RICE IN AFRICA

Proceedings of a conference held at the International Institute of Tropical Agriculture Ibadan, Nigeria, 7–11 March 1977

Edited by

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and

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PREFACE

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Rice in Africa? Rice connotes to most of us, Asian civilization and its base in the permanent rice agriculture in the alluvial deltas of the great Asian rivers. Rice, man's major food, is indeed Asian, where 90% of the world's rice is grown, and where it is *the* food of more than a billion people.

But we learn that rice is also African and that a different kind of rice was raised in West Africa 3000 years ago. We learn that rice has a long and interesting history in parts of Africa; that some African countries are just as much rice-oriented as any Asian country. We learn that although the volume of rice production may not be great today, it may be so in the future, with proper development of existing water resources. At present, West Africa alone imports 7% of the world's annual trade in rice. We learn that the types of environments and rice culture in Africa are as diverse as those in Asia and that there are also many differences based on varied cultural evolution and environment. We learn that there are diseases and insect pests in Africa different from those on other continents and that new ones are being found.

But rice is new to many African locations; its cultivation is complex and much knowledge is needed for successful production and development. To help stimulate needed communication on rice growing and on rice research within Africa, the International Institute of Tropical Agriculture, near Ibadan, Nigeria, convened a conference on "Rice in Africa" in March, 1977 and invited participants from many tropical African countries. This conference was held in collaboration with the International Rice Research Institute, the Institut de Recherches Agronomiques Tropicales, and the West African Rice Development Association. This was the first opportunity for many rice researchers from different parts of Africa to exchange ideas and information. It is to be hoped that the opportunity will happen again, with representation from more countries of Africa where rice is of interest.

The papers included in this volume are abridged versions of the contributed papers and abstracts of the country statements, both of which were originally presented in either English or French. We hope that they adequately reflect the authors' intent.

This volume is only a part of the knowledge on rice in Africa. There is considerable information available, especially in French, in *L'Agronomie Tropicale* and other journals which reflects research over many years that is not adequately represented in this volume.

The challenge for research and development on rice in tropical Africa is enormous, and the problems are many. The opportunity to answer this challenge mainly lies with the scientists and development officers of Africa. We hope that this volume will be a small contribution to aid them in their efforts.

The Editors

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The assistance of the staff of the Communications and Information Section, International Institute of Tropical Agriculture, is gratefully acknowledged. Special thanks are due to F.R. Moormann who translated and extensively edited several of the French papers. The assistance in the review of the papers by several other colleagues, particularly K. Alluri and H.C. Bittenbender is gratefully acknowledged. We also thank Y. Tanaka for his assistance with the figures. The photos at the end of each section were taken by I. Buddenhagen.

The Editors

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To the rice farmers of Africa

Ex Africa semper aliquid novi

(There is always something new out of Africa)

Pliny (23-79 A.D.)

Overview of Rice in Africa

THE HISTORY OF RICE IN AFRICA

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"The history of the introduction of Asian food crops into Africa is written on the wind, and the wind cannot read."

Introduction

A review of the origins and development of rice in sub-Saharan Africa is a considerable challenge for an agronomist presently working on food crop development on the islands of Zanzibar and Pemba, without easy access to the substantial literature on the subject. However, it is appropriate that someone living in this area, the hub of cultural and biological exchange between Asia and Africa for so many centuries should have an incentive to think about this subject. From the window of my room at the top of the 19th century Kilimo Ministry in Zanzibar town a constant stream of lateen-sailed dhows and outrigger canoes can be seen running into harbour, driven by the northeast monsoon. For more than twenty centuries these varied craft have been arriving from South and Southeast Asia bringing with them amazing new crops such as banana, *Colocasia*, coconut, mangoes, the annonacious fruits, durian, cloves, pulses, spices and of course, *Oryza sativa*.

African Wild Rices

However, the history of rice cultivation in Africa probably began long before the first navigator from Java or the Arabian gulf made landfall on the Tanzanian or Malagasy coasts. The African species, *Oryza glaberrima* Steud. was selected and established in a wide variety of habitats in West Africa more than two thousand years before any organised seaborne expeditions arrived. This species was selected from wild annual rice, usually named either *O.breviligulata* Chev. & Roer. or *O.barthii* Chev. The nomenclature of wild rices in Africa has been very confused and the names *O.stapfii* Roz., *O.breviligulata*, and *O.barthii* often occur with uncertain usage (Harlan, 1973). This group of species commonly occurs in shallow, seasonally flooded pools. Most forms set easily-shattering spikelets on stiff, rather unbranched panicles. These wild rices are still sometimes collected for food. Annual wild rice occurs from Senegal to Tanzania and is widespread in Zanzibar. It is regarded as being primarily a savanna species which later became adapted to the high rainfall forest zone.

The other common African wild rice is the perennial *O. longistaminata* Chev. & Roer., which is sometimes wrongly called *O.barthii*. It is a tall, rhizomatous, outcrossing rice which usually grows in creeks and drains and often sets only a few seeds. In Zanzibar the two types grow side by side in the bed and on the banks of streams, which leads one to speculate on the possibility of hybridization having occurred. Apparently these several wild rice species have been little collected or observed in tropical East Africa and most treatments (such as Portères in Harlan) do not indicate their existence in coastal East Africa. Recent theories of plate tectonics enable us to understand the concept of a very ancient tropical origin for the genus which became broken up so that wild rices, now different species, are presently strung out over each tropical region of the globe, to include even South America and Australia.

Selection by early African rice farmers led to the development of a great range of *O.glaberrima* cultivars. Even today one can collect floating varieties, weakly and strongly photoperiod-sensitive types, swamp and upland cultivars, short and long duration types, all with a number of variations of seed and inner and outer glume characters. The range of variation of *O.glaberrima* has been considered to be less than that of *O.sativa* (Chang, 1970). However, when one considers the smaller range of habitats, particularly in terms of altitude and the smaller number of farmers involved in developing the crop, the range of variation is quite remarkable; all the more so when the varieties are seen in the field rather than in collections. African rice was first grown in the central Niger delta, with other centres of diversity in the Gambia, Casamance and Sokoto Basins. It seems reasonable to suppose that it was introduced in the far western forest area into a bush-fallow upland farming system where it may have partially replaced the native *Digitaria exilis* Stapf which is still widely grown as an early crop on the previous year's rice land before re-fallowing to bush.

In West Africa *O.glaberrima* was partly displaced by *sativa* varieties at least from the 15th century onwards. Less is known of the history of the species in East Africa, but I collected typical examples of the species from rain-fed rice fields in Zanzibar in 1976. A few *glaberrima* plants can be found even today in upland rice farms from Guinea to Liberia and the Ivory Coast. There exist farms

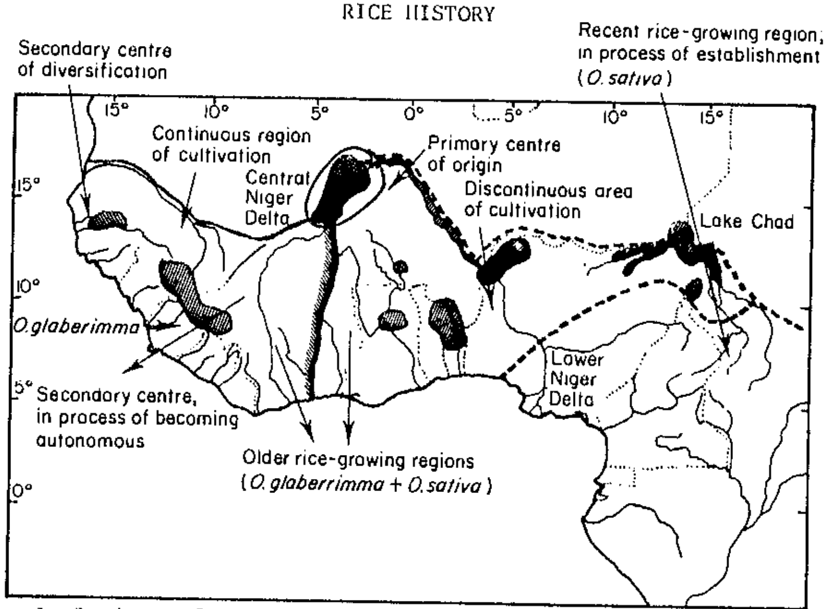

Fig. 1. Regions of cultivation, origin and segregation of *Oryza glaberrima* Steudel (from Portères, 1957)

which grow pure stands of African rice. Perhaps the most successful area for the species is as a floating rice on the Sokoto fadamas of Nigeria where yields of 3 t/ha were reported in the 1960's. This was higher than the available *O.sativa* floating cultivars which were preferred because of less shattering and better grain quality. In general, upland 'glaberrimas' cannot compete with the better 'sativas' in yield today, but there is considerable overlap between the best 'glaberrimas' and the poorer 'sativas'. The competitive position of the Asian rice must have been poorer in early days when a small, relatively unselected gene pool was first introduced.

Introduction of O.sativa from Asia

How did the *Oryza sativa* varieties reach Africa? The history of the arrival of the Asian food crops was written by the wind. The first visitors from Malayo-Polynesia probably began sailing their outrigger canoes from Java a few centuries B.C. They were driven by the south-east trade winds which blow all the year round and are especially strong between May and November (Figure 2). These outrigger canoes are fast and the 3500 mile trip could have been completed in about a month, the key to the successful transfer of perishable aroids and bananas. I feel sure that every canoe that made the trip carried a substantial supply of paddy rice which is an excellent source of non-perishable starch food for a long, warm, wet trip into unknown waters. The evidence is that these seamen-farmers

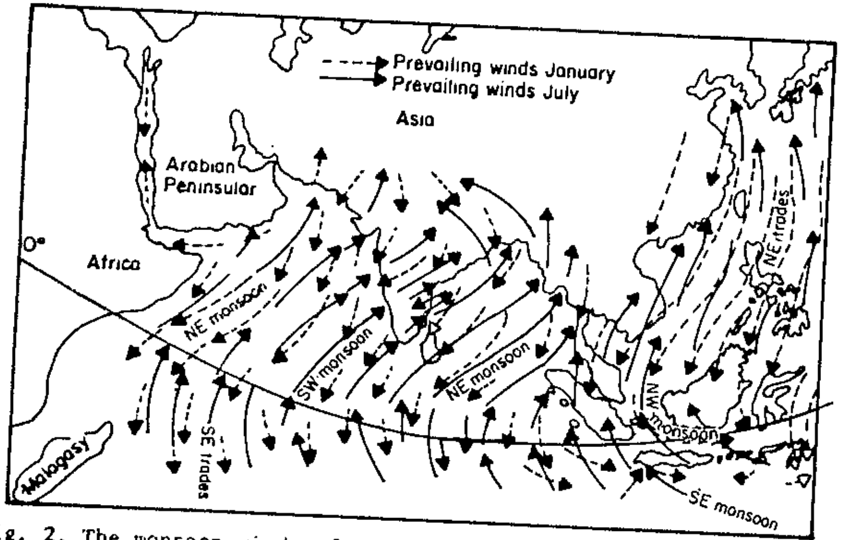

Fig. 2. The monsoon winds of southern Asia. The monsoons blow for six months in one direction and six months in the other. Sailors found that they could travel across the Indian ocean on one monsoon and back on another. (From "Eastern Islands, Southern Seas", Aldus Books, London, 1971. p.15)

found Malagasy uninhabited and they arrived equipped not only with paddy but also with intensive rice-growing technology and established the remarkable range of cultural methods which exist there today. Although Malagasy retains a high degree of cultural identity, exchanges with the main continent across the 200-mile channel were obviously continuous and frequent and rice must have travelled in almost every boat leaving for the African mainland. Terraced rice fields, outrigger canoes and certain musical instruments (e.g. marimba) were some of the other innovations brought by the Malayo-Polynesians. The new crops spread throughout East Africa, but the terraced fields of intensive rice production did not.

The second important contact with Asia was the route from Sri Lanka and India via Oman and then on the north-east trades to Somalia, Zanzibar and Kilwa. From about the dawn of the Christian era, South Arabia was the centre for the trade in spices, aromatic gums and incense from India, and the gold, ivory, ebony, tortoise shell and slaves from Africa. East winds from Sri Lanka and India carried ships to Aden and then the northeast monsoon, blowing steadily from December to February, made possible an easy passage all along the east coast of Africa. Again, all these boats probably carried rice as a food reserve and sold or exchanged the surplus paddy at the ports they visited. Continuous introductions of *sativa*

rices from Malaysia, India and Sri Lanka probably occurred for about 2000 years. However, the dhow traders were not farmers and they brought no new rice growing methods with them. Indian migrants were interested in trade not farming. Hence, rice cultivation in East Africa remained largely a coastal rainfed crop with some more intensive cultivation around the lakes.

The final penetration of *sativa* rice into Africa was along the slave trading routes from the East coast and Zanzibar to Zaire. Portères (1950) produced good evidence that Asian rice was introduced into Senegal, Guinea-Bissau and Sierra Leone by the Portuguese about 1500 A.D., on their return from expeditions to India. Whether this rice came directly from India or was collected in East Africa en route is not known. It is also not clear if Asian rice might have penetrated earlier into the Senegal-Liberia higher rainfall rice area via Zaire, Cameroon, Nigeria and Ghana. Another possibility is the migration of Asian rice from Egypt where it was introduced about 800-900 A.D. south and then west across the savanna to West Africa (Nayar, 1973). What is certain is that there was considerable traffic from the savanna African kingdoms to Egypt and Mecca since Muslim conquest and conversion of these African peoples. Ethno-botanical research of the stature of Portères' is needed to clarify the earliest routes of Asian rice into West Africa (Figure 3).

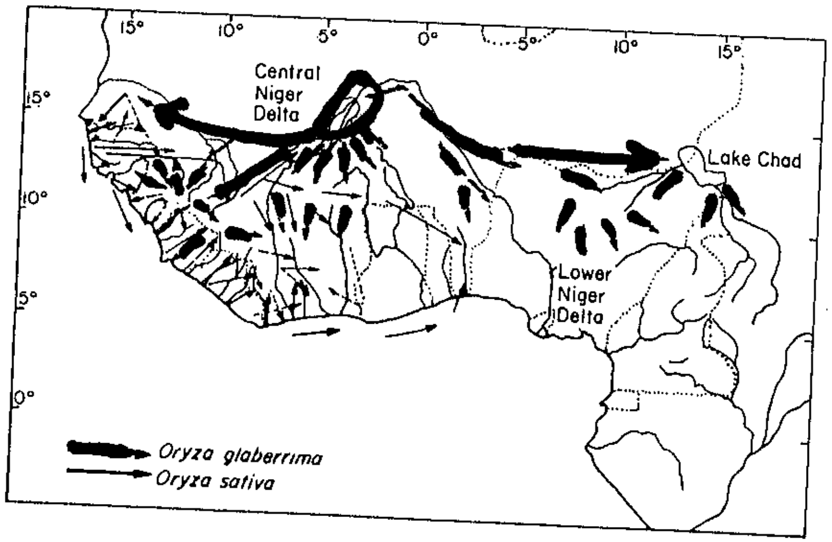

Fig. 3. Migration of rice varieties in West Africa (from Portères, 1957)

Development of rice culture, 1500-1900

During the 400 years which covered the socially and economically destructive disaster of the slave trading era, African farmers developed a series of flexible methods for extensive rice growing. For example, in Sierra Leone, the Temne people migrated into the estuaries of the Great and Little Scarcies river at the end of the 19th century. They discovered that by felling the tidal mangrove forest, transplanted rice could be grown when the early rains had washed away the sea salt left by the dry season tides. Rich silt deposits maintained fertility from year to year and the salt tides killed most of the weed species. About 20,000 hectares of dense mangrove forest were felled and brought into production over a forty year period. Rices with short duration and salt tolerance were selected for the seaward areas of the estuaries and a test planting system to check that salt levels in the fields had fallen to a safe level was developed. Another method of reclaiming mangrove lands was developed in Guinea by the Baga people. They migrated to the coast from the Niger valley where they had also grown rice. They used a special oar-shaped spade, the "kofi", to construct bunded fields to exclude the sea and allow salt flushing by the early rains. They also transplanted rice on *billons*-low ridges built by inverting slices of soil with the kofi to allow salt flushing and to control weeds. In Liberia, upland rice grown in bush fallow rotations was protected against rodents by carefully constructed log slab or palm frond fences. Intercropping with early, protein-rich vegetables, which had a useful cash market value, became almost universal in Liberia and contributed to a preference for upland rice over flooded valley rice where the intercrops could not flourish. Tanzanian farmers around Mwanza built contour bunds to collect run-off for the rice crop. In West Africa *crue* and *decrue* systems of matching varieties of correct duration and flood resistance to the rising and falling floodwaters of the great West African rivers were developed. Little use was made in Africa of small irrigation systems, levelled terraced fields, animal traction, organic manuring and other features of intensive Asian rice culture.

Development since 1920

Several books and hundreds of papers have been produced to record developments in rice culture since 1900. References to most of these are available in the bibliographies and seminar papers produced by WARDA since 1971. Perhaps it is worthwhile here to give an historical overview of some of the strategies adopted since 1920. There seem to be three phases of intervention into the rice growing system developed by African farmers. The first

type is the large-scale irrigation scheme exemplified by the tremendous project of the Office du Niger in Mali, and the schemes in the Senegal River and in coastal Guinea, around Lake Aloatra in Malagasy and more recently the Mwea scheme in Kenya. These projects were largely concerned with resettlement of farmers in more productive circumstances and they drew their inspiration from the successful Gezira scheme in the Sudan.

A second phase was the introduction of mechanization, particularly for rainfed rice. Most West African countries introduced contract ploughing services for farmers in the 1950's and 1960's. The Sierra Leone Boli and southern grasslands developments, and schemes in northern Nigeria, Ghana and in the Faranah area of Guinea are examples of this approach.

Thirdly, a period of intensification of irrigated rice farming, largely initiated by Chinese specialists working closely with farmers, began in many countries during the 1960's. Many of these small scale schemes have been very successful, particularly in the Ivory Coast. In many cases the large scale irrigation projects have been more expensive than anticipated, because the detailed problems of obtaining high yields at the field level were underestimated. Too much emphasis may have been placed on engineering expertise and not enough on the basic agronomic requirements of high yielding rice and the special problems of farmers transferred into a completely new system without the tradition of intensive rice cultivation which stood the Indonesian pioneers in such good stead in Malagasy.

In the case of mechanization projects there is no doubt that increased family incomes and decreased stress on the farmers were beneficial. However, the high cost of imported equipment and fuel, the difficulty of operating them in dusty or wet conditions far from adequate workshops and replacement parts, design inadequacies in Western-evolved machines, shortage of management skills and finally, inflation, meant that more and more subsidies had to be built into these programmes. African farmers were not protected by the political umbrellas operating in the European Economic Community and in North America; most African economies cannot sustain development along all fronts of education, health, communications etc. and also subsidize farm services. This has become a major problem in Tanzania in the last few years. Additionally, especially in high rainfall areas with low soil fertility and low cation exchange capacity, mechanized ploughing has led to erosion and increased leaching and rapid loss of productivity.

It is well known that investment, extension and research into African food crop production has been badly neglected in the past in favour of the development of cash crops and mineral resources of interest to the industrialized countries. The situation is improving but the task ahead is enormous. In Zanzibar there are good prospects of producing a large food surplus in the next ten years, using already existing technology. However, FAO has projected an estimated domestic demand increase for food in Africa of 3.9% each year to 1985, while production only rose by 2.5% in the 1961-73 period. Obviously, there is much work to be done.

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RICE ECOSYSTEMS IN AFRICA

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Introduction

Rice cultivation and attempts to modernize its culture in tropical Africa differ in several fundamental ways from the Asian rice situation. These differences may be analyzed to advantage in order to understand the differing potentials and problems of African rice development.

To the observer familiar with Asian rice culture, the most notable characteristics of rice growing in Africa are its apparent newness and its primitive state. This generally primitive culture extends to most food crops in tropical Africa, and thus it is not due to the newness of rice in Africa, but rather to the character of peasant agriculture itself. There is little adjustment between rice growing and stable land use and, instead, one finds a constant exploration of new land areas and ecosystems, with different types of rice culture. In this context, an ecosystem is defined as a pattern of relations among physical, biological and evolutionary factors in an area. The types of rice culture include simple introduction of mechanized, irrigated rice schemes in areas never before having rice, attempts to develop inland valley swamps in old rice areas where dryland rice was traditional, and expansion of dryland rice into savanna areas previously only grazed by cattle, or sporadically cultivated with sorghum or maize.

In spite of this apparent 'newness', indigenous African rice, *O.glaberrima*, derived from *O.breviligulata*, has been utilized by man in three areas of West Africa for about 3,000 years (Portères, 1976). These areas were the central Niger floodplain, the coastal Gambia river, and the mountainous areas of Guinea. Indigenous rice culture in these areas was primitive and stagnant, and modern efforts to expand rice production in Africa have focused on the recently introduced *O.sativa*, and on Asian techniques of rice growing and rice improvement, largely ignoring the African heritage.

In many ways Africa and Latin America are similar with regard to rice culture since both are continents where rice (*O. sativa*) growing became established in new areas as a peasant activity for local consumption following the intercontinental movement of people and crops which occurred from the mid-1500's onwards. In both continents the early peasant rice culture with *O.sativa* was largely in the wet lowland forest zone, becoming a component of slash-and-burn agriculture under free draining, 'upland' conditions. In both continents, rice invaded cultures whose basic foods came from other crops. In both continents, other *Oryza* species had evolved but only in West Africa had an ancient rice culture developed with one of them. Here it was both a flood or swamp culture and a forest upland culture. Also, in East Africa, the original introduction of *O.sativa* long predated the European exploration, having been introduced along with Asian paddy rice growing techniques into Malagasy by the original Indonesian migrants more than a thousand years previously.

In many areas of West Africa, rice growing commenced only after about 1850, with expansion occurring locally from 1950 to date. In some areas along rivers, especially where indigenous rice had been grown or harvested, the new rice was grown under a flood-plain situation in drier climates. Only recently have efforts been made to develop the water control so characteristic of Asian rice culture. This development enabled rice to become a broader market commodity, and has also pushed rice into more diverse ecosystems, both complicating the problems and increasing the opportunities for rice improvement.

The original rice areas in Africa involved the ecosystems of arid savanna climates for flood-plain rice in several West African river systems and a localized wet-forest zone in Guinea-Liberia for upland rice under both dryland and hydromorphic soil conditions. On analysis, it is clear that different types of rice culture can cut across broad floristic zones or climatically and geologically determined ecosystems. While these broad ecosystems yield sufficient information for analysis of potentials for most crops which are grown under free-draining upland conditions, this is not true for rice, a crop which can be grown under widely diverse hydrological conditions.

Major Biological Ecosystems

The background for the major biological ecosystems in Africa is provided by both the geologic history and the climate, acting upon a long-isolated biota. These have resulted in flora-dominated ecosystems running generally east-west in most of tropical Africa but breaking into patchy areas in East Africa where orographic rainfall, elevation differences, proximity to the Indian Ocean, and

localized, richer soils from recent vulcanism make for a complex mixture. In lowland West and Central Africa the wet-forest zone near the equator shifts first to Guinean savanna then to Sudanian savanna and then to desert as one proceeds either north or south, with a quicker shift to dry conditions in north-central than in south-central Africa (Trewartha, 1961). The major vegetation zones in Africa are shown in Figure 1.

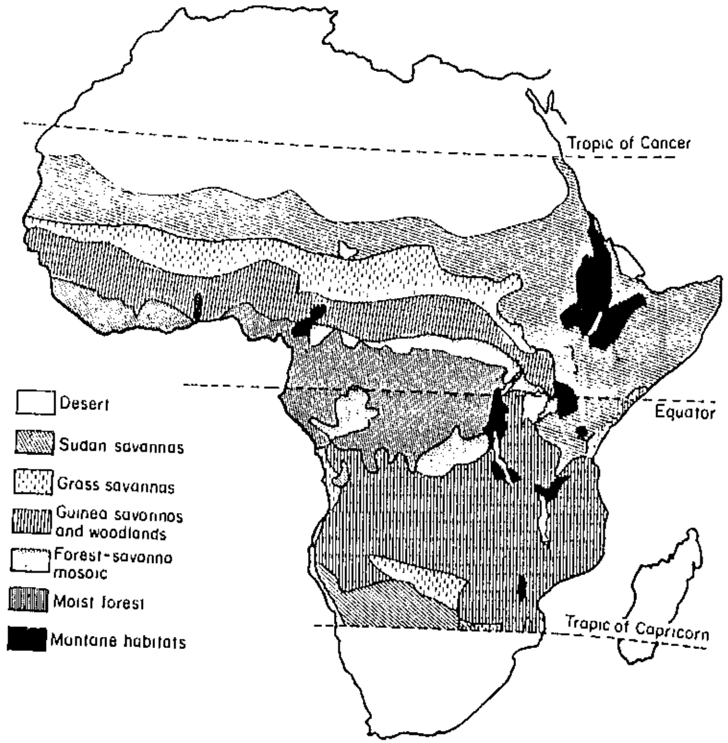

Fig. 1. Major vegetation zones in tropical Africa.

The primary determinant of vegetation and agricultural crop pattern is the length of the dry (or the wet) season (Figure 2), rather than total rainfall (Figure 3). This may range from close to zero to 12 months. The duration of the humid and dry seasons can be computed, using rainfall, temperature, and potential evapotranspiration as parameters (Papadakis, 1966). The broad climatic belts which form the basis for floristic zones and for different types of agriculture are determined by these parameters.

Although complicated by temperature and evapotranspiration differences, in general, in the lowlands (where the rainy season exceeds about eight months and the rainfall is greater than annual evapotranspiration) the natural vegeta-

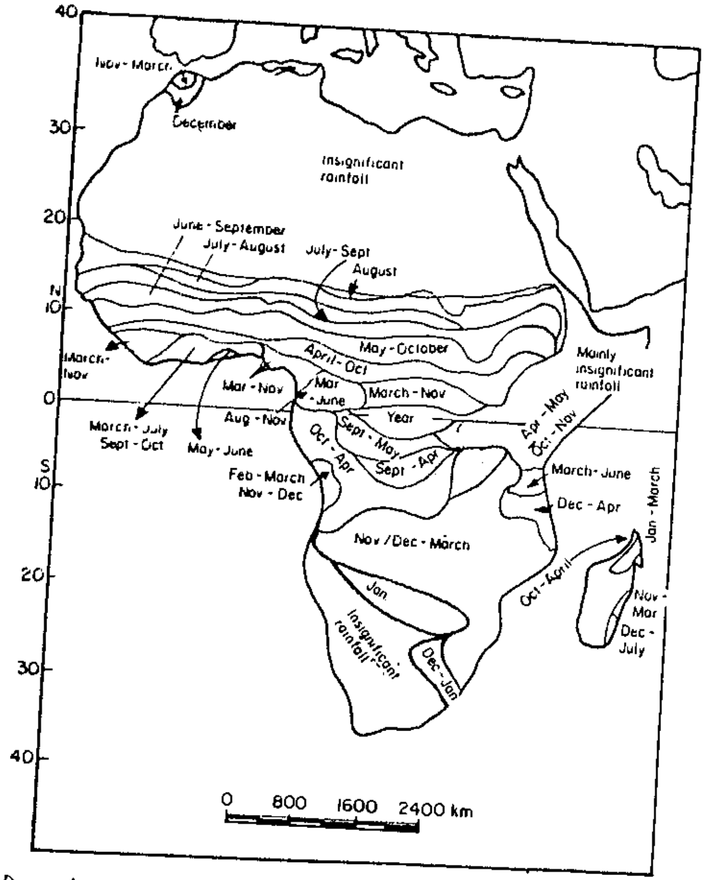

Fig. 2. Duration of wet season: Average monthly rainfall greater than 100 mm (from Thompson, 1975).

tion is closed forest, with increasing density and complexity with increased wet months (Figure 4). The influence of man with his slash-and-burn agriculture converts the marginal forest areas into 'derived savanna', altering the original vegetation pattern (Figures 5 and 6). At the interface between forest and savanna, there is, in some areas, a 'transition zone', characterized by a bimodal rainfall pattern which results in a drought period of 3-6 weeks during the normal summer rains. In such areas the original low-forest flora is easily converted to derived savanna or 'low bush' by man's influence. In areas of increasing bimodality, pure savanna even reaches the coast as in parts of Ghana and Togo.

Papadakis (1966) has classified these climatic belts as:

a) Forest (1.1, humid semi-hot equatorial)
b) Guinean savanna (1.4, hot tropical)

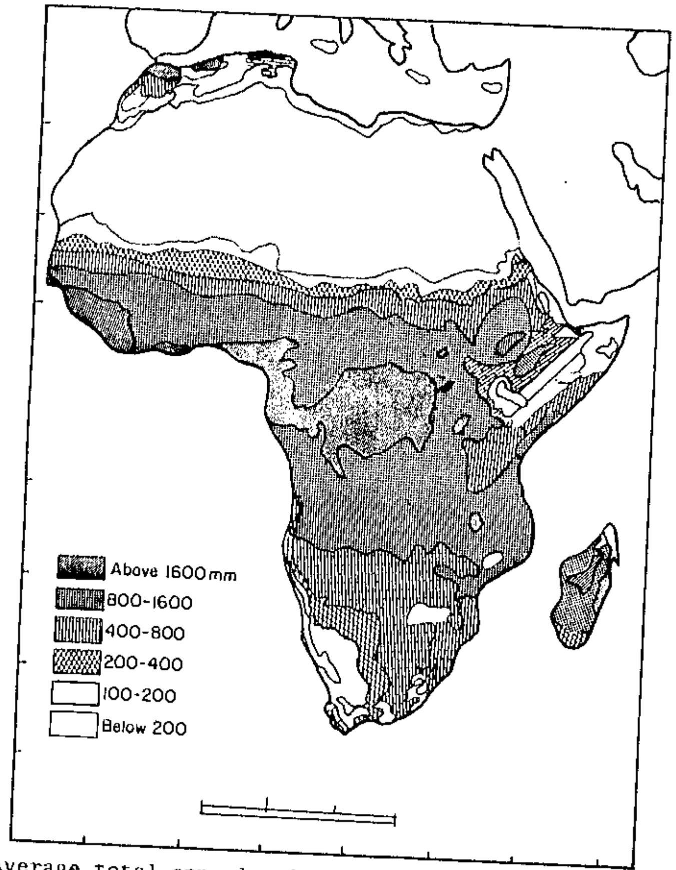

Fig. 3. Average total annual rainfall.

c) Sudanian savanna (1.5, semi-arid tropical)
d) Dry coast (1.3, dry semi-hot tropical).

In addition there is:

e) Frostless highlands (1.7, humid tierra templada).

(The number code and names in parenthesis are technical climate designations which relate the West African belts to world climate classification.) In this paper the 'frostless highlands' are referred to as mid-altitude, but include under mid-altitude, areas of East Africa with a less humid climate.

Although the major floristic-climatic zones can be divided into the aforementioned five broad groups, subdivisions of them have been made whose differences greatly influence crop possibilities. The forest belt in Africa has been divided into four divisions on the basis of water surplus (leaching rainfall) and the number of dry months (Papadakis, 1966). These are:

Fig. 4. Rainforest in western Ivory Coast.

1) Ever-humid forest belt (coastal areas around Greenville, Liberia),
2) Forest belt without dry season (Monrovia, Liberia; Abidjan, Ivory Coast; Lagos, Nigeria; Yangambi, Zaire; Brazzaville, Congo Rep.),
3) Forest belt with one to three dry months (Suakoko, Liberia; Cotonou, Rep. Benin) and
4) Forest belt with four or more dry months (Aledjo, Togo; Abeokuta, Nigeria).

Two of these divisions (forest belt without dry season and forest belt with one to three months dry season) have been subdivided into 3 and 5 subdivisions, respectively (Papadakis, 1966; Figure 7). These divisions influence rice culture possibilities especially through their differing long-term effects on soil characteristics and their seasonal influence on diseases, insects and harvest and

storage of grain.

The Guinean savanna or middle belt which covers more than 50% of West Africa, has traditionally been the poorest agriculturally. It has been divided into five section based on the relationship of seasonal rainfall to annual potential evapotranspiration, the number of humid and dry months, and the magnitude and continuity of the humid period (Papadakis, 1966). Three of these have been further subdivided into 2, 3 and 4 subdivisions. It is in the Guinean savanna with its many climatic subdivisions where rice culture has been attempted with varying degrees of success - a variability probably largely due to the climatic variabilities which are often little understood or appreciated.

Although most of the rice production and rice research in Africa is conducted in climates within the sub-divisions of the forest and the Guinean savanna belts, great potential exists within the Sudanian savanna because of the unique river routes across this area (Figure 8). In fact, it is this area in Senegal, Mali and northern Nigeria where indigenous rice culture exists and where increased water control could result in greatly expanded high productivity,

Fig. 5. 'Slash and burn' agriculture, in preparation for sowing rice, central Liberia.

