are common. 4. Same as 3, but the humid season is interrupted in August (climate 1.22); early sown rice should be harvested in August, except on adequately flooded land. 5. Soils well provided with bases, often concretionary; 5 or more months are humid and form a continuous series. Upland rice competes with yams; it is preferred in more or less flooded soils; sometimes the two crops are associated. 6. Same as 5, but the humid season is interrupted in August (climate 1.122 and 1.134), when early sown rice should be harvested, except on adequately flooded land. 7. Climate water surplus (Ln) below 20% of annual potential evapotranspiration; 5 or more months are humid and form a continuous series (climate 1.41); soils are formed from old consolidated rocks, often concretionary. Upland rice is grown where soils do not drain freely or are flooded. 8. Climate same as 7, but the humid season is interrupted in August (climate 1.412). Upland rice is grown only in well-flooded soils. 9. Climates with 3 or less humid months. Irrigation or flooding is necessaary. 10. Voltaian basin. Soils with poor drainage prevail and many are flooded. Upland rice is important. Flooding regulation or irrigation is often required. 11. Low Volta plains. Soils are usually adequate for rice; but flood regulation and irrigation are necessary. 12. Sandy soils from unconsolidated sands under humid climate. These soils usually drain too freely and are inadequate for rice. 13. Fadama (floodplain) land. These soils are good for rice. Flood regulation or irrigation is necessary. Not shown in the map; they are especially found in regions 9, 6, and 5. When flooding is deep, special varieties are required. 14. Chad basin. Soils are usually fertile. Vertisols (black plastic clays) are good. Irrigation is necessary. 15. Terres de Barre. Soils generally drain too freely for rice growing and the humid season is not sufficiently humid. Rice is grown in the black earth and drainage or irrigation is necessary.

Thick lines refer to rice ecologic regions; thin lines refer to climatic subdivisions within these regions.

cially by planting early-maturing rice varieties. Efforts are being made to increase upland rice production in the Dodoma region of Tanzania.

Although bush fallow is expected to restore native fertility through nutrient recycling, the quality and speed of restoration depend on bush regrowth, composition of bush vegetation, and soil erosion. The erosion tolerance of tropical soils is low and variable. In the long term, erosion damages soils more than the depletion of nutrients by crops.

Upland rice generally is grown in the humid forest zone, where it is intercropped with other food crops (maize, cassava, yam, pigeonpea, vegetables, etc.) (App. 3) and Little fertilizer or plant protection chemicals are used. Weeds reduce yield when rainfall is abundant, and blast disease and drought stress during dry spells take a heavy toll. These constraints frequently cause farms to be abandoned to the next cycle of bush fallow.

In the humid forest zone, hydromorphic soils in floodplains and inland valleys are less vulnerable to soil erosion and provide better conditions for continuous rice cultivation. However, inland valleys and swamps constitute a relatively small area of land that is hard to clear, drain, and develop. Crops grown in these soils suffer from alternate drying and flooding. Farmers also fear health hazards such as schistosomiasis and river blindness that occur in those areas.

PRODUCTION CONSTRAINTS

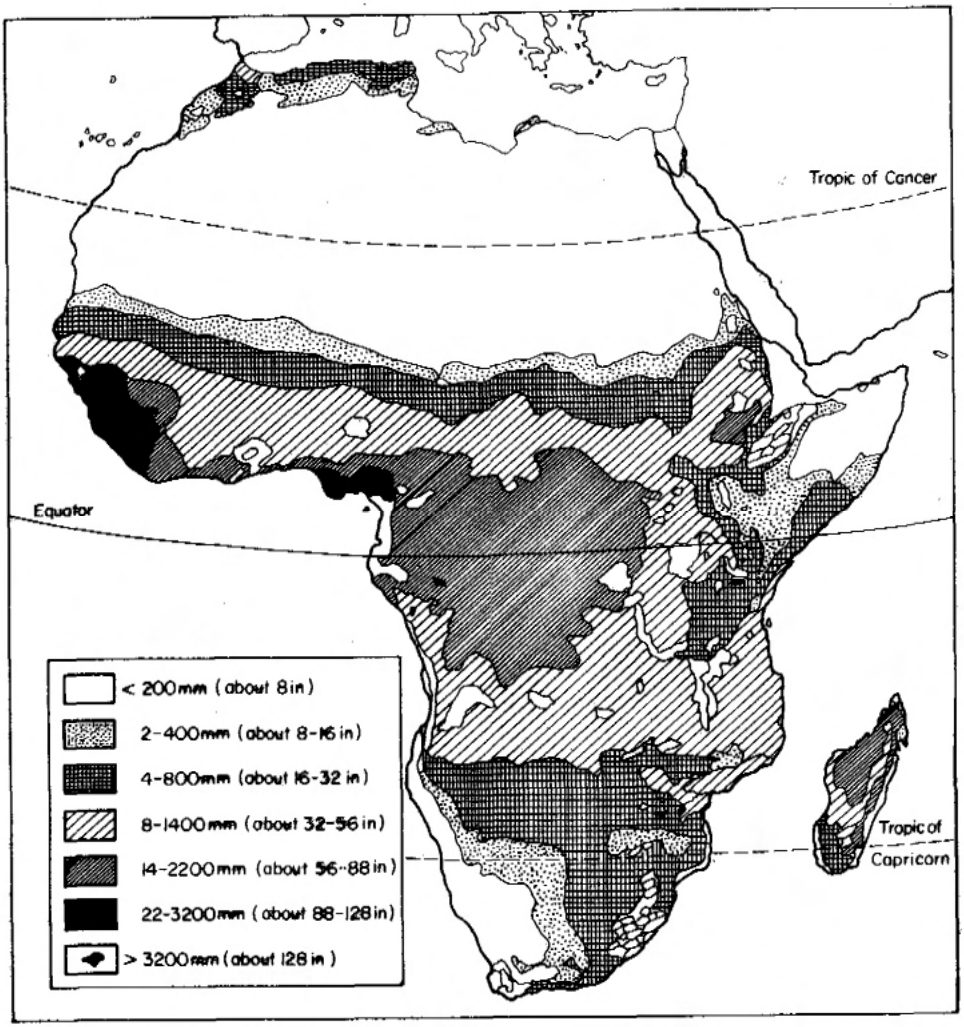
Climate

Rainfall quantity, pattern, reliability, duration, and frequency are the most crucial factars determining the success of upland rice cultivation (Fig. 2).

In East Africa, where mean annual precipitation is low and unreliable, water supply is the most limiting factor for upland rice.

In major parts of Central Africa, such as Zaire, Cameroon, Gabon, and Anyola, rainfall regimes are more favorable, but the full potential of upland rice production in these countries has not yet been fully assessed. Social factors and food preferences must also be considered. For example, rainfall in eastern Nigeria is favorable for upland rice, but the dominant food crops are cassava and yam. This situation may be changing to more emphasis on rice.

A systematic and coordinated assessment of soil moisture, radiation patterns, rainfall distribution and variability, and soil temperature is needed in relation to cultivation of upland rice and related crops. Unlike the world's major rice growing areas, tropical and subtropical Asia, Africa has harsh and diverse climates.

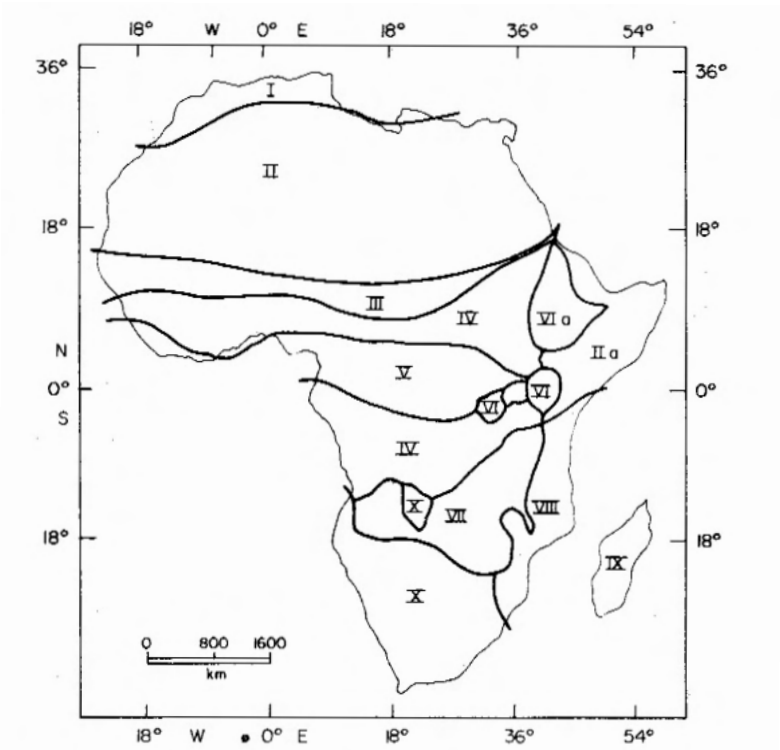


2. Mean annual precipitation in Africa (Grove 1978).

The 30 million km^2 continent of Africa can be classified broadly into 10 basic climatic zones (Fig. 3, Griffith 1974).

Using rainfall regimes shown in Figure 3, areas with well-drained soils suitable for upland rice cultivation occur in region V (equatorial wet) and the northeast part of region IX (Malagasy). Other areas suitable for upland rice cultivation are in regions IV (tropical wet-dry) and VIII (east central lowlands), but production in these areas is limited to hydromorphic soils where soil moisture stress is not a serious problem.

Climatic limitations for upland rice in Africa are rainfall, soil moisture, and solar radiation. More pre-



Zone	Region	Percentage area
I	Mediterranean	2.6
II	northern desert	33.0
IIa	Horn of Africa	5.3
III	semiarid	1.2
IV	tropical wet-dry	19.4
V	equatorial wet	7.1
VI	East African highlands	1.0
VIa	Ethiopian highlands	2.3
VII	south savana plateau	7.2
VIII	E. Cent. lowlands	3.5
IX	Malagasy	2.2
X	southern Africa	9.2

3. Climatic zonation of Africa (Griffith 1974).

cise data are needed on potential water balance (precipitation vs evaporation). The probability of dry spells in the equatorial wet zone should be determined. The length of dry period and variations in intensity and time must be determined for the tropical wet–dry zone. In the semiarid zone, upland rice production is inhibited by length and variability of the rainy season.

To clarify these crucial issues, a more reliable assessment of climatological data is necessary. In Africa, however, only limited measurements of climatological factors are available, making it impossible to

check all empirical and theoretical methods, such as those for evaporation and evapotranspiration, against the actual situation in many parts of the continent.

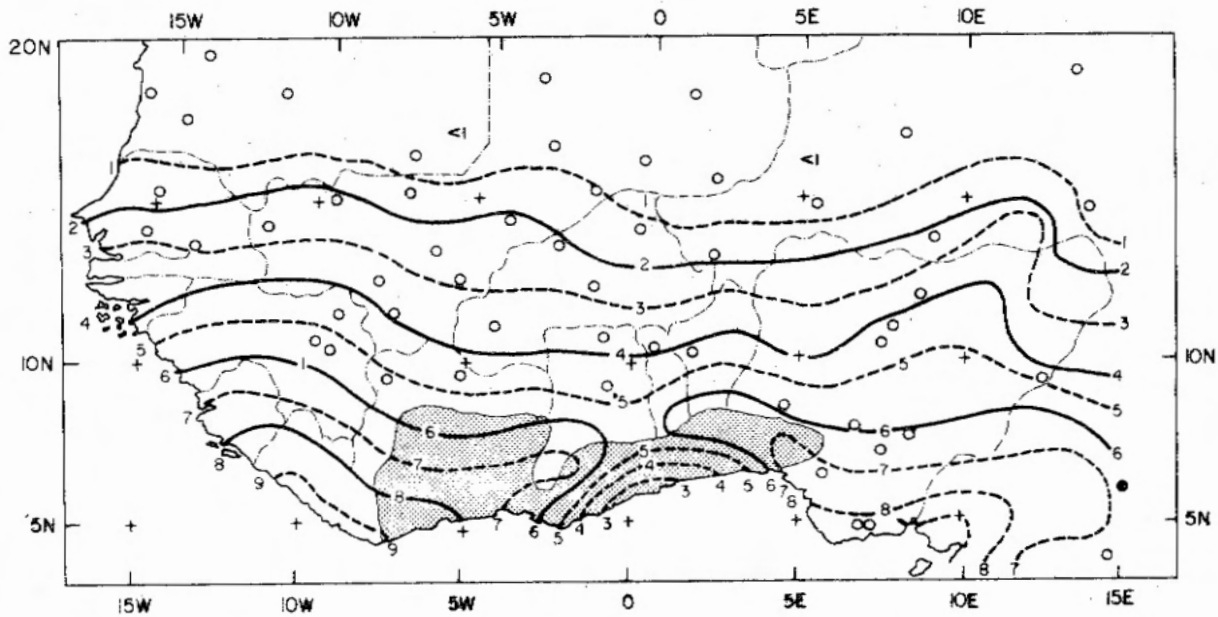
Rainfall data for West Africa have been well documented (Lawson 1979). The northern part of the region has a monomodal rainfall pattern; the annual onset or cessation of rains is highly variable. South of this region, roughly between latitude 8°N and the coast and the longitudes 7-1/2°W and 5°E, a pronounced drop in rainfall during July-August breaks the period March-April to October into 2 distinct cropping seasons. Neither zone is strictly suitable for upland rice, even on the basis of a 200-mm minimum monthly rainfall requirement for the crop during the growing season. Furthermore, much of the shaded area in Figure 4 is also prone to intraseasonal short-term variability in precipitation. Drought spells are likely to occur during the early part of the growing season (May). Upland rice cultivation in the bimodal zone requires more reliable prediction of dry spells.

A third rainfall regime in West Africa, best characterized as pseudobimodal, generally prevails east and west of the bimodal zone (Fig. 4). In August, precipitation declines, but not so much as to constitute a break in the cropping season. Annual rainfall is reasonably high (≥1500 mm) and so is the number of rainy days.

High intensity rains (max 50-100 mm/ha) are common in these three zones, and often cause soil erosion of poorly structured, coarse-textured Alfisols, Ultisols, and Inceptisols, particularly when planted to upland rice, which provides a poor cover on the soil surface early in the growing season.

Given the high water requirement of rice and the generally poor water-holding capacity of the coarse-textured kaolinitic soils in most of West and Central Africa, there is high risk of drought during the upland rice growing season. Moderate-to-high evaporative demand coupled with the relatively shallow root systems of rice plants accentuates the effect of dry spells in West Africa. Water requirement for rice ranges from 4-4.5 to 5-6 mm/day for upland variety OS6 grown at IITA, Ibadan. Along a south-north transect of the West African region, 4-6 mm water/day is available during the growing season.

Crop production is the conversion of solar energy, water, and nutrients into an economic end product. The long-sustained myth about the high agricultural potential of the humid tropics was based on the high level of solar radiation that was assumed to prevail in the region. Recent agronomic and physiological studies show that the levels of insolation in the wetter part of the tropics limit rice yields. The reproductive and ripening phases are particularly sensitive to low light intensity, especially if nutrient and moisture are good.



4. Number of months with positive water balance precipitation ⩾ evaporation in the bimodal rainfall/cropping area of West Africa.

The temporal and spatial variation in radiation in most of West and Central Africa are important to the growth of upland rice. These climatic factors emphasize the importance of a rice breeding and improvement program that is supported by an integrated team of scientists studying soils, climatology, and physiology.

Soil resources

The world's most productive riceland is on young alluvial soils in river deltas and inland valleys. These soils are predominantly hydromorphic Entisols and Inceptisols with fine or medium texture and montmorillonitic and vermiculitic clay mineralogy.

The reserve and supplying power of nutrients are generally high because the soils have high cation exchange capacity and weatherable mineral contents. The distribution of such fertile alluvial ricelands in the wetter regions of tropical Africa (Region IV and V in Fig. 3) is limited, and is a major limitation to rapid expansion of rice production in Africa.

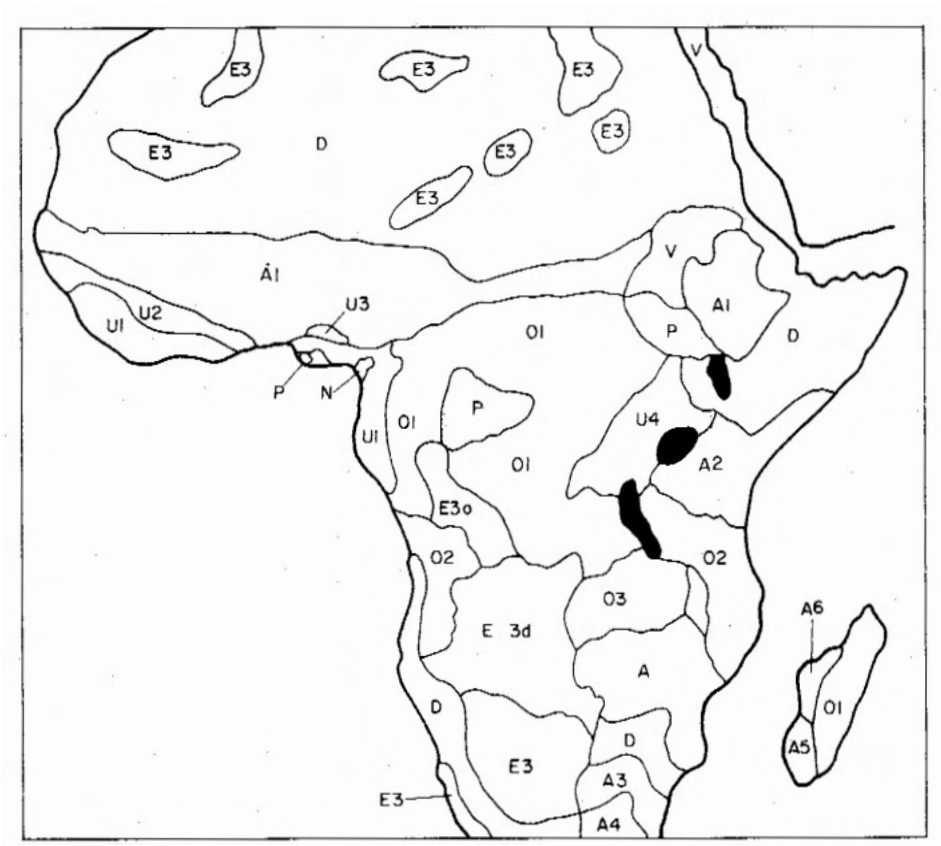
A simplified soil map of Africa with legend and the explanation based on the US Soil Taxonomy Classification is given in Figure 5. Except for large areas of Aquepts and Aquents in the lower Niger River Delta, the Congo Basin, and the upper White Nile swamps of southern Sudan, hydromorphic soils (Aquents, Aquepts, Aquults, Aquols, etc.) are not shown on the map because of their restricted and scattered distribution. Major soils important to upland rice cultivation in the three climatic zones of Africa are in Table 3.

Important soil constraints to upland rice cultivation in Africa are drought stress in the well-drained upland soils (Alfisols and Ultisols) of the wet-dry region, severe nutrient deficiencies and leaching losses in the high-rainfall equatorial wet region, and soil toxicities, especially iron, in inland hydromorphic valleys.

Well-drained upland soils

The well-weathered Alfisols, Ultisols, and Oxisols in the tropical wet-dry region of Africa are only marginally suitable for growing upland rice because they have low water-holding capacity caused by sandy surface horizon and kaolinitic mineralogy. Even relatively short dry spells are detrimental to upland rice growth. Therefore performance of upland rice depends on the available soil moisture reserve and varietal tolerance for drought stress. Suitability of well-drained soils for upland rice production is judged by soil texture at 60-cm depth, the presence or absence of gravel, and the level of soil organic matter.

Research results indicate that because of slow hydraulic conductivity, groundwater deeper than 50 cm does not directly influence the performance of rice



5. A simplified soil map of Africa according to U.S. Soil Taxonomy Classification (Kellog 1975). *Ultisols* — coarse, and medium-textured acid soils with clayey acidic subsoils: *U1,* Tropudults and Plinthudults with some Orthox, Aquults, and Aquents in restricted areas; *U2,* Paleustults and Plinthustults with Paleustalfs, and Aquepts and Aquents; *U3,* Paleustults and Plinthustults; *U4,* Tropudults with Orthox. *Oxisols* — strongly weathered, fine or coarse-textured soils with little variation in texture with depth; *O1,* Orthox with Tropudults; *O2,* Ustox with Ustalfs; *O3,* Ustox with Ustults. *Alfisols* — coarse to medium-textured, high base saturation soils with clayey subsoils; *Al,* Paleustalfs and Plinthustalfs with Tropepts and some Aqualfs, Aquolls, Aquents, and Vertisols in restricted areas; *A2,* Rodustalfs and Paleustalfs with Vertisols and Mollisols; *A3,* Ustalfs with Ustox; *A4,* Udalfs; *A5,* Plinthustalfs with Ustorthents; *A6,* Ustalfs with Troporthents. *Inceptisols* — young soils with limited profile development: *P,* Aquepts with some Aquents. *Entisols* — young soils derived from alluvial materials with no horizon development: *E3,* Psamments; *E3d,* Psamments with Orthox; *E3e,* Psamments with Ustox. *Vertisols* — dark clayey soils formed under drier climates containing large amounts of swelling clay minerals (montmorillonite): *V,* Vertisols (Usterts with Aquepts). *Andisols* — soils derived from volcanic ash containing large amounts of amorphous materials (allophane): *N,* Andisols with Tropudults, Tropudalfs, and Tropohumults. *Aridisols* — soils of arid regions, such as desert soils: *D,* Aridisols, some are saline.

plants on multilayered Alfisol profiles at the upper reaches of a soil toposequence.

Nutrient requirements and imbalances

Nitrogen content is the most limiting plant nutrient for upland rice cultivation. Soils with seasonally

Table 3. Major soils suitable for upland rice in different climatic regions in tropical Africa south of the Sahara, classified according to Soil Taxonomy Classification.