Fig. 6. Derived savanna in southern Nigeria with mixed cropping in lower part of the landscape including rice, cassava, *Dioscorea*, *Colocasia* and *Xanthosoma* yams.

as it has in river plains in western India and in Pakistan. The Sudanian savanna includes areas with three humid months (Kano and Sokoto, Nigeria), two humid months (Maiduguri, Nigeria) and one humid month.

The humid highlands of West Africa have been divided into three subdivisions based on the number of dry months of 0, 1-4 and 5 or greater (Papadakis, 1966). Examples of the last subdivision are Jos, Nigeria and Moshi, Tanzania. Different mid-altitude areas, with their particular climatic influences on rice and rice diseases and insects occur in many places in Africa including Liberia, Guinea, Togo, Congo, Cameroon and much of East and Central Africa. In East Africa, mid-altitude areas suitable for rice are often drier and have a savanna flora.

This brief outline of climatic zones in tropical Africa can serve as a framework for discussing rice ecosystems, but more extensive references should be consulted, especially Papadakis (1966, 1970a, 1970b); Phillips (1959); Robertson (1975); Moss (1969); Thompson (1975); Trewartha (1961); and Brown and Cocheme (1973).

Rice Ecosystems

Agriculture depends on climate. Crop ecological regions may differ somewhat from climatic regions, but they are areas in which crop ecological conditions follow the same pattern. The soil factor can override other influences for crops even though it itself is shaped by climate. This is especially true for rice because of the importance of hydrologic soil conditions. With the great genetic plasticity of the species, rice can be grown across many climatic zones, crop ecological regions, and even soil differences. It is these interactions with the genotypic diversity which pose the challenge to the rice scientist.

In Africa, different systems of rice culture have been grouped in various ways (Chabrolin, 1976, 1977; Moormann and van Breemen, 1977; Jordan, 1968). In our research, we have divided African rice culture into four main types and eight sub-types:

1) Upland - a) dryland
   b) hydromorphic
2) Irrigated
3) Inland swamp - a) non-toxic
   b) toxic
4) Flooded - a) riverine shallow
   b) riverine deep
   c) boliland
   d) mangrove.

Many of these divisions transect most of the climatic divisions outlined previously, at least for rice cultivation based on ground, river or irrigation water. The rice ecosystem circumscribed by the direct influence of climate is the free-draining dryland type of upland rice culture. The other systems are circumscribed due to topography in relation to water source - the phreatic or fluxial types of rice culture according to the classification of Moormann and van Breemen (1977). As an example, flooded or irrigated rice may occur in any of the forest climates, in Guinean or Sudanian savanna, or in either humid or arid mid-altitude areas.

The significant point is that the climate, especially the amount of rain and the length and continuity of the humid period, provides the major influence on the biological stresses - the diseases and insects - which affect the rice crop. The same type of rice culture may be subject to blast, or to *Diopsis*, or to rice yellow mottle virus (RYMV) in one location but not in another. Moreover, the climate, acting over time, topography and on geologic background, provides the presence or absence of hydromorphic, toxic, or imbalanced soils, and the degree of cation exchange capacity, all of which influence genotype/environment interaction and thus varietal performance. Even more directly, climate determines photosynthetic rates, notably reducing them in the continuously wet-forest

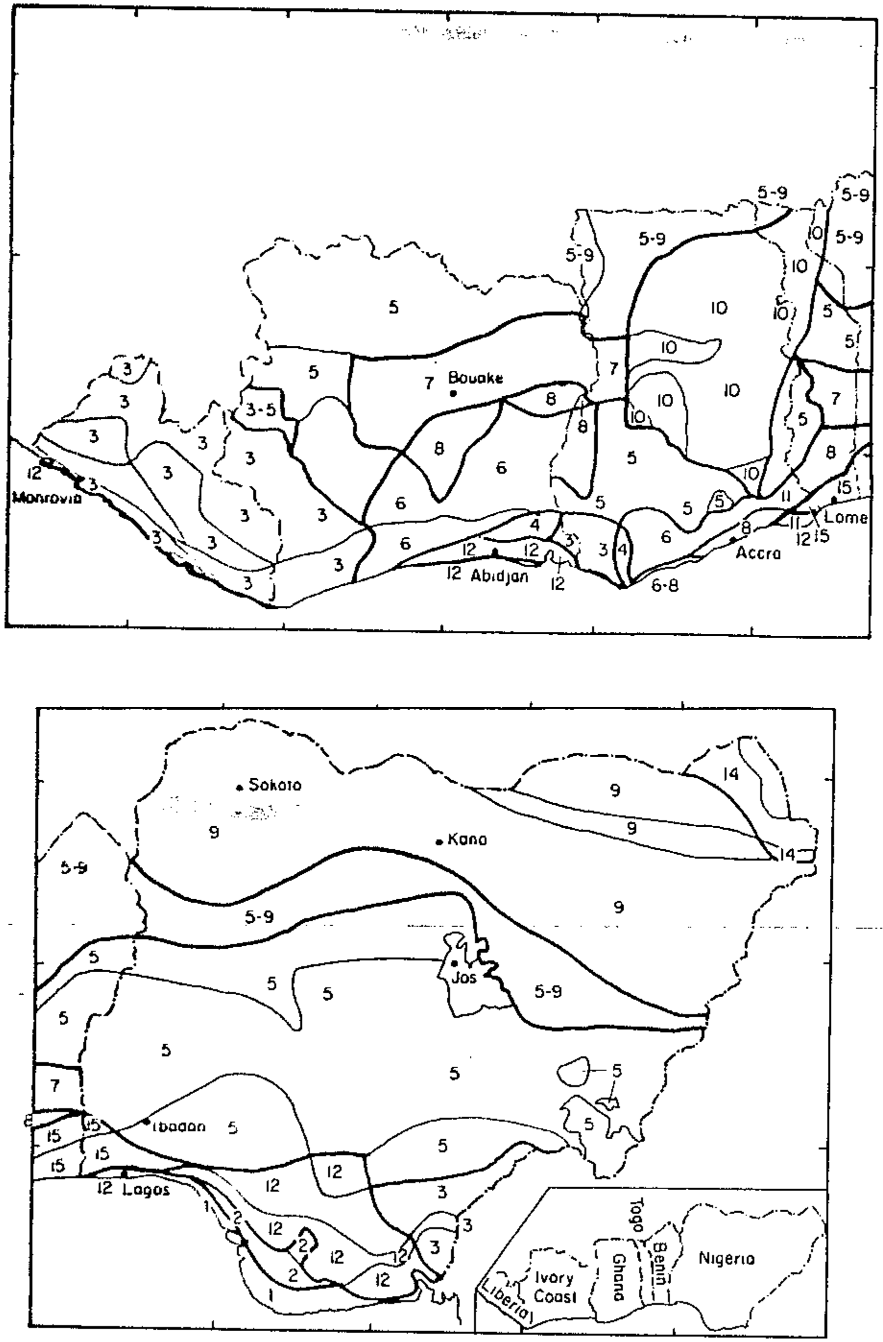

Fig. 7 (a) and (b). Rice: Ecologic regions (from Papadakis, 1966).

Fig. 7 (opposite) (cont'd)

1. *Mangrove swamps.* Flooding regulation, drainage and/or irrigation works are usually necessary; possible danger of sulfuric acid formation. Humid climate makes rice harvesting difficult.
2. *Fresh water coast swamps.* Flooding regulation, drainage and/or irrigation works are usually necessary. Some difficulty in rice harvesting.
3. *Forest belt with soils poor in bases and often concretionary.* Yams are not grown and pluvial rice is sown as the first crop on fallow land. For this reason rice is extensively grown; this is the *rice-cassava belt.* Phosphorus and other mineral deficiencies common.
4. *Same as 3, but the humid season is interrupted in August (climate 1.122);* early sown rice should be harvested in August, except in adequately flooded land.
5. *Soils well provided with bases, often concretionary; 5 or more months are humid and form a continuous series.* Pluvial 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);* early sown rice should be harvested in August, except in adequately flooded land.
7. *Climate with water surplus (Ln) below 20% of annual potential evapotranspiration; 5 or more months are humid and form a continuous series (climate 1.41); soils formed from old consolidated rocks, often concretionary.* Pluvial rice is grown in soils that do not drain freely or are flooded.
8. *Climate same as 7, but the humid season is interrupted in August (climate 1.412).* Pluvial rice only in well flooded soils.
9. *Climates with 3 or less humid months.* Irrigation or adequate flooding is necessary.
10. *Voltaian basin.* Soils with poor drainage prevail and many are flooded. Pluvial rice is important. Flooding regulation and/or irrigation are often required.
11. *Low Volta plains.* Soils are usually adequate for rice; but flood regulation and more especially irrigation are necessary.
12. *Sandy soils from unconsolidated sands under humid climate.* These soils usually drain too freely and are rather inadequate for rice.
13. *Fadama (flood plain) land.* These soils are very good for rice, but flood regulation and/or irrigation are necessary. Not shown in the map; they are especially found in regions 9, 6 and 5. When flooding becomes very 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; moreover the humid season is not sufficiently humid. Rice is grown in the black earths of the Lama depression and other hydromorphic soils; flooding regulation, drainage and/or irrigation are necessary.

Thick lines refer to rice ecologic regions, the thin lines refer to climatic sub-divisions within these regions.

Fig. 8. Rice flood plain in the inland Niger delta in Mali.

zones in locations of coastal Sierra Leone and Liberia. Continuous heavy rainfall also influences the ease of harvesting, and the drying and storing of rice grain, and thus influences varietal duration, harvesting methods, etc. The great reservoir of rice types in old rice cultures illustrates the vast amount of adaptation to macro and micro climates and the diversity of their stresses, which has occurred in the plastic genus, *Oryza*. Parallel development of types of rice culture and parallel selection for adaptability to each type of rice culture have gone on in similar climates in widely different locations on different continents. Due to chance evolution in the total biota, however, different microbiological stresses and insects occur on each continent.

The modern trend to narrow this great genetic diversity in rice by concentrating on only one or two types of rice culture and with isolation or protection from the biological and physiological pressures of specific environments, is only now gradually shifting to an appreciation of environmental complexity and the utility of traits earlier unrecognized.

The focus then becomes the specific rice ecosystem itself, which includes man's technological level, his economic flexibility, his other crops and even his health. In Africa, human diseases such as onchocerciasis, trypanosomiasis and especially schistosomiasis cannot be ignored when considering expanding rice culture.

Also, for rice improvement, differing needs and poten-

tials for both peasant rice and 'commercial' or larger scale rice production dictate different types of selection criteria.

The rice ecosystem itself becomes a function of the a) type of rice culture; b) climate and soil conditions; c) biological evolution of the region and the d) technological level of agriculture and the culture in which it is based.

A few examples are:

1) Dryland rice x continuously humid forest x Liberia-Sierra Leone forest biota x peasant farming.
2) Ditto above but x commercial farming instead of peasant farming.
3) Dryland rice x humid forest dry 4-5 months x borderline forest biota x peasant farming.
4) Dryland rice x Guinean savanna x West African savanna biota x commercial farming.
5) Ditto above but x East African savanna biota.
6) Hydromorphic rice x humid forest dry 4-5 months x borderline forest biota x peasant farming.
7) Hydromorphic rice x Guinean savanna x northern Ghana biota x commercial farming.

These should suffice to show the many different combinations of conditions upon which both rice improvement programmes and rice cultural management research objectives must be focused. Many more rice ecosystems exist in Africa, based firstly on differing types of rice culture or hydrology. The complexities of the rice ecosystem itself should be the focus both for selection criteria and cultural management research, and for quantification of the conditions and constraints affecting the rice crop.

Some of the important differences among these ecosystems and among rice varieties which may affect selection criteria for the ecosystem are:

Pests and Diseases:

- blast disease (especially panicle blast); leaf feeding insects; borers and *Diopsis*; sheath blight, sheath blotch, leaf diseases; panicle-discoloration fungi; virus diseases;

Agronomic characteristics:

- plant type, especially height, leafiness, tillering; early seedling vigour; drought resistance; panicle size; spikelet retention on panicle; lodging response to added N; rooting characteristics; vigour under low available Fe; vigour under low fertility.

Some differences of cultural management affecting potential practices and research on them are:

N effects, especially relative to 'slash and burn' or continuous rice culture in different climates; P effects, especially availability related to timing of application and leaching rainfall and soil differences; also sources of P; K effects, ditto; importance of weeds and differing weed control practices; tillage and no-tillage methods in relation to erosion;

NPK and high yield effects on minor element imbalance; iron and manganese toxicity, direct and indirect effects; spacing, especially in relation to drought, disease and fertility levels; crop rotation, especially in relation to soil and agricultural stability; duration and planting date in relation to drought stress at flowering; harvesting methods; storage methods; credit, transportation, input availability, education level, infrastructure.

A realization of the diversity of only the 7 listed dryland-hydromorphic rice ecosystems and some of the differing factors affecting both genotype suitability and relevance of management practices reveals why research progress on 'upland' rice has been so slow. It is complex, and quantified data describing these ecosystems are rare. Moreover, the separation of the ecosystems has not even been attempted and genetic improvement has been unfocused beyond the general term 'upland', which confounds not only dryland and hydromorphic rice, but ignores the diversity of both climatic and rice ecosystem differences from location to location.

From many experiments and observations a few generalities can now be drawn. Blast disease is related to drought stress, but it may be severe even in the humid forest. In some transitional areas it may be sufficiently sporadic to preclude selection against it. In humid, mid-altitude areas with cool nights, blast disease is severe and limiting on dryland rice. In sufficiently dry areas, blast may not occur and resistance to it is not required. Foliage and sheath diseases increase as one proceeds into the humid forest. Some leaf-feeding insect damage increases similarly, as does damage due to borers and *Diopsis*. The virus designated as RYMV occurs both in the wet forest and in the Guinean savanna, and in both West and East Africa, but it is apparently distributed sporadically. Soil fertility and complexity of fertilizer management differ greatly among climatic zones. Especially in the highly-leaching, ever-humid forest there is a need for split dosages of P and K, and proper sources for these elements for slow release in order to maintain stable rice culture, previously never accomplished. A strong interaction between planting density, drought and fertilizer levels exists in dryland rice situations in the Guinean savanna. The need for drought resistance in dryland rice varies depending on location. Much upland rice in the humid forest is not subjected to drought stress. In areas of Guinean savanna, especially in East Africa, rainfall is erratic and high drought resistance is needed if dryland rice is to become a stable crop.

The duration required for dryland rice differs greatly as one proceeds from the savanna to the humid forest, varying from about 100 to 160 days. Photoperiod response is needed for dryland rice in some forest areas but not in others, nor in most savanna situations.

In African peasant dryland agriculture, semi-tall varieties are needed, with long, heavy panicles and tightly held spikelets. For commercial agriculture where fertilizers are applied and harvesting is not done by single panicle cutting, a shorter plant type with higher tillering, smaller panicles and more fragile spikelets is possible. However, even here, different climates and degrees of drought stress will probably influence the suitability of such altered plant types.

The other types of rice culture practiced in Africa are not detailed in this brief paper. Although they are less complex they do not depend directly on rainfall. Only irrigated rice with good water control is closely akin to the Asian rice situation. The other types of rice culture, given the primitive state of technology, differ from their counterparts in Asia. These types of rice culture, inland swamp, boliland, shallow and deep flooded mangrove, are in the process of expansion and modernization. Thus, many areas are being reclaimed from their natural state for rice culture. This poses special problems of genetic adaptation, and cultural management, especially to soil toxicities in inland swamps. In addition, the effect of differing climates on diseases and insects overrides the type of rice culture. As with upland rice, these rice culture types transect climatic zones and thus the rice is subject to different biological problems depending on location.

Lastly, it should be mentioned that several of the major pest and disease problems now so important in Asian rice genetic improvement programmes, such as bacterial blight, tungro virus, leafhoppers and planthoppers, are either absent in Africa or, in the case of the hoppers, not damaging to rice culture in Africa. It is to be hoped that these problems can be kept out of Africa both by exclusion and by genetic improvement methods designed to preclude the fostering of high insect populations and new biotypes. Already existing in Africa are indigenous diseases and insect problems which differ from those in Asia, presenting ample challenge to rice improvement efforts. It is clear that the biological systems evolving on rice in Africa differ from those in Asia or America. None of the virus diseases of rice in Asia or America are known to occur in Africa. None of the mycoplasma diseases of rice in Asia has been confirmed to be present in Africa. The same is true for the major bacterial disease, bacterial leaf blight. In spite of reports of its presence from time to time, none has been substantiated. The author has surveyed many areas for these Asian diseases and has yet to find them. Bacterial leaf streak, however, caused by an easily seed-transmitted bacterium has been found in several countries of West Africa and in Ethiopia. It occurs in West Africa in the savanna zones, so far mostly on seed propagating stations except in Mali where it is more widely established. Many, if not all of the fungal diseases of rice in Asia also occur in Africa. It is not yet known if these make up different and old, evolved pathosystems or if these are just seed-introduced problems of recent vintage. It is considered that at least blast represents a self-contained African pathosystem, but proof is still lacking.

In summary, much research to describe rice ecosystems in Africa in qualitative and quantitative terms is needed, and great opportunity for creative research exists. With such research and with innovative approaches to genetic improvement for the problems peculiar to the various African rice ecosystems, much can be accomplished. Already, upland rice from Africa has been shown to be uniquely adapted for stable production under our conditions and it is being utilized as parents in Asia and Latin America, to improve upland rice in general.

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LAND AND RICE IN AFRICA: CONSTRAINTS AND POTENTIALS

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Introduction

While this treatise will deal mainly with soils, we prefer to use the wider concept of land, which includes all reasonable stable and predictable cyclic attributes of a specific area. In the relationship environment-crop production, soil is only one of the attributes determining the actual suitability and potential agronomic capability of land. It should not be seen apart from other attributes such as climatic, hydrologic, topographic, biological and human ones. Hence, our insistence on emphasizing this concept of land.

Cultivation of *Oryza sativa* in West Africa is relatively recent if compared with China (Chang, 1976) and, certainly in its initial stages, rice has been grown by the West Africa farmer using the same methods and technology with which he was familiar for his other more important dryland food crops.

Rice is the only major annual food crop (with the partial exception of aroids) which thrives on land which is water saturated, or even inundated during part or all of its growth cycle. This means that major constraints and potentials of rice land cannot be seen as separate from use and manipulation of water derived from any source. Thus, the African farmer, basically a dryland farmer, has been and still is handicapped with regard to the development of rice production as an important crop for his livelihood.

In the context of this article, not all constraints and potentials for rice in Africa can be examined. Many of these are locale-specific and require further *in situ* studies in actual or projected rice growing areas. Thus we do not present this paper as a complete treatise but rather as a way-station in the study of the African agro-ecological conditions where rice is, or can be, grown.

Water

General

Rice (*Oryza sativa* L.) is a semi-aquatic plant, in all probability originating from, and domesticated in, the well-watered valleys of eastern Asia (Chang, 1976; Huke, 1976). Its range of environmental tolerance extends to the wet parts of the landscape, where other cereals fail. On the other hand, towards the dry side of such environmental conditions, rice is much less tolerant of low soil moisture than other cereals, thus strictly limiting the production of rice to land where water is not in short supply during part or all of the growth cycle. Various studies (e.g. IRRI, 1975; IITA, 1975, 1976; Le Buanec, 1975) show that the main factor involved is the relatively shallow effective rooting depth of the rice plant. In terms of soil and water parameters, this means that the rice plant has to rely for its water supply, needed for productive vegetative and generative growth, on water available in the upper 20 or 25 cm of the soil profile. Since it is this part of the profile which will be most rapidly depleted, during periods of defective water supply, the rice plant will suffer from drought sooner than almost any other cereal crop, even though its consumptive water requirements are quite comparable to those of other cereals (Slayter, 1967).

Available water in the upper 20-25 cm of the soil profile varies not only with water supply, but also with the water retention properties of that layer as determined by texture, kind, and amount of organic matter and its clay mineralogy. These parameters will be discussed below.

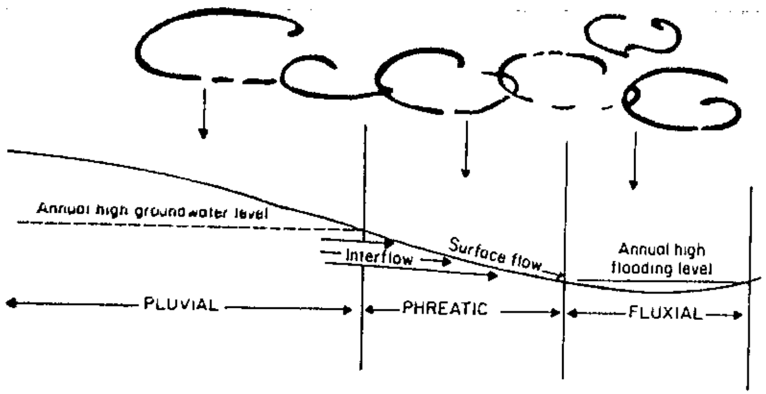

Fig. 1. Model of classes of riceland according to topography and water supply.

Types of rice land as a function of water regime

In West Africa, artificial water management of rice lands by bunding and levelling is as yet only sporadically applied and controlled irrigation is found even less. African rice lands without such water management can be classified as in Figure 1, according to their position in the landscape and to the water supply. Table 1 summarizes the type of water supply of the three main natural categories of rice land.

TABLE 1

Sources of natural direct water supply in rice lands

Source of water	Categories of rice land: Pluvial	Phreatic	Fluxial
Rain	Always	Partial[a]	Partial[a]
Subterranean	Not	Always	Partial[a]
Surface	Not	Not	Always

a) Except in the most arid, desert climates where rainwater or more seldom, no subterranean water, is received by rice fields.

The term 'upland' used by WARDA (1975) and most authors would include both 'pluvial' and 'phreatic'. 'Fluxial' rice land would include 'swamp', 'deep water' and most of the 'mangrove'. At IITA (Moormann *et al.*, 1976) the terms 'dryland' and 'hydromorphic' have been introduced and are equivalent for pluvial and phreatic, respectively.

Hydrologic restraints in pluvial rice lands

In pluvial rice lands, water availability in the root zone during the growing cycle of the rice crop is determined by:

a) climatic factors, mainly those related to rainfall
b) inherent soil characteristics
c) soil management factors
d) varietal characteristics of the rice as regards the use of soil water.

Here we will deal mainly with the first two sets of factors. On pluvial rice land, the main production-determining factor is the nature of the rainfall. Though total effective rainfall is important, rainfall distribution is even more so. Rice requires at least 600 mm of rain to complete its growth cycle (Cocheme, 1971), but a 1000 mm annual precipitation with a monthly rainfall of 200 mm during the growth cycle is reported to be a minimum requirement (Brown, 1969; De Datta, 1975).

Less annual rainfall is required for a monomodal than for a bimodal rainfall pattern. In general, for most soil conditions, pluvial rice cultivation appears to be submarginal with a rainfall of less than 1000 mm, marginal between 1000 and 1300 mm, and fair between 1300 and 1600 mm, while the *amount* of precipitation ceases to be a major restraint for pluvial rice cultivation at a higher average annual rainfall. These figures have to be modified by rainfall pattern and distribution, the rate of evapotranspiration, and by soil properties.

The daily rainfall distribution or, alternately, the expectancy of drought during the growth cycle of pluvial rice becomes critical in zones with a relatively low annual rainfall. But even in high rainfall zones, such rainless periods often are damaging to the rice crop. Such drought periods occur regularly in areas of extensive pluvial rice cultivation in West Africa (Moormann, 1973), even in areas with an annual rainfall of 2000 mm or over.

The interplay between drought stress and soil characteristics in pluvial rice cultivation is not well understood. Clayey soils, derived from basic rocks (e.g. basalts, amphibolites) are superior to those from more acidic parent rocks which are usually sandy or coarse loamy. Moreover, clay mineralogy plays an important role as regards available water, and in this respect, the fact that most West African soils are kaolinitic is a restraint for rice cultivation.

Hydrologic quality of phreatic rice lands

Compared to pluvial rice lands, shortage of water is a less severe restraint for phreatic rice cultivation. The presence of groundwater in the root zone during at least part of the growing season diminishes the severity of stress during drought periods.

The superior quality for rice growing of phreatic rice land in Africa is recognized by the farmers, who have extended rice cultivation into hydromorphic areas of the drier climatic zones, where conditions are submarginal for pluvial rice cultivation unless the effective waterholding capacity of the soil is high. The preferred use of phreatic rice land (*riziculture a nappe*) have been studied in Senegal by Bertrand (1973), while Killian (1972), Moormann (1973) and Moormann *et al.* (1976) have emphasized the usefulness of such groundwater-influenced terrains.

Hydrologic restraints on the use of such land for rice cultivation are partly of the same nature as those for pluvial rice land. The degree of hydromorphism plays an important role, and on the drier part of the phreatic range, rice may, and often does, suffer from drought if long dry spells occur during the growing season whereby the groundwater is lowered below the zone where it can feed the rice roots. Rice on such marginal phreatic rice lands then may suffer in the same way as on pluvial rice lands.

Alternate drying and wetting of the root zone in many phreatic rice lands may have a negative effect on the nitrogen status of such soils, especially as regards nitrogen applied as fertilizer. When the rootzone is oxygenated, NH_4-nitrogen is oxidized to NO_3-nitrogen but in subsequent reducing conditions, denitrification takes place below the surface, and nitrogen is lost as N_2 and N_2O. This phenomenon, described for paddy soils (see e.g., Shiori and Tanada, 1954), seems particularly strong in phreatic rice lands (Moormann *et al.*, 1977) where groundwater levels fluctuate during the growth cycle.

Hydrologic quality of fluxial rice land

Fluxial rice lands, as found in river plains, deltas, coastal fringes with mangroves, and also in minor valleys, generally have qualities such as those described for phreatic rice lands. The soil is water-saturated or even inundated during part of the growing season, assuring a sufficient water supply. Nevertheless, where flooding is often uncontrolled in Africa, various negative factors may influence the productivity of the rice crop.

Part or all the rice land may revert to dryland conditions in years when the flood waters are reduced during the growing cycle of the rice crop.

With drying out of such fluxial rice land during the season, drought stress occurs as it does regularly in the semi-arid climates, e.g. in the Senegal river and upper Niger river valleys.

On the other hand, in the wetter zones of Africa, floods may be damaging. Gentle rise of the flood water (mainly less than 15 cm/day) is not particularly damaging in view of the possibility to grow adapted deep water (floating) varieties. But flash floods of a few hours to a few days, often occurring in the narrow valleys in high rainfall zones such as Guinea, Sierra Leone and Liberia, may physically damage the rice crop. Moreover, flash floods, even of a short duration are a severe restraint on the introduction of high yielding, short strawed varieties.

Another limiting factor in fluxial rice lands can be the quality of the flood water in coastal areas, being subject to salt water intrusion. In some West African river estuaries, rice is grown on cleared mangrove land without protection from sea water intrusion (Moormann and Pons, 1975). In normal or wet years, the flux of good quality river water is sufficient to suppress salinity in the rootzone. In dry years, when river flooding is reduced, rice crops fail in the seaward part of these unprotected rice growing areas.

Soils

General

Rice is grown on all soil orders, though some are especially important, while on others, like Aridisols, Histosols and Spodosols, rice is seldom grown. In general, the wet (Aquic) suborders and subgroups are most extensively used, and, globally, it is estimated that only 14-18% of the rice acreage is planted to 'upland rice' (De Datta, 1975; Le Buanec, 1975). Since part of land used for 'upland rice' is in fact phreatic (hydromorphic) rice land, the surface of the freely drained soils planted to rice is even more restricted. In West Africa, rice grown on freely drained soils is relatively more important than in the old rice growing centres of tropical Asia. Pluvial rice lands in West Africa are mainly on Alfisols and Ultisols; the latter order being the most widely used. Phreatic rice lands are mainly found on the Aquic (wet) suborders of Entisols, Inceptisols and the Aquic subgroups of the already mentioned orders. Fluxial rice lands are mainly on wet suborders of Entisols and Inceptisols (Aquents, Aquepts). In the drier Sahel zone, irrigated rice is found on Inceptisols mainly, and on Vertisols and Aridisols in the second place.

The morpho-genetic classification of Soil Taxonomy, and the data from the FAO/UNESCO soil map of the world are useful in making a general evaluation of land quality for rice in West Africa. It is clear from these data that Central and West Africa have a lesser overall potential for rice growing than, for instance, South and East Asia. The major river plains and deltaic areas of that part of the world, which are the "backbone of rice cultivation", are largely absent in Africa.

As regards pluvial (dryland) rice lands, the total available surface in the climatically suitable area of West Africa is, of course, enormous. But the quality of that land for sustained, high-yielding production of rice is low. Soils are generally leached (dominance of Ultisols), have a kaolinitic clay mineralogy with unfavourable cation retention characteristics, mostly have a sandy to coarse loamy surface soil texture and are, for a major part, highly erodable. These, and other related soil factors are responsible for the fact that pluvial rice in Africa is generally low yielding, and that it is mainly if not exclusively grown in a shifting-cultivation pattern.

The situation for the lowlands of Africa is much better. While their total surface in West Africa is rather small in relation to the total land surface, sizeable areas of land with a better actual or potential water regime are still available. Soils of the lowlands in the Sudan and Sahel climatic zones have generally good qualities for (irrigated) rice cultivation. They are not strongly leached, have a better clay mineralogy and a higher cation retention and are, on average, finer textured. In the increasingly wetter areas of the various forest belts, the quality of the soils in the lowlands, whether in broad valleys and coastal plains or in the narrower valleys, is less favourable than in the drier areas. Soils are more acid, and stronger leached and, in the narrow inland-valleys or lower terraces, frequently sandy. Nevertheless, because of their better water regime, they are increasingly becoming the favoured environment for sustained rice cultivation. This preference for the low lying hydromorphic soils is, for example, particularly clear in southern Senegal, where rice is now mainly cultivated in such low areas, even though their general soil quality is less than that of the adjacent plateau areas (Birie-Habas *et al.*, 1970; Bertrand, 1973). The rapid expansion over the last 20 years of rice cultivation in the lowlands of the Abakaliki area, Anambra State, Nigeria, is almost exclusively in such lowland soil areas.

In these lowland soil areas, the superior hydrologic conditions often override soil-imposed restraints. Thus, for instance, while sandy soils are almost always unsuited for pluvial rice cultivation, this is no longer so when such soils are found in hydromorphic areas. They still have a distinctly lower production potential than more finely textured hydromorphic soils, but rice cultivation with reasonable assured returns is possible. Soils of the inland swamps of Sierra Leone, for instance, are dominantly sandy, but are extensively used for rice cultivation on a permanent basis, while pluvial rice lands in the surrounding areas, most of which have finer textured soils, are only used in a shifting cultivation pattern (Odell *et al.*, 1974).

Problems in African rice growing which are related to soil conditions

In this section, some specific problems related to soils in their African environment will be discussed. Soil properties mentioned here are reasonably stable ones, thus mainly excluding those which can be easily influenced by management such as the nutrient status of surface soils. Many more locale-specific problems which may be expected are excluded, both relating to physical and chemical soil properties.

Texture. The often sandy texture of African soils may be considered as a restraint to productivity. For pluvial rice lands, this was already mentioned earlier; effective water retention in such soils is low, and plants will readily suffer from drought. In the lowlands, soils with sandy profiles will lose water rapidly by percolation and nutrients will leach below the reach of rice roots.

Fertilizer management on the sandy soils is, therefore, unfavourable, especially with regard to nitrogen. Even under improved management levels, sandy soils remain relatively low in their productivity (Moormann and Dudal, 1968; Higgins, 1964).

Very high clay contents, as in Vertisols and in some of the marine alluvial soils (e.g. in the Senegal river delta) also have several disadvantages. While with a sufficient water supply such soils can and do produce good rice yields, land preparation is often difficult, requiring an advanced level of mechanization. Shortage of water supply on very fine clay soils can be damaging because of a restricted hydraulic conductivity. Exceptions to this are very fine clay soils, developed on volcanic materials which have a high content of active sesquioxides and consequently a very good structure. Such soils, some of which occur in the volcanic areas of western Cameroon, and on basic rocks such as amphibolites elsewhere in the basement-complex areas of West Africa, have excellent available water holding characteristics for pluvial rice.

Soil mineralogy and parent material. Studies of clay mineralogy of rice growing soils in the last decade have underlined the importance of clay mineralogical composition on inherent fertility and management characteristics of such soils (see e.g. Kawaguchi and Kyuma, 1978). The quantitative influence on productivity of rice growing soils is difficult to evaluate, since clay mineralogy is not an independent growth determining factor, but acts together with others, e.g., texture and organic matter content. Nevertheless, soils that are predominantly or entirely kaolinitic, are known to be less productive than soils containing 2:1 lattice clay minerals in the form of smectites, illites, and vermiclites. Soils with a high content of amorphous materials, such as found in parent materials from volcanic origin, usually have better characteristics for growing rice, though phosphorus may be strongly fixed.

The influence of clay mineralogy is mainly related to differences in effective water-holding characteristics and in cation retention characteristics of the surface soils. Both these values are low to very low for soils with a predominantly kaolinitic clay mineralogy. The great majority of upland soils in West Africa are kaolinitic. Only in the lowlands, except in the perhumid and humid zones, do soils frequently have a more favourable clay mineralogy. Valleys in which the soil materials are derived from adjacent volcanic formations are particularly valuable for rice growing; examples are the plain of Mbo and the plain of Ndop in Cameroon.

From the above statements on clay mineralogy, the role of the nature of the parent material is already partly apparent. Parent materials leading to formation of the better rice growing soils are mainly basic rocks, and especially where young alluvial sediments of mixed origin and without an exclusive kaolinitic clay mineralogy have been deposited. The latter are found in major river plains, lacustrine plains (as Lake Chad) and in coastal plains and deltas. The eolian deposits which cover parts of the Suden and Sahel zones, are moderately rich to poor parent materials for soils in these zones. The best are the loamy to silty textured eolian sediments (loess) and their alluvial/colluvial derivates. The sandy portions of these areas dominated by eolian sediments are much less rich, though their alluvial/colluvial derivates in valleys are frequently finer textured and of better quality for rice growing, if water is available.

The majority of the soils in the wetter zone of West and Central Africa are derived either from intermediate to acid crystalline rocks (basement complex), or from various sedimentary rocks, which are mostly arenaceous. These parent rocks predominantly give rise to soils with a poor inherent potential for rice.

Organic matter. The role of organic matter in regard to the inherent quality of soils on which rice is grown is almost as diverse as the environmental conditions of the crop. Its most important functions are to increase the available water holding capacity, to increase cation exchange capacity, to improve soil structure and, through the process of mineralization, to provide nutrients, mainly nitrogen, to the rice crop. For pluvial rice lands, all these functions are of prime importance. For phreatic and fluxial rice lands, the role of improving water-holding capacity and structure becomes relatively less important with increasing wetness of the soils during the growth cycle of rice. An excess of organic matter, as in peat and peaty soils (Histosols), causes negative effects on the performance of the rice crop. Since such soils are rare in West Africa, no further details are given.

The important role of organic matter in pluvial rice lands is reflected in the cropping system used by the local farmers in West and Central Africa for growing rice. On these dryland soils, the initially moderate content of total organic matter is favourable immediately after clearing from fallow bush or savanna. However, after 1-2 years of cultivation, this content diminishes to the order of 0.5-0.8 percent organic carbon in the topsoil. While the role of organic matter as a nutrient source can be replaced by fertilization, the available water-holding capacity and the CEC of the surface soil will inevitably decrease. This is not so serious on soils with a clayey texture and favourable clay mineralogy. On the predominantly sandy kaolinitic soils on which dryland rice is grown, however, the land may be expected to become progressively more droughty and less fertile in the years after the initial clearing, and this is one of the important reasons that pluvial rice in most of Africa is best grown immediately after clearing in the shifting cultivation cycle. There are also many other reasons for this, and it should be noted that the low organic matter content of continuously cultivated drylands in much of the area under discussion paired with the average sandy surface soil texture and the unfavourable clay mineralogy is, in most cases, a definite restraint for sustained production of pluvial rice.

Calcareous soils. Few rice growing soils in Africa are reported to be calcareous; such soils occur almost exclusively in the drier zone of the African continent. While rice under irrigation can support the somewhat alkaline pH values found on such soils, some deficiencies, especially of zinc (Tanaka and Yoshida, 1975), may become acute under such conditions. Zinc deficiency has been reported on rice in Africa, e.g., on the neutral to calcareous Vertisols near Lake Chad (Kang and Okoro, 1974). Iron deficiency occurs also, but tends to diminish or even disappear when rice is grown on submerged (paddy) lands.

Salinity in rice lands. Moormann and van Breemen (1978) distinguished four basic types of salinity and alkalinity in rice growing areas, according to the sources and to the occurrence in the landscape.

- Marine salinity, derived directly from sea water intrusion.
- Interflow salinity of alkalinity, derived from lateral influx of drainage water, mineralized by weathering of salt bearing rocks above the level of the rice growing lands.
- Groundwater salinity or alkalinity.
- Surface water salinity or alkalinity, due to evaporation of moisture, brought in by river floods or irrigation, on soils of low permeability.

In Africa, all four types of salinity and alkalinity occur, but only the marine and groundwater salinity are of some importance in rice growing; the latter occurs exclusively in the dry zone (Sahel) where rice is grown under irrigation.

Marine salinity of lowland coastal West Africa is at present often a limiting factor. This is mainly related to the fact that, with few exceptions, no satisfactory marine land reclamation has been developed. A typical example of this type of salinity can be found in some river estuaries in southern Senegal (Moormann and Pons, 1975). Here, mangrove swamps with saline Hydraquents are reclaimed without any further protection or water regulation. When the rivers are in flood, and after sufficient leaching of the surface horizon, rice is planted in the land freshly cleared from mangrove. In years with a normal river discharge, salinity during the growing season is low enough to produce a yield of rice. In years with a low rainfall in the catchment and cultivated areas, however, yields can be strongly depressed or fail altogether. The West African low coastal lands, influenced by saline water intrusion, are at the same time potentially acid (acid sulphate soils), which makes their more definite reclamation by empoldering frequently a hazardous and uneconomic enterprise. Small areas of marine saline land without potential acidity will offer excellent possibilities for establishing rice land. Surveys and research is required to locate and delineate such areas.

Iron and manganese excess in the root zone. Nutritional disorders, related to high Fe^{2+} content in the rootzone of rice during flooding, have been extensively studied by IRRI scientists (Ponnamperuma, 1972; Tanaka and Yoshida, 1975). *In situ* development of toxic levels of Fe^{2+} in the rootzone will take place at a low soil pH, strongly reduced conditions, and a low content of 'active' iron. When the active iron content is high, Fe^{2+} levels in the soil solution will, after an initial increase, diminish below toxic levels so that *in situ* iron toxicity in flooded soils though repeatedly demonstrated in pot experiments has only infrequently been observed in the field, e.g. in acid sulphate soils.

In West Africa, however, of much greater importance, is the influence of Fe^{2+} containing interflow water, upwelling phreatic and fluxial rice lands in and adjacent to valley bottoms. While Fe^{2+} level in the rootzone is not necessarily at a toxic level, the continuous inflow of such water appears to cause nutritional disorders, which largely remain to be studied. Yellow and orange discoloration of leaves, increasingly stunted growth, and lower yields are common in such zones of upwelling. In the more serious cases, high levels of Fe^{2+} can be found both in the soil solution and in the plant, leading to characteristic bronzing of the leaves and strong depression of growth and productivity of the plants. This interflow iron toxicity is most severe in areas where the adjacent uplands are strongly leached Ultisols. The source of dissolved iron in the interflow water is usually the weathering zone of rock formation; but ferrous iron may also be derived from plinthite formations in the uplands adjacent to the affected valleys.

In West Africa, the various stages of the effects of Fe^{2+} containing interflow water are widespread. Nutritional disorders, without clear iron toxicity occur in many valleys even in areas dominated by Alfisols with high base saturation. Typical iron toxicity occurs frequently in Ultisol-dominated landscapes of the high rainfall zone, e.g. in Sierra Leone and Liberia.

Chemical improvement by liming of soils affected by Fe^{2+}

containing interflow water is short lasting, and often ineffective. The development of tolerant rice varieties is promising. When the landscape and hydrologic conditions permit it, land improvement and adapted management techniques can solve the problem, i.e.,

- seasonal drying of affected lands, to cause the oxidation of Fe^{2+} into insoluble Fe^{3+} compounds.
- general drainage of the rice land; affected land in Japan and Taiwan is often tile-drained, but such measures are clearly not yet economic under African conditions.
- interception of the interflow water by deep drainage ditches across the line of flow. This method can be recommended in affected areas of West Africa, where local topographic conditions are favourable.

Not many pertinent data are known on excess manganese and its toxicity in rice fields. Variable Mn^{2+} concentrations may occur in interflow water derived from crystalline and other rocks, high in manganiferous minerals. In Asia, it appears that the Mn^{2+} content in the root zone of rice, though sometimes relatively high, remains below the critical level for rice (Tanaka and Yoshida, 1975).

Acid sulphate soils. Acid sulphate soil conditions are found in coastal areas under past or present mangrove vegetation. In their original swampy conditions, these soils contain variable amounts of pyrite (FeS_2) which, upon aeration of the soil will oxidize, leading to acidification of the soil material (van Breemen, 1977). Collateral effects are the periodic high content of Al^{3+} and Fe^{2+} which when present in the rooting zone will affect the growth and production of rice to a variable degree (see e.g., Bloomfield and Coulter, 1973; and Moormann and Pons, 1975, for the management aspects of such soils).

The majority of the mangrove swamp soils along the west coast of Africa are potential or actual acid sulphate soils. Considerable research on their development for rice has been carried out, especially at the Rokupr Station in Sierra Leone, and several pilot projects have been initiated in the West African mangrove belt. The general conclusion is that development is expensive and, in terms of economic returns, often marginal or submarginal. Plans for rice land development in mangrove swamps recur regularly. Only on mangrove soils with low or zero potential acidity are such plans warranted. Pre-project research and survey in prospective areas are required to avoid costly failures. In West Africa, most mangrove reclamation projects are not justified because of adverse soil conditions (Moormann, 1973).

Conclusion

Considerable land areas in West Africa are suitable for

rice cultivation to a varying degree from the point of view of soil and hydrological conditions. The development of rice-based cropping systems, with continuous land use is difficult for pluvial rice lands. Few soils in the climatically suited areas of West Africa lend themselves to such a system of permanent cropping. Indeed, in the prevailing environmental and socio-economic context of the area, pluvial rice is and will be grown mainly in a shifting cultivation pattern in the foreseeable future. Under phreatic and fluxial conditions, the prospects for the development of permanent rice-base cropping systems are considerably better. On such land, yield potential is higher. The key for increasing production here is improved land and water management. The logical sequence of events would be a development from the simple, non-improved utilization of lands with sufficient additional water over and above the water provided by rain, towards the improvement of such lands by levelling and bunding (paddy construction), and, in a later stage, controlled irrigation. This development sequence can even at the present time already be seen in various parts of West Africa. While most ricelands in the valley bottoms and other hydromorphic areas are still undeveloped with regard to land and water management, there is a definite trend towards better utilization of such lands. Moreover, many of these lands are now in continuous use for rice, without fallowing. The total surface of land suited for improved systems is not large in relation to the total surface of arable land in the zone under discussion. Nevertheless, much of this type of land is as yet not utilized or is definitely underutilized in West Africa, and the potential for improved lowland rice cultivation is considerable.

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GENETIC DIVERSITY OF INDIGENOUS RICE IN AFRICA

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Introduction

This paper describes studies by IRAT and ORSTOM on the distribution and variability of indigenous rice in Africa, especially the annual species, *O.glaberrima* and *O.breviligulata*, and the perennial, rhizome-forming species, *O.longistaminata*.

Six of the twenty identified species of the genus *Oryza* are of African origin. These are: *O.breviligulata*, *O. brachyantha*, *O.eichingeri*, *O.glaberrima*, *O.longistaminata*, and *O.punctata*. The chromosome number, genome groupings and geographical distribution of the 20 species of the genus are shown in Table 1.

Oka and Chang (1963) did much of the early collection and assessment of African rice. They considered that the yield potential of the indigenous rices was less than that of *O.sativa* but that *O.glaberrima*, a cultivated species, was more tolerant to adverse conditions such as deep water, drought, blast and diopsids, which commonly occurred in its native habitat (Chang, 1976).

Approximately one thousand samples of *O.glaberrima* and related species have been collected by IRAT and ORSTOM in Mali, Senegal, The Gambia and other West African countries (Figure 1), and these have been grown in the Ivory Coast. The general characteristics of the species collected are:

O.glaberrima: Cultivated type, self-fertile with some cross-pollination; shedding occurs in intermediate types of *O.glaberrima* - *O.breviligulata*.

O.breviligulata: Wild type, mainly self-fertile with some cross-pollination; shedding with a strong dormancy; completes its cycle before cultivated rice; occurs among

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TABLE 1

Oryza species: Chromosome numbers, genome groups and geographical distribution (after Chang, 1976)

Oryza species (x = 12)	2n	Genome	Distribution
O. alta	48	CCDD	Central and South America
O. australiensis	24	EE	Australia
O. barthii (*O. breviligulata*)	24	A A^g	West Africa
O. brachyantha	24	FF	West and Central Africa
O. eichingeri	24, 48	CC, BBCC	East and Central Africa
O. glaberrima	24	A^g A^g	West Africa
O. grandiglumis	48	CCDD	South America
O. granulata	24	-	South and Southeast Asia
O. latifolia	48	CCDD	Central and South America
O. longiglumis	48	-	New Guinea
O. longistaminata (*O. barthii*)	24	A^1 A^1	Africa
O. meyeriana	24	-	Southeast Asia, Southern China
O. minuta	48	BBCC	Southeast Asia, New Guinea
O. nivara (*O. fatua*, *O. rufipogon*)	24	AA	South and Southeast Asia, South China, Australia
O. officinalis	24	CC	South and Southeast Asia, South China, New Guinea
O. punctata	48, 24	BBCC, BB(?)	Africa
O. ridleyi	48	-	Southeast Asia
O. rufipogon (*O. perennis*,	24	AA	South and Southeast Asia, South China
O. fatua, *O. perennis* subsp. *balunga*,			
O. perennis subsp. *cubensis*)		A^{cu}, A^{cu}	
O. sativa	24	AA	Asia
O. schlechteri	-	-	New Guinea

crops and at the edges of rice fields, sometimes in clusters with *O. longistaminata*.

O. longistaminata: Wild type; perennial via rhizomes; mainly cross-pollinated; shedding; suppression of: occurs in homogeneous populations.

O. breviligulata and *O. longistaminata* are species closely related to *O. glaberrima* and may be crossed with *O. glaberrima* and *O. sativa*.

Variability

Methodology

Intra- and inter-region variability of recent collections was examined at various levels to determine the centre of origin (i.e. centre of maximum variability) and the extent of diversity of the species. The reproductive barriers between various indigenous species were examined at autopolyploid and allopolyploid levels.

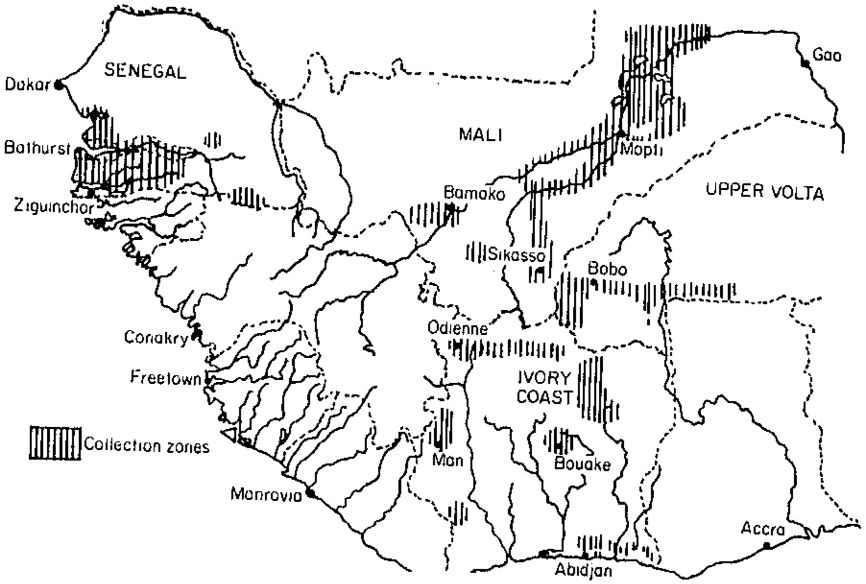

Fig. 1. Rice collection sites in West Africa, 1974-76.

Initially, the collections were grown under the same conditions and observed from early growth stage to maturity in order to define the characteristic profile of each and to assess the phenotypic variability among them. The characters were later subjected to numerical taxonomy in order to group similar samples, show the extent of genetic homogeneity within the group, and to demonstrate the relationships among the groups. The clustering of similar samples allowed homogeneous samples to be combined and further work was done with a smaller number of populations.

Variability was also examined by isozyme separation by electrophoresis on starch gels. The enzymes studied for *O.glaberrima, O.breviligulata, O.longistaminata* and *O.sativa* were esterases, peroxidases, acid phosphatases, malate dehydrogenases and leucine aminopeptidases. These studies gave information on variability of loci, comparative variability of populations and on the geographic distribution of the variability.

Ecology of Indigenous Rices

Genome A, which defines the *sativa* complex of *Oryza* is represented in Africa by *O.longistaminata, O.breviligulata (O.barthii), O.glaberrima* and now, *O.sativa*, the last having been introduced relatively recently. These species are compatible when crossed but there are many reproductive barriers. The distribution of the major indigenous *Oryza* species in Africa is shown in Figure 2.

O.longistaminata was found by us in diverse habitats, all of which received abundant sunshine. These included the salt lagoons of the Casamance delta, the deep waters of the

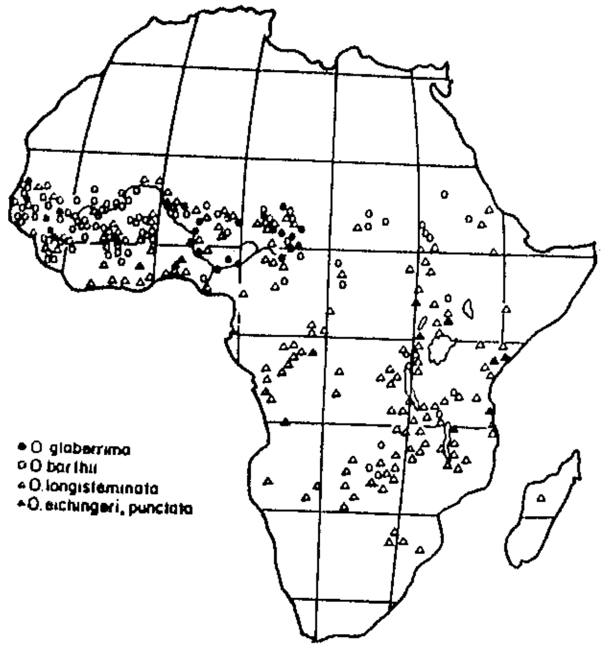

Fig. 2. Known distribution of four indigenous rice species in Africa.

Niger inland delta in Mali and the dry, sandy rice fields of Senegal. It occurred in both running and stagnant water, dry river beds and pools. It was also found in the forest zone in Cameroon.

O.breviligulata occurred in the savanna in low-lying areas subject to flooding, especially those with enriched soil due to their use as watering holes. The species produced many large seeds and strongly-bearded spikelets. A weedy type was found in cultivated rice fields in the central Niger delta.

O.longistaminata and *O.breviligulata* sometimes occurred together around water holes. In the central Niger delta, *O.breviligulata* was a weed in cultivated rice fields, but *O.longistaminata* became dominant once the field was abandoned. The former annual species had a competitive advantage in disturbed and enriched habitats.

O.glaberrima was widespread in Casamance, Senegal, where it occurred mainly as early-maturing types; floating and late types were found in Central Niger delta. It was found infrequently in The Gambia, Upper Volta and Ivory Coast.

Enzyme Variability

Enzymatic variability among *Oryza* spp. has been reported earlier by several workers (Chu, 1967; Chu and Oka, 1967; Shahi *et al.*, 1969). In this work, enzymatic variability was studied for 500 lines of *O.glaberrima* and 300 lines of *O.breviligulata*, from 280 and 105 different populations respectively from Malian and Senegambian centres and a few from Upper Volta and Ivory Coast. The variability of *O. sativa* was examined in 95 lines obtained from Ivory Coast, Mali, Senegal, and INRA, Montpellier, France (japonica types).

Five enzymatic families were examined in extracts from young or mature leaves: esterases, peroxidases, leucine aminopeptidases, acid phosphatases and malate dehydrogenases. The results have been published in more detail elsewhere (Bezancon *et al.*, 1977a, 1977b) and the interested reader is referred to this publication for detailed figures.

Esterases. The zymograms had a wide variety of enzyme forms which differed in their migration speed and their differential affinity for the α and β forms of the substrate. The analysis of the zymograms for species is given in Table 2.

The variability of *O.breviligulata* included that of *O. glaberrima*. There were many cases of coincidence among the three autogamous species but in no instance did the African and Asian lines match perfectly. *O.breviligulata* was richer individually in forms of esterases than *O.sativa*,

TABLE 2

Analysis of esterase zymograms

Species	*O.breviligulata*	*O.glaberrima*	*O.sativa*
Character			
No. visible bands			
Max.	12	10	9
Min.	9	9	7
No. variable bands (combinations)	5	2	7
Avg. no. different types on same band (presence/ absence/different positions)	1.64	1.18	2.18

with *O.glaberrima* lying between the two. There was most variability in *O.sativa*, due to the loss of certain bands. Homogeneity in *O.glaberrima* is connected with this individual richness in forms of esterases, more than *O.sativa*.

Peroxidases. The conclusions were the same as for esterases, in that the variability of *O.breviligulata* was higher than that of *O.glaberrima*, which it included completely, and the Asian and African forms were not identical.

Malate dehydrogenase. Four of the 5 species studied had a single five band zymogram. *O.longistaminata*, however, had ten different zymograms with four to nine bands each.

Acid phosphatases. No variability was found in the two annual African species, which have, in common with *O.sativa*, the most frequent zymogram of the *japonica* types (Pai *et al.*, 1975). However, *O.longistaminata* was of a more variable type. The banding pattern is shown in Figure 3 as an example of the type of result obtained.

Leucine amino-peptidase. The variability of *O.sativa* included that of *O.glaberrima* and *O.breviligulata*.

Geographical Distribution of Enzyme Variability

The samples analysed have been classified in relation to the area of collection. The geographical distribution of the esterase variability in *O.breviligulata* (B) and *O.glaberrima* (G) is given in Table 3. Mali in the table is the part of Mali separate from the inland Niger delta and Northern Senegal is along the Senegal river near Richard Toll. Three types of esterases (A, B, C) were common to the two species, they are the most frequent types in *O.breviligulata*. Most of the samples of *O.brev-*

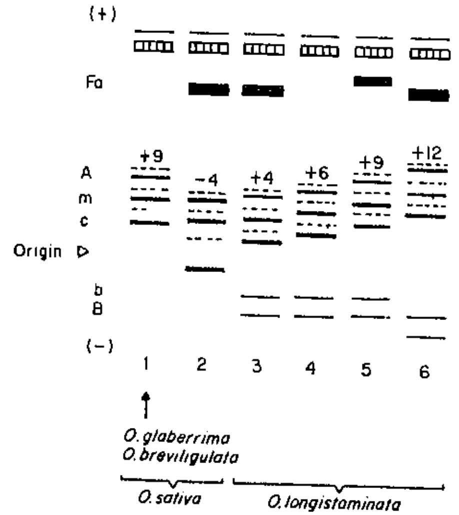

Fig. 3. Band variability observed for acid phosphatases of different rice species. (Not all the zymograms of *O.longistaminata* have been shown.)

iligulata represented the weedy form of the species. Different zymograms of A, B and C have been found in the wild populations of *O.breviligulata* in which they occurred frequently. Further analysis of wild populations of *O. breviligulata* should make it possible to determine whether this species can be divided into wild and weedy populations on the basis of enzyme variability. The B and C esterase types are clearly differentiated by area, on a similar pattern for both species. In each area the percentages of different types were similar for both species.

More detailed analysis showed that the "floating" population (late, with a high number of internodes) have only the A and C types, whereas the "erect" populations (early, with fewer internodes) have the A and B types. The geographical separation of the B and C types are therefore explained by the fact that floating rice is mainly found in the Niger delta in Mali while the erect types are also grown in non-flooded areas.

In terms of the overall enzyme variability, *O.glaberrima* has maximum variability in the Niger delta area where both erect and floating types are grown. The variability of *O.breviligulata* occurs outside the Niger delta, mainly in the wild forms which are found in river beds disturbed by cattle in the savanna zone.

Zymograms of autogamous species are those most frequently found in *O.longistaminata*. However, for the highly variable enzyme (esterase) *O.longistaminata* does not include the autogamous species' variability.

TABLE 3

Percentages of A, B, and C esterase types of O.breviligulata (b) and O.glaberrima (g) from different regions

Esterase type	Sene-Gambia b	Sene-Gambia g	Northern Senegal b	SE Senegal g	Mali b	Mali g	Inland Niger delta b	Inland Niger delta g
A	67	80	7	45	27	27	28	28
B	33	20	-	48	73	62	7	4
C	-	-	93	8	-	10	65	68

(Column heading over the regions: Area species)

Population Variability

The variability within populations was examined. Samples from individual populations were heterogeneous for esterases and peroxidases. Therefore one population could contain all the variability possible within the species. There was a trend towards homogeneity in the populations compared with interpopulation variability. Heterogeneity was higher for *O.breviligulata* than *O.glaberrima*. However, individual plants and their progeny were homogeneous in their enzymatic patterns.

Enzymatic variation in *O.longistaminata* from Mali and Senegal was compared to that of *O.perennis*, a related Asian species. There was much greater variation in *O. longistaminata* than in *O.perennis*, *O.breviligulata* or *O. glaberrima* for esterases, peroxidases, malate dehydrogenase and acid phosphatases.

The high enzymatic variability of the allogamous groups of *O.longistaminata* compared to the autogamous Asian and African rices is associated with the greater tolerance of the species to environmental stress. For example, seeds vary in their heat sensitivity, providing sufficient variation within the population to allow some seeds to develop at extreme temperatures which are unsuitable for the autogamous species.

The adaptability of *O.longistaminata* to its environment is both spatial and temporal, in that it can also adapt to various pressures which appear during its evolution. The theory of fitness in a structured environment (Levins, 1965) explains this heterozygosis in a heterogeneous environment. An allele may be dominant in a population while at the same time allowing a great deal of variation around the optimum.

There are reproductive barriers between the autogamous and the allogamous types of *O.longistaminata*. These allow *O.breviligulata* to invade certain habitats that have been

invaded and enriched by animals and at the same time maintain occasional interchanges with *O.longistaminata*.

These reproductive barriers may be regarded as filters of genetic flow selected at an adjusted level by the species (Pernes *et al.*, 1975). The homozygosity of the autogamous groups makes them retain out of the total variability only those variations strictly suited to their habitat. Hence the convergence of the variability of the African and Asian autogamous groups. The convergence increases during domestication when the species acquire stricter autogamy, which is linked to a man-controlled environment. The acquired autogamy and domestication also result in reduced enzyme variability.

The simplification of zymograms is more marked as one moves towards more developed cultivated types. Thus *O. sativa* has lost some bands relative to *O.glaberrima*. The differentiation of ecotypes may cause the loss of certain isozymes. It is also possible that there is a relationship between the adaptability of a line and the number of enzymes it contains.

The genetic pool of *Oryza* genome A in Africa can be considered to be of two types according to the definitions of Pernes *et al.* (1975). These are:

a) *Reservoir compartment: O.longistaminata:* The perennial habit and self-incompatability which are linked with vegetative reproduction allow it to carry a heavy genetic load (alleles that are silent or have little adaptation in the present environment). High heterozygosis preserves many other variants besides the best adapted dominant allele which is often retained in the autogamous section. This variability enables it to survive in an area in which there are some slow environmental variations but it develops best in an area free of abrupt changes.

b) *Colonisation compartment:* The acquired autogamy leads to a lower variability suited to a particular environment. The reduced genetic load gives a high reproductive potential which enables them to spread rapidly in a scattered migrant habitat with differentiation into ecotypes. Many recessive alleles are fixed, which results in poorer enzyme resources, enzymatic degeneration and reproductive barriers caused by the formation of pairs of complementary lethal genes.

In Africa, a "filter of gene flow" has apparently developed which has preserved high heterozygosity in the allogamous pool, allowing substantial storage of allelic variability. It also operates by restriction of *O.longistaminata* from the localized ecological site of *O.breviligulata*.

The two sections form two largely independent entities that are nevertheless connected, and they represent the overall pool of variability of native African types.

By studying populations where the two species exist side by side it will be possible not only to sample their respective variability but also to gain a better understanding of possible introgressions. However, to collect maximum allelic variability, it is preferable to use the large populations of *O. longistaminata* which retain maximum heterozygosity.

From the wild pools one may repeat the process of domestication to obtain transgressions for new ecological areas that can be cultivated. It also may be possible to introduce new characters into cultivated varieties, such as self-incompatibility.

Study of Variability by Factor Analysis of Correspondences

Correspondence analysis was used to study variability within *O. glaberrima* and *O. breviligulata*, since no *a priori* hypothesis is introduced on the characters or the samples, and it enables them to be projected simultaneously on two planes. The dispersion of these projections on the most discriminant planes makes it possible to assess and compare the variability of each group of individuals.

A total of 858 individuals were examined, collected in the inland Niger delta, central, southern and south-eastern Mali, eastern Senegal and Casamance.

Forty-nine characters were observed at various growth stages and thirty-two of these were retained for the analysis. Two different sets of planes I-II and I-III were used for interpretation (Figures 4 and 5).

Results

The following variability in agronomic characters was observed:

Plant height	69-235 cm (avg. 148 cm)
No. shoots	4-100 (20-48 with 2 modes)
No. panicles at flowering	4-75 per plant (23-28 with 2 modes)
Avg. no. nodes per stalk	4-14 (4.8-10 with 2 modes)
Avg. panicle length	13-34 cm (avg. 25.3 cm)
Length of cycle, planting to maturity	90-210 days (avg. short cycle, 120 days; photoperiod-sensitive types during short days, 140 days)
Lodging	307 lodged; 551 not-lodged
Shedding	482 shedding; 476 non-shedding

In general, the observations of two modes corresponded to erect and floating ecotypes.

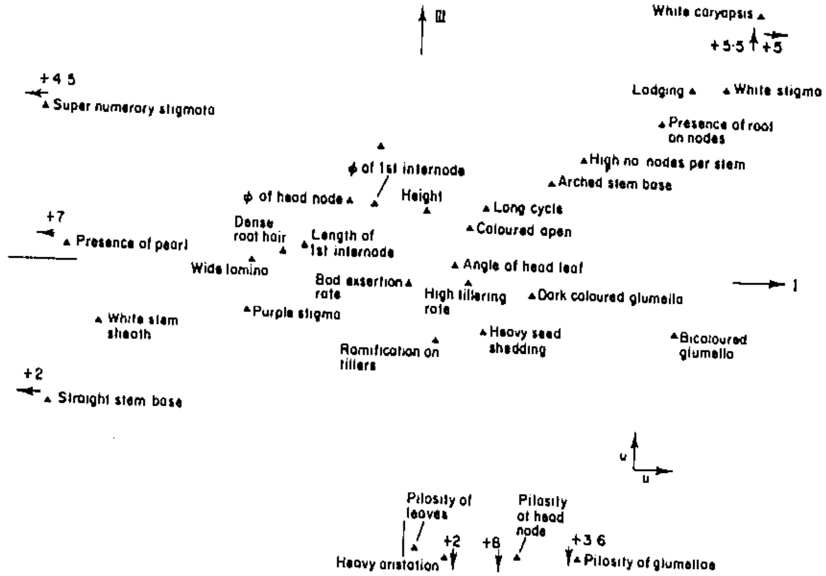

Fig. 4. Characters used in factor analysis by correspondences and their projection on axes I-III.

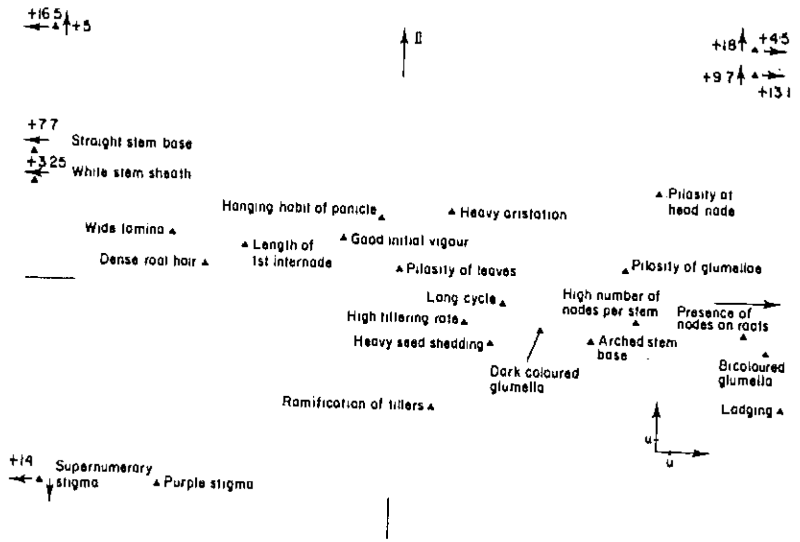

Fig. 5. Characters used in factor analysis by correspondences and their projection on axes I-II.

Dispersion of the characters

O.glaberrima is much more variable than *O.breviligulata* whose variability is contained completely within that of *O.glaberrima* (Figure 6). Most of the *O.breviligulata* samples appear to be weedy forms which are very similar to the cultivated species. However, some characters, such as aristation, and leaf pilosity are discriminatory.

The characters of roots on nodes, number of nodes, lodging, seed shedding, coloured stem sheath and ramified stems describe the floating habit, whereas the converse forms describe the erect type. Floating-late and erect-early types were observed in all regions surveyed.