Soil order	Suborders		
	Equatorial wet (V)	Tropical wet-dry (IV)	East Africa lowland (VI)
Entisols	Orthents	Aquents	Aquents
	Psamments[a]	Fluvents[a]	Fluvents[a]
	Aquents[b]		
	Fluvents		
Inceptisols	Tropepts	Tropepts[a]	Tropepts[a]
	Aquepts[b]	Aquepts	Aquepts
Alfisols	Aqualfs	Aqualfs	Aqualfs
	Udalfs	Ustalfs	Ustalfs[a]
Ultisols	Aquults	Aquults	Aquults
	Udults	Ustults[a]	Ustults[a]
Oxisols	Orthox	Ustox[a]	Ustox[a]
Vertisols	–	Usterts[a]	–
Mollisols	–	Aquolls	Aquolls

[a]Marginally suitable and site specific except aquic subgroup. [b]Deep flooding during peak rainy season.

fluctuating groundwater tables may have severe nitrogen deficiency. This is particularly so in soils with rolling, undulating topography that are between the well-drained upland zone and the valley bottom wetland.

Experimental results suggest that good fertilizer management for upland rice grown on these land types is crucial and location specific (Moormann et al 1977). Iron deficiency is a common problem of upland rice grown on Alfisols in the dry-wet region. Some varieties have Fe deficiency tolerance.

Leaching losses, soil acidity, and multiple nutrient deficiencies in high-rainfall regions my cause severe production problems for intensified upland rice cultivation on strongly leached Ultisols and Oxisols (Udults and Orthox). This is particularly so for improved rice varieties with high nutrient requirements.

Assessment and evaluation of potential riceland in Africa

A systematic assessment of soil conditions and land characteristics has not been done for upland rice cultivation in Africa. A brief assessment of West African rice growing areas was made by Moormann (1973).

Information on East and Central Africa is particularly scarce. Lack of detailed soil and land use surveys for most African countries is a major constraint to increasing rice cultivation.

The Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres and the Food and Agriculture Organization of the United Nations land resource survey reports indicate there are substantial areas of under-

developed potential riceland in Cameroon. In Malagasy and Tanzania (Zanzibar and Pemba Islands), most riceland is irrigated, and fertilized rice is grown on a wide range of soils and land types. Even where rainfall is adequate in mainland Tanzania, rice is less likely to be grown than other food crops. However, there is potential for expanded rice cultivation in the Kilombero valley, the swampland in Kimba and Shinyanga regions, and the Rufiji Valley.

Soil and land suitability evaluations, such as the study of land in two typical inland valleys in Southern Nigeria by Veldkamp (1979), are necessary to identify the essential parameters for evaluatiny soil and land quality for upland rice cultivation.

Biotic constraints

The Portuguese introduced Asian rice in West Africa about 1500 A. D. The Asian variety Oryza sativa was introduced in East Africa before coming to West Africa. Other varieties of commonly planted upland rice trace their ancestry to more ancient Asian rice and some recent introductions from Latin America.

Upland rice varieties planted in Africa are generally panicle weight types with low tillering potential and tall stature. They lodge when planted in high crop density on fertile soil with adequate soil moisture -- conditions which are infrequently encountered. The varieties are drought tolerant and may have horizontal resistance to blast disease and tolerance for fungal diseases that cause dirty panicles or grain discoloration.

Performance of productive semidwarf varieties (IR8 type) under upland conditions is variable and unpredictable. Yields are acceptable when there is no drought and semidwarf varieties are not attacked by blast disease and dirty panicle fungus. When these stresses occur, yield advantages over established upland varieties are not realized and yield loss can be substantial.

PLANT TYPE SELECTION

Developing a modern rice variety with suitable plant type for upland cultivation in Africa has been difficult. Evaluation of several high yield potential semidwarf rice cultivars indicated that most have poor potential for upland cultivation (Table 4). Although most superior upland cultivars developed at IITA are of intermediate stature, research shows that performance of semidwarf cultivars in uplands is cultivar specific and not a general plant-type characteristic (Alluri et al 1979, IITA 1981).

To obtain higher yields, greater crop density, fertilizer use, mechanization, and weed control --

Table 4. Performance of improved semidwarf rice cultivars (except OS6, a tall variety) with high yield potential at different locations in Nigeria, 1978.

Cultivar	Grain yield[a] (t/ha)			
	Paddy	Upland		
	Ibadan	Onne	Ikenne	Ibadan
BG 66-1	6.74	0.85	3.10	0.0
C4-63	7.23	N.T.	0.81	0.30
IET 1996	6.88	0.69	2.61	0.20
IR8	6.73	0.97	3.56	0.0
IR1416-131-5	6.60	0.60	N.T.	1.24
IR43	6.92	1.23	3.23	0.0
IR2035-120-3	8.23	1.66	4.43	0.42
IR2035-244-3-2-2	7.19	0.73	3.34	0.27
IR2061-228-3-9	6.87	0.88	1.75	0.33
IR42	5.75	N.T.	2.44	0.83
IR2071-588-3	6.04	0.81	2.32	1.36
PMI 6624-257-1	7.00	1.54	2.53	0.0
RP4-14	7.21	1.23	2.41	0.0
RPW6-17	6.87	N.T.	3.15	0.0
ITA121	7.67	N.T.	4.58	1.15
BG90-2 (check)	7.90	1.21	2.40	0.0
OS6 (check)	N.T.	1.08	2.38	0.92
s.e.	0.22	0.09	0.21	
C.V.	12.6	31.2	29.7	

[a]N. T. = not tested. Zero grain yields were caused by severe drought and blast damage.

introducing a higher level of crop management -- will be necessary. As an interim measure, improved varieties with better adaptation to local cultural practices than current upland varieties are being sought in breeding programs. Mutation breeding may also be used to develop semidwarf varieties suitable for upland cultivation.

RESISTANCE TO RICE BLAST DISEASE

Blast is the most serious rice disease in Africa. Hence a major aspect of any breeding program must be selection for blast (Bl) resistance. Upland rice yields are particularly low when rice is decimated by Bl during dry spells. Although not a prerequisite for Bl, drought aggravates the disease.

Varietal resistance to Bl caused by Pyricularia oryzae Cav. is unpredictable. Resistant varieties eventually become susceptible. Many adapted upland varieties from Africa appear to have good horizontal resistance, which is not strain specific and does not break down. Successful rice improvement for disease resistance, particularly Bl, depends upon selection methods

that will distinguish genotypes which show a slow rate of disease increase under natural conditions.

DROUGHT RESISTANCE

In almost all African locations where upland rice is grown, drought is a serious limitation to yield. No single selection criterion or screening methodology for drought resistance has been found adequate. The various mechanisms of drought avoidance, drought tolerance, and drought recovery, all of which contribute to drought resistance, usually are associated with cultivar of different plant types. Design of cultivar growth duration to suit regional rainfall pattern (Alluri and Vergara 1975) and selection for thick and deep roots (Alluri et al 1981a) are accepted methods for combating yield reduction caused by drought (O'Toole and Chang 1979).

DISEASE CONSTRAINTS

Other diseases that are constraints to upland rice production in Africa include leaf scald (*Rhynchosporium oryzae*), which usually affects the basal leaves. Infection often starts from the leaf margins and the leaf apices show distinct infection and characteristic zonation.

Brown spot (*Cochliobolus miyabeanus*) is also a serious problem in upland rice. It affects rice seedlings, leaves, and panicles especially in areas with poor soil. It also is one of the causes of panicle discoloration.

Dirty panicle syndrome is one of the most serious constraints to upland rice production. Where there is high humidity during the ripening stage, the fungal infection causes incomplete grain filling and substantial yield reduction. This problem is lessened under dry conditions. *Sarocladium attenuatum* is a major cause of panicle discoloration syndrome. Other fungi that cause damage are *Curvularia*, *Alternaria*, and *Helminthosporium*. TOX86 is reported to have less glume discoloration and may be a source of resistance. Although virus diseases such as rice yellow mottle have not been a serious problem, they may pose a future threat to upland rice cultivation.

RICE PRODUCTION SYSTEMS

Understanding and improving local rice-based farming systems is essential to increasing rice production in Africa. Researchers are working to develop more efficient food production systems with production intensification and permanent cultivation to replace tradi-

tional bush fallow systems now used to grow rice and other staples.

Preliminary cropping systems studies have identified potentially successful groups of cropping systems, including rice-based cropping systems. Technology packages are being developed using the following components:

1. improved high yielding crop varieties resistant to pests and tolerant of various environmental stresses;
2. relatively low-energy and low-cost inputs, and appropriate technology involving tools or practices that minimize drudgery, increase productivity, and are within the means of small farmers to obtain, use, and repair;
3. weed and disease management by ecologically sound and compatible methods; and
4. land development and soil management methods that make use of biological nitrogen fixation and related processes that link soil and crop management systems.

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APPENDICES

Appendix 1. African rice area, yield, and production (1970, 1981)) (FAO 1972, 1980).

Region, country	Area (thousand ha)		Yield (t/ha)		Production (thousand t)	
	1970	1980	1970	1980	1970	1980
World	134,389	145,391	2.3	2.7	308,767	399,719
Africa	4,097	4,918	1.8	1.7	7,388	8,429
West Africa	1,977	2,527	–	–	2,234	3,001
Benin	2	9	2.7	1.3	6	12
Gambia	28	23	1.4	1.1	41	35
Ghana	55	80	1.2	.78	69	62
Guinea	408	400	.8	.87	350	350
Guinea Bissau	42	40	1.7	1.0	67	40
Ivory Coast	289	450	1.1	1.2	316	550
Liberia	182	197	.8	1.2	138	243
Mali	166	190	.8	1.0	138	200
Mauritania	1	2	1.3	1.9	1	4
Niger	16	21	1.1	1.5	71	32
Nigeria	300	550	1.6	1.3	490	725
Senegal	88	85	1.0	1.5	91	130
Sierra Leone	332	425	1.4	1.3	458	565
Togo	28	15	.6	1.1	18	23
Upper Volta	40	40	.8	.75	34	30
North Africa	485	412	–	–	2,611	2,355
Egypt	480	408	5.4	5.7	2,605	2,348
Sudan	5	4	1.2	1.7	6	7
Central and East Africa	1,552	1,953	–	–	2,515	3,072
Cameroon	17	20	.9	1.9	14	45
Central African Republic	13	20	1.0	1.0	13	20
Angola	25	20	1.5	1.0	39	20
Comoros	9	12	1.3	1.3	12	16
Kenya	5	7	5.4	5.7	26	40
Malawi	8	47	1.1	1.1	9	50
Burundi	4	4	3.4	2.5	12	10
Congo	4	4	.9	1.0	3	4
Mozambique	65	75	1.6	.9	102	75
Zimbabwe	3	3	1.7	1.7	5	5
Uganda	15	18	.4	.6	6	10
Tanzania	151	190	1.2	.9	182	180
Zaire	258	280	.7	.8	188	230
Malagasy	935	1,216	2.0	1.9	1,865	2,327

Appendix 2. African rice imports (FAO 1974, 1981).

Country	Imports (thousand t)				
	1970	1974	1978	1980	1981 (6 months)
World	8,989.6	8,709.7	9,196.5	11,276.3	5,950.0
Africa	801.0	1,196.0	1,619.2	1,862.9	917.0
Cameroon	7.8	20.0	18.8	20.7	12.0
Gambia	1.4	6.7	30.0	30.0	15.0
Guinea	25.0	25.0	54.0	128.0	70.0
Ivory Coast	78.7	72.9	126.2	230.0	0
Liberia	49.0	34.7	61.0	86.7	40.0
Libya	23.1	40.0	33.6	44.8	25.0
Madagascar	20.3	129.0	125.2	161.0	80.0
Mauritius	58.8	87.4	78.5	88.0	49.0
Nigeria	1.7	6.7	563.8	387.0	250.0
Reunion	56.4	49.6	53.7	51.1	30.0
Senegal	119.2	230.5	237.8	275.3	150.0
Sierra Leone	50.1	45.0	18.5	41.1	25.0
South Africa	75.0	70.9	103.5	126.1	65.0
Tanzania	7.2	71.1	47.2	90.0	50.0
Upper Volta	2.6	12.3	10.2	29.0	16.0
Zaire	25.5	50.0	32.2	40.0	25.0
Others	145.8	204.2	–	–	–

Appendix 3. Average production estimates and annual mean growth rates for 6 major food crops in tropical Africa, 1961-65 and 1972-74a (FAO 1972, 1973, 1974; ECA Africa Statistical Year-book 1974.)

Region	Crops	Average annual production		Increase in production		Annual growth rate[a]
		1961-65 (thousand t)	1972-14 (thousand t)	Absolute (thousand t)	Relative %	
West Africa	Cassava	11,654	15,119	3,465	29.7	2.4
	Maize	2,124	2,248	124	5.8	0.5
	Rice	1,603	2,149	546	34.1	2.7
	Sorghum/millet	10,277	8,995	-1,282	-12.5	-1.2
	Sweet potato	462	442	- 20	- 4.3	-0.4
	Yam	17,766	18,037	271	1.5	0.1
	Total	43,886	46,990	3,104	7.1	0.6
Central Africa	Cassava	13,183	20,699	7,516	57.0	4.1
	Maize	1,033	2,118	1,085	105.0	6.7
	Rice	234	390	156	66.7	4.8
	Sorghum/millet	1,896	1,284	- 612	-32.3	3.6
	Sweet potato	1,832	2,506	674	36.8	2.9
	Yam	–	5	–	–	–
	Total	18,178	27,002	8,819	48.5	3.7
East Africa	Cassava	5,741	6,500	759	13.2	1.2
	Maize	3,369	4,815	1,446	42.9	3.3
	Rice	1,714	1,994	280	16.3	1.4
	Sorghum/millet	1,600	1,870	270	16.9	1.5
	Sweet potato	1,612	1,876	264	16.3	1.4
	Yam	24	30	6	25.0	2.3
	Total	14,060	17,085	3,025	21.5	1.8

[a]Growth rate assumed constant and compounded at $(1 + R)\ n$ where R = annual growth rate expressed as a percent and n = 11 years between the 1961-65 midpoint and the 1972-74 mid-point.

UPLAND RICE IN WEST AFRICA

WARDA

WEST AFRICAN UPLAND RICE ENVIRONMENTS

Upland rice is one of the most important West African food crops. Many subsistence farmers depend almost entirely on upland rice production for food, despite low yields and other serious constraints.

About 2.3 million hectares are planted to rice in West Africa, 65% of which is upland rice. Upland rice is planted in diverse farming situations including fully aerobic conditions during vegetative and reproductive phases, occasional soil submergence by runoff water, continuously supersaturated soils, and in areas with aerobic and anaerobic conditions at different crop phases. This paper contains information about upland rice environments, cropping systems, crop production, varietal improvement, and disease and insect pests for the most important upland rice producing countries in West Africa -- Sierra Leone, Guinea, Nigeria, Ivory Coast, and Liberia (Table 1).

Upland rice ecology

The West Africa Rice Development Association (WARDA) has divided upland rice into four types:

a. **hill rice** is cultivated on 115,000 ha (5% of the total rice cropping area) in Sierra Leone, Liberia, and southwest Ivory Coast;

b. **flatland rice** is cultivated on 1,322,000 ha (57.5% of the total rice cropping area) in Sierra Leone, Liberia, Guinea, Ivory Coast, Ghana, Nigeria, and at the humid fringes of the savanna in other nations;

Table 1. Total rice area and percentage of upland rice in West Africa (FAO 1970),

Country	Total rice area (thousand ha)	Upland rice area (thousand ha)	Upland rice area (%)
Sierra Leone	320	194	60
Guinea (Conakry)	280	168	60
Nigeria	160	100	62
Ivory Coast	290	260	89
Liberia	230	280	100

c. **upland rice dependent upon groundwater and rain** is planted on 46,000 ha (2% of the total rice cropping area) in Senegal, where it grows on shallow soils where the water tabla is near the surface; and
d. **upland rice grown using groundwater only** is cultivated on 12,000 ha in Mali (0.5% of the total rice cropping area) on flood recession areas of lakeshores on soils with high water retention capacity.

Flatland rice

Flatland rice cultivation with minimum to adequate rainfall represents the major upland rice area and can be divided into the drought-prone and the moist forest zone, depending upon moisture distribution.

Drought-prone zone. Although total upland area within the drought-prone and moist forest zones is not documented, available figures indicate that the drought-prone zone is small.

Adequate drought tolerance is the most essential trait for rice varieties to successfully produce grain in this zone, but plants must also tolerate high levels of solar radiation and high temperatures that accompany drought periods. Varieties for this region must sometimes adapt to occasional short periods of high moisture conditions.

Moist forest zone. Most of the flatland rice area is within the moist forest zone, which has heavy to very heavy rainfall during the upland rice growing season. Hill rice also is grown in moist forest zone conditions. Both types are cultivated using slash and burn bush fallow cultivation systems and are often planted with other crops.

The moist forest zone has adequate rainfall distribution, milder temperatures than other areas, and low solar radiation levels during the rice growing season. Drought does not occur regularly. In most of the moist zone, low tillering and earliness are not essential, making it possible to increase upland variety productivity.

Soil water conservation, fertilization, proper agronomic practices, and scientific crop mixture will also increase yields. Lack of suitable varieties and nitrogen-deficient soils are the major yield constraints (De Datta and Feuer 1975).

Moormann and Veldkamp (1978) classified West African upland rice lands without water management by topography and water supply. Table 2 lists the type of water supply associated with major natural categories of rice land.

Table 2. Sources of natural direct water supply in rice lands.

Rice land category	Availability of		
	Rain	Subterranean water	Surface water
Pluvial	always	not	not
Phreatic	partial[a]	always	not
Fluvial	partial[a]	partial[a]	always

[a] Except in the most arid desert climates where no rain falls, or more seldom, no subterranean water is received.

According to Moormann and Veldkamp (1978), upland, as used by WARDA, includes pluvial and phreatic water supplies, while dryland and hydromorphic are equivalent to pluvial and phreatic.

The Technical Advisory Committee (TAC) to the Consultative Group on International Agricultural Research (CGIAR) (Lamey et al 1980) defined upland rice as rice grown using no water control or additional water beyond rainfall or natural changes in water table; soil water level not normally above soil surface, except during occasional flooding; and flat or undulating topography where bunding my or may not be present.

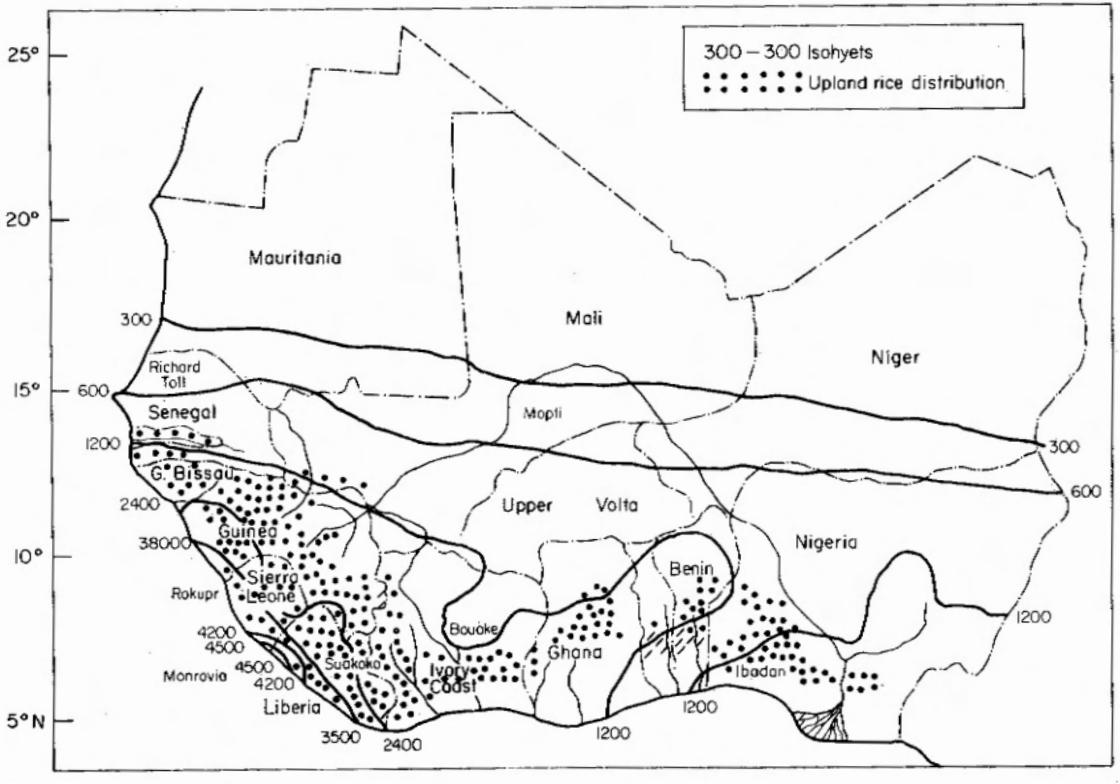
CLIMATE

Rainfall

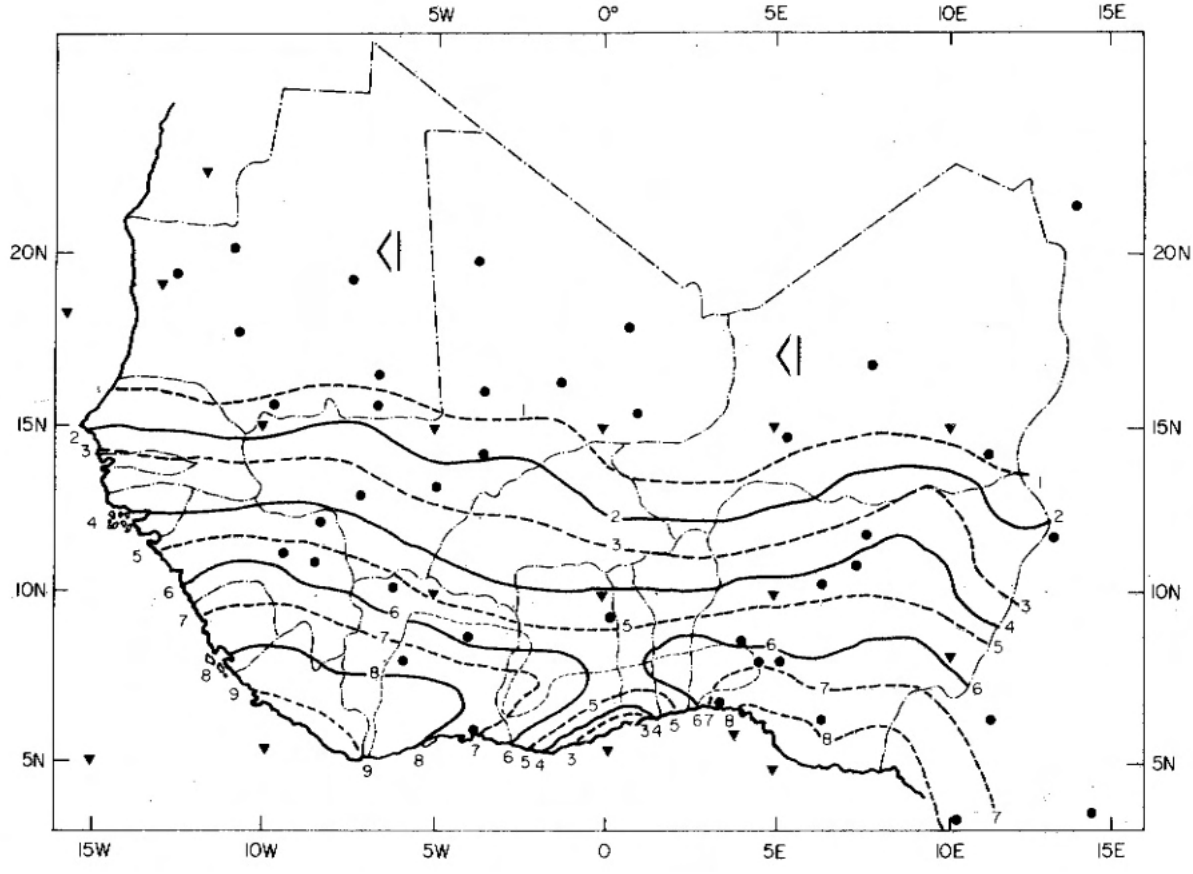
Rainfall is the most important factor for upland rice cultivation. The rainy season in West Africa may begin between March and July and continue to October. Rainfall distribution may be monomodal (one peak) or bimodal (two peaks) with a 1- to 4-week dry period in between.