Fig. 6. Comparison of samples of *O.glaberrima* (-) and *O.breviligulata* **(o), with character sites** (Δ) plotted on axes I-III.

Characters that are unsuitable for cropping such as lodging, arched stem bases, ramified stems and seed-shedding were present on many floating types collected from the inland Niger delta. Converse characters were common in samples from Casamance where there exists a long tradition of rice cultivation with more advanced cultural practices.

An analysis by regions (diagrams not presented) showed that east Senegal has the least variability for *O. glaberrima*. The inland Niger delta where all the inter-

mediate forms between wild and cultivated types occur, has the maximum variability for this species. In the central area of Senegal there is a wide range of cultivated types, ranging from non-flooded to floating types (Figure 7). In each region, *O.breviligulata* covered only a small portion of the variability of *O.glaberrima*. In the plane I-II, the specific characters of *O.breviligulata* were much less discriminant than in the plane I-III, giving a variability for the wild species comparable to that of the cultivated. In a region by region analysis, this is not so apparent. The widest range of variability of the delta area is on axis II, whereas the dispersion of the southern and central area is at its highest on axis I. Rice in Casamance is most affected by domestication.

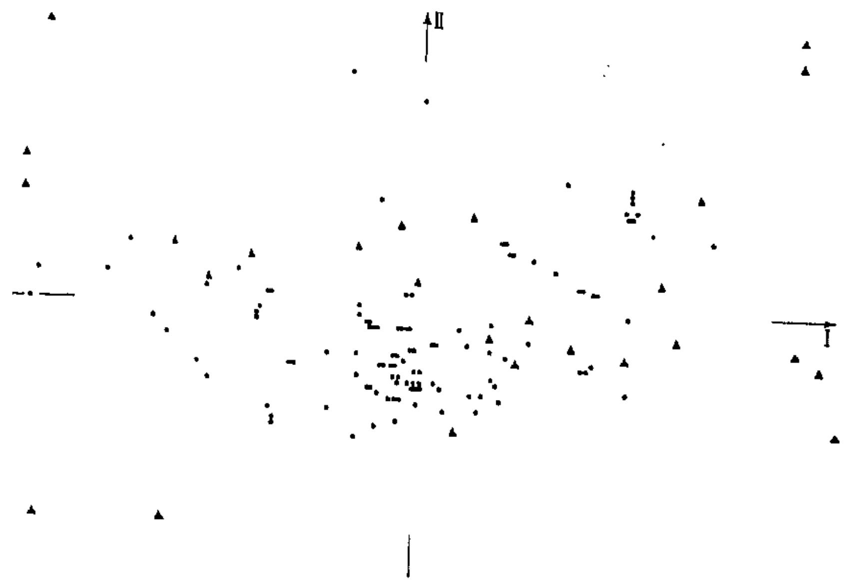

Fig. 7. Variability of *O.glaberrima* (o) and *O.breviligulata* (-) samples from central Mali, with character sites (Δ) plotted on axes I-II.

Practical Application of Variability

The aims of an improvement programme involving indigenous rices are to use *O.glaberrima* in association with *O.sativa* and to improve *O.glaberrima* itself, relative to *O.sativa*.

In using *O.glaberrima* in association with *O.sativa*, the beneficial characters of either parent could be incorporated with appropriate back-crossing to avoid loss of desirable characters. Alternatively, a new species could be created by tetraploidy. *O.glaberrima* is favoured by some West African farmers because of its adaptation to the area and also because of its cooking qualities. Hence, varietal improvement of this species alone, as has been done for *O.sativa*, might be useful.

In hybridization between *O.sativa* and *O.glaberrima*, a high proportion of sterility among the progeny occur. Jacquot (pers. comm.) reported high sterility in F_1 populations irrespective of the direction of crossing. In F_2, fertility varied and in F_4, it varied within the lines, but breeding for fertility was positive. Diallel crosses should enable compatible and incompatible genome structures to be identified.

Conclusion

Extensive investigations in Mali and Sene-Gambia during 1974-1976 showed that:

1. There are two forms of *O.breviligulata*, a relatively rare wild type, and a frequently-encountered weedy type. Homologous variation was observed in weedy *O.breviligulata* and *O.glaberrima* in terms of their geographical distribution and their division into two ecotypes, erect and floating.
2. The enzymatic variability was higher in *O.breviligulata* than in *O.glaberrima* and it included the latter.
3. The allogamous species *O.longistaminata* showed high enzymatic variability. Autogamous African and Asian species showed a lower and converging variability.
4. There is a maximum genetic variability in *O.longistaminata*, which is a large and polymorphous population. Some populations of this species should be collected, sampled with precision and exploited as much as possible.
5. The variability of the African autogamous species, *O.breviligulata* (wild and weedy types), *O.glaberrima* and *O.sativa* is geographically scattered. Sampling should be done throughout their areas of distribution. In particular, *O.glaberrima* should be collected where it has resisted introduction of *O.sativa*. The wild form of *O.breviligulata* should be collected outside the areas of cultivation of *O.glaberrima*.

It is considered that the range of genetic diversity in indigenous African rices and the ability of these species to withstand stresses commonly encountered in their environment offer considerable potential for their use in varietal improvement programmes for both *O.sativa* and *O. glaberrima*.

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COLLECTION AND CONSERVATION OF EXISTING RICE SPECIES AND VARIETIES OF AFRICA

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African rice, *O.glaberrima*, was domesticated in parts of West Africa about 3,500 years ago (Portères, 1956). Its origin was independent of Asian rice and it was domesticated from a different wild progenitor, *O.barthii* (syn. *O. breviligulata*). Today, intergrades between these two species are found and are known as weed forms of *O.barthii* (Bezancon *et al.*, 1977a, 1977b) or as '*stapfii*' forms (Chang, 1976). They are basically hybrids of different degrees and are not a species. In addition to these species endemic to Africa, are other indigenous species, the most closely related of which is *O.longistaminata*, a perennial rhizomatous species of wider distribution (Fig.1).

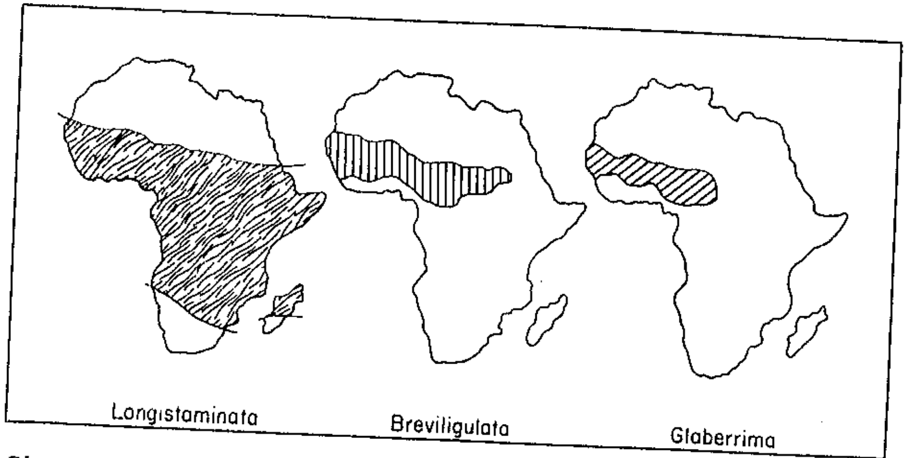

Fig. 1. Distribution of *O.longistaminata*, *O.breviligulata* and *O. glaberrima* in Africa.

Thus, there are three endemic species in Africa paralleling *O.sativa* and its progenitors in Asia. These three species are classified in the series 'Sativae' of the section 'Oryza' of the genus *Oryza* (Sharma and Shastry, 1965) (Table 1). These three species and intergrades among them of all the African indigenous members of the genus, are the most important to collect. This is because hybridization between them and *O.sativa* is possible, and they may have useful characters for crop husbandry (Oka, 1977b). Like *O.sativa*, they are all diploid with 24 chromosomes and have the A genome. To the non-botanist, many forms of *O. glaberrima* would pass for rice as it is known in Asia. The other species differ sufficiently so that they could not be mistaken for cultivated Asian rice.

Other species exist in Africa, classified in the series Latifoliae, which are more distant, being shade-loving perennial plants of the forest zone. They are classified as *O.eichingeri*, *O.punctata* and *O.schweinfurthiana*. They have different genomic constitutions and one of them is an amphidiploid.

Even more distant is a group classified in the section Angustifolia, which is endemic to tropical Africa. There are four species in this section, intermediate between typical *Oryza* and typical *Leersia*, which are small plants adapted to shallow water and open habitats.

Perhaps *O.sativa* came to West Africa with the Portuguese in the 16th century. Despite its relatively short history in West Africa, numerous agro-ecotypes of *O.sativa* have either evolved or at least have become established within traditional African farming systems. To a large extent, these adapted Asian rices, and now recently-bred types, have replaced *glaberrima* in West Africa. Consequently, the area occupied by African rice is decreasing, and at the same time, genetic diversity in the species is being eroded.

Oryza sativa in Africa

Unfortunately, the history of the introduction, establishment, and migration of Asian rice on the African continent is lost in the sands of time. The Asian cultivated rice and the Asian paddy growing techniques were introduced into Malagasy at a very early date by Malayo-Polynesians. These people travelled along the trade wind routes and rice was probably a major food to sustain them along the voyages. Its movement to the east coast did not take much time thereafter. The subsequent Arab and Indian visitors were traders (not farmers) and they did not introduce any methods of cultivation (Carpenter, 1978).

There are three hypotheses regarding the introduction of the Asian rice into tropical West Africa. Portères (1956) believed that Portuguese introduced *O.sativa* from East Africa and/or Asia into Senegal, Guinea-Bissau and Sierra Leone around 1500 A.D. According to Nayar (1973) the Asian rice was introduced by Berbers across the Sahara not much later than it came to Egypt (9th-10th century A.D.). Carpenter (1978) suggests that it may have been introduced into West Africa from East Africa through Central Africa along early trade routes i.e. Zaire, Cameroon, Nigeria and Ghana. At any rate, the European colonial powers systematically introduced rice from Asia and encouraged its cultivation in tropical West Africa.

Thus the cultivation of Asian rice in tropical West Africa is more than 450 years old and the crop has so acclimatized itself that the region could be treated as a new centre of genetic diversity. The introgression of characters between *glaberrima* and *sativa*, if real, may have added new dimensions to the variability of *O.sativa*. The genetic diversity in these 'old' *sativa* cultivars of Africa, however, is being lost as new and improved types are adopted. Collection and conservation of these naturalized *O.sativa* cultivars from Africa, therefore, cannot be over-emphasized.

Portères (1956, 1957) studied the variation in the African types of *O.sativa* and in *O.glaberrima* and classified them on the basis of their morphological characters. He indicated the areas of spread for different groups of cultivars and their possible directions of movement. This pioneering effort has not been pursued and it is possible that a renewed effort based on greater in-depth botanical and ethnographic research might unravel the story.

Exploration

Exploration of Africa for rice was first done by the National Institute of Genetics, Misima, Japan. This Institute has sent four exploration teams to Africa since 1959. K. Furusato collected from the West African countries in 1959 and 1960 but unfortunately he left no report of his collection. H.I. Oka and W.T. Chang visited West Africa in 1963-63 and, besides many samples of cultivated and wild rices, collected *O.tisseranti* in the living form for the first time. T. Tateoka explored in East Africa in 1964 and made the first living collections of *O.punctata*, *O.eichingeri* and *O.perrieri* (Oka, 1977a). Collections built at the Rice Research Station at Rokupr (Sierra Leone) and Badeggi (Nigeria) had the earliest assemblage of rice genetic resources in West Africa. Carpenter, while working for UNDP/FAO in Liberia, collected rice germplasm from that country in 1970. In 1974, IRAT and ORSTOM collected from Mali, Senegal and The Gambia. These two institutes are still engaged in the collection of rices in Africa. IITA, located at Ibadan, Nigeria has collected from Sierra Leone, Liberia, Ivory Coast, Mali, Ghana and Nigeria. WARDA envisages collection from the areas of its activity. It is expected that these various institutes will be able to explore the whole of sub-Saharan Africa in the coming four or five years.

An International Board of Plant Genetic Resources (IBPGR) has been constituted to promote collection, conservation and evaluation of plant genetic resources. Under its auspices, a Rice Advisory Committee has been formed which advises IBPGR and IRRI on how best to promote the cause of conserving rice germplasm.

The International Rice Research Institute, Los Banos, Philippines, has taken a keen interest in all aspects of conservation of rice genetic resources and has facilities for long term storage of rice germplasm. The seed can be dried to 6% moisture content and kept sealed in waterproof containers at -20°C for about 50 years without losing viability. As an added precaution, a duplicate set is preserved at Fort Collins, Colorado, U.S.A. The International Institute of Tropical Agriculture, Ibadan, Nigeria plans to establish a long term store to cater to the needs of workers within Africa. There are plans for medium term storage of rice seed at Bouaké, Ivory Coast. Seed can be kept at 5°C and 60% RH up to 5 years without losing viability appreciably. This kind of storage is more useful for the breeder, to keep his working collection in viable form.

Evaluation

The morphological characters of African *O. sativa* and *O. glaberrima* were studied by Portères (1957), particularly for spikelet characters. He utilized these data for the classification of cultivars, and for mapping their areas of distribution and probable direction of past migration. Oka and his associates have studied the genetic barriers between *O. glaberrima* and the closely related species *O. barthii*, *O. longistaminata* and *O. sativa*. They have induced mutations at several loci in *O. glaberrima* (Oka, 1977a, 1977b). Some of the agronomic characters of *O. glaberrima* have been studied by IRAT at Bouaké and crosses have been made between *sativa* and *glaberrima* to inter-transfer their characters. IRAT has studied the electrophoretic isoenzyme patterns of its collections (Bezancon *et al.*, 1977a, 1977b). This has helped to show the extent of variability in these species and their phylogenetic relationships. IRRI has studied a part of its collections for their morpho-agronomic characters with a view to determining the scope of their possible exploitation in breeding programmes and has concluded that the diversity of *O. glaberrima* is not as wide as that of *O. sativa* (Chang *et al.*, 1977).

Evaluation of African rice at a single place for morphological and agronomic characters, and for reaction to various physiological stress conditions, for disease and pest resistance and for grain quality characters, needs urgent attention. *O. glaberrima* is still cultivated in many

TABLE 1

Classification of the species of the genus Oryza[a]

I. Section Padia (S.E.Asian)		
Series Schlechterianae	:	*schlechteri*
Series Meyerianae	:	*abromeitiana, meyeriana, granulata*
Series Ridleyanae	:	*ridleyi, longiglumis*
II. Section Angustifolia (African)		
Series Perrierianae	:	*perrieri, tisseranti*
Series Brachyanthae	:	*brachyantha, angustifolia*
III. Section Oryza (Pantropic)		
Series Latifoliae	:	*australiensis*, in Australia *collina, officinalis, minuta, malampuzhaensis*, in Asia *punctata, eichingeri, schweinfurthiana*, in Africa *latifolia, alta, grandiglumis*, in America
Series Sativae	:	*rufipogon* (=*balunga*), *nivara, sativa*, in Asia *longistaminata, barthii* (=*breviligulata*), *glaberrima*, in Africa *glumaepetula* (=*cubensis*), in America

a) Based on Sharma and Shastry (1965)

pockets and various merits are cited by the farmers, such as better competition with weeds, nutritive value, good keeping quality of the cooked rice, etc. Only extensive and intensive screening of the collections can bring out the real merits (or lack of them) of this species. It is important that characters be recorded in coded form for ease of handling large amounts of data and for use with computers. IRRI has published a catalog of its rice collections, and IRAT has published a catalogue of all its rice genetic resources maintained in the Ivory Coast. Catalogs of rice are also available for some national collections such as Indian, American and Japanese collections. These catalogs record data on any African rice material maintained in their collections. It is hoped that all the African rice genetic resources will be evaluated and that a catalog will be prepared and published to meet the requirements of African rice workers.

The role of IITA

The International Institute of Tropical Agriculture, based at Ibadan, Nigeria, has an active interest in the collection, storage, evaluation and documentation of African rice genetic resources. This Institute has a Genetic Resources Unit to look after all aspects of germplasm conservation of rice and some other crops. It has necessary personnel and funds not only for collection but also for medium term storage of the material. Long term storage, which is expected to be established shortly, will go a long way to serve the whole African continent for germplasm conservation of certain crops.

IITA plans to collect the rice genetic resources from the whole of sub-Saharan Africa in the next 4 or 5 years, and maintain seed under medium and long term storage, evaluate them for various standardized characters, assess the agronomic and other useful potentials, publish a catalog describing all their characters, and also supply seed to all interested rice workers. It is hoped that this can be accomplished with the cooperation of other national and international institutions concerned with the conservation of African genetic resources.

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RICE DEVELOPMENT STRATEGIES IN AFRICA

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Introduction

Amongst the cereal grains, rice is second only to wheat in terms of total world production with 344 million tons recorded in 1975. Moreover, it is the most important cereal for human consumption, since little is used for animal feed or industrial processing.

Approximately 90% of the world's rice is grown in Asia. African production of 7.2 million tons of paddy per annum between 1970 and 1974 represents about 2.5% of the total world output. Of this, approximately 60% is grown in Egypt (2.4 million tons) and Malagasy (1.8 million tons). In West Africa, thirteen countries produce 1.85 million tons, which is 25% of Africa's production and 0.6% of world production (Table 1).

Rice is largely produced for home consumption, so that only about 4% (7.3 million tons in 1974) of the world's production is traded in the free market. Of this, the majority comes from the United States (23%), Thailand (18%) and China (15%), with smaller contributions from Japan (7%), Burma (7%), Egypt (5%), Italy (5%) and Pakistan (5%) (WARDA, 1975). Thus, the world market price is dependent upon production in a few countries and is subject to considerable fluctuation. Between 1968 and 1972, the price fell sharply and proponents of the "Green Revolution" thought that this would continue. However, since 1972, the price has again been increasing to levels at least twice as high as in 1967.

Rice is important to the economies of many African countries, especially in West Africa, where several countries import rice. It is with these countries that this paper is especially concerned.

West African Rice Economies

The production, price paid to the paddy producer, and the imports of rice into the thirteen WARDA countries in

West Africa are given in Table 1. Although the area produces only 0.6% of the world's rice, it receives 7% of the total exports. These countries are amongst the least self-sufficient rice producers in the world, importing about 30% of their total requirements.

TABLE 1

Rice production, producer price and imports in WARDA member countries, average 1970-74[a]

Countries	Production (1000 metric tons paddy)	Price to paddy producers (US $/t paddy)	Imports (1000 tons)
Benin	6.6	144	8.1
The Gambia	29.4	168	18.1
Ghana	69.0	310	41.0
Ivory Coast	366.3	260	102.5
Liberia	194.6	264	44.2
Mali	145.7	80	35.4
Mauritania	2.6	240	24.5
Niger	30.4	140	2.2
Nigeria	401.4	480	2.8
Senegal	82.0	166	175.2
Sierra Leone	475.7	150	35.5
Togo	12.7	160	2.8
Upper Volta	37.9	180	3.5
Total (1000 t paddy)	1,854.3		495.8

a) Source: WARDA Rice Statistics Yearbook, 1975

One of the main reasons for this is that many countries in the region (especially Senegal, The Gambia, Sierra Leone and Liberia) have depended on export crops and mining. The plantations and mines have employed many rural people, and food-crop agriculture has been neglected. Even where export crops were grown on family farms, these were preferred to traditional food crops because of their cash value. To compensate for the resulting food shortages, rice was often chosen as the imported food because of its high caloric value, taste, and ease of cooking and storage.

The second, more recent reason for increasing dependency on imported rice is the urbanization and higher salaries which have occurred after the independence of these countries since 1960. Rice is also progressively replacing sorghum and millet, the traditional cereals, in the savanna and Sahelian areas, and the root and tuber crops in the forest zones. This phenomenon is particularly marked in the Ivory Coast and Mali where it was accel-

erated by the relatively low prices of rice on the world market from 1960-1972, and by the drought in the Sahel f 1969-1974. The amount of rice imported into West Africa increased from 276,000 tons/year in 1960-1964 to 496,000 tons/year in 1970-1974, an increase of 80%, at a time wh total world rice exports were unchanged.

In some countries, where attempts were made to increa food crop production, rice was the crop chosen for intensification. In Liberia, LAC 23, the most widely grown r variety even today, was selected by the Liberian Agricultural Company which is primarily concerned with rubber production. In Ivory Coast, where coffee and cocoa were dominant, irrigated rice cultivation has been easily accepted because it enabled farmers to grow a crop valued by their labourers.

Rice is therefore of prime importance to many countrie both the main importers, Senegal, The Gambia and Mauritania, and the main consumers, Liberia and Sierra Leone. It is also important to relatively small importer like Mali and Upper Volta because of their balance of tra deficits. Rice imports are a major drain on their small foreign exchange reserves, especially during droughts.

The situation was particularly acute in 1974, because the unprecedented high price of rice on the world market and a large rice deficit in West Africa because of drough The thirteen WARDA countries spent US$ 225 million on imported rice that year. This dependence on imported ric need not exist since the natural conditions for successfu rice cultivation (e.g. climate, availability of land and water) are found in West Africa. Recently, the goal of reducing rice imports has become of major importance to most economic and political leaders in West Africa.

Efforts to increase rice cultivation in West Africa ha been through intensification of controlled swamp or irrigated rice culture, and relatively recent. Several of th early pilot schemes in the 1960's based on Asian varietie and technology were highly successful, largely because varieties of high-yield potential, such as Taichung Nativ 1 and IR8 were available.

However, the recent introduction of irrigated rice cultivation in West Africa also implies sociological and economic production constraints. The successful extensio of modern rice cultivation requires its assimilation and its adaptation to the particular needs of the area. Land clearing and water management are a major cost of intensification in West Africa, in contrast to traditional Asia rice economies where intensified production is obtained by increased inputs of high-yielding varieties, fertilizers and pesticides.

Rice Development Strategies

Aims

A major aim of the West African rice-producing countries is self-sufficiency in rice as soon as possible. This may be self-sufficiency in good years only, or self-sufficiency in poor years as well, in which case provision must be made for storage or export of surplus during years of good harvests.

In Ivory Coast, it has been decided to aim for self-sufficiency even during years of poor harvests. Plans have been made to accumulate sufficient reserves for six-months' consumption in the towns.

Stabilizing production has been a major concern in many countries. In Senegal, a delta land-development scheme established in 1965 was originally planned to control flooding, while rice germination remained dependent on rainfall and river flooding. By 1968, it was obvious that this was too hazardous and pumping plants were constructed to alleviate problems due to low rainfall or floods, so that a system of internal water control operated. In general, the extension of irrigated rice cultivation in West Africa is aimed at minimizing risks associated with water stress and weed growth and to optimizing nitrogen fertilizer use.

In the Sahel, water control is essential for stable food production. Rice is the best cereal for large-scale irrigation schemes because its yield potential is sufficiently high to compensate for the costly irrigation schemes, in contrast to millet and sorghum which produce low yields, have a low grain/straw relationship and respond poorly to fertilizers. Consequently, all the major irrigation schemes in the Sahel are mainly for rice cultivation.

Methods

Price stabilization. The means to achieve these aims vary in nature, diversity and importance, according to the complexity of the situation, the social and political factors and available finance. For each country, this requires government to fix and guarantee the price to producers, as well as taking responsibility for research, training, extension, credit and in some form, capital investment.

In all WARDA countries, there is an official price paid to the farmer for paddy (Table 1). The official price varies considerably from country to country, but in each case, its aim is to protect local production against competitive imported rice. From a study of production costs in the region, it is possible to estimate the cost per ton of milled rice from the formula: $R = 1.6\ P + 100$ where R = cost per ton milled rice (US$), and P = producers' paddy price (US$).

Thus the cost of production varies from US$228 to US$865 per ton in Mali and Nigeria respectively. Importe[d] rice of similar quality ranged from US$170 to US$300/ton for broken and 25% broken rice respectively.

When prices were fixed, there was a greater incentive for commercial farmers to produce high yields for which they were guaranteed a respectable return. Production has also increased among traditional farmers who are mainly concerned with home consumption rather than production fo[r] the market.

Credit. Rice has been promoted in many areas by permittin[g] farmers to purchase essential services and inputs on credi[t] and to repay the debt after harvest. In Ghana, farmers were able to hire machinery (e.g. tractors, harvesters), and buy inputs for their first year of production on credi[t]. In Sierra Leone, farmers in the Kenema area were able to borrow money to pay for the clearing of new land.

Subsidies. These are frequently used to promote productio[n]. This may be in the form of a government-sponsored water management scheme, which is provided to the farmers at zer[o] or low cost (e.g. Ivory Coast). Fertilizers are commonly heavily subsidized (e.g. Ghana), as well as improved seeds and in some countries, machinery service. The problem wit[h] subsidies is that they are difficult to remove, even when they are initially intended only to encourage the farmers to adopt the new technology.

Investment. In areas where development costs are high, production may be limited by lack of funds. This may be overcome by community development projects, where land clearing is done by the local people instead of by heavy machinery. This restricts development costs to approximately US$ 1000/ha rather than US$ 10,000/ha required for the latter method. This has been applied successfully in Ivory Coast, Sierra Leone, The Gambia and Senegal.

Research. Because intensive rice cultivation in West Africa is relatively recent, applied research and training are important. These aspects have been limited in many countries because of the lack of specialists and funds. This has been partially overcome by regional cooperation through WARDA and by liaison with international institutes (IITA and IRRI) and bilateral institutes (IRAT).

Extension. The recent introduction of new techniques for rice cultivation requires a more effective extension service than is usually available. Most of the special projects have extension staff assigned to them who are also responsible for credit and marketing facilities. At the SODERIZ project in the Ivory Coast, a package of practices for irrigated rice and upland rice is provided for the farmers, together with the required inputs, and the farmer contracts to grow the rice in a specified way. The extension organization guarantees a minimum yield, below which a farmer does not have to repay the cost of the inputs. It also agrees to purchase the crop at a fixed price. In Nigeria, improved technology is demonstrated on farms alongside traditional practices.

Conclusion

Although it is too soon to assess the impact of the above strategies, the progress over the past two years has been hopeful. Rice production by WARDA countries increased from 1.85 million tons p.a. (avg. 1970-1974) to 2.3 million tons p.a. (avg. 1975-1976). Part of this increase was due to recovery from the drought in several of the WARDA countries. At the same time, imports decreased. Ivory Coast and Mali produced sufficient rice to meet domestic needs and have a small surplus for export or storage.

Although these improvements in the rice economy of the region are partially due to the development projects, other factors are involved: The climate in 1975 and 1976 was particularly favourable; the paddy producer price increased, and some of the domestic consumption was sold to take advantage of the higher price; and the consumer price increased, with a resulting decrease in demand in some areas.

Some major constraints are still to be solved, including the lack of infrastructure (roads, rice-mills, storage facilities) to enable farmers to take advantage of stable prices. In some instances, the cost of achieving self-sufficiency in rice needs to be considered against the nation's overall development plan.

In some countries, the goal of self-sufficiency is distant. Intra-regional trade could make it possible to achieve self-sufficiency on a regional base but problems arise: competitiveness of the world market, quality, transportation costs. These problems can most likely be dealt with by regional organizations for economic co-operation, such as the Economic Community of West African States (ECOWAS).

The increasing demand for rice in West Africa during the early 1960's made it necessary to develop rice production in the region. These measures are taking effect. By improving the strategies on the basis of past experience, and by developing greater cooperation in technology transfer and intra-regional trade, rice production and consumption in West Africa should continue to improve.

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RELATIVE IMPORTANCE OF RICE IN TROPICAL AFRICA AND THE NEED TO INCREASE THE FARM LEVEL ECONOMIC DATA BASE

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Introduction

The subject of rice in Africa is of growing interest as more land and increasing numbers of farmers are involved the production of this crop. The increase in rice production in tropical Africa is a relatively recent event, as farmers in this part of the world historically have been more involved in the production of other food crops.

This paper considers rice in perspective vis-a-vis the other principal crops grown in tropical Africa. Aggregate production estimates are derived on a regional basis for two time periods (an early and late period). The relative growth rates in production have been estimated for each of six food crops, including rice. Then, rice production in tropical Africa is examined in more detail in terms of aggregate production, land area, national yields, and average annual increases in production on a regional and country-by-country basis. Some important economic considerations for increasing rice production in tropical Africa are discussed.

The final section identifies the type of information considered useful for understanding existing rice production systems and suggests an approach to generate the data. The usefulness of farm-level, agro-economic data to assist in the design and evaluation of problem-orientated research is also discussed.

Major Food Crops produced in Tropical Africa

Regional output estimates

In tropical Africa, there are six food crops of major importance. In terms of these crops, 47% of the total tonnage is cassava followed by 20% for yam, 13% for sorghum/millet (considered here as one crop), 10% for maize and 5% each for both sweet potato and rice. (It should be recognized, however, that these gross figures obscure that the grains contain about 15% moisture, cassava 70%, and yams and sweet potatoes 75%. Percentages based on total tonnages of dry matter would be cassava 31%, sorghum/millet 26%, maize 19%, yams 11%, rice 10% and sweet potato 3%. In this paper all weight figures subsequently used are based on total weight, not dry matter.) In terms of land-use, their descending order of importance is sorghum/millet, maize, cassava, rice, yam and sweet potatoes (Table 1).

TABLE 1

Relative area and production of six major food crops in tropical Africa, 1972-74[a]

Crop	Area (1000 ha)	%	Production (1000 met.tons)	%
Cassava	6,005	13.8	42,318	46.5
Maize	9,694	22.3	9,181	10.1
Rice	3,671	8.4	4,533	5.0
Sorghum/millet	20,860	48.0	12,149	13.3
Sweet potato	1,381	3.2	4,824	5.3
Yam	1,852	4.3	18,072	19.8
Total	43,463	100	91,077	100

a) Area and production figures are average annual estimates for the period 1972 to 1974; from FAO Production Yearbook, 1974, Vol. 28-1 and ECA African Statistical Yearbook, 1974.

On a regional basis the situation is rather similar, but exceptions exist. In West Africa, the most important crops on the basis of aggregate production are cassava and yam. Virtually all the yam produced in tropical Africa is produced in West Africa and of this, 81% is produced in Nigeria. In this region cassava accounts for about 32% of the tonnage of these six crops; rice accounts for about 5% (Table 2).

In Central Africa, 77% of the tonnage of the six food crops is cassava which accounts for nearly 50% of the cassava produced in tropical Africa. In this region, sweet potato is the second most important crop and the quantity produced accounts for about 52% of the sweet potatoes

TABLE 2

Six major food crops in tropical Africa: Their relative importance and regional distribution of production, 1972-74[a]

Region	Crop	Volume (1000 met.tons)	% share region	% share trop.Africa	Area (1000 ha)	% share region	% share trop.Africa
West Africa	Cassava	15,119	32.2	35.7	1,823	7.2	30.4
	Maize	2,248	4.8	24.5	2,897	11.5	29.9
	Rice	2,149	4.6	47.4	1,874	7.4	51.0
	Sorghum/millet	8,995	19.1	74.0	16,756	66.3	80.5
	Sweet potato	442	0.9	9.2	76	0.3	5.5
	Yam	18,037	38.4	99.8	1,847	7.3	99.7
	Total	46,990	100		25,273	100	
Central Africa	Cassava	20,699	76.7	48.9	2,483	30.6	41.3
	Maize	2,118	7.8	23.1	2,470	30.5	25.5
	Rice	390	1.4	8.6	484	6.0	13.2
	Sorghum/millet	1,284	4.8	10.6	2,177	26.9	10.4
	Sweet potato	2,506	9.3	51.9	486	6.0	35.2
	Yam	5	0.0	-	1	0.0	0.1
	Total	27,002	100		8,101	100	
East Africa	Cassava	6,500	38.0	15.4	1,699	16.8	28.3
	Maize	4,815	28.2	52.4	4,327	42.9	44.6
	Rice	1,994	11.7	44.0	1,313	13.0	35.8
	Sorghum/millet	1,870	10.9	15.4	1,927	19.1	9.2
	Sweet potato	1,876	11.0	38.9	819	8.2	59.3
	Yam	30	0.2	0.2	4	0.0	0.2
	Total	17,085	100		10,089	100	

a) Production and area figures are averaged for the period 1972 to 1974; from FAO Production Year Book, 1972, Volume 26; 1973, Volume 27; 1974, Volume 28-1. ECA African Statistical Yearbook 1974.

produced in tropical Africa. Rice is a minor crop in Central Africa.

The two major crops in East Africa are cassava and maize. About 50% of the maize produced in tropical Africa is produced in East Africa of which 30% is produced in Kenya. About 44% of the rice produced in tropical Africa is produced in East Africa (compared to about 48% in West Africa) and of this quantity, 87% is produced in the Malagasy Republic.

Production growth rates for major food crops

On a regional basis, we have calculated the average annual production of each of the six crops for the period 1961-65 and for the period 1972-74. From this set of data, the absolute and relative change in production was calculated, along with the estimated average annual increase in production for each crop (Table 3).

On a regional basis the average annual percentage increases for each crop are presented graphically for West and East Africa (Figure 1a,b). In West Africa, the production of rice has increased, over the 11 year period, by 34%. The average annual increase in production has been estimated at 2.7% - the highest rate of increase among the six crops in West Africa. For this region, the estimated annual increase in production of cassava (2.4%) was second to rice and the production of yam and maize has been almost stable. The production of sorghum/millet declined, apparently due to the West African drought. It appears that rice is the only crop in which the increase in production has kept pace with population growth in the region.*

In Central Africa, the production of five of the six crops increased, the exception being sorghum/millet. The production of maize increased at the highest rate over the period under review (6.7% per annum) followed by rice (4.8%) and cassava (4.1%). The rate of increase in production of all the crops except sorghum/millet has been greater than the estimated population growth rate of the region.

East Africa is predominately a maize producing area and the rate of increase in the production of this crop has averaged 3.3% per annum over the eleven year period. Maize is followed by yam (2.3%); however, in absolute terms yam is relatively unimportant in this region. The annual rate of increase in the production of sorghum/millet was 1.5%, closely followed by rice (1.4%).

* Using 1965-73 growth rates the regional population growth rates are West Africa 2.6%, Central Africa 2.2%, and East Africa 2.6% per annum (World Bank Atlas, 1975).

TABLE 3

Average production estimates and annual mean growth rates for six major food crops in tropical Africa, 1961-65 and 1972-74[a]

Region	Crop	Average annual production 1961-65 (1000 met.tons)	Average annual production 1972-74 (1000 met.tons)	Increase in production Absolute (1000 met.tons)	Increase in production Relative %	Annual growth rate[a]
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
		-	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 per-cent and n = 11 years between the 1961-65 mid-point and the 1972-74 mid-point. Source: Derived from Table 2.

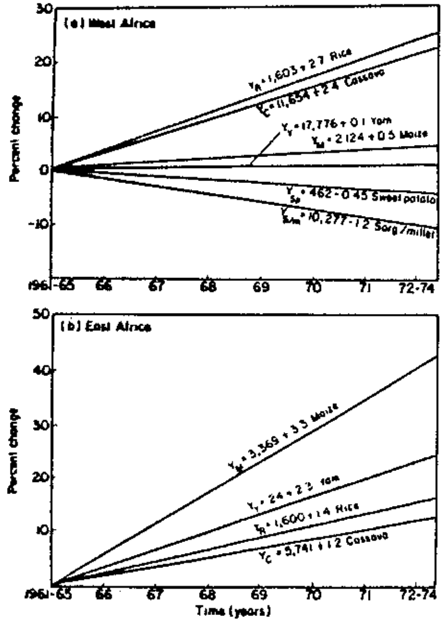

Fig. 1. Trends of total production of six major food crops in West (a) and East (b) Africa, 1961-74.
$Y_X = \bar{Y}_X (1 + R_X)^n$ where Y_X = trend of total production of crop x; $\bar{Y}_X$ = mean production, 1961-65 (metric tons); R_X = annual rate of increase of crop x (constant and compounded); n = 11 years between mid-point of 1961-65 and mid-point of 1970-74. In East Africa, the rate of increase of rice, sorghum/millet and sweet potatoes are similar (1.4 - 1.5%). Data from Table 3.

The data indicate that for West Africa, the rate of increase in crop production is greatest for rice, followed by cassava. In Central Africa the greatest rate of increase in production has been for maize followed by rice; in East Africa the greatest rate of increase has been for maize.

Rice Production in Tropical Africa

During 1972-1974, the average annual production of rice in tropical Africa was 4.5 million tons. About 47% of this output was produced in five countries (Table 4). Malagasy Republic is by far the leading rice producer in tropical Africa, producing about 38% of the total. Sierra Leone is second (11%) followed by Nigeria (9%), Guinea (8%) and the Ivory Coast (8%).

In terms of land-use, about 1.9 million hectares are devoted to rice production in West Africa, 0.4 million hectares in Central Africa and 1.3 million hectares in East Africa. The country with the largest land area devoted to rice in tropical Africa is Malagasy Republic (1.1 million hectares) followed by Guinea, Sierra Leone, Zaire and the Ivory Coast (Table 4).

National average rice yields

There is an extremely wide variation in the national average rice yields in tropical Africa (Table 5). The range is from a minimum of 0.45 t/ha (Uganda) to a maximum of 4.86 (Kenya). The mean yield in tropical Africa is 1.27 t/ha (Table 6). Among the three regions, East Africa has the highest mean yield per hectare (1.87 t/ha), owing to the high national average yields in Kenya, Botswana and Malagasy Republic. Three of the seven East African countries have average yields above 1.5 t/ha. Among the three regions, however, the variation in national yields is greatest in this region.

West Africa has the second highest average rice yield (1.15 t/ha) and on a regional basis the least variations in national average yields. The average national yield in Central Africa is very similar to West Africa (1.12 t/ha) but the variation in national yields is greater than in the West African region (Table 6).

National rice production growth rates

For each of the countries in West, Central and East Africa, the average annual increases in rice production have been calculated. In West Africa the notable average annual increases in rice production have been in the Republic of Benin (17% with a very low base), Niger (12% with a low base), Ghana (7%) and Nigeria (6.3% with a large base). Over the eleven years under review, the absolute production of rice has declined in four countries (Table 7).

In Central Africa, the greatest annual increases in rice production have been in Zaire (16%), Central African Empire (10.3% with a small base), Chad (5.5%) and the Cameroon (5.5%). Rice production has declined in three of the Central African countries.

In East Africa where rice production is relatively unimportant, except for the Malagasy Republic and to a lesser extent Tanzania, Malawi has experienced an annual growth rate of rice production of 15.8%, Kenya 8.5% and Uganda 7%.

The greatest absolute increases in rice production have occurred in Nigeria, the Malagasy Republic, Sierra Leone, the Ivory Coast and Guinea (Table 7).

Some Important Economic Considerations for Increasing Rice Production in Tropical Africa

In a few countries of tropical Africa rice is an important crop, in the sense that a large number of farmers are involved in its production and also in terms of the aggregate domestic output of rice compared to other prin-

TABLE 4

Major rice producing countries in tropical Africa and their importance in terms of production and area[a]

Region	Country	Production (1000 met.tons)	% Share (Region)	% Share (trop.Africa)	Area (1000 ha)	% Share (Region)	% Share (trop.Africa)	Yield (tons/ha)
West Africa	Sierra Leone	475.3	22.1	10.5	356.3	19.0	9.7	1.33
	Nigeria	400.7	18.7	8.8	280.0	14.9	7.6	1.43
	Guinea	378.3	17.6	8.3	396.7	21.2	10.8	0.95
	Ivory Coast	343.0	16.0	7.6	292.3	15.6	8.0	1.17
	Liberia	153.6	7.2	3.4	138.7	7.4	3.8	1.11
	Mali	141.7	6.6	3.1	166.3	8.9	4.5	0.85
	Others (8)	255.9	11.8	5.7	244.0	13.0	6.6	1.16
	Total	2,148.6	100	47.4	1,874.3	100	51.1	1.15
Central Africa	Zaire	193.0	49.5	4.3	303.0	62.6	8.3	0.64
	Mozambique	101.3	26.0	2.2	65.0	13.4	1.8	1.56
	Chad	30.3	7.8	0.7	52.3	10.8	1.4	0.58
	Angola	27.0	6.9	0.6	22.0	4.6	0.5	1.23
	Others (6)	38.7	9.8	0.8	41.7	8.6	1.1	1.30
	Total	390.3	100	8.6	484.0	100	13.1	1.18
East Africa	Malagasy Rep.	1,738.7	87.2	38.4	1,078.3	82.2	29.4	1.61
	Tanzania	173.7	8.7	3.8	175.0	13.3	4.8	0.99
	Others (6)	81.3	4.1	1.8	59.4	4.5	1.6	2.10
	Total	1,993.7	100	44.0	1,312.7	100	35.8	1.64

a) Based upon average annual production and area figures for the period 1972 to 1974; from FAO Production Year Book, 1972, Volume 26; 1973, Volume 27; 1974, Volume 28-1.
ECA African Statistical Yearbook 1974.

TABLE 5

Relative rice yields in tropical African countries: Average annual yields for 1972-74

Country	Region	Area (1000 ha)	Yield (tons/ha)
Kenya	East	7.0	4.86
Botswana	East	1.7	3.12
Rwanda	Central	1.0	2.33
Niger	West	20.0	1.90
Burundi	Central	2.3	1.85
Malagasy Republic	East	1,078.3	1.61
Mozambique	Central	65.0	1.56
Benin	West	3.7	1.54
The Gambia	West	30.7	1.54
Nigeria	West	396.7	1.43
Sierra Leone	West	356.3	1.33
Angola	Central	22.0	1.23
Ivory Coast	West	292.3	1.17
Liberia	West	138.7	1.11
Malawi	East	27.7	1.07
Mauritania	West	0.3	1.00
Gabon	Central	1.0	1.00
Zambia	East	1.0	1.00
Tanzania	East	175.0	0.99
Congo	Central	5.3	0.99
Guinea	West	396.7	0.95
Central African Empire	Central	14.0	0.93
Upper Volta	West	33.7	0.93
Senegal	West	62.3	0.91
Ghana	West	70.0	0.90
Mali	West	166.3	0.85
Cameroon	Central	18.0	0.70
Zaire	Central	303.0	0.64
Chad	Central	52.3	0.58
Togo	West	23.3	0.57
Uganda	East	22.0	0.47

Source: FAO Production Year Book, 1972, Volume 26; 1973, Volume 27; 1974, Volume 28-1, and ECA African Statistical Yearbook 1974.

cipal food crops. These countries include Malagasy Republic, Sierra Leone, The Gambia, Ivory Coast, Liberia, Guinea, Mali and Nigeria. In most of the other countries, rice is of much less relative importance. However, in many countries the annual rate of increase of rice production leads one to believe that rice is likely to become increasingly important in the future.

TABLE 6

Comparison of regional rice yields in tropical Africa, 1972-73

Region	Mean (t/ha) (Standard deviation)	Range	Coefficient of variation
West Africa (14 countries)	1.15 (0.34)	0.57-1.90	0.30
Central Africa (10 countries)	1.12 (0.54)	0.64-2.33	0.48
East Africa (7 countries)	1.87	0.47-4.86	0.78
Tropical Africa (31 countries)	1.27 (0.84)	0.47-4.86	0.66

The supply and demand for rice

There are other indicators which support the view that rice will become increasingly important. Rice is a preferred food in urban centers of many of the countries under review. It is not only the urban, high income household consumer who demands rice but also institutions (such as schools, hospitals, military establishments, hotels) because of the relative ease of preparation in catering for large numbers of people. As the domestic production of rice (and in some countries, food) has not kept pace with the increase in demand, imports of rice have increased dramatically in many countries.

Thus, there is at present a good market for rice, and potentially a good market for increased output in many countries, particularly in West Africa. How large this market is for additional increases in the domestic supply of rice on a national basis will depend upon several factors, including:

- the level of rice imports;
- relative costs of production of domestic output;
- domestic processing and marketing efficiency;
- current and future supply and demand relationships;
- competitiveness of domestic rice vis-a-vis imported rice in terms of price and quality;
- price and income elasticities of demand for rice;
- consumer preferences and the ease of substituting between rice and other food items; and
- population growth; particularly the higher-income, urban population.

The relative importance of the factors will vary among countries depending on the relative importance of rice in terms of production and consumption and internal price relationships.

How can smallholders increase the output of rice?

In tropical Africa agriculture is typically the principal sector of the economy. Agriculture is largely based upon smallholders who produce first for home consumption and second for market (even if one or two crops are largely produced as cash crops). Most smallholders have limited land resources and produce a wide range of crops relying primarily on household labour. They have little capital other than hand-tools and planting material stored from the previous harvest.

Often a production problem is considered to be 'low yields', 'traditional techniques', 'unresponsive farmers', a 'pest or disease' problem etc. Often, breeders attempt to develop high yielding varieties which require too high a level of input-use (e.g. fertilizer) as viewed by the smallholder. Often, production techniques are developed which either require too much labour from the point of view of the farmer, or capital he does not have and is unable to obtain. Often, experimental yields are not obtained in trials on farmers' fields or on farms under the farmer's own management, due to a host of possible reasons.

The *ability* of farmers to increase the output of rice and consequently the supply entering the market will depend primarily upon the:

1) quantity of labour, suitable land and capital under their control;
2) existing production techniques;
3) existing production constraints;
4) access to additional resources and techniques.

The *incentive* for farmers to increase their production of rice will depend upon the:

1) relative profitability of rice vis-a-vis the other crops in their farming system;
2) ability and cost of reducing present rice production constraints;
3) availability and cost of adopting proven output increasing technologies; and
4) perceived risk associated with new planting material and techniques.

From the farmer's point of view, the relative profitability of rice will depend upon cash expenditures, the labour requirements for each crop in his cropping system, relative market prices (or value to him for home consumptions) and consequently the net income of each crop.

In recent years increasing numbers of farmers have purchased improved seed for one or two crops they grow. More farmers are using fertilizer for one or two of their crops, but relative to the total number of farmers (or crops) this is still a small proportion. And even fewer farmers are using non-traditional power sources to complement or substitute for labour.

The reasons why more farmers are not using "improved"

TABLE 7

Average production estimates and average growth rates for rice in tropical Africa for 1961-65 and 1972-74

Region	Country	Average annual production 1961-65 (1000 met.tons)	Average annual production 1972-74 (1000 met.tons)	Increase in production Absolute (1000 met.tons)	Increase in production Relative %	Increase in production Annual growth rate[a]
West Africa	Benin	1	5.7	4.7	470.00	17.0
	The Gambia	33	43.3	14.3	43.30	3.4
	Ghana	34	63.0	29.0	85.29	7.0
	Guinea	278	378.0	100.0	35.97	2.8
	Ivory Coast	220	343.0	123.0	55.91	4.3
	Liberia	162	153.7	- 8.3	- 5.12	- 0.5
	Mali	170	141.7	- 28.3	- 16.65	- 1.8
	Mauritania	1	1.0	0.0	0.0	0
	Niger	11	38.0	27.0	245.45	12.0
	Nigeria	205	400.7	195.0	95.56	6.3
	Senegal	100	57.0	- 43.0	- 43.00	- 5.3
	Sierra Leone	336	475.3	139.3	41.46	3.2
	Togo	19	13.3	- 5.7	- 30.00	- 3.3
	Upper Volta	34	31.3	- 2.7	- 7.94	0.8
		1,604	2,149.0	545.0	25.36	2.7
Central Africa	Angola	27	27.0	6.0	0	0
	Burundi	3	4.3	- 1.3	43.33	3.3
	Cameroon	10	12.7	2.7	27.00	2.2
	Central African Empire	5	13.0	8.0	160.00	9.4
	Chad	29	30.3	1.3	4.48	0.4
	Congo	4	5.3	1.3	32.50	2.6
	Gabon	1	1.0	0.0	0	0.0
	Mozambique	94	101.3	7.3	7.77	0.7
	Rwanda	2	2.3	0.3	15.00	1.3
	Zaire	62	193.0	131.0	211.29	10.9
		234	390.2	156.2	66.75	4.8

TABLE 7 (cont'd)

Region	Country	Average annual production 1961-65 (1000 met.tons)	Average annual production 1972-74 (1000 met.tons)	Increase in production Absolute (1000 met.tons)	Increase in production Relative %	Increase in production Annual growth rate[a]
East Africa	Kenya	14	34.0	20.0	142.86	8.5
	Malagasy	1,563	1,739.0	176.0	11.26	1.0
	Malawi	6	29.7	23.7	395.0	15.8
	Mauritius	1	1.0	0.0	0	0
	Botswana	6	5.3	- 0.7	- 11.67	- 1.3
	Tanzania	120	173.7	53.7	44.75	3.4
	Uganda	5	10.3	5.3	106.0	7.0
	Zambia	1	1.0	1	1	1
		1,716	1,994.0	278.0	16.20	1.4

a) Source: Data derived from Table 3. Growth rate assumed constant and compounding at $(1 + R)^n$, where R = annual incremental rate, n = 11 years between 1961-65 mid-point and 1972-74 mid-point.

inputs and techniques vary with farmers, regions and countries, but the major ones are:

1) many farmers have meagre cash resources;
2) 'improved' techniques or inputs often do not solve the farmers' real problems;
3) new techniques are not viewed by the farmer as proven; having acceptable risks associated with them; profitable and socially acceptable, etc.;
4) the required inputs are unavailable at the required time or at a price smallholders can afford.

In most countries of tropical Africa, where the domestic supply of rice falls short of demand and relatively large quantities of rice are required to satisfy this demand, much of the increased output will have to come from smallholder producers.

Basic questions must be raised. How can small farmers increase their output of rice? Are they likely to? How can research be directed to increase the likelihood that the small farmer will increase the output of rice in countries where this is socially, politically and economically sound?

The first question, of *how* small farmers can increase the output of rice is very important. Let us consider the following hypothetical but realistic case.

An upland rice farmer cultivates three hectares of which one quarter is rice. His land base is relatively fixed. He has meagre cash resources and a fixed supply of household labour to work on his farm; he does not have access to credit. He stores his seed from the previous year, uses local cultural practices, a local variety, and no fertilizer. He has observed that improved production techniques will increase rice yields in his area by 50%, and he would like to use the improved package but he cannot afford to purchase the improved seed and level of fertilizer recommended. How can this farmer increase his rice output? He could allocate more of his fixed land base to rice, which would require that he reduçe the land devoted to other crops. Unless the market price is sufficiently high to compensate him for the reduced output of his other crops he is not likely to do this; if the additional labour required for land preparation, weeding or harvesting competed with the labour required for his other crops he is not likely to increase the land area devoted to rice.

Under these conditions, the rice farmer will assess the "opportunity costs" of re-allocating among his crop enterprises his fixed land and labour resources. Namely, what does he lose relative to the gain he could realize from his increased output of rice? Most farmers have already assessed these factors and this explains why they have the area devoted to rice and other crops that they do. In this case, given existing production techniques and farm resources, the farmer's principle constraints to increasing the output of rice is his fixed labour supply and the

competing demand for this labour among his crops, and the lack of sufficient cash to purchase improved inputs.

In another situation, a smallholder has sufficient cash to purchase improved seed and fertilizer for his rice plot. Both inputs are locally available. Based upon the experience of other farmers in the area, he is likely to increase his yield by 50%, his labour requirements in weeding by 20% and harvesting by 35%.

Is the farmer likely to purchase improved seed and fertilizer and thereby adopt the new system? Will he get the increased yield of 50% that a few other rice farmers have obtained in his area? Let us consider the yield aspect, assuming that the seed and fertilizer are subsidized and the farmer believes they will increase his yield, and uses them.

If there is no competing demand (labour required for other crops) for the required labour at weeding time the farmer will likely use additional family labour for weeding. Therefore, he is not likely to get a yield reduction because he did not weed on time or put in sufficient man-days on this activity. However, because of the additional yield (50%) and additional labour required in harvesting, he must use more labour during harvesting. In terms of family labour either more labour will be required within the same time period at harvest time than in the past, or the harvesting will take more time; or the farmer will have to hire labour. Which approach the farmer uses will depend on the availability of family labour (which depends on requirements for other crop activities, household activities, marketing activities etc.), and/or his ability to hire labour.

From these general cases, increasing the output of rice (or any other commodity) depends upon the farm level resource situation, the flexibility farmers have in altering their cropping systems, the opportunity costs of farm resources (land, labour, cash) particularly labour, and the ability of farmers to acquire additional resources or techniques.

The need to understand existing farming systems

In order to increase the production of rice in a given area, rice researchers, policy makers and those responsible for the design and implementation of rice development programmes need to have practical knowledge about rice production techniques and the farming systems in which rice farmers operate in the intended location of technological change, if potentially productive farm-level changes are to occur.

The agro-economics of rice production can be expected to vary a great deal among land types, farmers, production systems and regions. Some of the principal factors responsible for this variation are climate, soils, topography, production alternatives, existing production techniques, yields, management, activity or resource constraints, factor and product prices farmers face and the nature and degree of government support to farmers.

In order to identify, measure and understand the importance of these factors, descriptive and quantitative knowledge about the environment in which rice farmers operate, and what rice farmers do and why and how they do it, is required. The basic knowledge that is required is:

1) description of the land-type;
2) farm size and area devoted to rice;
3) size of the household and the number of men, women and children available for farm work;
4) degree to which household labour is supplemented with off-farm labour, and the wages paid;
5) identification of the crops and livestock comprising the farming systems and the relative importance of each in terms of land area, production, home consumption and market sales;
6) description of existing production techniques;
7) estimated quantities of inputs used in the production of major crops; and cost of purchased inputs;
8) yield and total output of the principal crops;
9) the agricultural calendar and the identification of seasonal peak demands for labour;
10) major production constraints for principal crops, as viewed by farmers;
11) estimated costs and returns for major crop enterprises.

The scope and depth of a study will depend upon the level of precision considered to be appropriate, the cost of acquiring the information, the skills available to undertake the study, the usefulness of previous studies, and how much time will be allowed to acquire the data. Several approaches have been used to acquire this type of production data. They include interviewing agricultural officers and other persons on location to obtain the best possible estimates; conducting "farm-business" surveys among a sample of farmers by interviewing them once or twice about their farm operations; and conducting intensive, "cost-route" village-level studies among a sample of farmers. The latter approach among smallholders in developing countries is considered to be the most appropriate if one desires reliable data on labour utilization particularly on the basis of specific plots, crops, and field operations.

The cost-route approach is based upon repeated visits and interviews with farmers over an entire crop cycle. Data on field operations (labour utilization and other input-use), purchasing and selling activities, output and disposition activities are recorded as the events occur, rather than later asking the farmers what they did. Since farmers are interviewed once or twice a week, even during slack periods, much useful information can be acquired about farmers, their production techniques, output constraints and their farming system.

Conclusion

Rice is becoming an increasingly important crop in many countries of tropical Africa. In a few countries, it has been an important food crop for several decades. Despite its increasing importance, average national yields are low (1.3 t/ha among the 31 countries under review). In addition, in most countries the domestic production of rice has not kept pace with demand and consequently many countries in the region are importing rice. Thus, there is a considerable potential to increase the output of rice.

Since most farmers in tropical Africa are smallholders, biological research and production campaigns need to be geared to the production goals and farm level resources of smallholders; to their cropping systems, production constraints, resource flexibility, production techniques, input and product prices and current performance in terms of output, yields, and income. From knowledge gained, it is possible that steps can be taken which will generate major increases in domestic rice production.

Plate 1. The major implement of farming in Africa, the short-handled, recurved hoe.

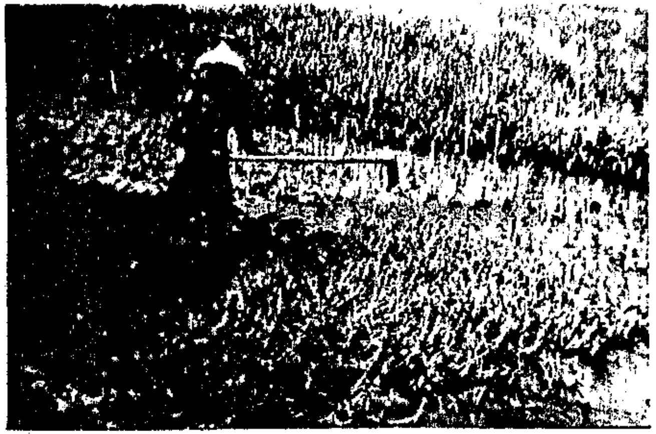

Plate 2. Swamp-rice land preparation in Sierra Leone (photo courtesy of Dr. A. Abifarin).

Plate 3. Stacks of bunded seedlings ready for transplanting into mangrove swamps, Sierra Leone.

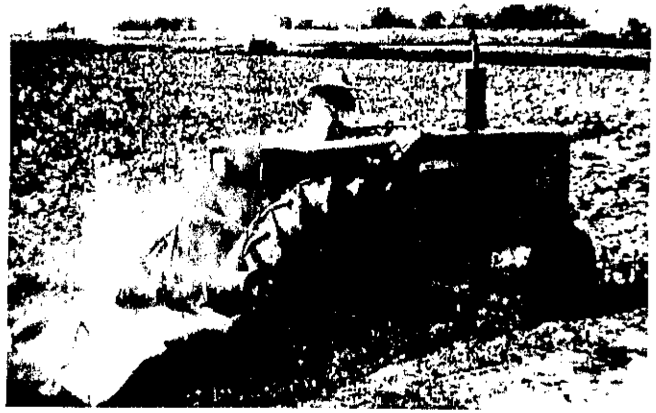

Plate 4. Mechanized dryland preparation for paddy, Nigerian/Japanese Rice Project, south-central Nigeria.

Plate 5. Harvesting flood-plain rice with a kitchen knife along the Niger River, Nigeria.

Plate 6. Panicle harvesting of dryland rice, Ivory Coast.

Plate 7. Snail-shell tool for panicle harvesting, Tanzania.

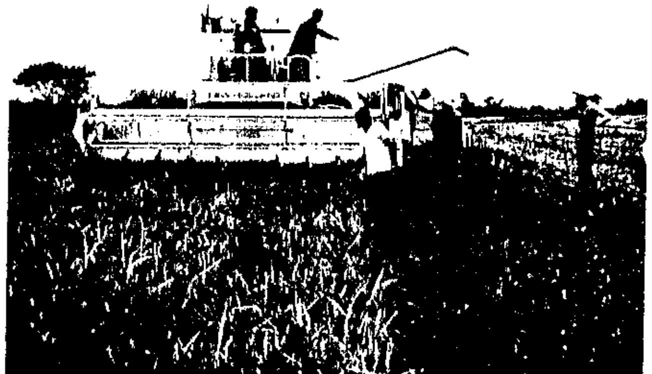

Plate 8. Combine harvesting of dryland rice in Ivory Coast.

Plate 9. Head-load transport of panicle - harvested rice by children in south-eastern Nigeria.

Plate 10. Drying stacked, bunched panicles in the rainy season on elevated platforms in western Ivory Coast, near Guinea.

Plate 11. Parboiling and drying rice at Nigerian/Japanese rice project, south-central Nigeria. This method will soon be replaced, following construction of a modern rice mill, seen crated in the background.

Plate 12. *Oryza longistaminata* in its *basfond* habitat in the savanna, Ivory Coast.

Plate 13. Flowering panicles of *Oryza glaberrima* (left) and *Oryza sativa* (right).

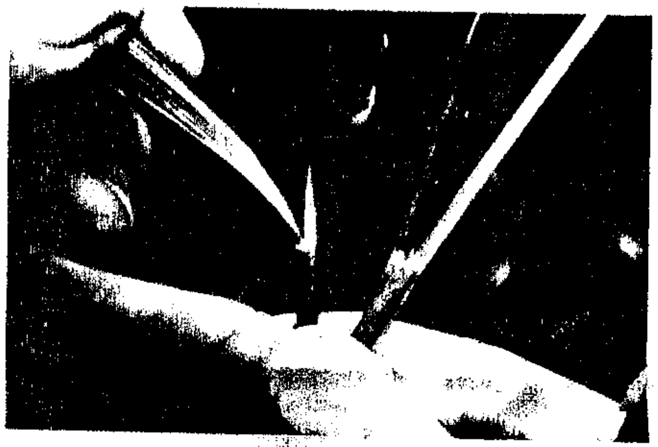

Plate 14. Ligule differences between *Oryza glaberrima*, truncated (left) and *Oryza sativa*, conical (right).

Genetic Improvement

RICE IMPROVEMENT IN TROPICAL ANGLOPHONE AFRICA

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Introduction

About thirty percent of Africa's rice is cultivated in the tropical anglophone countries of Sierra Leone, Nigeria, Liberia, Ghana, The Gambia, Malawi and Tanzania. Rice consumption has been increasing steadily, mainly because of the development of urban communities in these countries and because of the higher value attributed to rice compared with the more traditional foods of sorghum, millet, cassava, maize and yams. Efforts to increase rice production are being made in all these countries. Several national rice programmes have emphasized varietal improvement as an important part of improved production technology. This paper discusses past and present work on rice breeding and selection in tropical anglophone African countries.

Rice Ecologies

The major ecological-climatic zones in which rice is cultivated in tropical Africa are wet forest, transitional forest, savanna and mid-altitude. In each ecological zone there are distinct rice ecosystems; e.g. dryland rainfed, hydromorphic, valley swamps, irrigated paddies and deep water. These require varieties with traits for adaptation to the particular ecosystem.

Research Institutions

Rice research in Nigeria, Ghana and Sierra Leone began in a small way in the 1920's with Moor Plantation in Ibadan

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***International Institude of Tropical Agriculture, PMB 5320, Ibadan, Nigeria

as the main centre. At the Rice Research Station, Rokupr, Sierra Leone, established in 1934, research on flooded rice was the principal objective. The Rokupr Station was expanded in 1953 as the West African Rice Research Station to serve all anglophone West Africa but it became the Sierra Leone National Rice Research Station in 1962 when the association of these countries was terminated by independence. The Rice Research Station at Badeggi, Nigeria, was established in 1953 for research on irrigated rice. Limited rice research was initiated in Ghana by the Crops Research Institute, Kumasi, and by the Agricultural Research Station at Kpong. Rice Research in Liberia began in the 1950's at the Botanical Research Laboratories in the Plantation of the Firestone Plantations Company at Harbel, but shifted to the Central Agricultural Experiment Station, Suakoko, in the 1960's. Rice research in The Gambia is centred at Sapu. The main centres of research in Malawi are situated at Makanga, Kasinthula, Limphasa and Karonga, and although rice research was recorded as early as 1935 it was only during the late 1960's that the research programme was intensified (Lungu, 1974). In Tanzania, a concerted effort on rice-production research was initiated in 1965, with the breeding and genetic aspects of the programme centred at the Faculty of Agriculture, Morogoro, while a varietal testing programme was coordinated from the Ilonga Research Institute (Monyo and Mwaruka, 1974).

Rice Breeding before 1965

Emphasis was placed on selecting high yielding, well adapted, photoperiod sensitive, long duration, vigorous-growing varieties among the local or exotic germplasm. Photosensitive varieties were generally preferred, as they enabled farmers to stagger sowings during the season and still harvest at the same time. Longer maturity was considered to be correlated with high yield.

Pure line selection among the local heterogeneous varieties or populations was practised in the first stage. Bolo 108 was selected for mangrove swamp in Sierra Leone (Anon, 1953) and Gissi 25 and Gissi 27 were selected for valley swamps in Liberia (Pillai, 1970), while Agbede 16/56 (FARO 3) was selected for upland conditions in Nigeria in 1958 (Olufowote *et al.*, 1976).

Many varieties were introduced later, mainly from Asia, into Sierra Leone and Nigeria, and some into Liberia. Several varieties adapted to different ecological conditions were selected and released in Nigeria (Hardcastle *et al.*, 1954), Sierra Leone and Liberia; most were photoperiod sensitive (Table 1).

Hybridization was first attempted at Rokupr, Sierra Leone in 1951 (Anon, 1953). A modified pedigree method of selection was practised in which mass selection was done in F_2 and F_3 generations followed by selection of individual plants grown in pedigree lines in F_4 and subsequent generations (Anon, 1958a). Selection for blast resistance was initiated in the pedigree lines in 1957 (Anon, 1958b). Although a considerable amount of breeding material was generated through hybridization, most varieties released during this period were still selections from local and introduced varieties.

Use of the indigenous African cultivated rice *Oryza glaberrima* Steudel, which originated in the central Niger river delta of Mali (Portères, 1956), was attempted in the rice breeding programmes in Nigeria and Sierra Leone in the 1950's. Varieties of *O.glaberrima* were considered to be more resistant to flood, to have a high elongation rate and to be more resistant to alkaline soils as found in the Sudanian savanna region, than *O.sativa* (Oka and Chang, 1964). Many were also highly resistant to blast. In northern Nigeria, two *glaberrima* varieties, 'Baidande' and 'Jatau', out-yielded the most successful *sativa* varieties, 'Indochine blanc' and 'Maliong', introduced from French Guiana and Thailand, respectively (Oka and Chang, 1964). With the exception of some lines from The Gambia, *O.glaberrima* has red grains and shattering panicles. The *sativa* x *glaberrima* hybrids were made with the objective of combining the flood resistance of *glaberrima* with the high yield, white pericarp and non-shattering panicles of *sativa*. However, not a single progeny combining the desirable traits of both species was isolated. On the other hand, equally good floating *sativas* were found in Asia and inter-specific hybrids were discontinued in Sierra Leone (Anon, 1964). In Nigeria, new *sativa* x *glaberrima* crosses were attempted, without success; the major problem in the *sativa* x *glaberrima* hybridization programme was high sterility and continued segregation as far as the F_8 generation (Anon, 1971).