In monomodal areas upland rice is planted in May-June. In bimodal areas rice is usually planted during the first rainy season, which starts in March. Rainfall characteristics, prevailing high evaporative demand in certain areas, and the relatively infertile soils of West Africa interact to cause occasional moisture stress during the upland rice season (Lawson 1980). A rainfall distribution pattern for West Africa is shown in Figure 1. Drought-prone areas are found both in monomodal and bimodal zones. Most of the moist forest zone is in the monomodal area.

Northern West Africa has inonomodal rainfall with irregular onset and cessation of rains (Lawson 1980). The southern areas, roughly between 8°N latitude and the coast and 7-1/2°W and 5°E longitude, have bimodal rainfall with a pronounced drop in rainfall in July or August (Lawson 1980, Fig. 2). Ivory Coast, Ghana, Togo,



1. Rainfall and upland rice cultivation in West Africa.



2. Number of months with positive water balance (precipitation ≥ evaporation) in bimodal rainfall cropping area of West Africa (Lawson 1980).

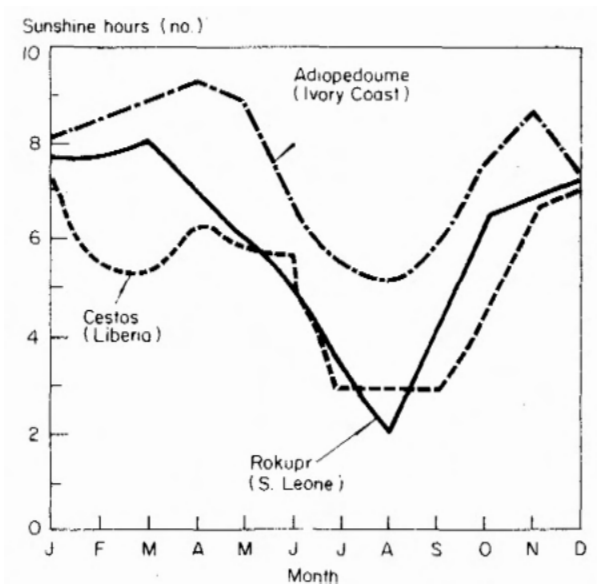
Benin, Nigeria, Guinea, and Liberia have areas within this zone (FAO 1970). A third rainfall zone, called pseudo-bimodal, where the July-August rainfall decline is not pronounced, is located east and west of the bimodal zone (Lawson 1980).

Solar radiation

In West Africa, solar radiation varies widely between the savanna and moist zones. At Rokupr, Sierra Leone, a typical upland rice area in the moist zone, clouds reduce average daily sunshine hours in June to 5.2. In August there are 2.1 sunshine hours each day. At Cestos, Liberia, August average daily sunshine is about 3.0 hours. Adiopedoume, Ivory Coast, also in the moist zone, receives about 4.7 hours of daily sunshine in August (Fig. 3).

Solar energy is a less critical factor than moisture supply for upland rice in Africa. Short sunshine hours in the moist zones do not limit yield because sunshine is rich in ultraviolet and blue light. The tendency of rice plants to grow taller under low solar energy and high temperatures is counterbalanced by the blue light, which inhibits plant elongation in most varieties (Vergara 1976).

High solar radiation does not improve upland rice yields in the savanna zones, and may be harmful if moisture supply is inadequate. Upland rice farming done



3. Average sunshine hours in selected areas in West Africa.

under the shade of trees sometimes minimizes upland rice drought susceptibility.

Temperature

Temperature is related to solar intensity in the moist zone, and is usually mild during the rice cropping season. In the savanna, which is drought prone, temperatures are higher during the growing season. High temperatures and low relative humidity sometimes cause high sterility and partial desiccation of leaves and spikelets.

Wind

Wind has little or no effect on upland rice in Africa. There are almost no storms or strong winds during the upland rice growing season in West Africa. Prevailing breezes are usually helpful. Rains are usually not accompanied by winds.

Evapotranspiration

Rice water requirements range from 5 to 6 mm/day (Chabrolin 1970). A mean maximum evapotranspiration value of 4 to 4.5 mm/day has been recorded for the upland rice variety OS6 (Lawson and Alluri 1980). Erosion from heavy rains often exposes coarse soils and reduces their moisture-holding capacity. Upland crops often are damaged if there is no rain for more than 10 days.

Day length

Although seasonal variation in day length is small for the whole of West Africa and some rice varieties could be affected in the north, most upland rice varieties grown in West Africa are photoperiod insensitive.

CROPPING SYSTEMS

Cropping systems in West Africa are determined by climate and land profile. Rice planting dates vary by rainfall pattern. Slash-and-burn systems where rice is intercropped with other upland crops are common in the forest belt. Shifting cultivation is also used. Mixed cropping and intercropping are practiced to minimize the risk of total crop failure.

In Liberia and southern Sierra Leone, farmers intercrop upland rice with cassava. In some areas of

Sierra Leone and Guinea, farmers also intercrop maize, cowpea, and pigeonpea (Mahapatra et al 1978). Cocoyams are grown with upland rice in Nigeria, Benin, Togo, and Ghana. Cassava and yams often are planted with upland rice in Ivory Coast. In the northern parts of these countries and in countries within the sub-humid zone, sorghum and pearl millet are intercropped with upland rice, but usually without a fixed pattern. About 10-20% of the area is planted to crops other than rice. Short-duration rice varieties are intercropped with long-duration pigeonpea, pearl millet, and sorghum, and long-duration rices are preferred for cropping with cowpea and maize.

Research has shown that traditional upland rice cropping practices can be improved by using modern cultural techniques and scientific land management technology to maximize outputs. Using a system that included rice, cowpea, sorghum, and maize, Mahapatra et al (1978) showed that proper land preparation, line sowing, fertilization, and weed control produced yields superior to those harvested using traditional methods. Rice yields have been increased by as much as 115% with improved cropping methods.

Rotational cropping has been studied for the comparative efficiency and economics of upland rice-based cropping systems (Mahapatra et al 1978, Table 3).

Where rice and cassava were grown together, 1.2 to 1.5 t of rice in addition to 12 to 15 t of tuber yield of cassava have been harvested as compared to a rice-crop-only yield of 1.2 to 1.4 t/ha.

Multiple cropping experiments in Sierra Leone that tested rice and 15 other upland crops in areas with high rainfall and sloping terrain showed that cassava and pearl millet yielded highest among root and tuber

Table 3. Mean yields of crops tested in the first year of a 3-year rotation (Mahapatra 1978).

Rotational pattern	Mean yields (kg/ha)	
	Rice	Other crops
Rice - rice - rice	1,226	-
Rice + pigeonpea - rice + cassava - rice	262	11,365
Rice + cassava - rice + pigeonpea - rice	1,196	14,786
Rice + pigeonpea - rice + cassava - rice	344	10,833
Rice + cassava - rice + pigeonpea - rice	671	14
Rice + cassava - rice + pigeonpea - rice	1,489	12,310
Rice + pigeonpea - cassava - rice	395	13,340
Rice - pearl millet - rice	1,363	1,711

and cereal crops. In 1978, a uniform crop of rice was yrown without fertilizer application to study the residual effect of continuous growing of various crops at the same site (Table 4).

In 1978, the highest rice yield (2.3 t/ha) was harvested from plots grown where cassava had been planted 2 years. Plots planted with cocoyam or pigeon-pea for 2 years produced the next highest rice yields of 1.5 and 1.4 t/ha.

SOIL-WATER-CROP MANAGEMENT

Rice is a semiaquatic plant. It tolerates wet lands where other cereals will not grow and also grows in drier soils, although it is much less tolerant of low soil moisture than other cereals. Rice production is limited to land where adequate water is available in the upper 20-25 cm of the soil profile during part or all of the plant growth period (Moormann and Veldkamp 1978). Water content at this level of the soil profile is that which will be most rapidly depleted during periods of low water supply; therefore, rice suffers from drought sooner than any other cereal crop, even

Table 4. Yield of crops grown in a 3-season multiple cropping experiment, 1976-78.

	Mean yield (t/ha)		Mean Over 2 years (t/ha)	1978-mean rice yield (LAC23) (t/ha)
	1976	1977		
Cereals				
Rice – rice – rice	1.3	1.9	1.6	0.4
Maize – maize – rice	0.4	0.8	0.6	0.6
Sorghum – sorghum – rice	0.1	0.4	0.3	0.5
Pearl millet – pearl millet – rice	1.7	5.1	2.9	0.9
Digitaria – digitaria – rice	0.5	1.0	0.7	1.1
Grain legumes				
Cowpea – cowpea – rice	0.2	0.08	0.2	0.9
Pigeonpea – pigeonpca – rice	0.1	–	0.1	1.4
Soybean – soybean – rice	0.8	0.3	0.6	0.9
Oil seeds				
Groundnut – groundnut – rice	0.4	3.8	2.1	1.1
Beniseed – beniseed – rice	0.01	0.01	0.01	0.7
Roots and tubers				
Cocoyam – cocoyam – rice	0.3	0.3	0.3	1.5
Cassava – cassava – rice	24.2	35.4	29.8	2.3
Vegetables				
Sweet potato – sweet potato – rice	1.4	1.9	1.6	1.11
Stringbean – stringbean – rice	0.1	0.1	0.1	1.2
Tomato – tomato – rice	1.3	0.4	0.9	1.1

though its consumptive water requirements are similar to those of other cereals.

Available moisture in the upper 20 – 25 cm of the soil profile varies not only with water supply, but also with the layer's water retention properties that are determined by texture, kind, and amount of organic matter and clay mineralogy.

Rainfall distribution and water availability

Moormann and Veldkamp (1978) recorded that water availability in the root zone during various upland rice crop growth stages is determined by rainfall and other climatic factors, soil characteristics, soil management, and varietal water use characteristics.

The primary production-determining factor for upland rice is the amount and distribution of rainfall. Rice needs 600 mm of rain to complete its growth cycle (Cocheme 1971). Brown (1969) reported that 1,000 mm of annual rainfall, with 200 mm monthly rainfall during the growth season, is a minimum requirement for upland rice cultivation.

Daily rainfall is more critical than monthly or annual rainfall. Moisture stress can damage or kill plants in an area that receives 200 mm in one day and receives no rainfall for the next 20 days. An even distribution of 100 mm precipitation/month is better than 200 mm/month received in 2 or 3 days. If, as Brown reported, upland rice cannot be grown with less than 200 mm/month of rainfall, many areas of the world, including West Africa, are unsuited for upland rice production (De Datta and Vergara 1975). Moormann and Veldkamp (1978) found that for most soil conditions, upland rice production is submarginal with less than 1,000 mm annual rainfall, marginal between 1,000 and 1,300 mm, and fair between 1,300 and 1,600 mm. With higher annual rainfall, water is not a constraint.

Daily rainfall is critical in areas with low annual rainfall, but rainless periods can damage the rice crop even in high rainfall zones. Drought periods occur regularly in upland areas of West Africa (Moormann 1973), even in areas with 2,000 mm annual rainfall or more.

Soil characteristics and drought stress

The interaction of drought stress and soil characteristics in upland rice cultivation is not well understood. Clay holds moisture better than acidic sandy or coarse loam soils. Clay mineralogy also plays an important role in water availability. Kaolinitic soils in West Africa constrain rice cultivation.

Most upland rice growing soils are freely drained or hydromorphic. In freely drained soils rice depends entirely on rainfall for moisture. Hydromorphic soils retain more moisture and are less dependent upon rainfall distribution patterns. Primary hydromorphic soils in West Africa are Entisols, Ultisols, and Vertisols. Riquier (1971) devised the following guide to soil suitability for upland rice cultivation in West African countries:

1. Senegal -- upland rice can be grown on Ferric and Gleyic Luvisols south of the Casamance River, where rainfall is satisfactory;
2. Guinea Bissau -- upland rice is grown on low fertility Ferralsols and in some mangrove soils;
3. Guinea -- upland rice is grown on Humic Ferralsols on hills;
4. Sierra Leone -- poorly drained areas are suitable for upland rice;
5. Liberia -- upland rice is grown on Oxisols that degrade rapidly;
6. Upper Volta -- in the north, soils are dry and fine textured and similar to sodic soils which are difficult to cultivate;
7. Niger -- northern valleys are too sandy for successful upland rice cultivation;
8. Nigeria -- substantial areas are suitable for upland rice cultivation; and
9. Ivory Coast -- upland rice areas are good.

Soil nutrients. West African soils generally have major nutrient deficiencies. Optimum requirements of major elements vary widely, but rice in all ecologies must receive fertilizer applications to produce satisfactory grain yield.

Problem soils are a major constraint to upland rice production in many rice growing areas of West Africa. Although nutrient problems vary, the most common are deficiencies of manganese, iron, phosphorus, calcium, sulfur, zinc, and nitrogen, and aluminum and manganese toxicity. Most soils need 30 to 60 kg N/ha, depending on rainfall, available nutrients, and rice variety. Optimum potash and phosphorus application levels have not been established.

Upland rice in West Africa is grown primarily on Alfisols and Ultisols. Ultisols are most common (Moormann and Veldkamp 1978). Other freely drained upland soils include Nitosols, Acrisols, Luvisols, Ferralsols, and Cambisols (De Datta 1981).

Total available West African area climatically suited to upland rice production is enormous; however, soil quality for sustained, high-yielding rice production is low, soils are generally leached, have kaolinitic clay mineralogy with unfavorable cation

retention characteristics, sandy to coarse loamy surface soil texture, and are highly erodable. Effective soil water retention is low, and plants often suffer from drought.

Organic matter. Moormann and Veldkamp (1978) determined that the role of organic matter in rice soil quality is almost as diverse as crop environment. Organic matter increases available water-holding and cation exchange capacity (CEC), improves soil structure, and provides nutrient, particularly nitrogen, mineralization process.

The importance of organic matter in upland rice lands is reflected by local cropping systems. When fallow bushlands are cleared, soil organic matter content is moderately favorable. However, after 1 – 2years of cultivation, topsoil organic matter diminishes to 0.5 – 0.8%organic carbon. Although nutrients provided by organic matter can be replaced by fertilization, available water – holding capacity and CEC decrease as organic matter diminishes. On the predominantly sandy kaolinitic soils, land becomes progressively more droughty and less fertile each year after the initial clearing. Upland rice yields best if grown immediately after land is cleared.

Upland rice lands often are sulfur deficient because most well – drained soils have low sulfur content and upland rice varieties use large amounts of sulfur. In pot trials at the International Institute of Tropical Agriculture (IITA) using an Entisol from western Nigeria with Less than 1 ppm SO_l and OS_6, IR20 cultivars grown as upland rice showed significant response to added sulfur (Kang 1973). Ofori (1963) showed that upland rice in the Hohoe district of Ghana yielded better when ammonium sulfate was used as a nitrogen source than when calcium nitrate or ammonium nitrate was used. Increased yield was attributed to added sulfate.

Soil erosion and soil water conservation

In West Africa, increases in yield per unit area or increases in rice area imply the change from shifting cultivation and bush – fallow systems to permanent arable or lay systems. If these changes become economically and technically feasible, large areas may become available for upland rice cultivation. It has been argued that improved upland rice technology may induce large – scale additional deforestation, massive erosion, and leaching damage to fragile soils in the more humid areas, and expand savanna areas populated with grassy weeds such as Imperata sp. However, improved pluvial rice technology may make it economically rewarding to change from shifting and bush – fallow cultivation to

permanent arable farming or lay farming with intensified intercropping that will make substantially increased food production possible (Lamey et al 1980).

Studies on soil and water conservation and zero or minimum tillage practices are necessary to learn how to combat massive erosion problems, leaching, and permanent damage to upland rice lands.

Crop establishment and machinery for upland rice

In West Africa 98% of the rice land is hand cultivated using methods that vary greatly between countries. Little or no tillage is used on lands under shifting cultivation. Rice grown in shifting or bush-fallow systems usually shows limited response to additional inputs. Small-holder farming prevails. Motorization is rare, most tractor schemes have failed, and animal traction is rare because of trypanosomiasis.

Farmers usually broadcast seed because there are no effective low-cost seed planters or dibbling machines available. Low seeding rates, improper planting methods and seed cover, and low seed germination cause low plant population, high weed infestation, and low grain yields.

Studies in Sierra Leone show that upland rice yield can be increased 75 to 190% by seed dibbling, 34% by timely weeding, and 60% by topdressing 40 kg N/ha. Although manual dibbling in fields with standing stumps is labor consuming, extra yield amply compensates for the additional labor investment. Improved implements 1ike the IITA-developed rotary-jab-planter and rotary-punch-planter which can be manipulated around stumps will encourage these practices. IITA is also developing a four-row no-till planter for upland rice that plants hills of seeds spaced at 25 x 25 cm. Planting rate is 8 to 10 hours/ha with this equipment, which is much less than manual planting, and improves rice stand.

Development and introduction of a suitable low-cost rice seed planter for small farmers are necessary, as are further studies on mechanical cultivation and use of animal traction. Use of good seed and proper seed storage also must be encouraged to assure good upland rice crop establishment and adequate plant population.

PEST MANAGEMENT

Weeds

Without effective weed control even the best rice variety will not produce maximum yield. Weeds are a major constraint to upland rice production in West

Africa, and are particularly limiting to large-scale expansion in upland rice growing areas.

Experiments at Suakoko, Liberia, with variety LAC23 showed that fertilizer application and weed control improve upland rice yields under bush fallow - rice - rice cropping systems (Das Gupta 1982). Line sowing facilitated weed control. Only marginal grain yield increase was achieved by bunding in humid conditions, and improved pest control techniques were not economically practical (Table 5).

Weeds compete with rice for light, nutrients, and water; are alternate hosts for insects and disease-causing organisms like fungi, bacteria, and nematodes; and are hideouts for rodents. Weeds also interfere with cultural practices, particularly harvesting, cause rice seed contamination with weed seeds, and block canals and dams.

Weeds cause severe damage to most crops in the first 30-40 days of growth. After this time rice competes well if it is adequately fertilized, there is no moisture stress, and plant population is optimum with no insect and disease problems. Estimated rice yield losses caused by weeds are shown in Table 6.

Informatioh on yield lost to weeds in West African upland rice production is scanty. Recorded yield losses vary widely by site and weed species. However, weed problems are so serious in some areas that upland rice cannot be profitably grown without weed control measures. Average upland rice yield reductions caused by weeds are shown in Table 7.

Weed flora in upland rice is more diverse (153 species recorded) than in lowland rice (104 species recorded) (Godderis 1981). Although upland rice is cultivated in ecological zones ranging from humid forest throuyh savanna, weed flora does not vary greatly, but intensity of infestation and dominant weed species in a particular habitat do vary. Some common upland rice weeds are grasses Imperata cylindrica (spear grass), Digitaria horizontalis (crabgrass), Rottboellia exaltata (corngrass), Brachiaria deflexa (paragrass), Pennisetum pedicellatum, and Eleusine

Table 5. Effects of various agronomic practices on yield and weed count, Suakoko, Liberia, 1981.

Agronomic practice	Yield (t/ha)	% over control	Weeds (no./m^2)
Fertilizer, line sowing, weed and insect control	1.3	126	162
Insect control	1.3	129	160
Weed control	0.7	19	331
Fertilizer	0.6	16	171
Line sowing	1.3	130	204

Table 6. Estimated rice yield losses caused by weeds (Olunuga 1981).

Crop	Yield reduction (%)
Upland rice	70-100
Lowland rice	33-75
Direct seeded rice	46-84

Table 7. Yield losses to weeds in some WARDA member countries.

Country	Yield loss (%)	Reference
Gambia	100	WARDA 1976
Ghana	84	Aryeetey 1970
Nigeria	80-100%	Fagade 1976, Williams 1975
Senegal	48	WARDA 1976
Upper Volta	62	WARDA 1976
Liberia	39-87	Carpenter 1973, WARDA 1976

indica; the broadleaf dicots Eupatorium odoratum (siam weed), Aspilia africana (sunflower), Striqa hermonthica (witchweed), Euphorbia heterophylla (milkweed), and Ageratum conyzoides; and the grasslike weeds Cyperus rotundus, Cyperus esculentus, Cyperus distans, Mariscus umbellatus, and Mariscus alternifolius.