Rice Breeding after 1965

The national rice research programmes in Africa have benefited from the work of the International Rice Research Institute (IRRI) in the Philippines. The International Institute of Tropical Agriculture (IITA) and the West Africa Rice Development Association (WARDA) were established in the West African region in 1967 and 1971, respectively. The anglophone countries began emphasizing rice research and development to increase their rice production, but hybridization and selection of segregating materials has been mostly conducted in Sierra Leone, Nigeria and Liberia, with a little in Tanzania. So far as we are aware, there are scientists working as full-time rice breeders in anglophone Africa only in Sierra Leone (one), Liberia (one), and in Nigeria (two). Only two of these breeders are employed directly by the national governments. Only in these three West African countries

TABLE 1

Origin and characteristics of important rice varieties selected from exotic germplasm and released in Nigeria, Sierra Leone and Liberia up to 1965

Variety	Origin	Ecology	Growth duration (days)	Grain[a] type
		Nigeria		
BG 79 (FARO-1)	Guyana	Shallow swamp	135-174	LS
D-114 (FARO-2)	Guyana	Shallow swamp	135-176	LS
Kavunginpoothala 12 (FARO-4)	India	Deep swamp	189-220	LS
Makalioka 825 (FARO-5)	Madagascar	Shallow swamp	135-154	LS
Indochine blanc (ICB) (FARO-6)	French Guiana	Deep flooded (floating)	176-198	LS
Maliong (FARO-7)	Thailand	Deep flooded (floating)	160-217	LS
MAS 2401 (FARO-8)	Indonesia	Shallow swamp	155-160	LS
Siam 29 (FARO-9)	Malaya	Shallow swamp	189-220	LS
Sindano (FARO-10)	Kenya	Shallow swamp	115-162	LS
		Sierra Leone		
D-99	Guyana	Shallow swamp	early	LS
Lead	Guyana	Shallow swamp	early	SM
BG 79	Guyana	Shallow swamp	early	LS
Nachin 11	Malaya	Shallow swamp	late	SM
GEB 24	India	Shallow swamp	early	LS
Faya	Malawi	Inland swamp	medium	LS
Indochine blanc	French Guiana	Floating	late	LS
Radin China 4	Malaya	Inland/mangrove swamp	late	LS
Kavunginpoothala (KAV 12)	India	Deep swamp	late	LS
Pokkali	Sri Lanka/India	Shallow swamp	early	SM
SR 26	India	Mangrove swamp	late	LS
Anethoda	India	Upland	early	SM
Vl. 28061	Sri Lanka	Upland	early	SM
		Liberia		
Sokotera 55	Zanzibar	Shallow swamp	medium	MB
Sokotera 107	Zanzibar	Shallow swamp	medium	MB
Sokotera 89	Zanzibar	Shallow swamp	medium	MB
Bentoubala 158	Guinea	Shallow swamp	medium	MB
Bentoubala 163	Guinea	Shallow swamp	medium	MB

TABLE 1 (cont'd)

a) LS = Long Slender, SM = Short Medium, MB = Medium Bold and to a lesser extent in Tanzania, is any hybridization and selection from segregating populations underway in 1977. Thus, the great majority of "breeding work" is only selection from among introduced lines as part of coordinated trial work by rice technicians or rice agronomists.

Nigeria

Earlier, major emphasis in the Nigerian rice breeding programme was on selection of tall, vigorous, photoperiod sensitive *indica* types such as SML 140/10 (FARO 12). With the development in Asia of short, erect, stiff-strawed, nitrogen-responsive varieties for irrigated lowland conditions, the improved plant type varieties were introduced into the country. IR8 was recommended in 1970 as FARO 13, for shallow swamps and irrigated conditions. In 1974, five more semi-dwarf introductions were released along with those varieties bred in Nigeria (Table 2).

TABLE 2

Improved plant type rice varieties released in Nigeria in 1974 for shallow swamp and irrigated conditions

Variety source	Duration (days)	Photoperiod sensitivity	Blast reaction[a]	Grain type[b]
FARO 15 (BG 79xIR8)	145-160	Weak	R	LS
FARO 16 (Tjina x TN1)	140-160	Weak	MR	LS
FARO 17 (MAS 2401xTN1)	145-160	Weak	S	LS
FARO 19 (IR20)	135-140	Weak	MS	LS
FARO 20 (BPI-76)(Bicol)	125-130	Insensitive	MS	LS
FARO 21 (TN1)	90-110	Insensitive	MS	ML
FARO 22 (IR627-1-31-4-37)	145-150	Weak	R	LS
FARO 23 (IR5-47-2)	145-150	Weak	MR	LS

a) R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible
b) LS = long slender, ML = medium long

For dryland rainfed conditions a hybrid, OS6, was introduced from Zaire, as FARO 11. This continues to be the best-adapted upland variety, yielding about 1500-2500 kg/ha. It is tall with long leaves and lodges with high fertility. It is low tillering but has long, exerted panicles and intermediate bold grains. The dwarfs that have been tried have been susceptible to diseases and some were too short to compete with weeds under farmers' conditions (Fagade, 1976; Olufowote *et al.*, 1976).

Selection for blast resistance has been in progress for some years with varieties and hybrid progenies screened every year in a blast nursery. Tadukan, H4, H5, Raminad 6, Tjina, BPI 76, Carreon and Tetep have been found to be highly resistant (Awoderu, 1972; Anon, 1972). FAROX 56/30 has been identified to be a blast resistant line, derived from the cross Jete x Tjina and released for dryland rainfed conditions (Olufowote, 1977).

Interspecific hybridization between *O.sativa* and *O. glaberrima* has been continued in breeding floating rice varieties at Badeggi. However, none of the pedigree lines derived from these crosses has established superiority over FARO 7 (Maliong) and FARO 14 (a derivative of Champa 133 x Indochine blanc). The latter was bred at Badeggi for the floating rice areas of northern Nigeria. During the past three years, the Nigerian rice breeding programme has been participating in the International Rice Testing Programme of IRRI, in various coordinated trials organized by WARDA, and in collaborative research with IITA.

Sierra Leone

Under the British, the work at Rokupr emphasized improving mangrove swamp varieties, but during the last 12 years equal emphasis has been given to improvement of varieties for upland and inland valley swamp conditions. The breeding methods involved selection among local and introduced varieties and hybridization. Several varieties selected for different ecological conditions have been released (Table 3) (Will, 1971; Will and Janakiram, 1974a, b).

During the past three years, varietal improvement has been strengthened by an IITA/FAO-UNDP project which provides emphasis on selection for disease resistance. Blast, leaf scald, brown spot, sheath rot, sheath blight and glume discoloration may occur seriously in the wet forest zone. A new virus disease, pale yellow mottle, has been found and resistance to this virus has been identified (Raymundo and Buddenhagen, 1976).

Liberia

Varietal improvement in Liberia concentrates on dryland rainfed and inland valley swamp ecologies in the wet-forest zone. In 1967-68, LAC 23, a selection from local *sativa* populations was selected by Dr. T. Hart of USAID working in the Liberian Agricultural Company (LAC, "Uniroyal"). Under tests on farmers' fields throughout the country, it outyielded the local populations by 50% (Carpenter, 1972). It is a tall, leafy, low tillering, medium duration (135-140 days) variety which has long, well-exerted panicles and red grains. It is resistant to blast but susceptible to leaf scald. For valley swamp conditions, IR5 was selected in the early 1970's (Carpenter, 1972, 1973). It has high yielding potential and 'improved' plant type but is moderately susceptible to blast, leaf scald, brown spot, sheath blight and iron-toxic conditions. For deep water-

TABLE 3

Rice varieties released at the rice research station, Rokupr, Sierra Leone, since 1965

Variety	Origin	Year of release	Duration (days)	Photoperiod sensitivity	Ecology	Grain type[a]
CP. 4	Seri Raja x Gantang	1971	175-200	Sensitive	Mangrove swamp	SM
B.D. 2	S.R. 26 x Wellington selection	1971	130-150	Sensitive	Mangrove swamp	LS
ROK 1	Tikiri Samba x 52 M.4.3	1974	128-135	Weak	Upland	LM
ROK 2	Azucena x Faya selection	1974	125-130	Weak	Upland	SM
ROK 3	Ngieya Yakei (farm selection)	1974	136-140	Weak	Upland	LM
ROK 4	S.R. 26 x Wellington selection	1974	134-150	Weak	Mangrove and inland swamp	LS
ROK 5	S.R. 26 x Wellington selection	1974	142-156	Weak	Mangrove swamp	LS
ROK 6	IR5-198-1-1	1974	140-155	Weak	Inland swamp and irrigated	SM
ROK 7	Anethoda x BG 79	1974	133-142	Weak	Inland swamp and upland	SM

a) LS = long slender, SM = short medium

logged swamps which have excess soluble iron, Gissi 27 was identified as better adapted (Pillai, 1970; Carpenter, 1973; Virmani, 1976).

In 1974, varietal improvement work in Liberia was intensified with the establishment of an IITA/IDA-financed rice project, with a rice breeder. More than 3500 lines have been introduced and evaluated in swamp and dryland rainfed conditions. For iron-toxic swamps, a high yielding photoperiod insensitive line (2526) has been selected and recently released as Suakoko 8. For non-toxic swamps, a blast resistant line, IR1416-131-5, has out-yielded IR5 (Virmani and Sumo, 1976). These varieties were tested under farmers' field conditions during 1976 and they showed good performance in particular ecologies, depending upon the prevailing stress.

None of the introduced varieties was strikingly superior to LAC 23 under dryland - rainfed local-farm conditions. In the past two years, several hybrid progenies have appeared promising both in Liberia and at IITA in Nigeria and superior selections for evaluation in yield trials have been made. These results have indicated that for the selection of varieties suited to the dryland rainfed ecosystem in West Africa, it is more useful to test large segregating breeding populations rather than limited numbers of fixed lines. A white-grain LAC 23 has been identified to add to the existing red grained LAC 23 in Liberia (Virmani and Tubman, 1976).

The Liberian programme is linked with the rice improvement programme of IITA, which provides segregating populations for evaluation and use in the breeding programme. The country also participates in the IRRI and WARDA coordinated varietal trials and initial evaluation trials.

Ghana

Rice production in Ghana has been encouraged during the past few years. Both upland and irrigated rice are cultivated, the former greatly predominating. Varietal improvement work is conducted at Nyankpala (northern Ghana) and Kpong (southern Ghana), consisting of the introduction of varieties and lines and their evaluation under local conditions (Aryeetey, 1976). Recently, the main sources of supply have been IRRI, IITA, and WARDA. IR442, IR20, and IR5 have been useful varieties for rainfed hydromorphic conditions in the savanna, while for irrigated conditions in the south, early duration varieties CICA 4, IR665-79-2, IR1561-228-3 and the medium duration variety, Vijaya, showed high yields (Aryeetey, 1976).

The Gambia

Rice in The Gambia is cultivated under irrigated, upland, deep-flooded, freshwater swamp, and saline mangrove swamp conditions. Applied rice research conducted at Sapu and Jenoi during the past few years has indicated that the highest yielding varieties were SE 302G from Senegal for dryland, IR442 for hydromorphic, ROK 5 from Sierra Leone for shallow fresh-water swamps, IR22 for irrigated conditions and Phar con En for saline mangrove swamps (ter Vrugt, 1976).

Malawi

Rice in Malawi is cultivated in rainfed natural flood, irrigated/improved and non-irrigated conditions. In 1966, the government decided to embark on a small-holder irrigation development programme based on paddy production (Guinan, 1974). Research commenced in 1969-70 to determine the optimum agronomic practices for the two main varieties. Later, attention was turned to the introduction, screening and field testing of new varieties for irrigated and rainfed conditions. The country is not traditionally a rice eating country and good grain quality rice is for export markets. The local rice variety, Faya, consists of many strains which vary in grain dimension, plant height, duration and other agronomic characteristics. Variation in grain dimensions causes milling problems while variability in agronomic characteristics is also unsatisfactory (Kumwenda and Kwangwa, 1974).

A pure-line selection programme (on a panicle basis) was commenced in 1969 to select a uniformly flowering, short strawed, high tillering long-grained, high-yielding variety. The selection 14/M/69 was identified as possessing long, slender, uniform grains.

A comparison of varieties introduced from the USA, and from IRRI, indicated that in general, the latter were better adapted. However, the American varieties Blue Bonnet-50 and Blue Belle, have been grown extensively in settlement schemes. Among later introductions, the Surinam variety SML 81b was found to be superior to USA varieties (Kumwenda and Kwangwa, 1974).

Tanzania

Both irrigated lowland and upland rice are important in Tanzania. The objectives of the Tanzanian rice breeding programme are: Evaluation of established Tanzanian varieties; selection of high yielding, disease and pest resistant strains from the variety Kihogo Red (Morogoro); and selection of parents from local and introduced varieties for a hybridization programme.

In 1972, the rice programme of the University of Dar-es-Salaam at Morogoro began breeding for high protein content and quality by nuclear techniques in collaboration with the International Atomic Energy Agency, Vienna. Hybridization and mutation methods of breeding have also been used recently for the general development of new rice varieties in Tanzania (Monyo *et al.*, 1973). Among the local germplasm, three lowland varieties have been recommended to farmers, Faya Theresa, Kihogo Red, Morogoro and Gamti. Although they are moderately high yielding, they lodge under heavy nitrogen fertilization. Moreover, Kihogo Red shatters at harvest and also cracks during milling (Monyo and Mwaruka, 1974). It was very heterogeneous and pure line selection resulted in the selection of a line which out-yielded the parent population by 40% (Monyo *et al.*, 1973). Among the upland varieties, Danduliya Milimani, Salama and Africa have been reported promising. Among the IRRI varieties, IR5, IR8, IR20, and IR22 out-yielded Faya Theresa. However, their cooking quality was unacceptable.

The Rice Breeding Programme of IITA, Nigeria

The Cereals Improvement Programme (CIP) of IITA is concerned with rice and maize improvement in tropical Africa. The rice programme develops and provides superior breeding materials to assist national programmes towards increased rice production and training in rice production and research. The major rice ecologies covered are dryland, hydromorphic (including fadama land in Nigeria and bolilands in Sierra Leone), irrigated inland swamps and irrigated paddy.

The programme has close cooperation with IRRI, WARDA and IRAT and with the national rice improvement programmes of Nigeria, Sierra Leone and Liberia, three countries where IITA scientists are involved in rice research activities. A team of scientists is involved in rice improvement, including pathologists and entomologists, and three main country locations enable screening of large population in the major rice ecosystems of West Africa.

A germplasm collection of about 5000 cultivars originating both in and outside Africa is maintained at IITA and further work to collect, conserve, evaluate and document more genetic resources of cultivated and wild rice species in Africa is planned by the IITA genetic resources unit.

The major objective of IITA's rice improvement programme is to develop varieties better adapted to each major African rice ecosystem, with stable and high yield and appropriate quality. The specific objectives differ with the stresses in each system. For dryland, the focus is on intermediate technology levels, initially with no increase in drought resistance, later with additional drought resistance for higher technology production systems. Horizontal resistance to blast is a key need for dryland rice in Africa, as is stable resistance to panicle diseases. For inland swamp and irrigated rice, stable resistance to fungi which become damaging under imbalanced nutrition, and resistance to high iron levels and to imbalanced Fe, Mn and K and P levels are all factors influencing rice improvement efforts. Most of the insect pests of rice in Africa, especially the stalk-eyed flies (*Diopsis*) are indigenous and can be considered to be potential pests of importance unless selection methods are developed to prevent their magnification into major pests.

Results to date from farm trials have shown that for existing agro-technology levels in the dryland forest ecosystem, the local varieties are quite close to ideal. OS 6, LAC 23 and ROK 3 are still the best varieties in Nigeria, Liberia and Sierra Leone among thousands of introduced lines. Use of fertilizer, especially nitrogen, and increased cropping intensity illuminates deficiencies in these varieties. Shorter stature (lodging resistance) and increased disease and pest resistance are needed for such technological changes.

IITA's current approach is to utilize balanced, locally-adapted varieties as the major base for genetic improvement, modifying them in so far as they have deficiencies, with least dilution of the adapted genotype.

An analytical transect screening method has been developed for dryland rice which ranges from very dry to dryland-hydromorphic conditions. A screening method has been developed for irrigated/swamp rice across paddies with different nutrients at low levels, and one for toxic soils.

Some varieties superior for toxic swamp/irrigated conditions under high disease pressure (including sheath and panicle diseases) in the wet forest, and others good for dryland rainfed conditions in the wet-forest zone have been identified (Table 4). These are some of the parents being

TABLE 4

Promising varieties for specific problems identified in IITA's rice programme

Dryland:		
Leaf blast	:	2/91/2. C 2, 563, Ebandioulaye
Neck blast	:	LAC 23, Fossagbe
Virus	:	63-83, Fossagbe, HT Moro, Iguape Cateto, Moroberekan, OS 6
Drought	:	63-83, IAC 25, Iguape Cateto, OS 6
Irrigated/swamp:		
Leaf blast	:	IR1416-131-5
Neck blast	:	IR1416-131-5
Caseworm	:	2526, IET 1996
Diopsis	:	IR2070-820-2-3, IR2071-77-9-3-5
Gall midge	:	Ptb 18
Low nutrients	:	IR578-95-1-3, Pelita 1-7
Nutrient toxicities and/or imbalances	:	2526, C168-134, Gissi 27, Mahsuri, SPR 6726-134-2-26

used in the breeding programme. It has been recognized that in the wet-forest zone, sheath and panicle husk diseases are major problems in varietal improvement. A pale yellow mottle virus disease has been found to be widespread in savanna and forest areas of Sierra Leone, Liberia and Ivory Coast. Useful resistance to this virus along with blast resistance, combined with high yields has been found (Raymundo and Buddenhagen, 1976; IITA, 1977).

An Overview of the Past Breeding Work and Future Strategy

The rice ecologies of Africa are diverse and complex. Several high-yielding varieties adapted to specific ecological conditions have been selected and released in tropical anglophone African countries. Various breeding methods such as pure-line selection, introduction and acclimatization and hybridization have been practised in different countries. The success for dryland in terms of the number of varieties released has come primarily from selection among African varieties and hybridization between African and exotic varieties. The latter has been practised on a limited scale in Nigeria and Sierra Leone. It is important to recognize that most of the popular rice varieties such as OS 6, LAC 23, ROK 3 and Faya, which have shown relatively high yield and stable performance under peasant farm conditions are mostly selections from farmers' varieties. Their major disadvantage is that they lodge with high nitrogen and better management.

Some exotic varieties also have been identified and released in different countries for lowland conditions (e.g. TN 1, IR5, IR8, IR20, BPI 76, BG 79, D 144, KAV 12, Maliong, MAS 2401) but in general they have not provided a stable performance over time. IR5 and IR20 probably remain today as the most widely planted of these. It is likely that their hybridization with well adapted local materials could result in better varieties.

Inter-specific hybridization between *O.sativa* and *O. glaberrima* was carried out in Nigeria and Sierra Leone to develop a better floating rice variety. Results thus far have not been encouraging but the programme is being continued in Nigeria. It is important that the merits and demerits of *O.glaberrima* be thoroughly determined. Since the inter-specific hybrids have been found to show sterility and continuous segregation, use of this species in the breeding programme can only be justified if it has some unique characteristics which are not present in *O.sativa*. The species needs to be conserved and evaluated for future use and this is underway.

Modern rice varieties in Africa need to be high-yielding, fertilizer responsive with improved plant type, resistant to diseases and insects, tolerant to soil toxicities and to have acceptable grain quality. In order to breed such varieties suitable for specific ecological conditions the following approach may be considered:

1. Specify the important ecosystems in a country and identify the ones in which rice is or could be an important crop.
2. Examine the available African genetic variability, which has not been adequately collected and utilized.
3. Evaluate indigenous and exotic germplasm to identify varieties which are well adapted to specific ecosystems.
4. Utilize varieties with certain desirable characteristics in a crossing programme.
5. Screen segregating populations and progenies in their proposed area of use in order to select the best adapted lines.

If such an approach is to be successful, it requires the collaboration of rice scientists working in national programmes and at IITA, IRRI, IRAT and WARDA. The scientific rewards of such collaboration can be great.

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VARIETAL IMPROVEMENT PROGRAMME FOR PLUVIAL RICE IN FRANCOPHONE AFRICA

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Introduction

This paper summarizes the work of IRAT, in collaboration with national institutes, on the improvement of pluvial (upland) rice in francophone Africa. The topics discussed are 1) genetic resources, 2) selection criteria, 3) breeding methodology, 4) culture of haploids (androgenesis) and 5) drought tolerance.

Historically, the National Institute for the Development of the Congo (INEAC, Zaire) began collecting rice ecotypes in 1933. This resulted in the release of varieties such as R 66 and OS 6. They came from crosses between local varieties and introductions from India, Malagasy and other countries. They remain widely distributed and useful varieties for pluvial rice throughout tropical Africa.

Research on pluvial rice in Casamance, Senegal commenced in the 1950's. Varieties such as 617A were developed from Malagasy stock while other suitable varieties, such as Iguape Cateto from Brazil, were introduced and distributed. IRAT has assumed responsibility for rice research in Senegal since 1960.

Prior to 1966, rice research in the Ivory Coast was conducted by the Ministry of Agricultural Research. Several useful varieties, including Moroberekan, were released. Subsequently, work on pluvial rice was assigned to IRAT. There was some opposition to pluvial rice because it was alleged that its cultivation resulted in soil deterioration. However, considering the topography and the available land in the Ivory Coast, rice cultivation could be extended into regions where pluvial rice was the only possibility.

Genetic Resources

Two major collections have been assembled at Bouaké, Ivory Coast, one of *Oryza sativa* and one of the indigenous African species *Oryza glaberrima*, *O. barthii* and *O. longistaminata*.

Oryza sativa collection

The entries of *O. sativa* are either old African varieties or introductions from other rice-growing regions. Many of the latter group are from IRRI, Philippines. About 4000 varieties were assembled at Bouake up to 1976. Of these, about 1,150 have been retained as having some suitability for pluvial rice improvement.

The origins of 3,421 varieties introduced up to 1975, and the percentages from each source that have been eliminated because of blast susceptibility, lateness, or other undesirable traits, as evidenced by observation over two years, are shown in Table 1.

The two most important agronomic characteristics of the 1,150 varieties retained through 1976 were the length of the vegetative cycle and plant height. The proportion of varieties in various classes for these characteristics is given in Table 2.

A catalogue has been prepared of the varieties obtained up to 1975, with their characteristics as determined in the field and laboratory. Of these characteristics, those relating to the major diseases are particularly important. Susceptibility to leaf blast was determined, using at first the methods described for the International Blast Nursery. However, it was noted that certain varieties (e.g. Zenith) were severely damaged by neck blast after they had been given a satisfactory rating for leaf blast.

The reaction of the varieties to leaf scald (*Rhyncosporium oryzae*) was also noted. There was considerable genetic variability in the resistance of the varieties.

A sample (260 varieties) of the collection was examined in detail, principally for morphological characters, and evaluated by factorial analysis.

Collection of indigenous African rices

During an IRAT-ORSTOM collecting expedition in Mali and Senegambia in October-December 1974, 1000 samples of *O. glaberrima* and 100 each of *O. barthii* (annual) and *O. longistaminata* (perennial, with rhizomes), were obtained. The samples were grown at Bouaké in 1975 under well-irrigated conditions in order to minimize blast damage. The agronomic characteristics of the samples were observed and, with the aid of factorial analysis and electrophoresis data, the organization and relationships of the groups were defined. This gave valuable information for

TABLE 1

Numbers and sources of introductions of O. sativa prior to 1975 to Bouaké, Ivory Coast; percentages and causes of elimination

Country of origin	No. varieties	% varieties retained	% varieties eliminated for: blast	lateness	other reasons
Zaire	50	78	0	0	22
Ivory Coast	161	70	2	1	27
Liberia	246	60	35	4	1
Taiwan	75	56	32	7	5
Thailand	107	41	30	10	20
Philippines	86	35	40	13	13
Laos	398	34	27	31	9
India	121	22	45	10	23
U.S.A.	166	21	49	11	19
IRRI	127	17	28	3	53
China	309	9	79	1	11
Senegal	289	9	5	78	9
Malaysia	493	3	9	88	1
Pakistan	100	2	36	2	60
Vietnam	77	1	6	87	5
Others	616	38	28	10	24
Total number	3,421	937	971	982	531

varietal improvement work using African species and in devising strategies for further collections of indigenous species.

The resistance of 367 varieties of *O. glaberrima* to leaf blast was tested. A few varieties (5%) showed satisfactory resistance. However, these varieties were all field susceptible to leaf scald (*Rhynchosporium oryzae*). Some varieties of *O. glaberrima* were less attacked by *Diopsis* than were varieties of *O. sativa*.

TABLE 2

Composition of the retained collection of 1,150 varieties of Oryza sativa at the end of 1976, Bouaké, Ivory Coast, in terms of plant height and length of vegetative cycle

	Late (>135 days)	Medium (110-135 days)	Early (<110 days)	Total %
indica long stemmed (>120 cm)	31%	31%	7%	69
indica short stemmed (<120 cm)	5%	19%	3%	27
japonica	0%	2%	2%	4
Total	36%	52%	12%	100

Other collections

In Malagasy and Senegal, important collections have been assembled mainly for the improvement of aquatic (paddy) rice. However, they may contain useful genetic material for the improvement of upland rice and rice cultivated on soils where phreatic water is present (hydromorphic conditions). In Senegal, the 222 samples of *O. glaberrima* have shown better resistance to borers than varieties of *O.sativa*. Also, the *O.glaberrima* varieties generally showed moderate reactions to blast, while the *O.sativa* varieties frequently were severely affected.

Breeding

The selection criteria established were:

1) *Yield potential*: Varieties with high yield potential under favourable climatic conditions and high inputs were selected. Also, varieties which yield well under variable climatic conditions and/or low inputs are being sought.
2) *Yield stability*: Varieties able to give regular yields despite stresses imposed by erratic rainfall patterns, drought, cold weather, pests or diseases are selected.
3) *Agronomic characters*: Desirable traits include lodging resistance, growth cycles adapted to fit different farming systems, and resistance to shattering.
4) *Grain quality*: Resistance to breakage, good milling quality, desirable grain appearance, palatability and consumer acceptability are sought.

Yield potential

The diverse rice ecologies in Africa necessitate the development of different varieties, each adapted to a particular ecological zone. The yields obtained varied from 1-6 t/ha. The best IRAT selections, growing under favourable conditions, have a yield potential of 7 t/ha, and have yielded 4 t/ha under large-scale cultivation. On marginal lands, they have a yield potential of 5 t/ha, and an average yield of 2.5 t/ha under large-scale cultivation.

Yield stability

Length of the vegetative cycle is of prime importance in most areas. Early maturing varieties (90-100 days; e.g. Dourado Precoce, IRAT 10, IRAT 11, SE 314G) are required for Senegal, Mali, Upper Volta, Niger, north Cameroon and south-east Ivory Coast. In other areas varieties with a longer cycle (130-135 days; e.g. IRAT 13) give more regular yields than early maturing varieties.

In the Ivory Coast, early varieties such as IRAT 10 and Dourado Precoce yield 3-4 t/ha on experiment stations and 2-3 t/ha on local farms. Medium-duration varieties such as Iguape Cateto and IRAT 13 yield on average 3 t/ha. In WARDA multi-location trials throughout West Africa, the short-duration IRAT varieties, gave an average yield of 3-4 t/ha, while those of medium duration averaged 2 t/ha.

Resistance to pests and diseases is important to yield stability. Leaf and panicle blast, caused by *Pyricularia oryzae* are serious threats to pluvial rice in Africa. In Ivory Coast, Upper Volta and west Cameroon, IRAT only releases varieties with resistance to blast. This is preferably horizontal resistance, i.e. moderate resistance to all races of the pathogen.

Leaf scald, caused by *Rhynchosporium oryzae*, is also an important disease, and resistance to it is desirable. There are other diseases of minor importance at present, for which varieties are not selected for resistance. However, any selections which are highly susceptible to a minor disease are discarded. These diseases are being kept under surveillance in case they increase in importance. Similarly, insect pests are being monitored. There are at present no major insect pests of pluvial rice. However, their importance may increase with increased cultivation, especially large-scale cultivation.

Agronomic characters

Lodging resistance. The major disadvantage of traditional varieties is their tendency to lodge when grown under conditions of high fertility. This is a limiting factor in developing more intensive pluvial rice culture. Lodging resistance is being sought. A plant height of 100-120 cm is considered optimal.

Length of cycle. In certain regions with two rainy seasons (e.g. M'Bos plain of west Cameroon), two crops can be grown per year. Early or mid-duration varieties are required. In other areas the length of the cycle must be adapted to different farming systems.

Grain quality

In general, the improved varieties are of acceptable quality in most areas, especially the Ivory Coast, Upper Volta and west Cameroon. Varieties are sought which have a low rate of breakage during milling, long, translucent grains, and taste and cooking qualities as desired by the consumer.

Crossing

Crosses have been made in Ivory Coast, Senegal and Malagasy. (The Malagasy work is presented separately in this volume.) Several methods were used to obtain varieties with reduced plant height, resistance to lodging and other desirable traits.

Indica x Indica. In crosses between traditional African varieties and upland rice varieties from either Africa or Latin America, little transgression was observed. Certain useful lines such as 2243 (Moroberekan x RT 1031-69) and IRAT 8 emerged.

Traditional African pluvial types times upland varieties of diverse origin gave interesting variability. The variety IRAT 10 resulted from the cross 63-104 x Leung Sheng.1. These types of crosses are being continued.

Indica x Japonica. Some interesting variability was observed in crosses of Dourado Precoce, RT1031-69 and 63-83 (IRAT 2) with Chianan 8 (IRAM 1632). F3 and F4 progeny of Dourado Precoce times Chianan 8 and 63-83 times Chianan 8 have been retained, but many of them are susceptible to shedding.

Sativa x Glaberrima. These crosses resulted in some interesting lines which are currently being monitored. Further interspecific crosses are planned after more detailed studies to find suitable parents.

Induced mutations. Gamma irradiation of 63-83 (IRAT 2) from Senegal resulted in short-strawed mutants which not only had increased lodging resistance but also had retained other desirable qualities for upland rice. Varieties IRAT 13, IRAT 78 and IRAT 79 resulted from mutations of 63-83. Moroberekan and IAC 25 were also subjected to mutation and the progeny are being studied in Ivory Coast. Cal345 and Kagoshima-Hakamuri were used for mutation work in Malagasy.

Crosses using semi-dwarfness. A number of donors of the character of semi-dwarfness (short straw) were indexed, including Taichung Native 1 and others possessing the same gene for semi-dwarfness, including IRAT 9 and IRAT 11. Some interesting selections were made using this gene. However, a limitation was that several undesirable traits, such as excessive tillering and a short and superficial rooting system, were also carried in association with dwarfness. This genetic system was largely abandoned, except in Senegal, where varieties Acorni, Dourado Precoce, Dawn, Mamoriaka, H4 and D25-4 were crossed with Senegalese selections (e.g. IRAT 11), carrying the dwarf gene from TN 1. The progeny of these crosses were at the F4 - F6

stage in 1976.

Three lines, 2243 from Moroberekan x RT1031-69, mutant 312A from 63-83 (IRAT 2) and IRAM 2165 (a mutant of Century Patna 231) carry a recessive gene for semi-dwarfness which is different from that in TN 1. These lines have been used as parents in crosses with Moroberekan, Dourado Precoce and other varieties. The segregating populations are being studied.

IRAT 13, a mutant from 63-83 (IRAT 2) is of medium height (110 cm). It also carries a recessive gene for reduced plant height (but not dwarfness) and it is a good source of other desirable agronomic characters. It has been crossed with several selections, including IRAT 10 which is another short-strawed variety.

Line 13d (*sativa*) and PI 215936 (*japonica*) have polygenic systems for a reduced plant height. They have been crossed with Moroberekan and R75 and the progeny is being studied.

Selection of progeny. Fixed line selections from Bouaké were tested at an early stage in many locations and in several countries. In this way, an early examination of the qualities of the selections and their adaptability was obtained. Early maturing lines from Ivory Coast were tested in northern Cameroon, Upper Volta, Mali and Senegal.

In Figure 1, the regions in which IRAT is involved in testing pluvial rice varieties and lines in Africa, the Indian Ocean (Malagasy and Reunion) and Latin America (Guyana) are shown. The stage of development of pluvial rice cultivation in these regions differs greatly. In some, improved varieties are already widely distributed, while in others, the first new varieties have just been released.

In Table 3, the varietal compositions of each region is given. This includes the varieties presently distributed, those which could be distributed to replace or complement their predecessors and those which have shown good yield potential but which require further testing.

In Guyana, the behaviour of four IRAT selections was compared to that of a traditional African variety and four varieties from Surinam. The results in Table 4 show the potential of the IRAT varieties, which out-yielded the South American varieties in the 1975-1976 trials.

Androgenesis

Research was conducted to obtain haploid plants by isolating the anthers and doubling their chromosomes. When techniques are perfected and put into practice they will be useful for varietal improvement, since fixed lines can be obtained directly from the progenies of the hybrids.