Control. Weed control practices in upland rice cultivation can be classified as physical weeding: by hand hoeing or cutlassing, using fire to destroy the existing vegetation during the dry season, and/or hand-pulled tractors, or mounted equipment like plows, harrows, ridgers, etc.; cultural control: biological agents like insects, fungi, and bacteria to attack specific weeds, and methods that prevent weed establishment by ensuring that rice seeds planted are free of weed seeds; and herbicide control: this method is cheaper to use than hand control; is more attractive to farmers because of reduced drudgery; interrow application is possible; preemergence herbicides provide early season weed control; reduces the need for tillage which often destroys soil structure, encourages erosion, and injures the crop; and is adaptable to small- and large-scale producers. It must be emphasized that good farm management most often combines two or more methods for good weed control. Integration of control methods makes it possible to use the most effective Weed control techniques for the crop development stage.

Diseases

Average upland rice yields in West Africa vary from 0.7 to 1.5 t/ha. Low yields can be partially attributed to

disease incidence. Brown spot disease (BS) (Helminthosporium oryzae syn. Dreschlera oryzae) causes upland rice yield reductions of 12–43% in Nigeria (Aluko 1970). Leaf blast (Bl) (Pyricularia oryzae), neck rot (Pyricularia oryzae), leaf scald (LSc) (Rhynchosporium oryzae), false smut (FSm) (Ustilaginoidea virens) also reduce upland yields. Bl is the most widespread and economically important disease in Sierra Leone (Raymundo and Fomba 1979). In varieties ROK 3, Mange 2, and CCA, neck blast (NBl) has caused yield losses that vary from 3.2 to 14.5%. Losses up to 80% have been reported for susceptible varieties. Bl losses ranging from 9.8 to 32.2% have been reported in Nigeria (Awoderu and Esuruoso 1974).

Although LSc affects both upland and lowland rice, it causes more damage under upland rice conditions. Up to 45% of the plants in a field can be affected. LSc is widespread in Nigeria, Niger, Liberia, Benin, Ivory Coast, Sierra Leone, Senegambia, Upper Volta, Mali, and Guinea–Bissau. FSm has seriously damaged upland rice in Ivory Coast, Sierra Leone, and Nigeria.

Upland rice is being produced in three climatic zones in West Africa. They are the humid or moist tropical zone, the Guinea savanna, and the Sahel (Sudan savanna). During WARDA monitoring tours in 1977–78, disease incidence and relative prevalence in different zones were recorded (Table 8). Disease problems were most severe in the humid tropical and the savanna areas.

Upland rice research programs must develop and incorporate disease control measures for their projects. Disease management must include methods to survey and forecast disease outbreaks and provide reliable

Table 8. Upland rice diseases in major West African climatic zones.

Common name	Scientific name	Disease incidence		
		Humid tropical	Guinean savanna	Sudanian savanna (Sahel)
False smut	*Ustilaginoidea virens*	xx	x	–
Sheath blight	*Rhizoctonia solani*	x	x	x
Pale yellow mottle	Virus	x	–	–
Grassy stunt		x	–	–
Seedling blast	*Pyricularia oryzae*	xx	xx	
Leaf blast	*Pyricularia oryzae*	xx	xx	x
Neck rot	*Pyricularia oryzae*	xx	xx	x
Brown spot	*Helminthosporium oryzae*	xx	x	–
Leaf scald	*Rhynchosporium oryzae*	xx	xx	–

[a]xx = prevalent, x = uncommon, – = absent.

Table 9. Major insect pests in rice ecosystems in Africa.

Insect	Occurrence[a]		
	Upland	Lowland	Irrigated
Maliarpha separatella	x	xx	xx
Chilo zacconius	x	x	xx
Chilo diffusilineus	xx	x	x
Chilo partellus	xx	x	x
Scirpophaga spp.	x	xx	xx
Sesamia spp.	xx	x	x
Diopsis spp.	x	xx	xx
Nymphla depunctalis	–	xx	xx
Orseolia oryzae	–	xx	xx
Nephotettix spp.	x	xx	xx
Epilachna similis	xx	x	x
Spodoptera spp.	xx	x	x
Gryllotalpa africana	xx	–	–
Aphids	x	–	–
Termites	xx	–	–

[a]xx = abundant, x = present but not abundant, - = absent.

data on the crop loss attributable to each disease. Most WARDA member countries lack such data.

A 1981 coordinated variety trial showed that IRAT 165 was resistant to LBl, NBl, and LSc and that IRAT 166 was resistant to LBl, NBl, LSc, and BS. The varieties yielded 2.0-3.5 t/ha. Emphasis should be placed on developing host plant disease resistance and more research must be done to determine horizontal resistance to existing diseases and multiple resistance to the major diseases in the upland ecology. Although pesticide management is expensive and hazardous, it is a necessary standby measure in case of serious unexpected disease outbreaks.

Insects

Several insects attack rice but only a few are key pests. Macro- and micro-environmental factors affect insect pest distribution and certain pests prefer one ecosystem to another. Thus, insect pests like caseworm Nymphula depunctalis, the gall midge Orseolia oryzae, and the- stalk-eyed flies Diopsis spp. are more frequently found on irrigated and lowland rice. Armyworm Spodoptera spp. and soil insects such as termites and the mole cricket Gryliatalpa africana are found in all ecosystems. Table 9 shows the general distribution of important insect pests in different rice ecosystems.

Research on insect pests of rice in Africa is limited and there is even less information on upland rice insects. However, a few countries like Ivory Coast and Nigeria have initiated programs to study upland

rice insects. Because most countries do not have research facilities and manpower to conduct insect research, a regionally coordinated effort should be developed. For major pests, control measures that utilize research work done in selected areas could be devised.

Some of the basic research needed includes survey and identification of insect pests of upland rice; ecological studies, including population dynamics research crop loss assessment and economic thresholds; control methods -- chemical (pesticide management), cultural (host plant resistance), biological (natural enemies); development of integrated pest management strategies; and effects of cropping systems on upland rice insects.

VARIETAL IMPROVEMENT

History

Rice research at Moor Plantation, Nigeria, was started in the 1920s to serve Nigeria, Ghana, and Sierra Leone. The National Institute for the Development of the Congo (Zaire) began collecting rice varieties in 1933 (Jacquot 1978). Crosses between local and introduced varieties produced OS6 and R66. OS6 is still successfully grown in some West African countries. The Rice Research Station at Rokupr, Sierra Leone, was established in 1934 to study flooded rice. It was expanded in 1953 to serve the anglophone countries of West Africa and to include upland rice. Upland rice research in Liberia was started in the 1950s at Harbel, then shifted to Suakoko in the 1960s. In Senegal, upland rice research was initiated in the 1950s. Variety 617A was developed and Iguape Cateto was introduced and distributed. Rokupr started a hybridization program in 1951, but the upland varieties released in subsequent years were mostly from pureline selections and introductions.

Upland selection criteria

The selection criteria for upland rice varieties in West Africa are semitall stature, long leaves, drought tolerance, Bl resistance, maturity to suit local conditions, low tillering for early maturity, medium tillering for medium maturity, deep root system, shattering resistance, resistance to common insects (stem borers), white slender to medium type grain quality, and low sterility.

Traditional upland varieties are 1.2 to 1.8 m tall, have 5 to 10 culms/plant in close row spacing; are thick stemmed with broad, rather long, bright or

dark green leaves, have long panicles, and high proportion of thick roots (Jacquot 1974). Since the early 1970s, top priority has been given to reducing plant height to prevent lodging, increasing fertilizer response, and making plants more physiologically efficient. Optimum plant height varies by growing condition, but 100-120 cm is a common range. Most traditional West African varieties have horizontal Bl resistance but most early introductions have vertical resistance (Jacquot 1974). Slightly spreading tillering habit and fully emerged panicles appear to reduce Bl infection (Jacquot 1974). Because panicle length is somewhat positively correlated to plant height and leaf length, reducing plant height probably will cause shorter panicles in new varieties,

Breeding programs

WARDA confines its varietal improvement activities to introduction of varieties developed in other countries and selection. Other national and international agencies use these methods plus hybridization and induced mutation. The Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (IRAT) and the International Institute of Tropical Agriculture (IITA) have conducted substantial varietal improvement work. National programs that have successful varietal improvement programs are National Cereals Research Institute at Ibadan, Nigeria; Institut Senegalais de Recherches Agricoles at Djibelor, Senegal; the Rice Research Station, Rokupr, Sierra Leone; and the Central Agricultural Research Institute, Suakoko, Liberia.

Since 1975, WARDA has provided one or two scientists to the Institute of Savanna (IDESSA) to strengthen the upland rice research program. Many lines developed at Bouaké have been screened at a variety of locations (WARDA 1978). In 1979 most promising lines bred at Bouaké were characterized and grain shattering

Table 10. Upland rice varieties developed at different stations.

Station, country	Variety
Djibelor, Senegal	1 Kong Pao, SE 302G, SE 314G, SE 319G, Dj 12-539-2
Sapu, Gambia	IR442-2-58
Rokupr, Sierra Leone	ROK 1, ROK 2, ROK 3, ROK 16
Suakoko, Liberia	LAC 23, LAC 23 (white)
Bouake, Ivory Coast	Dourado Precoce, IRAT 8, IRAT 9, IRAT 10, IRAT 13, IRAT 109, IRAT 110, lRAT 112, IKAT 133, IRAT 138, IRAT 142, IRAT 144, lRAT 170
Moor Plantation, Nigeria	OS6 SEL IRAT 194/1/2

Table 11. Upland variety trials conducted in the WARDA region, 1973-81.

Trial[a]	Locations (no.)[b]								
	1973	1974	1975	1976	1977	1978	1979	1980	1981
IET (upland and irrigated entries combined)	–	6 (15)	6 (62)	7 (76)	12 (400)	X	–	–	–
IET (upland)	–	–	–	–	–	8 (136)	12 (279)	14 (236)	11 (174)
Upland variety trial (short duration)	7 (7)	13 (7)	12 (10)	11 (12)	11 (14)	10 (14)	11 (14)	X	X
Upland variety trial (medium duration)	6 (9)	12 (13)	12 (17)	9 (11)	10 (13)	7 (14)	11 (14)	X	X
Savanna upland (short duration)	–	–	–	–	–	–	–	7 (14)	9 (14)
Moist zone upland (short duration)	–	–	–	–	–	–	–	18 (14)	17 (14)
Moist zone upland (short duration)	–	–	–	–	–	–	–	21 (14)	15 (14)

[a]IET = Initial Evaluation Test. [b]Figures in parentheses represent number of entries per location. – = no trial conducted, X = test/trial reorganized.

studies were started (WARDA 1979). Field experiments in 1980 tested selections from F_3 populations, screened varieties for shattering, investigated problems associated with varieties that have more opened glumes, and conducted varietal improvement trials (WARDA 1981).

Improved varieties

In recent years many improved upland strains have been developed by national and international programs in West Africa. Improved upland rice varieties are tested in the WARDA Initial Evaluation Test (IET), which is conducted in 14 West African sites every year. Varieties selected from IET are tested in the WARDA Coordinated Variety Trials (CVT) in member countries. The upland trial sites are Sefa, Senegal; Sapu, Gambia; Contuboel, Guinea Bissau; Farakoba, Upper, Volta; Rokupr, Sierra Leone; Suakoko, Liberia; Bouake, Ivory Coast; Nyankpala, Ghana; Sotoubova, Togo; Ina, Benin; Moor Plantation, Nigeria; IITA, Nigeria; Geuckedu, Guinea; and Sikasso, Manil.

National scientists identify superior varieties for their ecologies. This program has helped identify and release several superior upland rice varieties. Most of the recently improved varieties came from the IDESSA-IRAT project at Bouaké.

Since 1973 the upland rice improvement program in the WARDA region has resulted in some yield improvement. Because most activities have been confined to varietal development, newly developed upland rice varieties have specific adaptability and many lack some desirable characters. Varieties developed at different stations are shown in Table 10.

A list of coordinated upland variety trials conducted in the WARDA region is shown in Table 11. All the varieties developed in the region and many other introduced varieties have been tested, and some are still being tested, to determine their adaptability in different upland ecologies.

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UPLAND RICE IN ASIA

IRRI

BACKGROUND

Definition

Upland rice has been defined many ways in different parts of the world. For the 1982 Bouaké conference upland rice was defined as "rice grown in rainfed, naturally well-drained soils, without surface water accumulation, normally without phreatic water supply, and normally not bunded." Because it is grown in aerated soils, upland rice is often planted with or instead of other cereals (maize, sorghum), legumes (beans, cowpea), root crops (cassava, sweet potato), or sugarcane. Intercropping is common in upland areas throughout Asia.

Table 1 shows the areas of the major rice cultural types as they are planted In Asia (Huke 1982). Huke used the term dryland in place of upland, and defined it as "rice grown in fields that are not bunded, are prepared and seeded under dry conditions, and depend on rainfall for moisture," the traditional definition used by IRRI in upland rice research (De Datta 1975a).

Distribution

Upland rice is planted on about 11.6 million hectares, 13% of the rice area of tropical Asia (excluding China, Japan, and Korea) (Table 1). South Asia has nearly 7.0 million hectares and Southeast Asia 4.6 million hectares. More than half of all area is in India (6.0 million hectares). Indonesia is the only other nation with more than 1 million hectares of upland rice. Nine of 14 countries in the region grow upland rice on more than 0.3 million hectares. Upland rice areas are widely dispersed within the countries (Fig. 1, 2), contrasting with wetland rice, which is usually concentrated in river valleys and floodplains.

Average yields during the 1970s remained stagnant at around 1 t/ha (Barker and Herdt 1979). Research to increase productivity must consider numerous constraints caused by environmental diversity. Much more needs to be learned about the range of environments and their relative importance. Such information is essential to effective research efforts.

Table 1. Estimated rice area in major cultural types by country in South and Southeast Asia (source: Huke 1982).

Country	Area allocated (thousand ha)						
	Dryland	Deepwatcr	Irrigated [a]		Rainfed		Total
			Wet season	Dry Season	Shallow (0-30 cm)	Intermediate (30-100 cm)	
South Asia							
India	5,973	2,434	11,134	2,344	12,677	4,470	39,032
Bangladesh	858	1,117	170	987	4,293	2,587	10,012
Pakistan	–	–	1,710	–	–	–	1,710
Sri Lanka	52	–	294	182	210	22	760
Nepal	40	53	261	–	678	230	1,262
Bhutan	28	–	–	–	121	40	189
Total	6,951	3,604	13,569	3,513	17,979	7,349	52,965
Southeast Asia							
Burma	793	173	780	115	2,291	1,165	5,317
Thailand	961	400	866	320	5,128	1,002	8,677
Vietnam	407	420	1,326	894	1,549	977	5,573
Kampuchea	499	435	214	–	713	170	2,031
Laos	342	–	67	9	277	–	695
Malaysia	91	–	266	220	147	11	735
Indonesia	1,134	258	3,274	1,920	1,084	534	8,304
Philippines	415	–	892	622	1,207	379	3,515
Total	4,642	1,686	7,685	4,100	12,396	4,238	34,141
Grand total	11,593	5,290	21,254	7,613	30,375	11,587	87,712
%	13	6	24	9	35	13	

[a] Double-cropped areas ace counted twice.

Climate

Upland rice is more affected by uncertain rainfall distribution and variations in soil characteristics than wetland rice.

Rainfall. The most critical climatic determinants of upland rice yields are amount of rainfall during the growing season and rainfall distribution. These parameters vary widely in Asia.

During a 5-month growing season, average rainfall ranges from over 3,000 mm in Assam and West Bengal in eastern India to 600 mm or less in upper Burma and central India (Garrity et al 1982). Forty percent of the area receives 1,200 to 1,500 mm.

Length of growing season. Upland rice areas in South Asia have a short growing season, usually 3–4 months of rainfall adequate for crop growth. The extremely short, variable growing season in eastern Uttar Pradesh and Madhya Pradesh causes low average yields and frequent crop failures. Only very early-maturing varieties are adapted to these areas.

1. Dryland rice distribution in South Asia. Each dot represents 3,000 ha (source: Huke 1982).

Upland rice areas in Southeast Asia have adequate rainfall varying from 5 to 12 months per year. Indonesia and the Philippines have particularly long growing seasons. Medium-duration varieties (110-130 days) are most commonly grown.

Temperature. Most Asian upland rice is grown at low elevatlons where temperatures during the monsoon season range from 24 to 26°C (De Datta 1975b). Low temperatures are a constraint in some higher elevation

2. Dryland rice distribution in Southeast Asia. Each dot represents 3,000 ha (source: Huke 1982).

areas in India, Burma, Thailand, Vietnam, and Indonesia. Upland rice is not usually grown above 1,000 m.

Soils

Slope, soil texture, and soil fertility vary widely among major upland rice regions.

Slope. Most upland rice in India and Bangladesh is grown on level to gently rolling land (0 – 8% slope).

Little upland rice is found on steeply rolling or mountainous terrain.

In Southeast Asia, upland rice is usually grown where slopes exceed 8%. About 1.5 million hectares are planted in mountainous areas with slope greater than 30%. Soils in these areas often have excessive drainage and may erode rapidly. Shifting cultivation is often practiced.

Soil texture. Upland rice is most often planted on medium-textured soils in Asia. Fine-textured soils are most common in Southeast Asia. Coarse-textured soils are infrequent and limited to parts of South Asia.

Soil groups. The most common upland rice soils, according to the Soil map of the world (FAO 1979), are Acrisols (3.5 million hectares), covering 31% of the area (Garrity et al 1982), followed by Luvisols (2.3 million hectares), Cambisols (1.5 million hectares), and Nitosols (1.4 million hectares).

Orthic Acrisols are the most important upland rice soils. They are almost limited to Southeast Asia. Orthic Acrisols are chemically poor, strongly acid and weathered, and low in organic matter. They are most important in Thailand (0.5 million hectares), Burma (0.4 million hectares), and Indonesia, Vietnam, and Laos (0.3 million hectares each).

Dominant upland rice soils in South Asia are Ferric Luvisols, which have low fertility. The other major soils, however, have fair to excellent fertility. Upland rice soils with favorable fertility characteristics are more common in South Asia than in Southeast Asia.

Environmental complexes

A crop's physical environment is determined by the interaction of climate and soil. Preliminary classification of Asian upland rice has grouped sites with similar climatic and soil conditions. The most favorable environments, those with long growing season and fertile soils, make up only 15% of the total upland rice area. They are in east and southeast India (0.6 million hectares), Bangladesh (0.5 million hectares), Indonesia (0.3 million hectares), and the Philippines (0.2 million hectares). Improved upland rice technology is most likely to be developed and adopted in these areas.

The largest environmental complex is composed of sites with a long growing season but relatively infertile soils. It is the most important environment in Indonesia (0.8 million hectares).

Twenty-five percent of Asia's upland rice is planted where short growing season and infertile soils are major constraints. Yields will be difficult to increase under these conditions. Most of these ricelands are in north India.

UPLAND RICE-BASED CROPPING SYSTEMS IN ASIA

Upland rice-based cropping systems in Asia are diverse. Although the information reported in this section is limited, it seeks to show the diversity of upland rice-based systems by class and country. Published reports and personal communication with researchers in various Asian countries were combined to describe two predominant upland rice management systems -- those using permanent agricultural land, and systems employing shifting cultivation techniques. Technology from individual countries is discussed within each class.

Upland rice on permanent agricultural land

Most upland rice is grown on permanent fields. In Indonesia, Korea, Philippines, Sri Lanka, Bangladesh, India, and Nepal, almost all upland rice cultivation is on permanent agricultural land. Terrain varies from relatively flat to gently sloping or undulating. Soils are moderately to well drained. Cultivation practices in Bangladesh, India, and Nepal differ from other systems because some areas are alternately drought and flood stricken.

Indonesia. Major upland rice areas in Indonesia are West Java (129,000 ha), South Sumatra (127,000 ha), Lampung (119,000 ha), West Kalimantan (113,000 ha), and North Sumatra (110,000 ha). About 90% of the upland rice area is permanent agricultural land. Highest priority is given to lands that can be leveled to catch and conserve water for wetland rice, but population pressure has forced farmers to cultivate all available land.

Most farmers grow one rice crop intercropped with maize or cassava. After rice is harvested, legumes, maize, or cassava may be grown. Fertilizers are used in some areas of Java and in new transmigration areas outside Java. Average yields are 1-2 t/ha.

Although the productive capacity of red yellow Podzolic Soils, often infested with alang alang (*Imperata cylindrica*), in Lampung has been seriously questioned, McIntosh and Effendi (1979) found that large areas in Sumatra and West Java have adequate rainfall to grow upland crops all year. Rainfall exceeds 200 mm/month for 5-6 consecutive months and there are only 3 months when precipitation is below 100 mm. Soils are well drained and heavy rains do not inhibit upland crop cultivation. Runoff problems are minimized by rapid infiltration rates. Soils are leached and acid, but aluminum is not excessive and there is sufficient clay and organic matter to hold applied nutrients. Production constraints are low soil fertility, excessive drainage, low pH, and blast disease.

The Indonesian cropping systems network recommends the following cultivation pattern for these regions (Ismail and Sutjipto 1982):

> If fields are infested with alang alang, the weed is cut close to the ground and soil is cultivated before the rainy season. Land is left fallow for at least 1 month to let alang alang roots dry and decompose. At the onset of the rainy season, soil is prepared for planting maize and rice. Maize is planted in strips 2 m apart. Seeds are dibbled by hand, 50 cm apart. Two weeks later rice is planted between maize rows. Seeds are dibbled 10 cm apart in strips spaced every 40 cm. One month after rice planting (45 days after maize planting) cassava sticks are inserted between maize hills in every other row, spaced at 50 x 400 cm. By the time rice flowers maize is harvested. In this way maize does not shade rice in its most critical stage. When rice is harvested, straw is cut close to the ground and placed inside the cassava rows. Now peanut seeds are dibbled beside each rice hill. Rice straw is spread on the soil to suppress weed growth and conserve soil moisture. After peanut is harvested, cowpea or rice bean may be planted. Fertilizers are applied close to the root zone. Normally one or two weedings are enough.

Korea. In Korea, 9,000 ha of upland rice are grown on well-established agricultural land in Gyeonggi, Chungnam, and Jeonbug. Soils are clay loam. Rice is not intercropped, but wheat or barley is usually planted after the rice harvest. Nongrim is the primary variety cultivated. Farmers use a complete (22-22-22) fertilizer. Yields average 2 t/ha. Major yield constraints are water management, soil fertility, and blast disease.