The variety Cigalon was selected for use in this research in 1975. A total of 200 plantlets was obtained

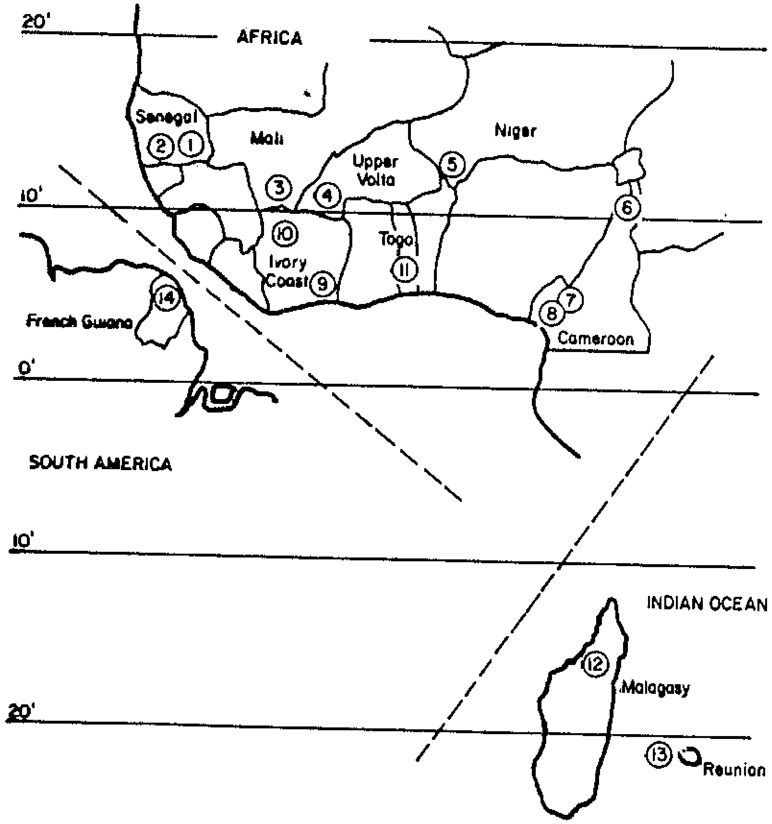

Fig. 1. Regions where IRAT pluvial rice selections are evaluated

at the rate of $3x10^{-3}$ from anthers.

The level of polyploidy of these plantlets was observed on a sample of 110 individuals, by examining root tips. The percentages observed were 80% haploids, 13% diploids, 6% triploids and 1% tetraploids.

The haploid plants were cultivated in a greenhouse in such a manner as to favour tillering. They were later divided and individuals of the clones were then soaked in 2-5% colchicine solution for four to eight hours. The proportion of doubled haploids was relatively low. It is possible that the application of colchicine treatment to very young plants would yield more diploids.

The work on another culture continued in 1976 when a dozen haploids were obtained and doubled by isolating the anthers of F3 plants from the cross IRAT 13 x Moroberekan.

TABLE 3

Varietal composition in regions where IRAT conducts trials

Countries	Regions (see Figure 1)	Varieties distributed	Varieties suitable for distribution	Promising varieties
Senegal	1	TS 123	IRAT 12	Lines of 63-104 x LS 1
Senegal	2	IRAT 11	Se 314 G	IRAT 10
Mali	3		Dourado Precoce, IAC 25	IRAT 10
Upper Volta	4	Dourado Precoce	IRAT 10	
Niger	5			
Cameroon North	6			Dourado Precoce, IRAT 10
Cameroon West	7			Daniela, IAC 25, IRAT 10
Cameroon West	8		Shinei	IAC 25
Ivory Coast	9	IRAT 2	85 B/1, IRAT 78, IRAT 79	
Ivory Coast	10	Dourado Precoce Moroberekan	IRAT 10	
Togo	11	Iguape Cateto	IRAT 13	
Malagasy	12	1345	RS 25 T	Ainanthen 14, IRAT 10 Mutants of 1345 Mutants of 1490 1642 2366
Reunion	13			Shinei, Dourado Precoce
Guyana	14			Lines of 63-104 x LS 1 IRAT 9, IRAT 10, IRAT 13

TABLE 4

Yield of African and Latin American varieties in Guyana, 1975-1976

Varieties	No.	Origin	Cycle (days)	Yield t/ha
IRAT 9	1716/2/3	TN1 x RT 1031-69	113	3.9
IRAT 10	144 B/1	63-104 x LS 1	114	3.5
IRAT 13	50/2/2	Mutant of 63-83	114	3.4
1345	Ca 345	Central Africa	120	2.8
IRAT 8	1487/9/5/7	Moroberekan x 63-105	113	2.8
Apani		Surinam	125	1.9
Alupi		Surinam	142	1.2
Pisari		Surinam	142	1.2

Resistance to Drought

In improving pluvial rice, drought tolerance can be useful in some ecotropical zones of Africa. Determination of the existence and levels of different resistance/tolerance mechanisms would be useful information for a breeding programme in order to select better parents and progeny. A number of tests have been used to determine the characteristics for drought tolerance in different varieties of rice cultivated under upland conditions. However, since the mechanisms of drought tolerance are not well known, the main criterion is the grain yield obtained after water stress during part of the growth period.

IRAT studies in 1975-76 showed that a deep rooting system and moderate tillering are two characteristics favouring drought tolerance. Two aspects were particularly studied; research on new criteria of selection for drought tolerance; and studies on the physiological aspects of drought tolerance.

The yield of 12 varieties was compared after applying drought periods at various growth stages (Table 5). IRAT 13 (a mutant of 63-83) was shown to have good tolerance to drought, irrespective of when it occurred. The vegetative growth stage of the plant is more sensitive than after heading.

Studies on root systems and root growth have shown that varieties differ in the depth and functioning of their root systems. Drought stress just before heading greatly increases root growth in some varieties.

Other studies have shown that water efficiency as determined through limiting transpiration to one-half, differed little among varieties in terms of dry matter production but did differ in terms of grain production. This may be due to effects on a regulation mechanism giving a shift from vegetative to reproductive growth or to dormancy. A weakness of present varieties is their production

of new tillers under stress, many of which yield no grain.

More research is required before perfection of screening methods for drought tolerance is achieved.

TABLE 5

Yield (g/sqm) of 8 varieties after a three week drought period was applied at various growth stages, Bouaké, Ivory Coast, 1976

Varieties	Initiation to booting	Booting to heading	Heading to filling	Filling to harvest
63-83	229	156	213	255
Iguape Cateto	191	196	211	303
IRAT 13	236	224	227	363
IRAT 9	129	190	151	254
IRAM 1632	193	256		
Dourado Precoce	162	160	102	244
Moroberekan	153	158	208	
Palawan	186	133	200	

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RICE BREEDING IN MALAGASY REPUBLIC

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Introduction

Rice has been cultivated for centuries in the Malagasy Democratic Republic (formerly Madagascar) and it is the staple food of most of the population. During this time, there have been a large number of varietal introductions. Also, a great diversity of ecosystems exist on the island, which range from tropical-humid to semi-tropical conditions and from altitudes of sea-level to 2200 m, the highest altitude on the island at which rice is grown on a large scale. These factors have resulted in a large number (1,200) of rice ecotypes of varying degrees of importance.

Rice cultivation in Malagasy is complex because of the diversity of ecosystems, ecotypes, crop seasons and farming systems. Most of the rice is grown under irrigated conditions. Breeding has played an important role in rice improvement and both local ecotypes and introductions have been used in hybridization and mutation breeding.

Breeding Programme

Local ecotypes

Rice was probably introduced into Malagasy by the original inhabitants who navigated from Indonesia sailing across the Indian Ocean from east to west, either directly or via Sri Lanka or southern India. This explains why one frequently finds amongst the good Indica types many Javanese ecotypes (e.g. Makalioka in Lake Alaotra area, Tsipala in the southwest). The varieties, such as Vary Lava, which are grown in the centre of the island are quite similar to some varieties in the Philippines.

Over the centuries, new types have emerged, because the ecosystems have exerted pressure for genetic change. There has been some farmer-selection of varieties, and there have been recombinations due to natural hybridizations or mutations. The result has been a large diversity of rice ecotypes, all derived from Indica and Javanica types, spread throughout the island.

There are approximately 1,200 ecotypes, which may be classified into several large groups. These are represented by varieties Tsipala, Makalioka and Fandrapotsy in the west and north-central zones; Lava, Rojo and Botry on the high plateaux; Bengala and Be in the north; Vato, Tsipala and Lava in the northwest; and Latsy in the highlands.

Selection

The earliest selections were made by the farmers themselves. Even today, it is common for farmers to select panicles and to mix certain ecotypes, such as Tsindrilahy, in the central part of the island. Research work commenced in 1927 at the Marovoay Agricultural Station in the northwest and later at the Alaotra Lake Station.

Pedigree-breeding was commenced by selecting panicles from local crops. High yielding varieties such as Makalioka 34, Vary Lava Marovoay 47, Ali-Combo, Tsipala A, and Rojofotsy 1285, were developed. The first three of these are presently cultivated on thousands of hectares throughout the country.

Since 1960, new varieties have been developed from previously collected local ecotypes. The new varieties include Boina 1329 and RS 25T for upland rice, especially in the northwest.

Some local ecotypes have been shown to be high-yielding when grown under good conditions, e.g. Ambalalava 1283, Vary Vato 462, Sandramaditra and Rojofotsy. Recently, selection among the local ecotypes from the high altitude areas produced three strains of the variety Latsika which gave higher yields than the unselected local type.

Varietal introductions

Approximately 1000 varieties have been introduced over the past 30 years, and these have been carefully tested for their suitability under various conditions. Certain varieties, notably Chianan 8 from Taiwan, performed well in all locations under 1600 m. It gave an average yield of 5 t/ha over 11 years. It outyielded the local varieties in all districts except one. Some varieties behave fairly well in most localities, and well in one particular area, e.g. Taichung Native 1, IR8, IR20.

None of the introductions were suitable for altitudes above 1600 m. The local material is unique in being adapted to these areas. Some of the introductions yielded well in the first year, but their yields fell sharply after that, usually because they lacked tolerance to the

prevailing pathosystem.

Some exceptionally good yields have been obtained from introduced varieties e.g. Chianan 8 in Fianarantsoa and Tananarive regions, 10 t/ha; Taichung Line 137 at Fianarantsoa, 12 t/ha. These were usually the highest yielding of all varieties throughout the island.

Multilocational trials

The results from more than 10,000 trials conducted between 1962 and 1975 were summarized in an IRAT (Malagasy) report in 1976. The trials showed that yields were better at higher altitudes (8 t/ha) than at the coast (5.5 - 7 t/ha). However, there is a potential for 2 crops per year on the coast, which would give a total annual yield of 12 t/ha. Higher yields were produced in the cool season than in the hot season. Yields of local varieties often remained low despite improvements in cultural practices.

Maximum yields increased from 1962-1968, but tended to fall after this, despite the same fertilization. Many reasons have been suggested for this, such as lack of minor elements, iron toxicity, and stress due to pathosystems.

The average yield of local varieties in experimental plots was 4.4 t/ha, compared with 2.9 t/ha in farmers' fields. This indicates that the average farm yield could be increased considerably by improved cultural techniques. Of 10,400 results, about 7% gave yields of 7-12 t/ha, indicating the excellent potential of some of the rice lands in Malagasy.

The percentage of acceptable varieties amongst those tested decreased with increasing altitude. It was 50% at sea-level, 20% at 1200 m, 5% at 1600 m, and 0.1% at 2000 m.

The yields were seldom stable and varieties which performed well over time in a specific ecosystem were exceptional, e.g. Chianan 8 at Tananarive (1200 m). Varieties which yielded more than local checks were Japonica types for 40% and Indica-Javanica types for 60%. However, above 1600 m the local varieties were the only suitable types.

Hybridization

The crossing programme has involved 738 crosses from 308 parents. 465 lines from 53 parents have been recorded in local catalogues. The following conclusions were drawn:

a) Indica x Indica crosses were undesirable except for grain quality.
b) The farther apart the parents were genetically, the less frequent were interesting recombinations, but the more potentially useful these were.
c) It was found preferable to make relatively few

crosses, but to select the parents carefully and to study the F_2 generation on a large scale. Approximately 100,000 individuals of an F_2 population were examined to find interesting recombinants. It was rare to find such recombinants in an F_2 population of 5000 individuals when the parents were genetically diverse.

d) The genes for semi-dwarfness were eliminated in the programme because they frequently led to undesirable characteristics. Transgressions frequently occurred during crosses between remote parents, so that reduced height could be obtained without the introduction of undesirable traits.
e) It was not difficult to obtain desirable phenotypes, such as lines 2523, 2532, 2619 or 2595, by using the amount of interchange that occurred in some crosses.
f) Indica x Ponlai crosses were particularly useful.
g) Back-crossing did not give valuable recombinants.
h) Bulk-crossing was abandoned after several unsuccessful attempts and the single-line method was preferred.
i) Male emasculation was carried out with hot water, using well-established procedures.

Mutation

Twenty-six varieties were studied and 21 useful lines were derived from them by mutation. Low dosages of chemical and physical mutagens gave the best results, using either 15 Kr gamma radiation, 0.9% MSE for 24h or exposure to MSE gas for 8-12h. The use of MSE gas was preferable since it avoided secondary effects due to hydrolysis, and was simple and efficient.

There was a large spectrum of mutants for several varieties. The mutants were similar, irrespective of the method used to obtain them. However, there were some varieties which produced few mutants. It was sometimes difficult to identify certain mutants which continued to appear in each generation.

Reversion to ancestral types with long straw, loose panicles and highly awned grains was rarely observed. Certain mutants were very transgressive. Some mutants were genetically interesting because they were hypersensitive to iron, had large grains which were often sterile, short straw (few cm) or compact panicles. Some mutants such as awnless were easily obtained, because of the recessive character of the mutation.

Extension

The results of multilocational trials over 15 years showed that it was possible to significantly increase yield and to obtain other desirable characteristics such

as shorter cycle, resistance to lodging, shattering, pests and diseases.

Significant yield increases have been measured over the past three years, when the best of the improved varieties have been compared to the local controls. Under good cultural conditions, including fertilization with 80 units N, 50 units P_2O_5 and 30 units K_2O, and weeding, the improved varieties have out-yielded the local varieties by 15-50%, and, in a few instances, up to 100%. The most outstanding example is the Japanese variety, Chinsei-asahi, which yielded 25 t/ha per year, with four harvests.

The major varieties which have been distributed are:
Introductions: Chianan 8, IR532-1-144, Taichung 178, IR20, Cica 4, Tainan 1, Kachsiung 21, Tainung 3, Tomoe Masari, Kagoshima-Hakamuri.
Local selections: Makalioka 34, Boina 1329, Vato 402, Rojofotsy 1285, Ali-Combo, Latsika, 2067, 1300.
Local hybrids: 752, 2523, 2532, 996.

Conclusion

Some of the recommended varieties are already widely grown e.g. Chianan 8 (30,000 ha); Makalioka 34 (50,000 ha); Ali-Combo, Kagoshima-Hakamuri and Boina 1329 (1000-2000 ha). A special case is Rojofotsy 1285 which is widely cultivated on several thousand hectares in the centre of the island, but as various local ecotypes. Considerable progress has been made in varietal improvement in Malagasy over the past twenty years. However, the wider use of improved varieties is essential for further economic development in Malagasy.

GENETIC EVALUATION AND UTILIZATION PROGRAMME OF THE INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI)

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Introduction

Few crops are cultivated under more diverse conditions than rice. It is found at latitudes from 0° to at least 48° and at elevations ranging from sea level to at least 2400 metres. It grows in a continuous gradient of water regimes ranging from upland to a maximum depth of about 6 metres. Rice is produced on many soil types and under a wide range of solar energy regimes. Disease and insect pests are numerous and of major importance in most rice-growing environments. The properties of the grain which affect nutritive value, milling and eating quality, and consumer preference provide an added dimension of complexity.

Common sense dictates that rice varieties should be tailor-made for specific locations, conditions and systems. So-called widely adapted varieties are probably nothing more than a reflection of a past void in local research capability. At IRRI, we have established a Genetic Evaluation and Utilization (GEU) Programme with the objective of assisting with the development of appropriate improved germplasm for every location and condition. It is an inter-disciplinary programme which focuses on agronomic characteristics, grain quality, disease resistance, insect resistance, protein content, drought tolerance, adverse soil tolerance, deepwater and flood tolerence and temperature tolerance. The programme has several inter-related components:

a) *Germplasm* collection and preservation.
b) *Research* in the various problem areas, aimed towards identification of the best genetic sources of resistance, tolerance, or of other desirable characteristics, and the development of rapid, effective screening techniques.
c) *Development* of superior genotypes with combined desirable characteristics. This is accomplished

through a high volume, multidisciplinary programme at Los Banos (Figure 1) and through cooperative work with national research programmes.

d) *Distribution* and evaluation of the improved germplasm from IRRI and national programmes through the International Rice Testing Programme (IRTP). The 14 international nurseries of this programme assure the regular exchange of improved germplasm among IRRI and local programmes where it can be further selected or hybridized to fit local conditions. These nurseries also provide feedback to IRRI and other programmes in the form of reactions to pests and adverse soils, yield potential and stability, etc. This information provides the base for further breeding work.

e) *Training* of young scientists in the methods and techniques of rice improvement. This training stresses the multi-disciplinary approach and prepares scientists to utilize the products of the GEU Programme at the local level and to develop or strengthen their own programmes which are essential to the development of varieties suited to specific locations, conditions and systems.

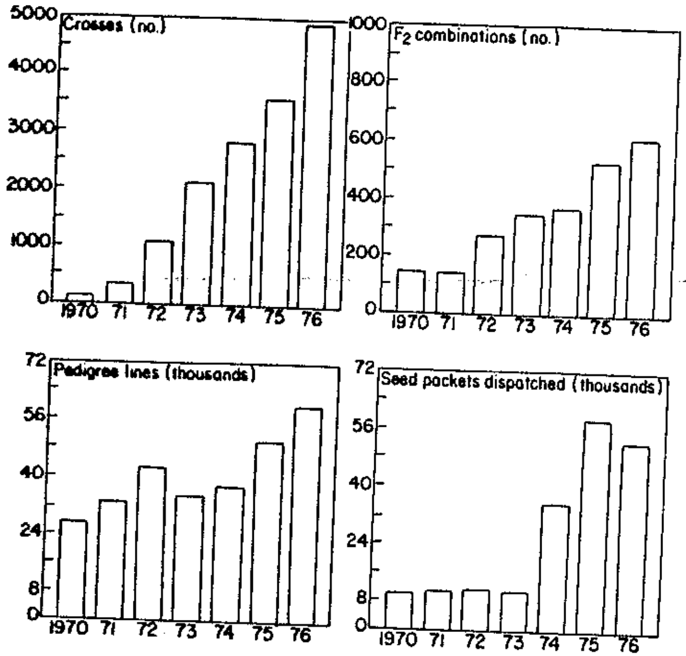

Fig. 1. Growth of the IRRI GEU Programme.

The several problem areas of the GEU Programme are discussed below with emphasis on those which are of importance to Africa.

Agronomic Characteristics

The yield potential of a variety is dependent upon a set of plant characteristics which are grouped under the general term of "plant type". The ideal plant type varies from one growing condition to another. Also, each growing condition has particular requirements for growth duration, photoperiod sensitivity, threshability and grain dormancy. Traditional cultural practices and methods of harvesting must also be considered.

Plant type

The characteristics and history of the IR8 plant type are well known. It is short and sturdy, highly responsive to nitrogen fertilizer, with erect leaves that make efficient use of the light. On farms with a relatively high level of management and good water control, it has been widely accepted. However, it is probably not suited for a very large segment of the rice growing environments in Africa. The IR5 plant type, which is somewhat taller and more competitive, is popular in areas of less dependable water control and/or lower levels of fertility and management, which is probably more typical of much of the present African situation. It is also popular in areas where harvesting practices discriminate against shorter types. IRRI's past breeding efforts have focused on these two types which occupy roughly 25 percent of the world's rice land. We have sacrificed some of the advantages of the IR8 type in order to incorporate essential disease and insect resistance. Also, the output of the IRRI programme has probably not reflected the demand for the intermediate height IR5 type of variety. However, we have begun to shift our emphasis and in the 1976 IRTP nurseries we have entered a number of lines which combine resistance to major diseases and insects with high yield potential and various heights and maturities (Table 1).

Growth duration

For expanding the rice area under irrigation, early varieties (105 days or less) are in great demand. They are also particularly suitable for multiple cropping systems which involve several crops of rice per year or one or two crops of rice in rotation with other crops. For rainfed areas where only one crop is possible, varieties of medium duration (130 days) are usually preferred. Most of our varieties and advanced lines have been of medium duration but our recent material (Table 1) repre-

TABLE 1

Characteristics of some outstanding advanced lines which are resistant to most of the major diseases and insect pests of the Philippines including blast, bacterial blight, tungro, grassy stunt, green leafhopper and brown planthopper. IRRI, 1976

Designation	Cross	Height (cm)	Growth duration (days)	Amylose content	Special traits
IR2070-414-3-9[a]	IR20^2/*O. nivara*//CR94-13	100	115	25	Resistant to whorl maggot
IR2070-423-2-5-6[b]	IR20^2/*O. nivara*//CR94-13	95	125	26	
IR2071-586-5-6-3[c]	IR1561-228//IR24^4/*O. nivara*/3/CR94-13	100	130	29	High yield potential at low levels of nitrogen
IR2071-625-1-252[d]	IR1561-228//IR24^4/*O. nivara*/3/CR94-13	80	110	27	
IR2307-217-2-3	CR94-13/IR1561-228	85	105	27	Early
IR2823-399-5-6	CR94-13/IR1529-680/3/IR24^3/*O. nivara*//IR1416-131-5	100	125	27	Resistant to salinity
IR2863-35-3-3	IR1529-680/CR94-13//IR480	95	130	27	High protein content
IR2863-38-1-2	IR1529-680/CR94-13//IR480	95	130	27	High and stable yield
IR3351-38-3-1	IR841-85/IR20^3/*O. nivara*/3/CR94-13	110	125	15	Resistant to gall midge Excellent grain quality
IR3464-75-1-1	IR628-68-3/IR841-67//IR2061-213	120	140	Waxy	Rainfed type
IR3880-10	IR841-67/C22/51//Pelita I-2/IR1541-76		130	16	Upland type; drought tolerant
IR3941-25-1	CR126-42-5/IR2061-213	95	100	27	Cold tolerant, very early
IR4215-4-3-1-1	IR2061-213/C4-63	120	125	23	Intermediate amylose
IR4219-35-3-3	IR2061-213/IR480	130	135	27	Excellent rainfed type
IR4417-179-1-5-2	IR2042-101-2/IR825-11-2	110	125	27	PK 203 tungro resistance
IR432-52-6-4	IR2061-125-37/CR94-13	100	125	27	Two sources of tungro resistance; resistant to gall midge
IR4442-207-2-3	IR2061-464-2/IR1820-52-2	105	120	27	Resistant to tryporyza
IR4683-54-2	IR1545-339/IR1721-11/IR2035-290	120	125	27	xa5 BB resistance
IR5853-118-5	Nam Sagui/IR2071-88//IR2061-214	100	110	27	Early vigor
IR26 (standard)	IR24/TKM 6	95	125	27	High yield potential

sents a complete range of maturity.

In certain areas where heavy rains occur for periods of 4-5 months, varieties with a longer growth duration (150 days or more) or with photoperiod sensitivity are required. In the vast river deltas of Thailand, Burma, Bangladesh and India, rice is planted in May-June before the onset of heavy rains. Photoperiod insensitive types planted in these areas mature in September-October which is a period of heavy rains and standing water. Large acreages cannot be harvested during these months because there are no drying facilities. We have begun to emphasize photosensitive types suitable for such areas but they are still in early generation. We have adopted the "single seed descent" or "rapid generation advance" method to shorten generation time and speed up breeding work in this area.

We plan to monitor the performance and popularity of existing varieties available to farmers and alter our breeding strategy for agronomic characteristics as necessary. It is our present concept that a wide variety of types, representing a continuous range from the high input to the nearly zero input type will be required. We use the term "input" to describe the level of fertility, degree of water control and the quality of management. We feel that the greatest gains can probably be made in the intermediate areas of this range for which we use the general term, "low input".

The foregoing describes the basic plant types as they are emphasized in combination with other appropriate agronomic characteristics. However, from an operational standpoint, our programme is directed toward developing improved germplasm for the following major sets of growing conditions:

- *Irrigated with good water control* - such areas now constitute 20-25 percent of the rice growing area in Asia but would be relatively less important in Africa. Resistance to the major disease and insect pests are of primary importance in such areas. Factors associated with intense production have magnified the importance of such pests as the brown planthopper. Early maturity and higher yield potential are also major objectives for such growing conditions.
- *Photoperiod-insensitive rainfed lowland* - the experience with IR5, Mahsuri and similar varieties has indicated that varieties with intermediate stature (115-135 cm) and medium maturity (125-145 days) are suitable for such areas. Such areas might comprise 20-25 percent of the area in Asia (no reliable figures are available) and would probably be suited for a

Footnote to Table 1 (opposite):
[a]IR40, [b]IR38, [c]IR42, [d]IR36 in the Philippines.

large area in Africa. Drought resistance is of critical importance in such areas.

- *Photoperiod-sensitive rainfed lowland* - there are vast areas in the large river deltas of Asia where such types are needed and there might be a demand in Africa. Suitable improved varieties are not yet available for such areas. They should have the characteristics of IR5 and Mahsuri, as discussed above, plus sensitivity to photoperiod so that the maturity is adjusted to the rainfall pattern. In certain locations, capacity to elongate and thereby adjust to seasonal and locational variation in water depth may also be desirable. Our "deepwater" project in Thailand is emphasizing the development of elongating prototypes for such areas.
- *Saline, alkaline and high temperature areas* - there are extensive coastal areas in Asia and perhaps in Africa where saline resistant varieties could be cultivated. In some areas, traditional types, highly tolerant of salinity, are already grown. New varieties for such areas should be of the photoperiod-sensitive rainfed lowland type but the overriding consideration is tolerance of the saline condition. With proper varieties, vast new areas might be brought under cultivation.
  Salinity and alkalinity, often combined with extremely high temperature, limit production in parts of most arid, irrigated areas. Early, high yielding dwarfs are needed, but, in contrast to the humid tropics, diseases and insects are usually not of major importance and the overriding considerations are the soil factors and extreme heat.
- *Upland areas* - much of the rice in Africa is cultivated under upland conditions. Varietal requirements for upland rice are very site specific because of edaphic and climatic factors. Although improved germplasm from IRRI or elsewhere may contribute to the improvement of upland rice in Africa, real progress can be expected only after strong local programmes have been established. Even then there is some doubt about the potential for the improvement of upland rice varieties in both Africa and Asia.
- *Cold affected areas* - such areas are of relatively limited importance in Asia and perhaps more so in Africa. Photoperiod-insensitive rainfed lowland types, with the added attribute of low temperature tolerance, are considered appropriate for most such areas.
- *Deepwater areas* - for areas where the water depth exceeds 1.5 or, at the most 2 meters, it is not clear whether plant types can be developed that are relatively superior to the traditional deepwater varieties. Some improvement in grain quality and other factors should be possible. Our efforts have focused on prototypes that would be suitable for more moderate depths (0.5 - 1.5 m). They would be of intermediate stature with the capacity to elongate with increasing water depth. There is some overlap between this area and that discussed above under the heading of *photoperiod-sensitive rainfed lowland*. At present we do not have adequate hydrological data to predict the utility of such types, as opposed to non-elongating photoperiod sensitive types.

Grain quality

The market price of a variety is determined largely by its grain quality. Grain quality characteristics may affect production in terms of the amount of milled rice recovered from paddy. Local preferences for grain shape and for eating quality are often the major determining factors in the acceptance of new improved varieties for cultivation.

Tropical rice is very divergent in physical properties of the grain, such as size and shape, and in the physiochemical properties of the starch. The relative amounts of the linear fraction (amylose) and branched fraction (amylopectin) of starch and its gel consistency are major influences on the eating quality of rice.

Our objective is to define specifically the grain quality preferred by the majority of consumers in each of the major rice producing countries and then to develop simple, rapid and reliable tests to identify desirable types. Based on past findings we are now seeking varieties with intermediate amylose content, or high amylose content with soft gel consistency. We strive for high yield of head rice (whole grain milled rice) and total milled rice (low hull content). Translucency is also considered desirable as are medium long grains. These general objectives do not apply to waxy rice, which is a special case.

Many of our advanced lines (Table 1) have intermediate amylose content and are highly desirable in terms of the other characteristics that affect grain quality.

Disease and insect resistance

Disease and insect pests of major importance in rice include blast, sheath blight, bacterial blight, tungro virus, grassy stunt virus, stemborers, leafhoppers and planthoppers, whorl maggot and gall midge. Varietal resistance is the only practical way to control diseases of rice in the tropics and it is an essential component of any effective insect control programme. Disease and insect problems will probably intensify in proportion to cropping intensity, especially in systems involving sequential crops of rice.

Resistance to diseases and insects has been a major thrust of the IRRI programme. Most of our advanced lines carry resistance to five or more major pests in the Philippines. In some cases this resistance holds in other countries but there is increasing evidence of biotype or strain differences. This further emphasizes the need for strong, local GEU programmes. Our best resistant lines are distributed to local programmes through a series of IRTP nurseries.

Protein

Rice protein is one of the most nutritious of all cereal proteins (about 4% lysine), but the protein content of milled rice is the lowest of all cereals (about 7% at 14% moisture). Screening a major portion of the varieties in the germplasm bank revealed a variation of 0.5% in lysine content. We have found that some cultivars show a consistent advantage of about 2% in protein content over presently cultivated varieties at comparative yield levels. Therefore, we have focused our research on the improvement of protein content while maintaining the nutritional quality and other essential traits of improved rice varieties. IR2863-35-3-3 is our best breeding line to date, with apparent improved protein content combined with other traits essential to modern varieties (Table 1). However, its possible advantage in protein requires further confirmation.

Drought

Drought resistance is essential for stable yields in nearly all rice growing areas that are not dependably irrigated. Our scientists have demonstrated major differences among varieties for drought resistance and they are now perfecting screening techniques. There are significant differences among our improved lines for drought resistance but, at present, those considered to have an adequate level of resistance are lacking in one or more traits essential to modern varieties. IR2071-625-1-252 (IR36 in the Philippines) is perhaps the best line for drought resistance among those considered adequate for other essential traits.

Adverse soil tolerance

Salinity, alkalinity, iron toxicity, manganese toxicity, aluminium toxicity, phosphorous deficiency, zinc deficiency, and iron deficiency limit rice yields in vast areas. Genetically conditioned tolerance to each of these problem soils has been identified. Our scientists are now developing rapid screening techniques for use in breeding

work and have organized a comprehensive programme emphasizing salinity because it is thought to be the most important. Our advanced lines are evaluated in as many of these soils as possible and many have been found tolerant to one or more of the adverse conditions.

Deepwater and flood tolerance

Farmers grow improved rice varieties extensively in the world's shallow water regions, where water depth ranges from 5 to about 50 centimetres. But the new rice technology has bypassed other areas including the vast regions where water is not controlled and may become too deep during the monsoon season for the semidwarf varieties. Estimates of such areas range from 25 to 40 percent of the world's rice land. Our scientists collaborating with Thai scientists have developed prototype selections for such areas. They are intermediate in stature and carry elongation genes from floating rice which allow them to respond to water depth. Also, preliminary screening of the germplasm bank material has shown dramatic variation for tolerance to submergence. In the future we expect that this research will greatly increase the stability and potential of yield in areas of uncontrolled water.

Temperature tolerance

Low temperature tolerance has always been important in rice growing areas at high elevations or high latitudes. The past importance of high temperature tolerance is uncertain. However, as traditional cropping systems have been displaced by new and more intensive systems, temperature tolerance in rice has become much more important. This is because planting dates are altered and the crop may reach a critical stage of growth during periods of adverse temperature.

Our low temperature tolerance programme has distributed several promising lines through the International Rice Cold Tolerance Nursery. The Kn-1b-361 type selections from Indonesia and IR3941 selections from IRRI are the most promising.

Major differences in tolerance to high temperatures have been identified and advanced lines are being evaluated in the phytotron. We are attempting to ascertain the relative importance of high temperature in limiting production, prior to the possible initiation of breeding efforts.

Conclusion

Our ultimate objectives is to develop an international GEU network for rice improvement. It is expected the national programmes or regional programmes, as may be the case in Africa and South America, the key components of this network, will function with an ever increasing degree of autonomy while retaining the linkages with IRRI/GEU that are beneficial to them or that contribute to the improvement of the network as whole. We feel that teams of interdisciplinary scientists from national or regional programmes and IRRI can take the lead in accelerating the utilization of the genetic potential of the rice plant to overcome many yield-limiting constraints. Our experience with the scientists who have participated in the monitoring of the international nurseries has clearly shown the value of soliciting the active participation of leading scientists of various countries in such an endeavour. Not only does it allow national and IRRI scientists to broaden their vision but it encourages the direct involvement of all disciplinary scientists in the total GEU programme.