Philippines. Important upland rice areas in the Philippines are Southern Tagalog (106,000 ha), Southern and Western Mindanao (95,000 ha), Western Visayas (36,000 ha), Bicol (33,000 ha), Cagayan Valley (22,000 ha), and Eastern Visayas (19,000 ha) (Dozina and Herdt 1974). About 40% of these regions have low fertility Ultisols. In Batangas (Southern Tagalog), a major upland rice area, and Southern Mindanao, soils are fertile Mollisols, Alfisols, and Inceptisols. Cropping patterns that include upland rice vary by climate and soil condition and by regional consumption patterns. Dozina and Herdt (1974) described 11 upland rice-based cropping systems. Forty percent of the farmers surveyed in eight upland rice provinces plant one upland rice crop each year and no other crop. Twenty-five percent

cultivate one upland rice crop intercropped with maize or root crops, or grown under tree crops. There is sequential cropping in areas with less pronounced dry seasons. On 16% of the fields, only upland rice is planted during the wet season. Nine percent of farmers intercrop other annual crops in the wet season and plant maize in the dry season.

Denning (1980) described two major upland systems in Zamboanga del Sur (South Mindanao): open upland, with unbunded areas not planted to coconut or other tree crops; and coconut upland, unbunded areas planted to coconut. In open upland 55.% of farmers grew 2 sequential maize crops and 30% planted rice in wet season and maize in dry seasun, Five percent grew only wet season rice. Upland rice and maize were intercropped in wet season by 5-10% of farmers.

In coconut upland, rice cultivation was less popular. Only about 15% used an upland rice-based system under coconut trees. Rice yields were lower under coconuts. Many farmers had previously grown upland rice, but as yields declined they switched to maize. Farmers felt maize was better than rice when fertilizers were not applied.

In Batangas, upland rice farmers are commercially oriented. Nitrogen (40-100 kg/ha) is applied to local and improved varieties and grain yields exceed 2 t/ha. Rice is usually followed by maize in a two-crop sequence. Improved varieties of both crops are widely adopted. In cropping pattern trials sorghum was an excellent alternative crop to follow upland rice (Garrity et al 1980). Rice is often followed by garlic, eggplant, or other high-value vegetable crops.

Productivity constraints in many upland rice regions are climate and soil related. Blast is sometimes cited as a constraint. Upland rice is usually grown in remote areas. Farmers cultivate rice for personal consumption, use a low level of technology, and harvest low yields. However, experiments in Southern Mindanao demonstrated yields could be markedly improved in areas with even rainfall and low fertility soils (pers. comm. with G. L. Denning, IRRI, 1982).

In one survey, 720 farmers, using a high-technology package, which included a high yielding variety (C22, C171, IR54) and good fertilizer and insecticide management, averaged 3.4 t yields/ha (ZDSDP 1982). However, high cultivation technology is justified only when extension workers and farmers are trained; if there is an organized seed production and distribution system: if there is credit to buy seed, fertilizer, and chemicals; and if farmers can easily transport their product to market.

Sri Lanka. Upland rice is cultivated on 52,000 ha in Sri Lanka, mostly in Batticaloa (21,000 ha), Trincomalee (10,000 ha), and Amparai (7,000 ha), all on the

east side of the island (Huke 1982). There is no information about intercropping or sequential cropping.

Bangladesh. Jessore (100,000 ha), Rangpur (99,000 ha), Mymensingh (72,000 ha), and Faridpur (57,000 ha) are major upland rice growing districts in Bangladesh (Huke 1982).

Dry-seeded, broadcast upland rice is cultivated on ridges at or above the flood level in low-lying areas. There is a high water table or shallow flooding in rainy season (Brammer 1982). Upstream ridges of major river systems are seldom flooded. Downriver fields are flooded more frequently. Fields are generally bunded, but bunds are not well maintained. Soil is permeable, usually acid silt loams over sandy subsoils.

Rice is planted before the monsoon, usually April, and harvested during rainy season (June-July). Depending on location, farmers either transplant a second rice crop on lower lying ridges, or plant a dryland crop such as mustard, chickpea, or wheat. Farmers grow local varieties and use little chemical fertilizer, although organic manure (cow dung, compost) is often applied. Yields are 1.2 to 1.5 t/ha. Lack of drought-resistant varieties is a major yield constraint.

India. Upland rice production in India is described fully on the next chapter. Fields are usually not bunded. There are few inputs, and yields are low. There is often a drought when rains do not continue, or severe flooding when there is excessive rainfall. Dry spells of 5 to 9 days occur during all monsoon months in 1 of 2 years; a 10- to 14-day dry spell occurs once in 4 years (all India average) (George et al 1974).

Nepal. An estimated 90,000 ha of upland rice are cultivate in Nepal -- 50,000 ha in the far west, 20,000 ha in the west, 15,000 ha in the middle hill region, and 5,000 ha in the high hill region. When new areas in the lower and foot hills are cleared, farmers cultivate maize-mustard seed rotations for 6 years, then shift to upland rice for 4-5 years. When the soil is compact and water-holding capacity improves, fields are bunded to accumulate and conserve water and farmers change to wetland cultivation. Traditional upland varieties such as Chaya, Bindeshwari, Amadi, Angoli, Suro, and Bhadhaya are planted during the premonsoon period. They produce few tillers so farmers use high seed rates. Yield is near 0.8 t/ha.

Crop rotations using wheat, barley, or oats in cool dry season, followed by upland broadcast rice in hot wet season are common. Uhlig (1978) reports that valleys south of the Himalayan main chain receive sufficient rain to cultivate rice in nonirrigated arable rotations on permanent fields. Rotation pattern usually is dry rice (first summer monsoon crop), wheat (winter crop), millet (second summer), fallow (second winter). He reports that dry rice has been increasingly replaced

by maize in some areas. Fields are on terraced, non-irrigated slopes. Uncertain water supply, weeds, low fertility, and blast are major constraints.

Upland rice in shifting cultivation

The first upland rice cultivators probably cleared land by cutting the forest and burning the dried vegetation, and planted rice seeds in cleared land after the rains began. The same land often could not be cultivated for more than a few years because many upland soils are infertile or are rapidly depleted of nutrients absorbed from the soil by the Crop. Accelerated erosion in cleared areas may also cause soil to lose productivity and increase pernicious grass weeds. Peasants regularly cleared more forest or returned to land that had remained fallow for some years.

While some ethnic groups, called "pioneer" shifting cultivators, cause extensive ecological damage, others practice a stable form of shifting cultivation that involves multiple year fallowing and recropping the same land. The Karen tribe of Thailand and the Hanunoo of Mindoro, the Philippines, practice this method.

In many cases forest destruction caused by shifting cultivation of upland rice has undermined the system (Kyuma 1978). In the Philippines 25% of total rice area was upland rice in 1960. By 1974 this was 11% (Dozina and Herdt 1974). In Indonesia upland rice area declined from 22% in 1966 to 14% in 1978 (Biro Pusat Statistik 1974, 1979). These relative figures also reflect increased wetland rice hectarages (Table 2). During the last 2 decades wetland rice increased, and upland rice areas decreased.

Most upland rice is grown below 1,100 m altitude. Uhlig (1978) writes, "Contrary to common belief, even within the inner tropical mountain forests (e.g., of Sumatra, Kalimantan, Sulawesi, Malaysia) the cultivation of upland rice in shifting cultivation does not occur at hiyher altitudes." The following discussion estimates upland rice area in shifting cultivation and lists cultural practices for several Asian countries.

Bangladesh. Shifting cultivation is practiced on 2-3%, 25,000 ha, of the total upland rice area in Bangladesh. It is mainly in the eastern and northern hills on deep, permeable, loamy acid soils along steep slopes where rainfall is abundant (Brammer 1982). Dominant soils are Dystrochrepts. Cleared areas are cultivated for 2-3 years before being abandoned. Rice is broadcast and sometimes intercropped with maize, sesame, millet, cotton, cowpea, or vegetables. Sometimes these are followed by a second crop of pulses or mustard seed. Farmers plant traditional tall, short-

Table 2. Annually harvested areas of wetland and upland rice in the Philippines and Indonesia.

Harvested areas (thousand ha)							
Philippines[a]				Indonesia[b]			
Year	Wetland	Upland	Upland as % of total area	Year	Wetland	Upland	Upland as % of total area
1960	2018	713	26	1966	6011	1680	22
1970	2702	412	13	1970	6679	1432	17
1974	3026	409	12	1974	7316	1161	14
1977	3147	400	11	1978	7653	1240	14

[a]Source: Dozina and Herdt 1974, Dept. Agric. Economics, 1981, Mabbayad 1982. [b]Source: Biro Pusat Statistkk 1974, 1979.

maturity varieties, although improved dwarfs such as Purbachi are also planted. No fertilizer is applied and yields are seldom more than 1 t/ha.

Himalayas. Shifting cultivation is restricted to the Assam Himalayas and the most northwesterly extension of the tropical rain forest found in that part of the Himalayan foot hills (Uhlig 1978).

Indonesia. Shifting cultivation is used on 95,000 ha, 5-10% of the total upland rice area. Most shifting cultivation is in Sumatra, Kalimantan, and Sulawesi. One rice crop per year is planted for 3-4 years. It is sometimes intercropped with maize and cassava. In dry season farmers may cultivate legumes and cassava. Yields are below 1 t/ha.

On the hillsides of the northern part of South Sulawesi peasants fell forest trees in July. Those are dried and burned. In November, at the start of rainy season, rice seeds, usually mixed with maize, are dibbled in the soil. Plots are fenced to prevent damage by animals. Usually at the same time, but occasionally after one or two cereal crops, farmers plant banana trees or coffee. Banana trees bear fruit after 2 years. The plot is a banana garden for several years, then the farmer may shift to another location (Furukawa 1982).

Malaysia. In West Malaysia only very small patches, not more than 6,000 ha, of upland rice are planted in shifting cultivation. This is the only up land rice grown. In East Malaysia upland rice is more important. In Sabah, hill rice is grown on 10,000 ha; in Sarawak 60,000 ha is harvested (Oldeman and Frere 1982). Yields are below 1 t/ha. The 10-year (1969-78) average was 765 kg/ha. Growing season is September-October to February-March. Little fertilizer is applied. Buntar B and Sampangan B are most common rice varieties.

Philippines. Shifting cultivation, either as a slash-and-burn or as a weed-and-burn system (Dozina and Herdt 1974), is practiced on 100,000 ha, 25% of the

total upland rice area in the Philippines. Major upland rice provinces are Western Samar, Zamboanga del Sur, and Isabela. Farmers prepare plots in dry season when fallen trees and uprooted weeds dry well for burning. Most farmers grow local varieties. Most planted areas are on steep sloping land with Ultisols. Seeds are dibbled with a pointed stick at 8–10/hole spaced 30–50 cm apart. Fertilizers are seldom applied (Mabbayad 1982).

Thailand. Upland rice is cultivated on slightly more than 200,000 ha. Estimates vary from 203,000 ha (Thailand Department of Agriculture 1979) to 223,000 ha (pers. comm. with B. R. Jackson, IRRI representative in Thailand, 1982). About 125,000 ha is in the upper northern regions -- Chiang Rai, Chiang Mai, Nan, and Ma Hong Son. Nan is the largest upland rice growing district. Another 45 000 ha is located in the southern provinces of Krabi, Phattalung, Songhkla, Pattani, Yala, Narathiwat, Surat Thani, and Trang. About 44,000 ha on the northeast plateau is planted to upland rice, and 9,000 ha is on the central plain. Shifting cultivation totals about 80% of upland rice area. Farmers in the upper northern region plant half of their land to upland rice and half to maize, groundnut, soybean, and mungbean (Thailand Department of Agriculture 1979). Local varieties such as Goo Muang Leuang, Dawk Payam, and Sieuw Mae Jan are grown. No fertilizers are used, and yields are 0.5–1t /ha.

In the south rice is often interplanted with rubber and fruit trees when trees are small. This provides farmers with rice to eat until trees produce.

In the highlands of northern Thailand, upland rice, next to the opium poppy, is the most important crop grown by hill tribe people (Mann 1981). Mann describes two major systems. In the first, fields are cultivated for 1 year, then are fallow for 3–10 years, depending on slope, land availability, and soil fertility. Tribes not growing opium poppy traditionally follow this system.

In the second system, farmers use land until it no longer yields satisfactorily. Upland rice is grown in rotation with maize and poppy. Land is cultivated for 2–5 years (occasionally up to 10 years). When it is abandoned, alang alang (I. cylindrica) takes over. If this is grazed, the broadleaf weed Eupatorium adenoporum will take over, A third system, recently introduced, rotates maize and kidney beans or maize and potato the first year and upland rice the next year. Depending on soil fertility, fields will be cropped 3–7 years and lie fallow for 2–3years.

Although upland rice is the most important crop in the highlands of northern Thailand and population is increasing, land for upland rice is decreasing because the Forestry Department is expanding reforestation

efforts. Existing land is not good and yields are declining. Farmers buy 50% of their rice needs. Cash needed to buy rice comes from growing and selling opium poppy. According to Mann, "If there are good rice yields, opium poppy growing would be reduced." He concludes, "A vast amount of information is available dealing with all aspects of upland rice culture, but very little practical information on how to improve cultural practices has been applied to hill tribe fields. If upland rice is to survive in the highlands then yields have to be improved, present cultivation areas maintained, and conservation cropping patterns implemented."

CROP ESTABLISHMENT TECHNIQUES AND CULTURAL PRACTICES FOR UPLAND RICE IN ASIA

Cultural practices and management intensities vary from shifting cultivation to traditional systems where farmers depend primarily on manual labor and native implements to till the land, to continuous upland cultivation systems with mechanization.

In most of India, land preparation for upland rice starts May-June when the monsoon season begins. Fields are plowed with an animal-drawn country plow and then harrowed with a blade harrow. Where shifting cultivation is practiced, bushes are cut down and burnt and the ashes are broadcast before the land is plowed. Shiftlng cultivation is discouraged in hilly regions because it causes soil erosion.

In Indonesia upland rice is often planted with maize, sorghum, cassava, and other crops to produce more food and minimize the risk of total crop loss in drought years. On hilly and flat lands in Burma and Bangladesh, upland rice is broadcast-seeded into poorly prepared dry soil. In Thailand slightly elevated areas are plowed by water buffalo and cattle, then hoed. On hills, fields are hardly cultivated (De Datta and Ross 1975).

Many Asian upland rice farmers use little or no fertilizer when growing traditional varieties in drought-prone areas. Nitrogen response may be high if modern rices are tested in favorable upland rice areas. Upland rice is usually grown on, acid soils, where phosphorus deficiency is common, as on most Ultisols in Asia (De Datta 1981).

Farmers usually apply nitrogen, and sometimes phosphorus, to Philippine Alfisols and Ultisols. In south Sumatra good responses have been recorded when nitrogen, phosphorus, and potassium are used on red yellow Podzolic soils.

The preceding observations suggest that substantial opportunities exist for research in upland rice land preparation, stand establishment, and nutrition.

WEED PROBLEMS AND WEED CONTROL IN UPLAND RICE IN TROPICAL ASIA

Weeds are a major problem to upland rice farmers. Common upland rice weeds in tropical Asia include grasses Echinochloa colona (L.) Link, Digitaria ciliaris (Retz.) Koel., Eleusine indica (L.) Gaertn., Dactyloctenium aegyptium (L.) Beauv., Paspalum dilatatum Poir., Rottboellia exaltata L. f.; broadleaf weeds Ageratum conyzoides L., Ipomoea triloba L., Portulaca oleracea L., Commelina benghalensis L.; annual sedge Cyperus iria L.; perennial grass Imperata cylindrica (L.) Beauv., and perennial sedge Cyperus rotundus L. (De Datta 1981).

Poor weed control is second only to inadequate water supply as a barrier to increasing upland rice production. Unchecked weed competition may result in rice yield reductions of 41 to 100% in the Philipines, 50% in Sri Lanka, and 2 to 25% in north Thailand, If weeds such as I. cylindrica and C. rotundus were controlled, upland rice areas in Indonesia could be increased by more than 1.3 million ha (De Datta 1980).

A weed-free period of about 40 to 60 days after emergence (DE) is essential to minimize losses of upland rice yields due to weed competition. Weeds often emerge simultaneously with the crop. Competition for light, nutrients, and soil moisture begins early, but the rice can tolerate some weed competition up to 14 DE without serious yield reduction.

The combination of weed species in rice fields changes from season to season. A weeding practice that tends to eliminate one species may directly or indirectly induce the multiplication of another. Generally, continuous cropping and clean cultural practices minimize weed problems.

In upland rice areas, soil characteristics and methods and degree of land preparation are diverse. Farmers prepare land based on their judgment of soil moisture status and rainfall patterns, topography, and degree of weed infestation. They use methods within their labor and power resource capability.

Sometimes, upland rice farmers reduce weed problems by shallow cultivation of weeds that emerge following onset of the rains. However, the tillage operation must be deep enough to kill the first flush of weeds, but not so deep that more weed seeds are brought to the soil surface.

In Asian upland rice areas poor rice crop germination often causes excessive weed growth, particularly if modern semidwarf varieties are grown or evaluated. To minimize severe weed competition, Philippine farmers use a modified broadcast method of stand establishment. The harrowed field is furrowed with an animal-drawn furrower (locally known as lithao) with 5 wooden pegs

20 to 25 cm apart. Seeds are broadcast at about 90 kg/ha and covered by a peg-toothed harrow, called a kalmot, pulled in the direction of the rows,

In India, weed control in broadcast-seeded upland rice fields is difficult. Line sowing is encouraged.

Hand weeding is the most common weed control method in upland rice. A single hand weeding requires 300-800 man-hours of labor/ha. When hand weeding is practiced, timing is a critical factor that determines a crop's success or failure. Several hand tools -- the hoe, harrow spade, Swiss hoe, knife, machete, and even pointed sticks -- are used with various success. In Bangladesh, weeds are controlled by a hand tool locally known as niranee.

Herbicides are rarely used on upland rice farms in tropical Asia, although several herbicides might be used to limit weeds to a manageable level. Herbicides, used with other control measures such as hand or mechanical weeding, should increase rice yield where improved varieties are grown.

DISEASES OF UPLAND RICE IN ASIA

Upland rice diseases in Asia include blast (Bl), sheath blight (ShB), brown spot (BS), sheath rot (ShR), bacterial Leaf streak (BLS), and tungro (RTV).

One of the most widespread diseases is BS, caused by Helminthosporium oryzae. Blast, caused by Pyricularia oryzae, is the second most widely distributed disease. Blast is the more serious and limits upland rice production around the world. As production intensifies, losses will increase unless appropriate control measures are practiced. Sheath blight, ShR, and virus diseases will become more serious problems as upland rice production becomes more intensive.

Narrow brown leaf spot (NBLS), stem rot (SR), leaf scald (LSc), udbatta (UDb), and soil sickness disease (etioloqy uncertain, but probably caused by Fusarium monlliforme) occur sporadically and do not cause major losses. As cropping practices intensify, they will probably become more serious.

Fungus diseases

Rice blast is a problem in upland rice growing areas in all of Asia. Blast has been thoroughly studied and its etiology and epidemiology are well documented (IRRI 1979). It can severely damage seedlings in nurseries and can infect foliage, nodes, and panicles in the field. Many pathogenic races of P. oryzae have been reported. Planting disease-resistant varieties; using chemical control; and using proper nitrogen levels, plant spacing, and water management help control Bl.

ShB disease, caused by Thanatephorus cucumeris, the perfect state of Rhizoctonia solani, has received little attention until recently. It causes serious losses in India, the Philippines, and other countries. The fungus survives between crops as sclerotia, as mycelium in plant debris in soil, and on weeds and other crops. Most of the rice germplasm collection has been screened and no suitable variety with a high level of ShB resistance has been found. Tolerant lines that have been identified and evaluated in the screening program are sensitive to environmental differences. The disease is controlled by cultural practices that include using lower nitrogen fertilizer levels, low broadcast seeding rates, and wider transplanted rice spacing. These practices do not increase rice yields. Chemical control is most effective.

Other important fungi diseases are BS, caused by Cochliobolus miyabeanus (Helminthosporium oryzae); SR, caused by Magnaporthe salvinii (Sclerotium oryzae); NBLS, caused by Cercospora oryzae; ShR, caused by Sarocladium oryzae; and LSc, caused by Gerlachia oryzae. Some rice varieties are resistant to these diseases. Broad-spectrum fungicides and cultural practices are also control measures. Using excessive nitrogen fertilizer usually increases damage.

Bacterial diseases

Bacterial leaf streak disease, caused by Xanthomonas campestris pv. oryzicola, is widespread in tropical Asia. Its controlled by using resistant varieties.

Virus and mycoplasma diseases

Fifteen virus and virus-like diseases have been identified since rice dwarf was first recorded in Japan in 1883. Most of these virus diseases have been found in lowland rice, but whether they are a problem in upland rice has yet to be ascertained.

Virus diseases are controlled by using varieties resistant to the vector, the virus, or both. They are also controlled by insecticides that limit vector populations, particularly when resistance is ineffective because of new biotypes of the vector or virus strains.

Nematode diseases

Several potentially significant upland rice diseases are caused by nematodes. Root nematode Hirschmanniella oryzae, root-knot nematodes Meloidogyne spp., and the ring nematode Criconemoides onoensis have been reported in upland rice. When damage warrants control measures, tolerant varieties are recommended.

Rice disease control strategies

Host resistance. Planting resistant varieties is the most economic and environmentally safe method of disease control. For several decades development of disease-resistant rice cultivars has been emphasized. Methods that have been developed to test varietal resistance use natural infection in the field and artificial inoculation in fields or greenhouses.

Disease resistance has been a front-line defense against disease losses. However, breeding for resistance tends to be a holding action when many diseases are involved and environmental conditions favor disease development, particularly with upland rice. To make breeding for resistance more than a holding action, scientists are identifying basic resistance mechanisms and the genes that control them, identifying and cataloguing specific genes useful to resistance breeding by developing specific pathogen isolates, and combining resistance with cultural and chemical control practices to form an integrated disease control system.

Cultural, physical, and regulatory control methods. Cultural disease control practices have often been integrated with other practices for so long that their disease control function is forgotten. Almost all cultural practices used in rice production affect disease dvelopment. Timing of planting, harvesting, cultivation, seed storage, fertilizer use, crop rotation, and weed control may all affect disease occurrence, severity, and control. Cultural practices can be manipulated to reduce or control rice diseases because they affect inoculum production, survival, and dissemination as well as infection and disease development.

To maximize the usefulness of cultural practices and to prevent unexpected epidemics that often follow changes in cultural practice, effects of each technique on major diseases are being studied. This area of disease control has high potential for reducing disease incidence on usland rice,

Chemical control. Chemical control agents for rice diseases such as fungicides, bacteriocides, insecticides, and nematicides have been identified. Some pesticides are pathogen specific, for instance, tricyclazole to P. oryzae. Other broad-spectrum pesticides control several diseases. Benomyl, for example, controls Bl, NBLS ShB, and SR.

Although the use of pesticides on irrigated rice production is increasing, the economics of pesticide use for upland rice must be evaluated. Disadvantages include high pesticide cost, application costs, unfavorable effects on nontarget organisms, and development of pathogen resistance. Research is being designed to integrate pesticide use and other control measures into a continuously changing disease management program which is dynamic, responds to chanqes affecting each

control practice, and minimizes development of epidemic conditions.

INSECT PESTS OF UPLAND RICE IN ASIA

Upland rice insect pests

Upland rice is attacked by insect pests that differ from those in wetland rice primarily because of the drier environment and the need for pests to survive a 7-8 month rice-free period.

Nonflooded environments favor soil pests -- ants, termites, white grubs soil crickets, root beetles, snout weevil -- and foliar pests -- seedling maggot and flea beetle. Root aphid and mealybug are numerous in times of drought.

The most serious wetland rice insects -- brown planthopper, green leafhopper, yellow stem borer, and gall midge -- are not pests of upland rice. Because these insects feed only on rice, the extended rice-free period enforced by a dry season limits their population. Planting dates in upland areas are highly synchronized and the crop is available as host to insects for only 4-5 months each year. Other crops are normally cultivated after rice, and rice stubble is plowed, removing stem borer aestivation sites. Gall midge is not an upland pest because it requires high humidity for egg hatching and larval development. Silver shoots are sometimes observed, but damage is negligible.

The only wetland rice pests that seriously damage upland rice are polyphagous and have dispersal capacity -- grasshoppers, armyworms, leaffolders, and rice bugs. Populations are limited by the dry fallow period and the low-quality food source of a drought-stressed crop.

Damage and yield loss

Highest yield losses in Asia are caused by the rice mealybug in northeast India and Banqladesh. Damage is severe because populations are favored by low rainfall. Drought and the plant sap-feeding mealybug destroy fields. In Thailand a snout weevil, Hypomeces squamosus can cause significant yield loss. Also, in many other areas, serious yield losses are inflicted by the rice bug Leptocorisa spp. which feed on developing rice grains and cause sterility. Besides these, several species of soil-inhabiting insects, foliage feeders, and stem borers occur sporadically and cause significant yield losses.

Yield losses caused by insects are generally low, primarily because of the sparse crop density of upland rice, In Thailand, yield loss to insects and diseases during 1976-80 ranged from 1 to 13% averaging 5%. A 20% yield loss on a crop yielding l t/ha (200 kg) often

cannot be ascertained with the normal field plot design (randomized complete block, 4-6 replications).

Control tactics

The low yielding potential of upland rice normally precludes insecticide applications as a control tactic.

Damage caused by pests that affect plant stand, such as ants, is minimized by high seeding rates used by farmers to control weeds.

Soil pests can be controlled by an inexpensive seed treatment or by applying a low-dosage granular insecticide to the soil at planting. Systemic insecticide seed treatment with bendiocarb will also control seedling maggot. This technology is probably unnecessary in most areas. Seedling maqgot, for example, is highly seasonal and because most upland rice is planted when monsoon rains begin, crops escape damaging populations.

Grasshoppers, armyworms, and leaffolders that attack vegetative and reproductive stages can be controlled by one foliar application of insecticide, when necessary. These pests are not particularly harmful because they attack the leaves. Upland varieties are tall and leafy and can tolerate more than 50% defoliation. Some studies have shown that defoliation (pruning) promotes yield in these varieties.

Rice bug might be a serious threat if planting was not highly synchronous.

Rice mealybug, the most serious pest, is difficult and costly to control with insecticides. In northeastern India and Bangladesh where it is most prevalent, development of resistant varieties should be emphasized.

Low-volume (ultralow volume [ULV]), controlled droplet applicator (CDS) sprayers (spinning disc or electromagnetic) developed for other crops can be used for upland rice. Foliar spraying using high-volume knapsack sprayers is impractical because water is usually scarce. ULV and CDS sprayers use only 1 liter of water to protect 1 ha.

Conclusion

Insect pests on upland rice are usually not very serious because of the general sparse stand of the crop. However, they remain to be a potential problem. If soil insect pests or seedling maggot are endemic to a region, prophylactic application of low-cost seed treatment or granular insecticides can protect the crop. Foliage insect populations can be controlled by foliar sprays applied with low-volume sprayers. Rice mealybug in northeastern India and Bangladesh is the

most important upland rice insect pest in Asia. Resistant varieties should be developed.

UPLAND RICE VARIETIES OF TROPICAL, ASIA

Morphoagronomic characteristics and yield potential

Most upland rice varieties in the world belong to *Oryza sativa* L. Only in West Africa do some upland varieties belong to *O. glaberrima* Steud.

Southeast Asian upland rices form a distinct morphoecologic group. Indian varieties are intermediate between the wetland type and the southeast Asian upland varieties. Although Southeast Asian upland varieties are usually classified as indicas, recent studies show they are more closely related to the Indonesian javanica race than the indica race.

Varietal diversity of Southeast Asian upland rices is considerably smaller than that of wetland rices in the same region, but diversity does exist, especially in drought resistance. Information from the IRRI germplasm bank and related studies show Southeast Asian upland rices share the following morphologic and agronomic features:

1. Tall plant stature;
2. Deep, thick, branched roots;
3. Low tiller number and rigid tillering ability
4. Pale green, long, broad and droopy leaves, sometimes glabrous;
5. Low leaf area index;
6. Plastic leaf rolling and unrolling, high stomatal resistance to transpiration, frequently high cuticular resistance to transpiration;
7. Poor recovery from water stress after drought is relieved;
8. Thick, brittle culms at maturation;
9. Long, well-exserted panicles;
10. 95-140 day maturity range, photoperiod insensitivity:
11. Large, broad, thick, heavy grains;
12. Endosperm with low to intermediate amylose content (18-25%), intermediate gelatinization temperature, and low to intermediate gel consistency;
13. High panicle fertility, even under drought conditions;
14. High blast disease resistance, susceptibility to leafhoppers, planthoppers, and virus diseases found in wetland areas;
15. Low response to added N, tolerance for endemic adverse soil factors -- P deficiency, Al and Mn toxicity, salinity;
16. Low but stable yields -- 0.5-1.5 t/ha; and
17. Low harvest index -- below 0.4.

Table 3. Top performing Asian lines in the International Upland Rice Yield Nursery entries, averaged across locations, 1975-81.

Year[a]	Rank	Entry	Av yield (t/ha)	Av duration (days)	Plant type	Country, organization
1975	1	IR43	2.9	126	Semidwarf	IRRI
	2	IR9575	2.8	122	Semidwarf	IRRI
	3	IR45	2.7	129	Semidwarf	IRRI
	4	IR2035-108-2	2.6	128	Semidwarf	IRRl
	4	IR1529-680-3-2	2.6	129	Semidwarf	IRRI
	4	MRC172-9	2.6	128	Intermediate	Philippines
1976	1	IET1444	3.5	103	Semidwarf	India
	2	IR36	3.3	107	Semidwarf	IRRI
	3	IR2061-522-6-9	3.2	105	Semidwarf	IRRI
	4	B541b-Kn-19-3-4	3.1	115	Semidwarf	Indonesia
1977	1	IET1444	3.0	116	Semidwarf	India
	1	IR36	3.0	118	Semidwarf	IRRI
	1	C22	3.0	130	Intermediate	Philippines
	1	C46-15/1R35*2	3.0	128	Intermediate	IRRI
1978	1	IR43	3.8	132	Semidwarf	IRRI
	2	IR9669 Sel.	3.7	138	Semidwarf	IRRI
	3	IET1444	3.6	116	Semidwarf	India
	3	IR36	3.6	124	Semidwarf	IRRI
1979	1	UPL Ri-5	2.8	131	Intermediate	Philippines
	1	IR9669 Sel.	2.8	136	Semidwarf	IRRI
	3	BG35-2	2.7	121	Semidwarf	Sri Lanka
	3	IR2061-522-6-9	2.7	118	Semidwarf	IRRI
	3	IR45	2.7	133	Semidwarf	IRRI
1980	1	IR5931-110-1	3.9	121	Semidwarf	IRRI
	2	BG35-2	3.6	119	Semidwarf	Sri Lanka
	3	B733c-167-3-2	3.5	124	Intermediate	Indonesia
	3	CR156-5021-207	3.5	124	Semidwarf	India
	3	IR52	3.5	127	Semidwarf	IRRI
	3	IR6115-1-1-1	3.5	121	Semidwarf	IRRI
1981	1	IR5931-110-1	2.6	123	Semidwarf	IRRI
	1	IR6115-1-1-1	2.6	119	Semidwarf	IRRI
	3	UPL Ri-5	2.5	126	Intermediate	Philippines
	3	IR43	2.5	127	Semidwarf	IRRI

[a] 1975-80 data are from final reports, 1981 data are from a preliminary report.

Rices in upland areas are adapted to erratic rainfall distribution, intense solar radiation, low N and P supply, blast incidence, and, frequently, acid soils. Deep, thick roots and high water retention potential in the plant tissues provide stable grain yield, but the rigidly low tillering capacity has restricted yield potential.

Rice varieties found in the fertile, wetter "upland" areas of fields adjacent to wetland areas are of the lowland type. Several new wetland varieties and semidwarfs have yielded well in favorable seasons, but drought and blast have been constraints in unfavorable seasons.

Table 4. Drought-tolerant entries from multilocation tests at international upland nurseries.

Traditional	
Aus 8	IAC25
Aus 61	Surjamukhi
Dular	ARC11775
CTG1516	ARC10372
Salumpikit	MI 48
DJ29	
Improved	
IR442-2-58	IR7777-7-1
I R5	IR2035-349-2
IR3880-29	IRAT10
BG35-2	

THE INTERNATIONAL RICE TESTING PROGRAM: UPLAND RICE VARIETIES AND BREEDING LINES

Interdisciplinary and interinstitutional collaboration are the key to future progress in upland rice improvement.

The International Rice Testing Program (IRTP) Was initiated in 1973. In 1974, multilocation trials in the Philippines led to the establishment of the International Upland Rice Yield Nursery (IURYN). The International Upland Rice Observational Nursery (IURON) was formed in 1975, the year IRTP was formalized by a grant from the United Nations Development Programme. Since then, upland varieties and breeding lines from numerous national programs have been tested for their suitability to upland culture at locations all over the world. Table 3 summarizes the results and lists the most promising 1975-81 IURYN entries.

Water deficit is a significant factor in varietal adaptability to upland (dryland) culture. Table 4 lists some traditional and improved rices that have shown drought stress tolerance in international trials.

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UPLAND RICE IN INDIA

D. M. MAURYA and C. P. VAISH

SOIL AND CLIMATE

Rice, the staple food of India, grows on 39.8 million ha, representing 27.7% of world rice hectarage and 13% of world production. Rice has adapted to many climatic differences, growing throughout the year from below sea level in Kerala to 2,000-m elevations in the Himalayas, from 8°N latitude in Kanyakumari to 35°N latitude in Kashmir. In well-drained soils, upland rice is intercropped with maize, millet, and pigeonpea, and deep water rice can grow in several meters of standing water. In Cherapunju, Assam, rice grows where monsoon rainfall averages 12,500 mm, and also in Rajasthan and Gujarat where seasonal rainfall averages only 250 mm. It grows in sandy loam laterites, in heavy black cotton clay soil, in acid and alkaline soils, and in temperatures varying from 45 to 4°C during the crop period (Table 1).

Upland rice is in about 33% of the rice area in India. In those areas, yield ana production are primarily determined by amount and pattern of annual rainfall (Table 2).

Although more profitable crops such as maize sorghum, and finger millet can be grown on these marginal and submarginal soils, prevailing socioeconomic conditions and favorable temperature and rainfall in July and August tempt farmers to grow rice. Varying rainfall and cropping conditions cause production to fluctuate from year to year.

In regions that receive 1,000 mm or more rainfall, soils are loose textured and acidic and fields generally are terraced because of the undulating topography. Regions with less than 1,000 mm rainfall have heavier soils with pH 7.0 and above and contain calcium carbonate at certain depths. Soil types and annual rainfall in major rice growing areas are shown in Figures 1, 2, and 3.

Upland topography and soil type vary greatly. Higher elevations and uneven topography make it impossible to contain water for a long time. Soils are gene-

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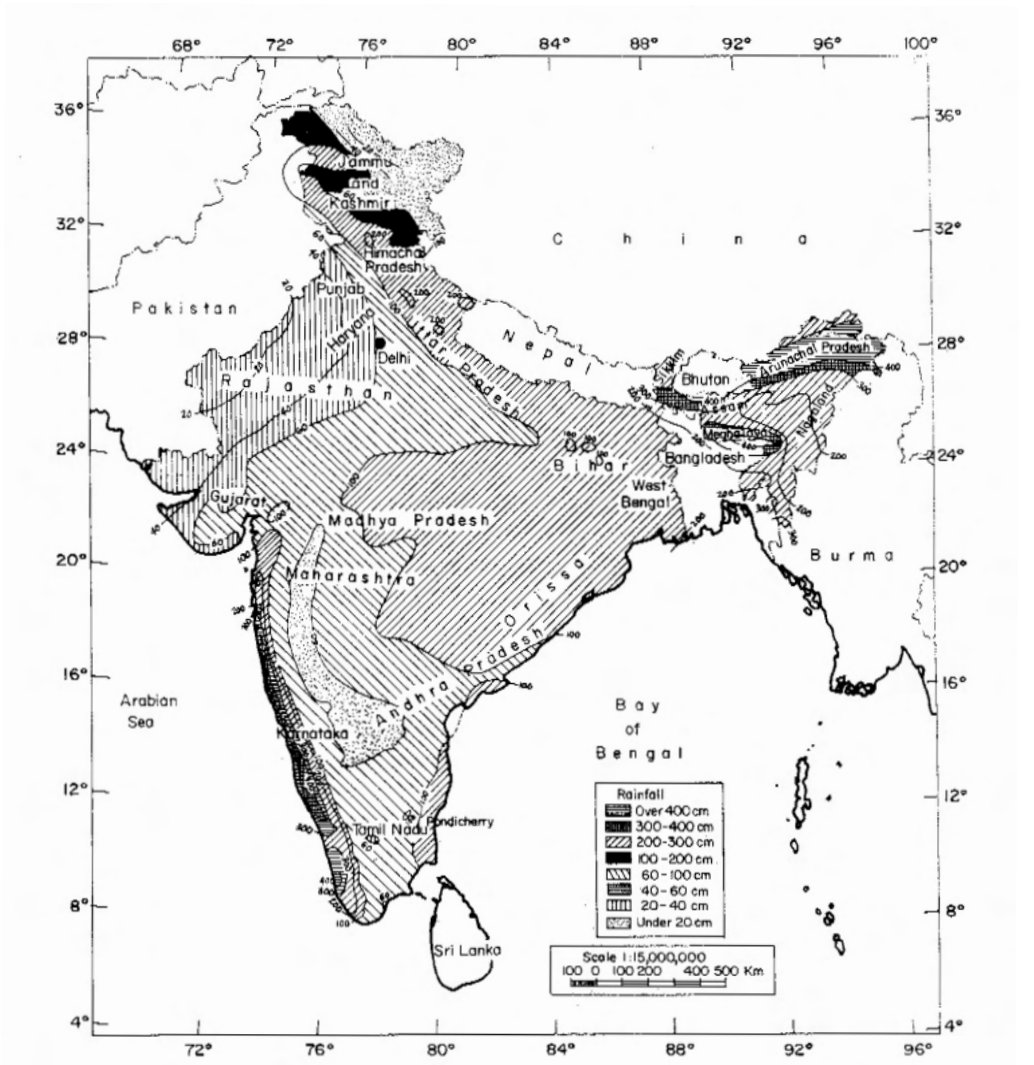
Professor and head, and assistant breeder, Department of Genetics and Plant Breeding, N. D. University of Agriculture and Technology, Faizabad 224001, Uttar Pradesh, India.

Table 1. Agroecological regions of India and their characteristics.

Region	Month	Temp. range (°C)	Rainfall (mm)	Moisture availability (%)	Soil
Humid Western Himalayan	Jan	4-8	1500	50 - 100	Forest and hill brown, mountain meadow soils (Paleuhumults)
	Jul	30-59			
Humid Bengal Assam Basin	Jan	10-25	2000	0- 50	Alluvial, red sandy, Laterite, and red yellow soils (Haplaquents, Ustifluvents, Udifluvents, Plinthudults, Haplustalfs)
	Jul	25-32			
Humid Eastern Himalayas and Bay Islands	Jan	11-24	2000	50 - 100	Riverine alluvial, red, and Laterite soils (Ustifluvents, Udifluvents, Haplustalfs, Rhodustalfs)
	Jul	25-33			
Subhumid Sutlaj Ganga alluvial plains	Jan	23-60	1000 - 1500	20 - 60	Riverine alluvial soils with saline and alkaline patches (Haplaquents, Ustifluvents, Udifluvents, Natrustalfs)
	Jul	25-41			
Subhumid to humid eastern and south eastern upland	Jan	16-28	750 - 1500	0- 40	Red and yellow, red sandy, black, and coastal alluvial soils (Haplustalfs, Rhodustalfs, Ustochrepts, Chromusterts, Propaqualfs)
	Jul	27-35			
Arid western plains	Jan	10-22	250 - 750	60- 80	Alluvial, sandy desert, and black soils (Ustochrepts, Caleiorthids, and Chromusterts)
	Jul	28-45			
Semiarid lava plateaus and central high lands	Jan	13-29	500 - 1000	40- 80	Black, red sandy, and red loamy soils (Chromusterts, Haplustalfs, Paleustalfs, Rhodustalfs)
	Jul	26-42			
Humid to semi-arid western ghats and Karnataka plateaus	Jan	20-29	750 - 2000	0- 40	Red sandy, black coastal alluvial, and Laterite soils (Haplustalf, Paleustalfs)
	Jul	28-39			

Table 2. Effect of drought on productivity of rice in India.

Year	Area (thousand ha)	Production (thousand million t)	Av yield (t/ha)	Remarks
1970-71	37,432	42,448	1.13	
1971-72	37,758	43,068	1.14	
1972-73	36,688	39,245	1.07	
1973-74	38,285	44,051	1.15	
1974-75	37,588	39,579	1.04	Partial drought
1975-76	39,475	48,740	1.24	
1976-77	38,606	42,787	1.10	Partial drought
1977-78	40,282	52,670	1.31	
1978-79	40,146	53,829	1.34	
1979-80	39,414	42,330	1.07	Acute drought
1980-81	39,773	53,231	1.34	

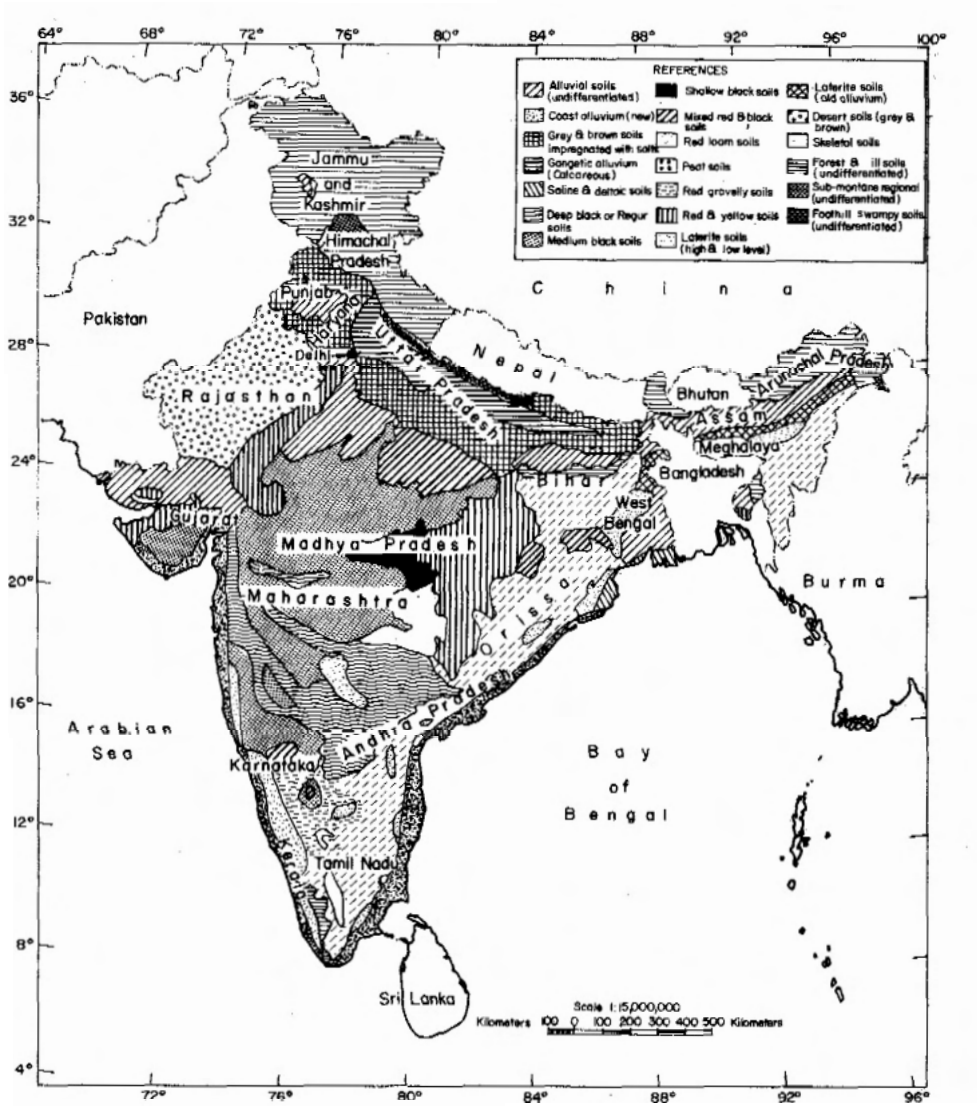


1. Annual average rainfall in India.

rally sandy loam with poor native fertility and low moisture and nutrient retention capacity. Applied fertilizer nutrients dissipate rapidly, making fertilizer investments risky. Low water retention caused by rapid percolation causes moisture stress soon after rains stop.

RAINFALL AND DROUGHT PATTERN IN UTTAR PRADESH AND BIHAR

In Uttar Pradesh (UP) and Bihar, erratic monsoon rains can cause severe water deficit or flooding as indicated by weekly rainfall data in Table 3. Data on magnitude and distribution of drought have been collected for



2. Soils of India.

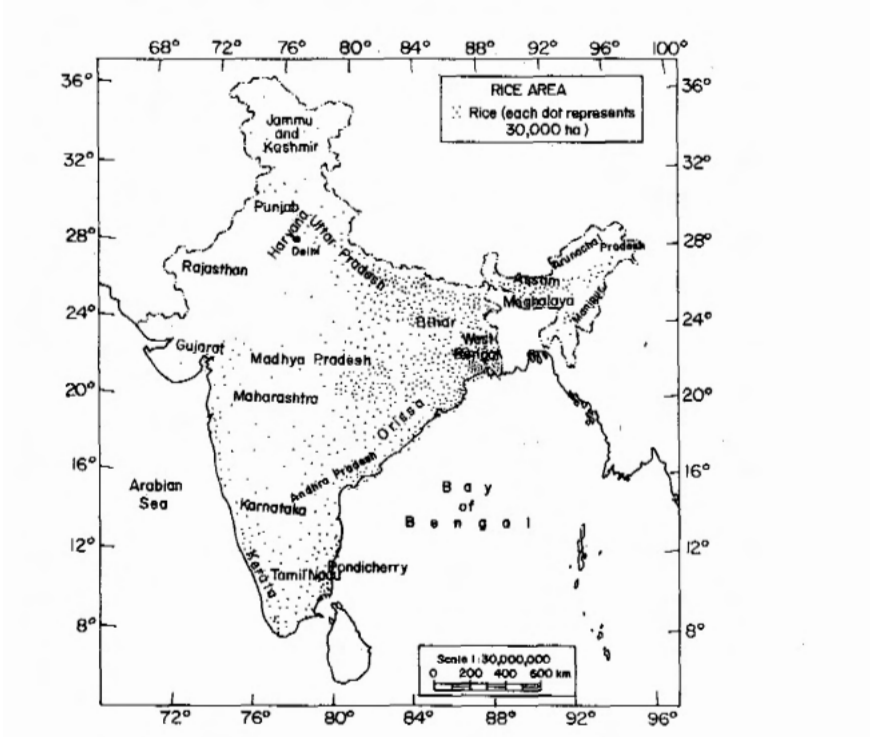
75 yr and provide a base for designing research programs for upland areas in eastern India.

In 4 of the last 75 yr, prolonged drought occurred during planting (premonsoon) season.

Figure 4 shows the magnitude of drought in India in 1979 and Figure 5 illustrates a 12-yr (1971-1982) rainfall pattern in UP.

TEMPERATURE AND DAY LENGTH

During the growing period, temperatures vary from 5 to 42°C (Boro paddy). Besides rainfall availability, low



3. Rice area of India.

temperatures restrict rice geographically as well as seasonally. In northern and western India with low winter temperatures (Fig. 6), only one crop is possible from April to October. The difference in day length during the growing season varies from less than 1 h south of Kerala and Tamil Nadu to about 2.5 h in northern India.

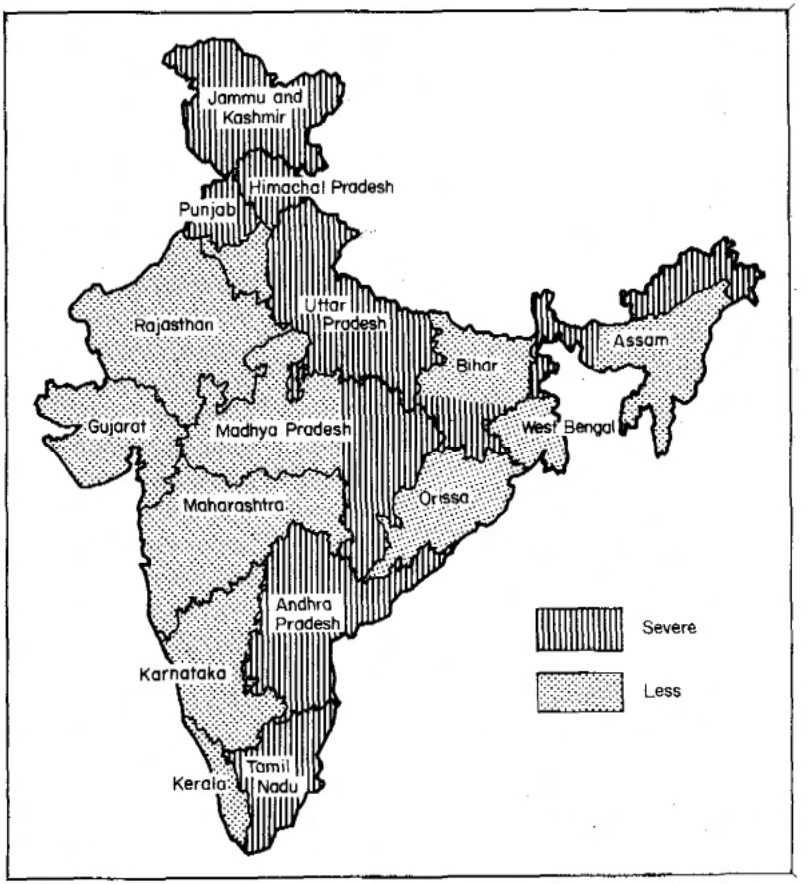
Photoregime influences the distribution of rice varieties. Long-duration, photoperiod-sensitive varieties grow in southern India, medium-maturing and weakly photoperiod-sensitive ones in central India, and short-duration photoperiod-insensitive varieties in the extreme north.

Despite multipronged rice technology, total rainfall, its distribution, and irrigation highly influence productivity. Although India identified water management as a significant factor in improving productivity, only 60% of the country can be irrigated. The other 40% is still rainfed and periodical drought is a common problem. The main upland rice areas are in Bihar, Uttar Pradesh, Madhya Pradesh, Gujarat, Maharashtra, Assam, Meghalaya, Nagaland, Tripura, Arunanhal, Orissa, some parts of West Bengal, Kerala, Nizoram, and Himachal Pradesh (Table 4).

Variation in the onset, duration, distribution, and intensity of the monsoon greatly influence rice

Table 3. Weekly rainfall at Faizabad during growing season.

Year	Rainfall (mm)																	Total no. of rainy days
	Jun				Jul				Aug				Sep				Total	
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV		
1968	–	–	–	68.6	28.6	214.2	96.8	68.6	25.2	30.6	37.0	169.9	–	–	44.2	–	783.7	35
1969	27.6	–	27.0	28.4	30.0	118.0	32.4	13.4	22.0	76.2	253.6	32.6	59.7	32.6	1.2	109.6	909.3	47
1970	9.4	18.2	38.0	72.6	12.0	186.6	2.0	34.0	46.0	115.4	16.0	46.1	9.4	183.1	107.6	30.5	923.9	47
1971	–	6.0	–	85.6	75.4	164.9	13.6	33.2	320.6	216.9	91.6	14.3	362.6	172.6	–	17.2	1,574.5	52
1972	–	–	–	27.4	26.2	20.8	95.9	9.6	103.4	98.4	17.8	3.4	29.2	297.2	3.2	128.7	851.2	33
1973	–	30.0	22.7	32.6	8.4	–	57.8	507.0	99.1	66.8	46.8	56.6	13.8	55.2	11.0	90.3	1,098.1	49
1974	–	–	2.8	32.6	–	67.4	137.8	81.6	229.2	16.0	73.2	50.2	–	20.8	454.2	50.8	1,216.6	31
1975	–	–	178.4	165.4	211.4	137.6	29.6	48.6	170.4	–	47.2	66.2	6.4	66.4	10.4	35.6	1,273.7	48
1976	–	21.6	–	8.6	–	146.0	33.4	32.0	109.6	218.0	133.6	77.6	–	214.6	13.6	84.6	1,093.2	29
1977	–	–	–	–	22.8	138.0	97.8	75.4	73.4	28.6	30.2	15.2	8.6	46.2	10.6	–	546.8	27
1978	–	55.6	61.2	15.2	2.6	3.4	420.0	75.2	14.0	115.2	45.4	6.2	33.2	57.8	71.8	33.2	1,010.0	44
1979	–	16.8	–	10.4	1.8	26.8	73.0	80.6	–	6.2	25.0	–	21.2	–	–	–	261.8	20
1980	–	41.2	29.3	28.6	18.8	120.6	242.6	34.6	39.6	201.7	–	205.4	245.8	–	167.0	21.6	1,440.3	49
1981	–	20.8	–	53.6	153.8	32.6	208.2	191.0	86.2	61.4	53.6	223.6	43.8	187.2	–	169.8	1,485.6	42
1982	79.8	108.2	–	–	–	159.8	–	34.2	77.8	64.7	61.4	130.0	143.2	298.2	–	6.4	1,161.7	33
Mean for 50 yr																	929.0	40



4. The 1979 drought wave in India.

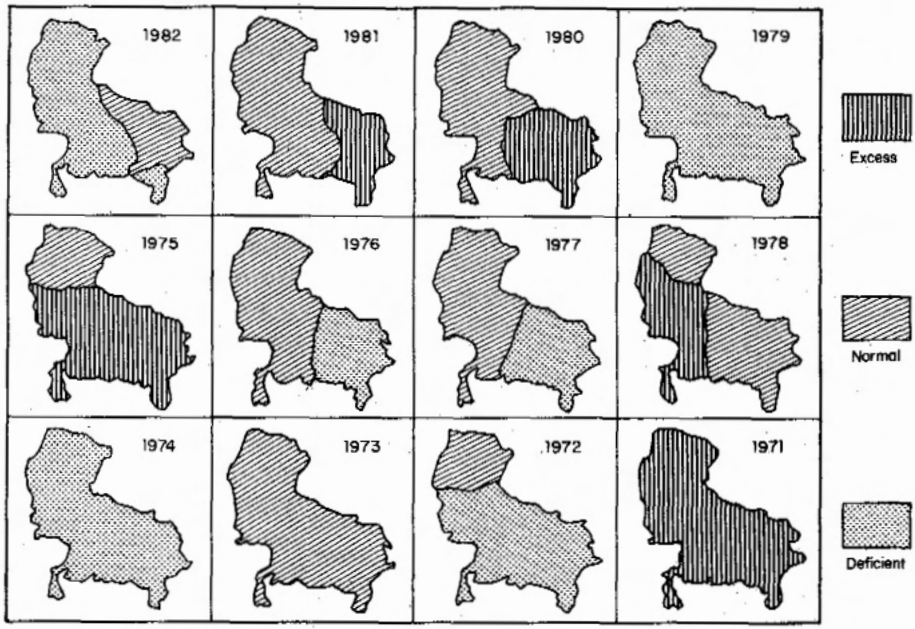
growth. Even though total rain is adequate for raising short-duration (100 d) varieties, its variability, distribution, and failure at critical crop growth phases disturb rice plant nutrition. Drought at the beginning of wet season delays soil preparation, sowing, and may severely decrease hectarage and production as in UP during 1979 (Table 5).

After sowing, a prolonged drought during the wet season may completely stop crop growth and in extreme cases scorch off the standing crop. Drought at the end of wet season may wither ripe rice and create adverse conditions for succeeding crops (Table 6).

PROBLEMS ASSOCIATED WITH UPLAND RICE CULTIVATION

Important agrophysiological problems in upland rice culture are

- uncertainty of planting (seeding),
- poor germination,

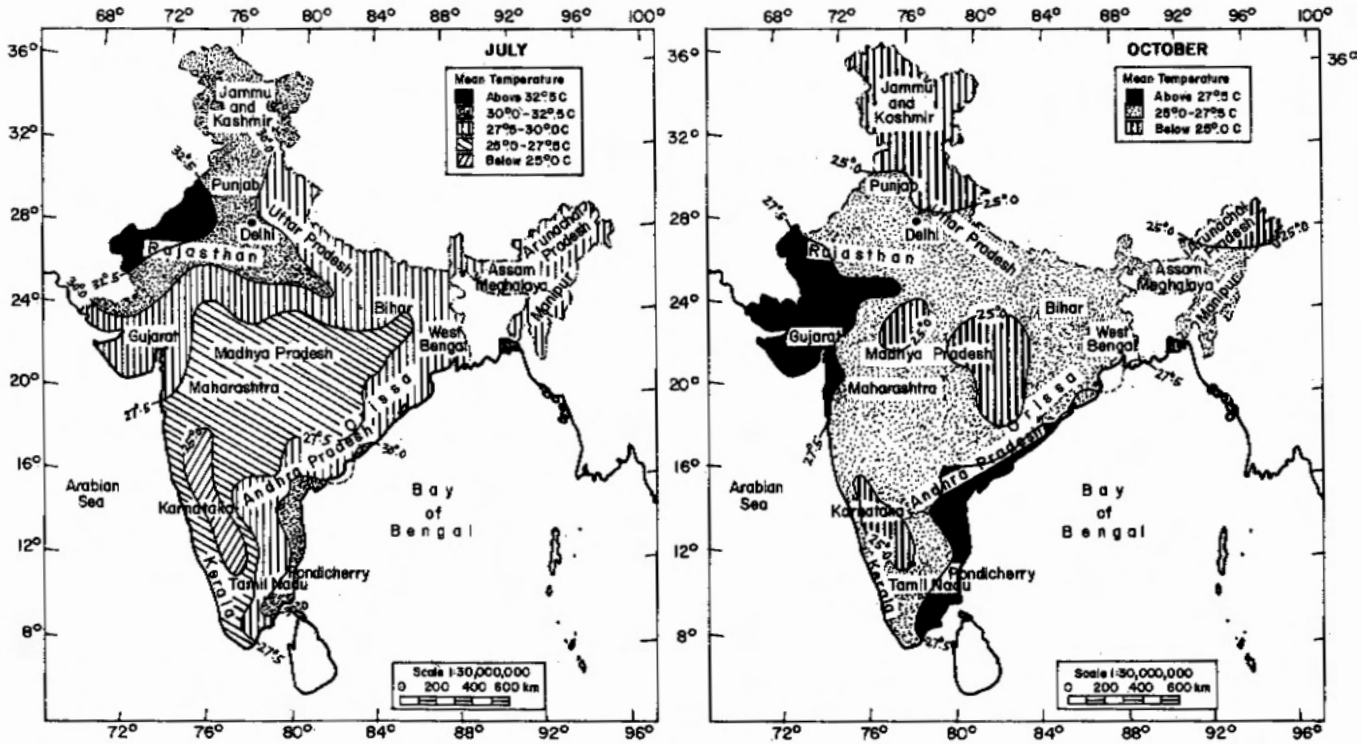


5. Rainfall pattern in Uttar Pradesh, 1971-82.

- plant mortality,
- opulent weed growth,
- leaf death,
- reduced leaf size,
- tiller death or reduced tillering,
- delay in heading,
- suppression of panicle emergence,
- reduced panicle size,
- reduction in seed setting,
- reduction in test weight, and
- difficulty in fertilizer application.

Plant sensitivity to drought

Duration of the stress is more important than the stage of the crop at which stress occurs. Rice is particularly vulnerable to insufficient water during the reduction division of phloem mother cells and at ear emergence. Seedling, tillering, and flowering stages are particularly sensitive to stress. Because farmers delay seeding until conditions are favorable and because heavy seed rate mostly overcomes dependence on tillering, drought tolerance at these stages is less important. Moisture stress at flowering is the most critical. The only way to avoid drought at flowering is to choose a variety of appropriate duration and to manipulate the sowing date.



6. Temperature during rice growing season in India.

Table 4. Upland rice areas in different States of India.

State	Area (thousand ha)	% of total rice area
Andhra Pradesh	124.7	3.6
Assam	529.9	27.9
Bihar	1,016.8	19.9
Gujarat	91.7	20.0
Himachal Pradesh	19.5	20.0
Jammu and Kashmir	26.8	10.0
Karnataka	110.0	10.2
Kerala	105.9	13.4
Madhya Pradesh	1,865.2	40.0
Maharashtra	583.0	39.2
Manipur	33.0	21.3
Meghalaya	30.5	29.8
Nagaland	37.3	51.2
Orissa	1,033.8	25.1
Rajasthan	37.1	20.0
Tamil Nadu	46.0	1.6
Tripura	80.0	31.4
Uttar Pradesh	1,744.5	35.3
West Bengal	628.0	12.8
Arunachal	11.3	20.0
Mizotam	22.0	34.8
Pondicherry	5.7	19.6
Goa, Daman, and Diu	4.4	8.2
Total upland area in India	8,250.1	21.19
Total rice area in India	38,937.7	–

Table 5. Area, productivity, and production of upland rice in UP.

Year	Total area (million ha)	Total production (million t)	Av rice yield (t/ha)	Remarks
1977-78	4.87	5.20	1.07	Drought in eastern UP
1978-79	5.15	5.96	1.16	Normal rainfall
1979-80	5.05	2.55	0.51	Severe drought throughout state
1980-81	5.29	5.57	1.05	Excess in eastern UP. Normal
1981-82	5.28	5.69	1.08	in rest.

MANAGEMENT PRACTICES

Although upland rice cultivation has problems and does not have high productivity, management experiments demonstrate that appropriate techniques improve productivity.

Time of sowing

By sowing as early as possible within the rainfall pattern, farmers can make full use of rainwater. Early sowing also permits use of slightly longer duration varieties which generally have higher yield potential. Experiments at Ranchi and Varanasi Centre under the All

Table 6. Area, production, and productivity of major succeeding crops after upland rice in UP.

Year	Wheat			Barley			Gram			Linseed			Remarks
	Total area (million ha)	Total production (million t)	Av yield (t/ha)	Total area (million ha)	Total production (million t)	Av yield (t/ha)	Total area (million ha)	Total production (million t)	Av yield (t/ha)	Total area (million ha)	Total production (million t)	Av yield (t/ha)	
1977-78	6.751	9.884	1.46	0.963	1.070	1.11	1.656	1.206	0.73	0.102	0.027	0.26	Drought in eastern UP
1978-79	7.390	11.457	1.55	0.869	1.001	1.15	1.640	1.227	0.75	0.106	0.027	0.26	Normal rainfall
1979-80	7.532	9.895	1.31	0.786	0.719	0.92	1.554	0.693	0.45	0.053	0.005	0.10	Severe drought throughout state
1980-81	8.009	13.133	1.64	0.782	1.023	1.31	1.493	1.284	0.86	0.061	0.015	0.24	Excess rain in eastern UP

India Dry Farming System revealed that if farmers sow during the third week of June, they can use 110- to 115-d varieties. With delayed sowing, they should choose short-duration (80-90 d) varieties and sacrifice high production.

Sowing method

Farmers can direct-seed rice in light soils with as little as 25-30 mm rain. But in certain areas of India, farmers wait for 50-70 mm of rain before transplanting. For puddling, they wait for 80 mm of rain within a week, which delays transplanting.

Also, upland farmers usually grow short-duration varieties which begin to flower in the nursery if farmera wait too long for enough rain to puddle the soil. A crop raised from such an aged nursery yields poorly.

Usually farmers direct seed by broadcasting, but drilling is more advantageous because seed placed 2 cm deep has better drought resistance (Table 7).

Seed rate

Based on early research trials, recommendations advocated low seed rate and wide spacing. This practice may be sound on small plot trials because of higher quality management. On large-scale cultivated fields, however, this practice results in low plant population because of uneven moisture distribution, birds, pests, and diseases. Experiments show that low seed rates increase drought resistance of established seedlings but risk low plant population. We recommend the old practice be reexamined and the seed rate increased 50% which will increase water use only 5-10% but will increase yield more than 25%.

The AICRIP and Dryland Projects results show how the high initial seed rate removes dependence on tillering for panicle number (Table 8). A high seed rate

Table 7. Effect of seed rate and sowing method on grain yield of upland rice at Faizabad.

Sowing method	Seed rate (kg/ha)	Grain yield (t/ha)		Mean
		1973	1974	
Broadcast	44	2.39	2.15	2.27
	66	2.99	2.80	2.87
	88	3.49	3.35	3.43
Drilling behind plow	44	2.83	2.57	2.70
	66	3.53	3.80	3.67
	77	4.10	3.99	4.04
LSD 5% Broadcasting		426	410	
LSD 5% Drilling		221	308	

Table 8. Effect of seed rate on grain yield from broadcast and drilled seed at Faizabad.

Seed rate (kg/ha)	Grain yield (t/ha)
Broadcast seed	
44	2.40
66	3.00
88	3.50
110	4.21
132	4.00
LSD 5%	0.43
Drilled seed	
33	2.51
44	2.84
55	3.33
66	3.52
77	4.10
LSD 5%	0.23

of 80 to 100 kg/ha overcomes undependable rainfall and distribution during tillering and also helps establish the crop on less fertile land.

Spacing

Research shows that optimum row-to-row spacing is 20 cm. Higher and lower spacing decreased yield (Table 9).

Fertilizer management

Over centuries, unirrigated soils are not only thirsty but hungry as well. When rains are timely and well-distributed, they overcome the thirst, but the starvation is permanent and a perennial source of poor yields. Alternate wetting and drying of soil promotes loss of both native and fertilizer nitrogen. Upland soils are prone to severe nutrient deficiency, low nitrogen, poor available phosphorus, and iron and aluminum or manganese toxicity.

For direct-seeded upland rice, we recommend reducing basal application of N to a minimum because

- nutrients in the seed sustain 15 d of seedling growth,
- in early seedling stage, root growth is not sufficient to intercept nitrogen, and
- most upland rices have difficulty retaining added fertilizer nitrogen.

Fertilization rate. Regional and national experiments with different varieties showed linear response to fertilizer up to 120 kg N/ha. However, fertilizer application in rainfed areas is risky because drought may occur and destroy the crop. Therefore, only moderate fertilizer application is recommended. The amount

Table 9. Effect of spacing on grain yield at Faizabad.

Row spacing (cm)	Yield (t/ha)		Mean
	1976	1978	
15	3.08	2.67	2.87
20	4.12	3.51	3.81
25	3.88	3.08	3.48
LSD 5%	0.28	0.23	

Table 10. Effect of nitrogen application on upland rice yield at Faizahad.

Nitrogen (kg/ha)	Yield (t/ha)							
	Bala (dwarf)				N 22 (tall)			
	1971	1972	1973	Mean	1971	1972	1973	Mean
0	1.96	1.60	1.57	1.70	1.70	1.19	1.54	1.48
30	2.57	1.95	–	2.26	2.18	1.56	–	1.87
60	2.91	2.44	2.46	2.60	2.49	1.71	2.37	2.17
90	3.20	2.92	2.82	2.98	3.06	1.88	2.84	2.59
120	3.74	2.96	2.85	3.38	3.44	2.11	2.98	2.85

Table 11. Effect of nitrogen dosage on grain yield of rice in rainfed upland fields at Faizabad during 1978.

Variety	Grain yield at given nitrogen (kg/ha) level				
	0 N	20 N	40 N	60 N	80 N
N22	1.03	1.63	2.21	2.76	3.03
Narendra-1	1.02	1.82	2.61	3.13	3.43
KR5-142	0.97	1.61	2.34	2.94	3.16
IET826	1.04	1.82	2.41	3.54	4.00
Rasi	1.04	1.61	2.51	3.38	3.84
Cauvery	0.92	1.79	2.64	3.14	3.38

of phosphorus and potash should be half that of nitrogen. The effect of nitrogen application on upland yield is presented in Tables 10 and 11.

Time of N application. Some fertilizer trials showed effective application to be 25% N and whole phosphate fertilizer applied basally and 50% N top-dressed at active tillering (30-35 d after sowing, after first effective weeding), and the rest of the 25% N applied at panicle initiation stage. However, our experiment showed that all or part of N should be applied after first effective weeding. Because rice takes time to generate and the initial seedling has sufficient nutrition to support growth, the plant cannot use basal

Table 12. Effect of N application method on grain yield of upland direct seeded rice[a] at different locations during 1980.

Time and rate of N application			Grain yield (t/ha)								Nitrogen response (kg grain/kg N)
15 d after sowing	Tillering	Panicle initiation	Tuljapur	Chiplima	Faizabad	Upper Shillong	Raipur	Derol	Palampur	Mean	
0	0	0	1.39	1.41	0.82	2.70	1.03	0.72	1.54	1.38	–
60	0	0	1.75	1.93	1.11	3.37	1.58	0.86	2.00	1.80	7.1
15	30	15	1.75	2.24	1.48	3.85	2.07	0.96	3.35	2.24	14.5
20	20	20	1.61	2.11	1.32	3.93	1.84	0.91	4.15	2.28	15.0
0	30	30	1.62	1.93	1.22	3.56	1.88	0.66	2.33	1.89	8.5
60	0	0	1.58	2.29	2.00	3.67	1.25	1.12	4.00	2.14	12.8
LSD (0.05)			ns	0.42	ns	0.16	0.44	0.17	0.23		
CV (%)			16.0	14.1	30.0	2.6	14.9	14.5	6.1		

[a] Varieties tested were Tuljapur-I, Parijat, Narendra-1, Batlong (local), GR-3, and Himdhan.

nitrogen. Instead the more competitive and vigorous weeds use the N.

The AICRIP national trial showed that applying 20 kg N 15 days after sowing, 20 kg at tillering, and 20 kg at panicle initiation stage was most effective. The maximum response (15.0 kg grain/kg N) occurred in 1980 (Table 12).

Nitrogen sources. Nitrogen fertilizers such as ammonium sulfate, calcium ammonium nitrate, ammonium sulfate nitrate, and urea perform equally well and are safe to use.

Micronutrients. Zinc and iron deficiencies exist in most upland soils in India. Application of zinc compounds and iron sulfate improved yields.

soil management for efficient fertilizer use

CRRI in Cuttack studied the effect of soil compaction on grain yield and fertilizer efficiency of direct-seeded upland rice. Data showed that more than 5 t/ha may be obtained from soil compaction up to soil bulk density of 1.6 g/cc and 100 kg N/ha. Compaction beyond 1.6 g/cc decreased grain yield (Table 13).

Weed control

In rainfed areas where water does not cover the land continuously, weeds thrive. Farmers sow after the first shower and the weed seeds start germinating before the rice. Excess weeds in direct-seeded fields can severely suppress rice causing a 60-70% loss,

Weed control should start with preparatory tillage immediately after harvest of the previous crop, taking advantage of off-season rains. Weeding with hand tools or bullock-drawn implements is possible when rice is sown in rows. Although hand weeding is still one of the predominant weed control methods, labor scarcity is becoming more acute. Chemical herbicides are usually more effective than one hand weeding but two hand weedings are more effective than herbicides.

One application of butachlor EC at 1.5 kg and 2.0 kg ai/ha, 7 d. after sowing, followed by 1 mechanical hand weeding was also effective.

Table 13. Effect of soil compaction in upland rice fields on variety IR48 grain yield,

Treatment	Grain yield (t/ha)			
	0 N	50 kg N	100 kg N	Mean
No compaction	1.0	2.5	3.9	2.3
Moderate compaction	1.4	3.8	5.1	3.4
High compaction	1.0	3.0	4.1	2.7
Mean	1.1	3.1.	4.4	

An All India Dryland Project experiment shows that weed control is critical during the second 2 wk after sowing, but not too important after then.

Disease and insect pests

Important diseases are blast, brown leaf spot, sheath rot, sheath blight, bacterial leaf blight, bacterial leaf streak, and panicle browning.

Screening of upland indigenous germplasm materials from different parts of India indicated that on a scale of 0-9, 93 of 98 genotypes showed a score of 4 or above for brown leaf spot, 82 for bacterial leaf blight, 53 for sheath rot, and 41 for bacterial leaf streak, under field conditions.

Even with these severe diseases in upland germplasm material, scientists have incorporated adequate resistance in new lines. An overview of disease in the new lines is shown in Table 14.

The International Upland Rice Observational Nursery test also screened material from other countries under field conditions and found improved disease resistance.

Important insects are termites, white grubs, soil crickets, rice bug, root beetle, armyworms, mealybug, and sometimes stem borers.

Mostly they are soil insects which flourish in nonflooded environments; therefore, it is important to apply soil insecticides during sowing. Dusting 20-25 kg gamma BHC/ha during the last preparatory tillage controls soil insects at germination stage. For severe infestation, farmers may also dust the standing crop and then hoe. There are no special techniques for other insects in upland conditions and farmers use few insecticides.

PRESENT VARIETAL STATUS

As a result of natural selection, two ecological groups of rice evolved: a long-duration and photoperiod-sensitive variety for the rainfed lowlands and the other a short-duration photoperiod-insensitive variety for uplands. Strains developed according to length of rainy season, amount of weed competition, temperature regime, variable soils, the specific grain preference, and insect and disease pests. Varieties for uplands should not exceed 100-day growth duration in northeastern India. Indigenous germplasm data collected from upland areas substantiate this. Most varieties flower in 75 d with total duration of 100 d and are 120-130 cm tall.

In many Indian states with well-drained fields and without irrigation, certain varieties from different research centers were identified, established by pure-

Table 14. Degree of disease resistance for new Indian rice strains.[a]

Strain	Blast reaction at					Strain	Brown leaf spot reaction at		Strain	Bacterial leaf blight reaction at	
	Shillong	Almora	Aduthurai	Mandya	Palampur Ranchi Majhera		Aduthurai	CRRI Cuttack		Faizabad	AICRIP Chinsurah, Pantnagar, Kaul, Kapurthala, Raipur
NDU-80	0	3	+	+	Less than 3	NDU-80	1	+	NDU-80	3	4-5
NDU-81	+	+	1	1	+	RP 1140-28-3-3-6	1	+	NDU-81	3	+
NDU-82	+	+	1	1	+	RP 1897-3790-30-1	1	+	NDU-82	3	+
NDU-84	0	3	+	+	Less than 3	RP 1670-2204-1586	1	+	NDU-83	3	+
Susceptible check (HR12)	7	7-8	7	9	7-9	NDU-83	+	2	NDU-86	3	+
Resistant check (Rasi)	3	3-5	3	3	3-5	AR 11123-4-6	+	2	NDU-88	5	1 to 5
						AD-98	+	2	Cauvery (check)	7	+
									(TN-1) check	+	7-9

[a]+ = not tested in that trial. [b]Tested under rainfed situation in station trial.

Table 15. Pureline varieties under cultivation in upland areas of India.

Variety	State	Height (cm)	Days to 50% flowering	Kernel color	Grain type [a]
N22	Uttar Pradesh	108	60	White	SB
Sudha	Uttar Pradcsh	100	60	Red	SB
Br 19	Bihar	120	70	Red	LB
Br 21	Bihar	125	70	Red	SB
Br 22	Bihar	128	70	Red	SB
Black gora	Bihar	121	72	Red	SR
Brown gora	Bihar	113	77	Red	SB
Ch 45	Bihar	105	82	White	SB
Dular	West Bengal	147	75	Red	MB
Bam-12	Orissa	125	85	White	LS
B76	Orissa	120	75	Red	SB
Kalkari	Orissa	102	65	Red	SB
MTU-17	Andhra Pradesh	95	85	Red	SB
Asd-8	Tamil Nadu	115	65	Red	MB
Asd-9	Tamil Nadu	125	65	Red	MS
Co-13	Tamil Nadu	113	98	White	SB
PTB-10	Kerala	115	75	Red	MB
PTR-28	Kerala	120	90	Red	SB
PTB-29	Kerala	120	80	Red	MB
PTU–30	Kerala	115	80	Red	MB
Swarna Modan (ARC-11775)	Kerala	120	75	White	MS
Tuljapur-1	Maharashtra	116	72	Red	SB
Ambemohar	Maharashtra	118	79	White	MB
Nagpur-22	Maharashtra	92	81		MB
Nagpur-27	Maharashtra	102	78	White	LS
E.K. 70	Maharashtra	120	90	White	LS
Satha-34-36	Gujarat	135	72	White	LB
Lalnakanda	Punjab	127	78	Red	SB
Jhona 349	Punjab	114	74	White	MB
Laloo-14	Madhya Pradesh	110	60	White	MS
Safed Dhan-3	Madhya Pradesh	115	85	White	MS
Dumai	Assam	125	55	Red	SB
M-142	Assam	140	70	Red	MB
M-175-1	Assam	105	70	Red	MB
C203-3	Assam	100	70	Red	MB
M36-30	Assam	130	75	Red	MB

[a] SB = short, bold; LB = long, bold; MB = medium, bold; LS = long, slender, MS = medium, slender.

line selection, and recommended for local planting. The most important varieties of different states are mentioned in Table 15.

After introduction of high-yielding dwarf varieties for irrigated areas, farmers also demanded high-yielding varieties for upland areas. Although there was no program for breeding upland varieties, short-duration, partially drought-tolerant varieties were identified and recommended for cultivation in specific areas. Table 16 lists the important dwarf varieties released.

Table 16. Dwarf varieties released for upland areas in India.

Variety	Days to 50% flowering	Height (cm)	Grain type[a]	Kernel color	Area of adaptability
Cauvery	87	80	SB	White	Throughout country
Bala	80	75	SB	White	Throughout country
Rasi	85	80	MS	White	Throughout country
Akashi	80	80	SB	White	Throughout country
Pusa 2-21	80	80	SB	White	Throughout country
Kanchan	70	97	SB	White	Bihar
Kiran	75	80	SB	White	Bihar
Annapurna	70	80	SB	White	Kerala
Narendra-1	75	85	MB	White	Uttar Pradesh
Govind	84	85	MS	White	Uttar Pradesh
G. R. -3	70	—	LS	White	Gujarat
Kalinga-1	75	80	SB	White	Orissa
Kalinga-II	75	85	SB	White	Orissa
Tripti	95	85	LB	White	Madhya Pradesh
Pallavi	70	90	MS	White	Orissa
Poorva	60	80	LS	White	Madhya Pradesh
MDU-1	85-90	75	LS	Red	Tamil Nadu
Triveni	75	90	SB	—	Kerala
Rohini	78	85	LB	—	Kerala

[a]See footnote of Table 15.

CURRENT RESEARCH ACTIVITIES

The important upland research centers in India are indicated in Figure 7. The upland rice program at Faizabad Centre in UP began in the early sixties, and intensified later in the decade with these current research activities.

Germplasm management

Major efforts have included a survey of upland areas during the rainy season, collection of indigenous germplasm and its maintenance, agrobotanical study, and evaluation for quality, drought resistance, root penetration, and disease and insect resistance. The center also obtains upland material from other national and state programs and has documented and maintains about 200 strains for national and international use.

Screening results

During screening in natural drought conditions, indigenous tall varieties grew better than national and exotic dwarf strains. Most exotic strains could not even flower. In flowering strains, spikelet sterility ranged from 4 ta 100%. Indigenous strains (Anjani, Kachni, Duddhi-White, Ranikazel, Sarya, Thelai, and Mutmuri) also showed better seed set than national and exotic strains.

Problems of traditional varieties

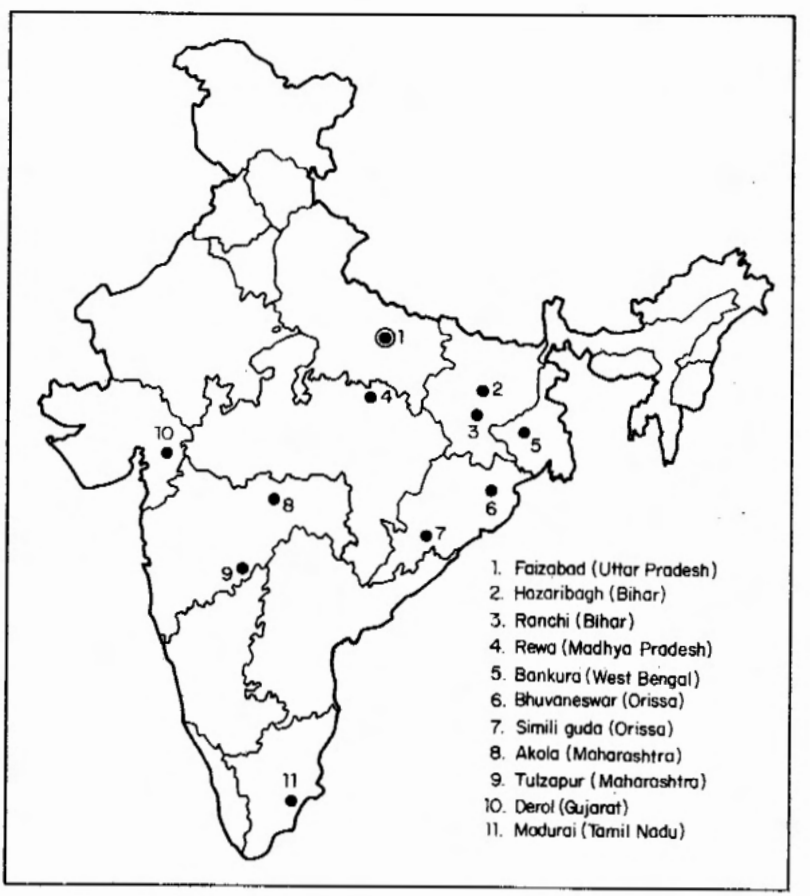
Problems of traditional varieties include

- lodging in favorable conditions,
- low yield potential,
- susceptibility to diseases and insects,
- poor response to good management,
- shattering, and
- coarse grain and red rice.

Problems of dwarf varieties

Problems of dwarf varieties include

- poor competitive ability against weeds,
- lack of vigor,
- lack of adequate seed dormancy, and
- inadequate leaf area under streas situation.



7. Upland rice research stations in India.

Requirements of upland varieties

Plant requirements for upland areas include these qualities:

- early vegetative vigor,
- intermediate height (100-120 cm),
- resistance to lodging,
- moderate tillering,
- maturity of 90-105 d,
- vigorous root system,
- quick recovery from drought stress,
- tolerance for problem soils (iron, phosphorus, and zinc deficiency, aluminum toxicity),
- resistance to diseases (sheath blight, helminthosporium, Cercospora, bacterial leaf blight),
- acceptable grain quality (medium to fine grain with white kernel and high amylose content),
- nonshattering, and
- adequate seed dormancy.

Using tall and semitall breeding lines, we identify strains, based on phenotypic performance, to produce these traits.

Crosses and mating designs

Upland rice requires three basic traits: intermediate height, nonlodging behavior, and short-duration cycle matching the rainy season. A combination of any of these traits is easy to achieve, but it is difficult to combine all three. Besides single crosses, researchers are using backcrosses and three-way and double crosses. By segregating the material, we have achieved some rare strains. We are still testing their stability and performance. Some of the crosses yielding good strains are White Gora/Annapurana, White Gora/Panidhan, White Gora /FH109, White Gora/IET3262, White Gora/IET1444, White Gora/MW-10 (CRM-l3), N22/IET1444, KR5-142/IET3262, KR5-142/IAC25, Narendra-1/CR 245-1, Dular/FH207, ARC-11775-6/Sc. 322 G, and Dular/Panidhan.

Selection techniques

At the Faizabad center, we follow three selection cycles. In the first cycle for the early segregating generation (F_2 and F_3), we emphasize morphological traits (semitall stature) and physiological traits (short-duration).

In all cycles, we select by rejecting unfit material (culling technique) because it is easier to reject than to select at early stages.

In the second cycle, we concentrate on nonlodging, tillering, panicle weight, and disease resistance.

In the third cycle, we identify lines with the desired features and subject these to physiological

stress such as drought and tolerance for iron and zinc deficiency.

Finally, after lines show desirable features through all three cycles, we perform several yield tests: Initial Evaluation Trial (IET), Preliminary Varietal Trial (PVT), Standard Varietal Trial (SVT), and Regional Adaptability Trials (RAT).

Other centers have not adopted special breeding techniques, but instead use the traditional technique of pick and choose.

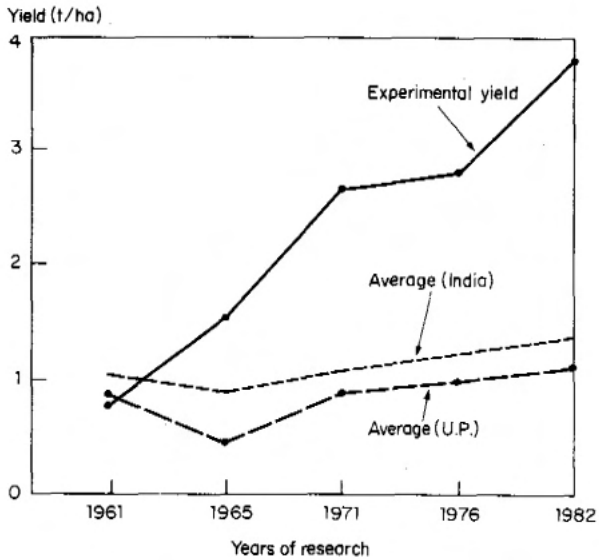
Multilocation tests

Material generated at different centers is being tested through All India Coordinated Research Project, under optimum conditions through PVT-l and UVT-l, and in a drought screening nursery monitored by the Faizabad center.

Results with new lines at 5-yr intervals are shown in Figure 8. Experimental yields increased from 0.7 t/ha in 1961 to 3.7 t/ha in 1982 because of better genotypes and management. Despite better genotypes, however, the increase in average yield of the UP State as well as India remained very low (1.01 t/ha in 1961 to 1.34 t/ha in 1980-81) because of poor transfer of technology about genotypes and crop management.

Problems

We face practical problems in combining the three



8. Progressive yield levels of paddy under upland situation at Faizabad compared to national and state average rice yields.

essential traits into one plant because only two traits combine easily.

The second problem is that drought resistance, a must for upland culture, is not easily identifiable and is difficult to achieve without a suitable screening technique. This is especially true when evaluating segregating material in large-scale field conditions.

FUTURE STRATEGIES

We will concentrate on efforts to incorporate all three essential traits by multiple crossing and intermating in the early segregating generations.

To achieve adequate drought tolerance, we will screen genetic material at many locations and planting times to represent natural field conditions.

We will also follow a multiple selection technique to optimize the desired basic traits for upland situation.

UPLAND RICE IN LATIN AMERICA

CIAT

In Latin America, upland rice cultivation is substantially mote important to total rice production than in Asia. Ralnfed lowland rice, using the Asian definition, plays a smaller role in Latin America. Cultivation similar to the Asian rainfed lowland is found in Ecuador (20,000 ha in the Pozas system), in the Varzeas of Brazil (520,000 ha), and in a small region in the Dominican Republic. Rainfed lowland rice is planted on less than 7% of the regional rice area and contributes about 10% to regional production.

The upland rice definition adopted for this workshop (rice grown in rainfed conditions on well drained soils without surface water accumulation, normally without phreatic water supply, and normally not bunded) applies reasonably well to most of the estimated 6.14 million hectares of upland rice in Latin America (1980) except fur some highly favored upland areas with access to phreatic water at some stages of the growing season.

Upland rice is grown in a wide range of Latin American environments. Upland subsystems in Latin America have been classified as favored upland, moderately favored upland, and unfavored upland. Favored upland tends to be more common in the Andean countries, moderately favored upland in Mexico and Central America, and unfavored upland is mostly found in Brazil.

This paper gives a general description of upland rice cultivation in Latin America. Martinez (1984) and Seguy (1984) give detailed descriptions of the upland cropping systems in the region and Steinmetz et al (1984) describes methods of classification and zonation of upland rice environments.

DISTRIBUTION AND IMPORTANCE OF UPLAND RICE

National production statistics for rice in Latin America generally separate production information for different upland rice environments. Data on upland rice production for each country have been estimated mainly from information provided by cooperators in the International Rice Testing Program (IRTP) network for Latin America. Most data group favored and moderately