OBJECTIVES AND PROGRESS OF THE INTERNATIONAL RICE TESTING PROGRAMME

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Introduction

Rice is one of the most widely grown crops in the world, and the obvious ecological diversity of the habitats and the many associated problems led to the realization by rice scientists of the need for cooperative testing. Suitability of a rice variety in a given situation is determined by the interaction between the variety and the environment. While some varieties express their genetic potential under a wide spectrum of situations, others are not adapted beyond a limited single environment. Systematic coordinated testing therefore has obvious merit. Recommendations from the 1959 meeting of the International Rice Commission (FAO) to organize the uniform blast nurseries served as a prelude to the concept of the International Rice Testing Programme. This was followed by informal cooperative testing in the early 1970's for yield and bacterial blight resistance. A large scale coordinated testing programme was organized under the auspices of the All India Coordinated Rice Improvement Project and was fully operational by 1971. A UNDP grant to IRRI in early 1975 formalized IRRI's administration of an international rice testing programme (IRTP). The policies and programmes are developed cooperatively by rice scientists from various countries.

The IRTP effectively links various national rice improvement programmes in a testing network. IRRI's Genetic Evaluation and Utilization (GEU) programme is one of the components of that network.

The activities of IRTP include primarily the following:

a) Organization and distribution of nurseries composed of entries from various rice improvement programmes.
b) Organization of monitoring tours by a group of scientists from different countries for a joint review of research material and nurseries in various countries.

c) Compilation and dissemination of data from international nurseries and of other relevant information.
d) Review and discussion of results and planning by international forums.

Nurseries

The three categories of nurseries are:
a) Yield trials (lowland and upland and different maturity groups);
b) General observational nurseries;
c) Specific stress nurseries (environmental, disease and insects).

The yield trials include promising, advanced material and they help in identifying varieties with wide adaptability or regional suitability. The general observation nurseries (IRON, IURON), composed of breeding lines from different sources, are subjected to many diverse environments and serve as potential sources for identifying lines with broad adaptability and resistance. The specific stress nurseries include both breeding lines and donor varieties and these, apart from helping in identifying the potential donors for individual stresses, shed light on genetic variation (biotypes and strains) of insect pests and pathogens.

Fourteen different nurseries were composed during 1976 and 573 sets of these nurseries were distributed to 40 countries (Table 1). About 75% of the nurseries were sent to Asia and approximately 10% each were sent to Africa and Latin America and a few to Oceania and Europe (Table 2).

Forty-nine percent of the 2,000 entries in 1976 nurseries originated from national programmes, 39% from IRRI's breeding programme and 12% from the IRRI's germplasm bank. Entries from national programmes increased by 14% from 1975 to 1976, which demonstrates the growing participation by collaborating rice scientists from different countries.

Varieties with high yield potential combined with wide adaptability and donors for important stresses, such as the brown planthopper were identified in the 1975 nurseries (Table 3). Greater participation in the future will insure continued results benefiting several rice growing countries.

A survey of national collaborators during 1976 indicated that a high percentage of IRTP entries evaluated in 1975 were being used by the collaborating scientists in national programmes either for crossing or for further yield evaluation (Table 4).

Monitoring Tours

One important component of IRTP's activities is organization of monitoring tours involving a group of rice scientists from different countries who jointly review

international nurseries and national research programmes in selected countries. This provides an excellent opportunity for 'on the field' interaction among different scientists. Recommendations by these scientists, based on their observations and discussions, provide an effective supplement to the data from IRTP nurseries in formulating future plans. Table 5 summarizes particulars of the seven different monitoring tours organized in 1976 in which 50 scientists from different national programmes and from IRRI participated. Three monitoring tours (Brown Planthopper, Problem Soils and Deep Water Rice) terminated in special conferences on the respective topics. The observations and recommendations of the participants of the monitoring tours are summarized into a report and copies are available to all collaborating scientists.

Communications

The IRTP endeavoured to develop an effective communication system to monitor the needs and interests of rice scientists around the world and to supply them with appropriate nurseries and information. Special field books were designed to facilitate data recording on a uniform format. These books describe objectives and methodologies of specific nurseries and provide background information on test entries.

A computerized data management system has been initiated to analyze test results and report them rapidly to scientists in the national programmes. The nursery reports serve as 'working documents' for appropriate review and follow-up by individual scientists. Salient findings from IRTP nursery tests are highlighted in the International Rice Research Newsletter. At annual IRTP planning sessions, attended by scientists from IRRI and national programmes, the nursery results are discussed and future programmes are formulated. The 1975 planning session helped to develop a booklet "Standard Evaluation System for Rice" which provides guidelines for evaluating various traits in the nurseries on a uniform scale of 0-9 which not only lends a common language but facilitates computerization. Collaborators have been supplied with copies of this booklet.

Efforts are being made to collaborate with other international institutes in organizing specific testing networks in the regions for which these institutes have a primary responsibility. A special joint IRRI-CIAT conference was held at the International Centre for Tropical Agriculture near Cali, Colombia in August 1976, to streamline international testing in Latin America.

TABLE 1

Numbers and sources of almost 99,000 seed packets of varieties and lines distributed through the International Rice Testing Programme nurseries in 1976

Nursery[a]	No. of sets	No. of entries/ nursery	Number of entries from: Nat.progs.	IRRI Improved lines/varieties	IRRI Germplasm bank	Number of entries from: Nat.progs.	IRRI Improved lines/varieties	IRRI Germplasm bank
IRYN-E	64	19	11	8	-	792	576	-
IRYN-M	52	31	23	8	-	1,380	480	-
IURYN	43	24	12	12	-	528	528	-
IRON	91	330	195	135	-	18,720	12,960	-
IURON	62	185	78	87	20	4,914	5,418	1,260
IRBN	49	478	156	234	88	7,956	11,934	4,488
IRSHBN	22	196	49	86	61	1,127	1,978	1,403
IRTN	18	219	145	43	31	3,335	989	713
IRBPHN	20	97	65	4	28	1,495	92	644
IRGMN	23	106	61	44	1	1,464	1,056	24
IRSBN	21	68	36	30	2	756	630	42
IRSATON	39	71	28	39	4	1,148	1,599	164
IRCTN	51	135	72	50	13	3,816	2,650	689
IRDWON	18	50	47	1	2	940	20	40
Total	573	2,009	978	781	250	48,371	40,910	9,467

[a]IRYN-E = International Rice Yield Nursery - Early; IRYN-M = International Rice Yield Nursery - Medium; IURYN = International Upland Rice Yield Nursery; IRON = International Rice Observational Nursery; IURON = International Upland Rice Observational Nursery; IRBN = International Rice Blast Nursery; IRSHBN = International Rice Sheath Blight Nursery; IRTN = International Rice Tungro Nursery; IRBPHN = International Rice Brown Planthopper Nursery; IRGMN = International Rice Gall Midge Nursery; IRSBN = International Rice Stem Borer Nursery; IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery; IRCTN = International Rice Cold Tolerance Nursery; IRDWON = International Rice Deep Water Observational Nursery.

TABLE 2

Regional distribution of nurseries of the International Rice Testing Programme, 1976

Region	Number of IRTP nurseries			Observational		Diseases			Insects			Env. stress			Total
	IRYN-E	IRYN-M	IURYN	IRON	IURON	IRBN	IRSHBN	IRTN	IRBPHN	IRGMN	IRSBN	IRSATON	IRCTN	IRDWON	No.
East Asia	2	-	-	2	1	2	3	1	3	-	1	-	3	-	18
Southeast Asia	13	13	13	10	16	10	7	6	9	8	8	8	10	7	138
South Asia	30	25	14	56	23	11	7	9	8	15	9	16	18	9	250
West Asia and North Africa	5	4	1	4	2	4	-	-	-	-	3	5	2	-	30
Sub-Saharan Africa	4	2	3	13	10	8	3	-	-	-	-	7	12	-	62
Latin America	9	7	12	6	10	14	2	2	-	-	-	3	4	2	71
Europe	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Oceania	1	1	-	-	-	-	-	-	-	-	-	-	1	-	3
Total	64	52	43	91	62	49	22	18	20	23	21	39	51	18	573

TABLE 3

Highlights of results from 1975 IRTP nurseries

Nursery	Promising lines
Yield	
IRYN-E	IR2071-625-1-252; IR2061-465-1-5; IET 1444; IET 2845
IRYN-M	BR51-91-6; BG90-2; BR52-87-1; IR2058-78-1-3
IURYN	IR1529-430-3; IR2035-242-1; IET 1444; BPI 76^9/Dawn
Observational	
IRON (general)	IR30; IR1529-680-3-2; BG90-2; IR2070-199-3-6
IRON (blast rest.)	IR1544-181; IR1820-210; IR2588-60; IR2851-41; IR2798-88
Screening	
Disease:	
IRBN	Several Tetep derivatives
IRSHBN	Bahagia; Pankaj; IR1544-340-6; K 8 mut.
IRTN	Several ARC lines
Insect:	
IRBPHN	Gangala, Ptb 19, Ptb 21, ARC 6650
Other stress:	
IRSATON	Pokkali, DA 29, Nona Bokra

TABLE 4

Utilisation of entries from 1975 trials in 1976 national programmes

Nursery	No. of countries	No. of entries used in crosses	No.of entries promoted to Station trials	State trials	National trials
Yield					
IRYN-E	6	43	35	12	3
IRYN-M	6	14	42	15	30
IURYN	4	5	12	4	12
Observational					
IRON	8	34	528	268	285
IURON	2	2	21	21	10
Screening					
Diseases:					
IRBN	5	55	23	6	10
IRSHBN	4	14	-	-	-
IRTN	4	14	47	-	-
Insects:					
IRBPHN	3	19	25	-	10
IRGMN	1	-	5	-	-
Other stresses:					
IRSATON	1	-	16	-	-
IRCTN	4	30	30	-	17
IRDWON	1	-	13	-	13

TABLE 5

The IRTP monitoring tours and their accomplishments for 1976

Focus of tour	Participants	Countries represented	Countries visited	Research institutes and stations visited	Nurseries observed	Significant accomplishments
Pest problems and plant types	8	4	3	9	9	- Observed the performance of semi-dwarf plant types (Indica x Japonica crosses). - Evaluated insect and disease problems.
Cold tolerant rices	10	5	1	6	1	- Discussed the methodology for future testing programme of IRCTN.
Problem soils	9	5	3	9	1	- Identified some varieties/lines resistant to alkalinity and/or salinity. - Discussed the methodologies in studying salinity tolerance. - Developed strategy for breeding rice varieties suitable to problem soils.
Brown planthopper	7	5	2	7	1	- Attended the first meeting on "BPH Working Group" to accelerate adequate control of the BPH problem. - Observed the screening for BPH resistance in the greenhouse and in the field.
Yield - South Asia	7	4	3	9	4	- Evaluated IRTP yield and observational nurseries and observed breeding materials in national programmes.
Yield - Southeast Asia	9	6	3	12	10	- Identified promising entries from the IRYN-E, IRYN-M, and IRON.
Deep water rices	9	6	3	3	1	- Identified some promising IRDWON entries. - Observed national deep water trials. - Attended the deep water conference in Bangkok.

Plate 15. A new rice disease, crinkle, in the West African ecosystem. Etiology is still unknown.

Plate 16. Complete devastation due to neck blast at 1000 m in central Nigeria.

Plate 17. Weaver-bird nests in the savanna, Nigeria. Bird damage by various species is a major problem on rice during the grain-filling stage in much of tropical Africa (photo courtesy of Dr. P. Soto).

Plate 18. Hand weeding of dryland rice on small Sierra Leonian farm.

Plate 19. Weed control in land preparation for paddy rice by inverting the surface into mounds and flooding, Nigeria.

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Rice in Africa

1978

II. 187

SCREENING FOR HORIZONTAL RESISTANCE TO RICE BLAST (*PYRICULARIA ORYZAE*) IN AFRICA

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Introduction

Rice blast disease, caused by *Pyricularia oryzae* Cav., was first reported from Africa in Uganda by Small (1922). Subsequently, it has been reported from most of the rice-growing countries of Africa (Williams, 1971). *Pyricularia* spp. have also been recorded on several grasses in Africa: *Digitaria horizontalis, D.marginata, D.scalarum, D.velutina, Eleusine coracana, E.indica, Pennisetum purpureum, Rhynchelytrum roseum* and *Rottboellia exalta* (Peregrine and Siddiqi, 1972; Riley, 1956, 1970).

Rice blast was first recorded in the Ivory Coast in the 1950's where it occurred infrequently on irrigated rice (Ravise, 1957, 1962). It was later observed in northern Ivory Coast but was not causing serious losses (Davet, 1963). It was subsequently found to be widespread and damaging on irrigated rice in the western zone and in the swamps, especially in poorly irrigated fields. Leaf, neck and panicle blast were observed (Ravise, 1962). The variety IR8 was particularly susceptible (Delassus, 1968). Since 1969, blast epidemics of varying intensity have occurred each year on pluvial rice in the Ivory Coast.

In Nigeria, yield losses of 10-40% were reported by Awoderu (1974). In 1976, a 200 ha field of the variety Sindano from East Africa, cultivated under pluvial conditions at 1200 m, was completely destroyed by neck blast.

The rapid extension of rice cultivation in West Africa since 1960 altered the balance between host and pathogen because of the extension of rice-growing into new land areas, the introduction and cultivation of new varieties which were less resistant than the traditional ones, and the modification of cultural practices in a manner which favoured the pathogen.

Blast is presently the most serious fungal disease of rice in Cameroon, Egypt, Ivory Coast, Liberia, Mali, Nigeria and Senegal, and presumably in other African countries. Infestation of the necks and panicles is more damaging than that on the leaves. Severe epidemics occur in rice growing under pluvial conditions (Bidaux, 1976; Williams, 1971).

Recent studies of the disease mainly have been related to breeding of resistant varieties. Some morphological or pathological variability of the pathogen has been studied in Sierra Leone (Onofeghara *et al.*, 1973), Ivory Coast (Bidaux, 1974), Malagasy (Notteghem, 1976a, 1976b) and Nigeria (Awoderu, 1970). The epidemiology of the disease in Africa has not been studied.

Since 1972, IRAT has been investigating blast on pluvial rice in Ivory Coast and on irrigated rice in Malagasy with the view to producing varieties which have stable resistance and high yield potential, and are adapted to the environment in which they are to be grown. The effect of soil type and mineral nutrition on the disease has been studied in Cameroon.

Definitions

The following terms are used according to the definitions proposed by Robinson (1976), which are abstracted here:

Auto-infection: Infection of a plant from a spore (pathogen) generated on the same host plant or cultivar.

Allo-infection: Occurs when a spore from a different host lands on a second host's infection site.

Esodemic: That part of the epidemic which involves only auto-infection.

Exodemic: That part of the epidemic which involves only allo-infection.

Vertical resistance: Involves a gene-for-gene relationship between the host and the parasite. There is a differential interaction between the host varieties and the parasite races; it operates against some races of the parasite only; it is within the capacity for micro-evolutionary change of the parasite and is usually temporary resistance in agriculture.

Horizontal resistance: Does not involve a gene-for-gene relationship; operates equally against all races of the parasite; it is beyond the capacity for micro-evolutionary change of the parasite and is thus permanent resistance in agriculture.

The onset and development of any epidemic depends on the characteristics of the host, pathogen and environment and the interactions among these factors. Thus, the duration and severity of epidemics vary from one area to another, and hence the level of horizontal resistance required for control also varies with locality.

The amount of disease (x_2) present at the end of the epidemic depends on the amount of disease present initially (x_1) and the rate of its increase; it may be calculated by the formula $x_2 = x_1 e^{rt}$ where t is the time between the x_1 and x_2 readings and r is the progression coefficient of the epidemic. The longer an epidemic progresses, the smaller r must be in order to minimize x_2 and obtain a satisfactory yield.

In order to correlate disease development with yield losses, it is necessary to know the time of the first attack on the panicles, the duration of the epidemic (t) and the coefficient (r) of a range of varieties at several sites.

The value of r is not constant throughout an epidemic. It varies in relation to the aggressiveness of the pathogen, changes in environmental conditions, waves of inoculum production and development of the number of susceptible sites of the host (Van der Plank, 1975).

In order to measure horizontal resistance, it is necessary to take several disease records during the season in order to follow the progress of the epidemic satisfactorily.

Epidemiology

The characteristics of blast epidemics in Africa are poorly understood. What are the sources of primary inoculum and what is their relative importance? What is the average duration of an epidemic? How far do epidemics spread? Which infected leaves contaminate panicles? How does panicle infection develop? Does the aggressiveness of the pathogen evolve during the course of the epidemic?

Bouaké, Ivory Coast, is in the forest/savanna transition zone and has a bimodal rainfall pattern. A single crop of pluvial rice is grown, with planting in early June. Blast epidemics usually commence in mid-July or early August, after the rice has been subjected to water stress. The date, duration and intensity of the stress varies, but no blast has been observed before this stress period since 1972.

The development of the disease on several varieties during 1975 is illustrated in Figure 1. The epidemics lasted up to 120 days but shifted from leaf to panicle blast. They developed more quickly in October, at the end of the season. Many varieties were then observed to have neck and panicle blast but no leaf symptoms (Table 1). This difference is important for resistance screening and it emphasizes that ratings based only on leaf reaction of young plants do not necessarily predict neck blast

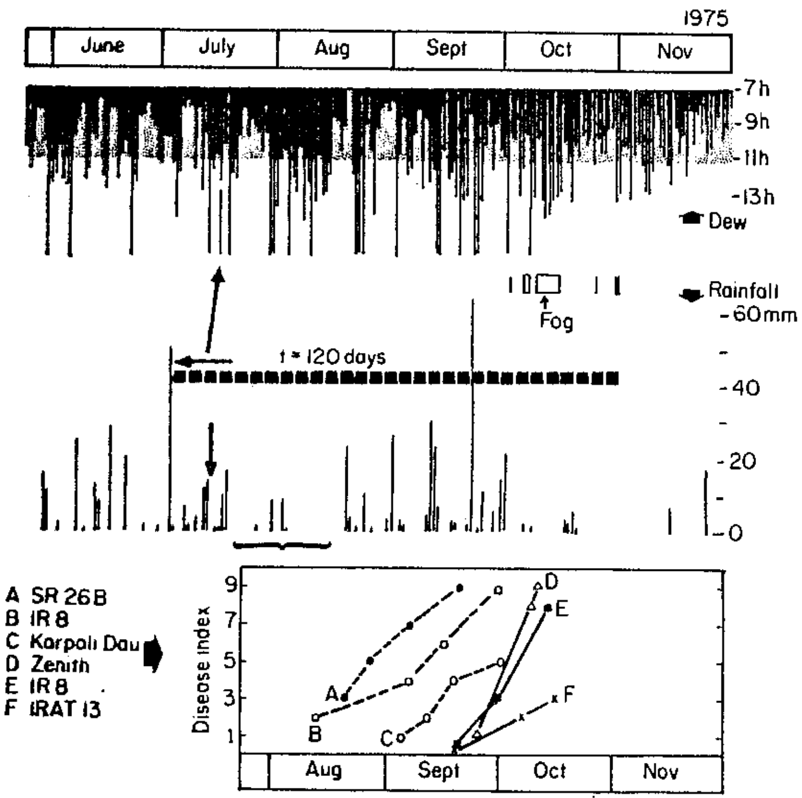

Fig. 1. Development of leaf blast (A,B,C) and panicle blast (D,E,F) on some varieties in relation to dew and rainfall.

susceptibility (Figure 2).

The variation between leaf and panicle blast may be due to:

a) A low inoculum level at the onset of the epidemic, under trial conditions;
b) vertical resistance mechanisms which operate so efficiently that matching races can only multiply successfully late in the season, after heading;
c) horizontal resistance mechanisms which slowly select the most aggressive pathotypes for multiplication;
d) the mechanisms of foliar resistance may differ from those of neck or panicle resistance, affecting either vertical or horizontal resistance differently;
e) experimental artifacts, due to the location of the varieties in the field relative to the sources of infection.

In a genetically homogeneous host population the epidemic begins as an exodemic, when inoculum comes from

TABLE 1

Incidence of blast on varieties in the 1974 International Upland Blast Nursery and on mature plants, 1974-1976 at Bouaké, Ivory Coast

No.	Variety	IUBN 1974 (seedlings)	Mature plants Leaves	Panicles	Yield	Year
3	617 A	3(4) (5)	1[a]	100[b]	1.07[c]	1976
10	OS 42	3-4-5	5	100	1.00	1975
20	R 52	1 (4)	0	80	2.20	1975
1	500 A	3-4-5	2	100	1.70	1975
145	Tunsart	1(3-4)	0	100	0.10	1974
195	RE 18 A	1 (4)	0	57	4.00	1975
195	RE 18 A		0	67	1.40	1976
373	IR 578.95	5	2	100	0.60	1976
438	DS 10	1(3-4)	4	83	1.08	1975
789	Natala	8	2	26	2.60	1975
856	Mekeo-White	3(4) (5)	0	87		1975
856	Zenith	3-4	4	100		1974
856	Zenith		2	83	0.50	1976
892	Mamoriaka	3-4	0	100		1974
950	Ca 902 b2.1	1(3)	0	100		1974
1120	HB DA 2	-	3	100	0.10	1976
1232	Ci 9545	8	0	100		1974
1286	BM 5	1(4)	4	100		1975
1301	Woo Co Chin Yu	1(3-4)	5	100		1975
1303	Century Patna	231 6	2	100	0.30	1976
1442	Kan Chan	3(4)	4	70	1.30	1975
1485	Pai Chiao Ju	1(4)	4	100	1.30	1975
1637	PR 147	1(3-4)	5	100		1975
1654	H 30	1(4)	3	100		1975
1681	Storm Proof	1(3-4)	3	100		1975
1684	Zenith	1(3)	4	100	1.00	1975
1689	Early Rexark	1(4)	4	100		1975
1854	Serendah Kuning	1(3)	6	86		1975
1923	2	1	4	100		1975
1985	Kiansi 36-13	3(4)	7	84		1975
1995	Mon z Wuan	1(3-4)	4	98		1975
2108	3228	3(4)	7	100		1975
2142	Pursighi	1(3)	3	91	0.70	1975
2175	Dan Kwang H.L	3(4)	9	100		1975
2248	Jansussau E32	1(4)	7	100		1975
2282	Kh kaseun	1(3)	8	100	0.00	1975
2655	Leuang keo	1	0	100	2.10	1975

a) Scale 1-9 of increasing severity; b) Percent panicles diseased; c) Grain yield in t/ha.

outside the crop. After the first successful allo-infection, the second phase of the epidemic commences, in which there are infections from both inside (auto-infection) and outside (allo-infection) the crop. In a large host population, the epidemic becomes an esodemic when the number of allo-infections becomes insignificant relative to the number of auto-infections. During the esodemic, only horizontal resistance mechanisms function. In this phase, the progression coefficient, r, can be calculated from periodic measurements.

The duration of the exodemic depends on the initial proportion of virulent races in the parasitic population, on plot size and on the cross-effects of adjacent hosts with different vertical genotypes. It was measured for several varieties at Bouaké in 1972 by growing them in 6 m x 1 m adjacent plots, with 1 m between plots (Bidaux, 1973). The delay in initiation of the epidemic varied from 2 to 30 days (Table 2).

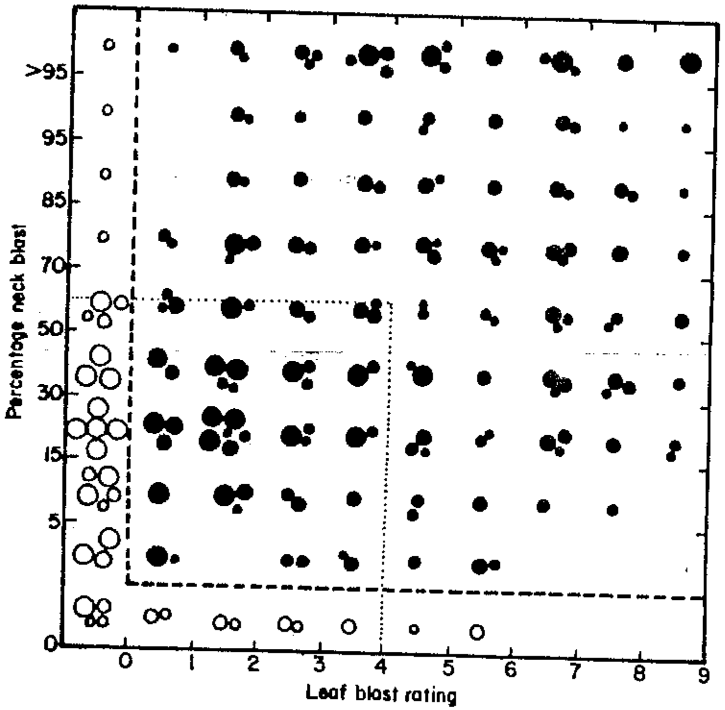

Fig. 2. Plot of 1048 varieties in relation to leaf blast (x axis) and neck blast (y axis) No. varieties: ● = 15, ● = 7, ● = 4, ● = 2, ● = 1. Open circles, same value, but signify absence of either leaf or neck blast.

TABLE 2

Estimation of the retardation of the initiation of the epidemic on differential varieties, in comparison with variety IR5

Varieties	Genes for resistance	Retardation (days)
IR5	?	0
Shin 2	Pi-ks	11
Aichi-Asahi	Pi-a	2
Kanto 51	Pi-k	10
Fujisaka 5	Pi-i, Pi-ks	9
K1	Pi-ta	10
Pi no. 4	Pi-ta^2	30
Oou 244	Pi-z	19
Toride 1	Pi-zt	17
K2	Pi-a, Pi-kp	12
K3	Pi-kh	13
Bl 8	Pi-b	11
Stl	Pi-f	9
Zenith	Pi-a, Pi-z	11

Pathogenic Variation

Kiyosawa (1972) in Japan identified thirteen genes for resistance and assembled a number of differential varieties with which it was possible to analyze the virulence spectrum of isolates of *P. oryzae*. The pathogenic variation in *P. oryzae* in the Ivory Coast was studied in order to estimate the frequency of virulence genes in the parasitic population and thus to determine the implications of this frequency on attempts at control based on vertical resistance.

The virulence spectrum of 90 single spore cultures was tested on Kiyosawa's differential varieties after syringe inoculation. The results showed that eight genes were very frequent, occurring in 46-100% of all entries (Table 3). There were four other genes which occurred less frequently (26-45% of entries) and one which occurred rarely (6%). The pattern of the virulence spectrum of various isolates was tested over a 3 year period, and little variation was observed with time (Bidaux and Notteghem, 1973).

There are some problems in the interpretation of a resistant or susceptible reaction on the basis of symptom expression because some intermediate cases occur. Also, the stability of the phenotypic expression of the genotype of the differential varieties is not known. Some differential varieties show clear differences among the races, while for others there is variation. In the latter case, some late-acting vertical genes or horizontal resistance based on an entire gene may be operating.

The virulence gene Av - ta^{2+} was rare in the parasitic population sampled in the Ivory Coast. The corresponding resistance gene Pi - ta^2 may be useful in breeding, but one needs to know if it is a strong and stable gene for African growing conditions.

TABLE 3

Estimation of the frequency of genes for virulence in 90 isolates of Pyricularia oryzae from the Ivory Coast

Genes	1975		1975	
	No.	%	No.	%
Av-a$^+$	90	100	85	94
Av-b$^+$	24	26	3	3
Av-i$^+$	82	91	57	63
Av-f$^+$	62	68	5	3
Av-k$^+$	42	46	40	44
Av-kh$^+$	37	41	22	24
Av-kp$^+$	52	57	47	52
Av-ks$^+$	87	96	57	63
Av-m$^+$	33	36	3	3
Av-ta$^+$	46	51	27	30
Av-ta^{2+}	6	6	1	1
Av-z$^+$	48	53	1	1
Av-zt$^+$	34	37	3	3

Horizontal Resistance

Neck and panicle blast are regularly severe on pluvial rice in the central region of Ivory Coast, which makes it an ideal area for screening for resistance; 5,000 varieties have been screened for horizontal resistance using a modified new design. The severity of the disease was assessed on leaves by rating plants on a 1-9 scale of increasing severity and on necks by recording the percent diseased panicles. The progress of the epidemic and the value of the coefficient r has been estimated for some varieties (Table 4).

In 1974, 2,300 varieties were tested in the IUBN in Ivory Coast, and 115 were scored 1-4 (resistant). Subsequently, many of these proved to be susceptible to neck and panicle blast when grown under normal conditions of cultivation in 2m^2 plots. In the IUBN design there was much allo-infection. Consequently, any delay in the epidemic caused by a long latency period or weak conidial production was eliminated. Screening for foliar blast as is done in the International Upland Blast Nursery (IUBN) will not measure horizontal resistance.

During 1975 and 1976, neck and panicle blast were assessed at regular intervals on 1,100 varieties, and of these, 400 were selected on the basis of yield (average

grain yield equal or greater than that of local variety, Moroberekan), and panicle infestation (50% or less). These were tested for horizontal resistance, using a more appropriate design as described later, for the estimation of the coefficient r.

The traditional varieties OS 6, Moroberekan, Pate-Blanc, Nou-Nou, Fossa and 63-83 and some new or introduced varieties (IAC 25, IRAT 13, Iguape Cateto, Chianan 8) inhibited the progress of the epidemic and produced satisfactory yields. Preliminary studies showed that the varieties Moroberekan, 63-83 and IRAT 13 were resistant to infection and had a long latency period.

Design of field experiments to assess horizontal resistance

One aim of field experiments designed to measure horizontal resistance is to identify those factors which allow certain varieties to inhibit the progress of the epidemic. Both leaf and panicle symptoms should be taken into account.

The following precautions should be taken:

a) Plot size: Should be sufficiently large to reflect likely behaviour of varieties in farmers' fields.
b) Test duration and growing conditions: Conduct trial to harvest so that panicle blast can be measured; grow under normal growing conditions and measure yield.
c) Inter-plot interference: Restrict inter-plot interference by barrier plots.
d) Esodemic: Should occur early and be long so r can be calculated with precision.
e) Parasitic pressure: Ensure that sufficient parasitic pressure is exerted equally on all varieties at the beginning of the season in order that the exodemic is short. The pressure should not be too great, otherwise all varieties except those with efficient vertical resistance are destroyed.
f) Standards: Include several reference varieties in each trial in order to be able to relate the performance of test varieties to that of the standards, and to be able to compare the severity of successive epidemics and parasitic pressure in different years.
g) Artificial inoculation: Inoculate with an aggressive isolate having a broad spectrum of virulence.

The design developed by Notteghem (1976a) in Malagasy (Figure 3a) was compared with that developed by Amin and Buddenhagen (1972) at the All India Coordinated Rice Improvement Project (Figure 3b), with those of IRRI and of India's Central Rice Research Institute (CRRI) (Figure 4a and b). Calculations were made for the total auto- and allo-infection spore loads which could be present at the centre of the circles (see Figures), based on hypotheses of similar and different abilities of spore production on

TABLE 4

Incidence of blast on leaves and panicles in 1975 on some varieties in 2m² plots

No.	Varieties	Epidemic on leaves(a) a	b	c	d	e	f	g	h	Date	% diseased panicles/days 1	2	3	4	Yield (t/ha)	r
4118	SR26B	1	3	5	7		9		9	Total	destruction before flowering					
2352	Chao-Khao	2		8			9		9	Total	destruction before flowering					
2175	Dan Kwang Hwa Loo	3		7		9			9	Total	destruction before flowering					
2319	Khao-Keo		2		5	7	8		8	02/10			72.8	100	-	0.745
1283	IR442-2-58	2		3	4	6		8	9	26/9			86.1	100	0.1	0.730
4725	IR28				2	3	4			26/9	51.2	84.3	90.3	100	-	0.286
475	Bengala Morimo		3				4		6	29/9			31.1	98.2		0.361
2313	Khao Noi			2	4		5	5		04/10			10.2	22.2	1.1	0.140
2478	SVA 21	2			4		5	5		29/9		25.1	78.2	67.3		0.121
2625	Mak Pho	5					7			02/10		9.0	39.2	74.3		0.194
1166	IR8	2			4	6			9	02/10			28.8	90.2	0.1	0.390
429	Taichung (N) 1			3	4	5	6			02/10			65.1	85.2	0.4	0.139
4725	IR30				2	3	4			02/10		22.0	98.2	100.3		0.370
1167	Jaya				2	3	4			02/10	2.0	4.1	21.2	34.2	2.3	0.219
4730	IR1746.194			2	3		5			22/9	2.0	11.8	82.2	100.3		0.216
4633	IR1750.FSB14			1	3	4	5	7		22/9		5.8	95.2	100.3		0.356
4634	IR1752.FSB1			2	3		4			12/9		0.6	19.2	84.3		0.237
10	OS 42	2			4		5			13/9		0.5	14.2	35.3	1.0	0.394
422	1 Kong Pao		2					4		15/9		0.3	38.2	68.3	1.0	0.156
336	Dourado Precoce					3				15/9	0.1	1.2	3.3	8.3	2.5	0.167
388	Pratao Precoce					5				16/9	0.6	1.2	4.2	20.3	2.6	0.232
3423	Blawe Hand							4		29/9	0.9	7.1	17.2	33.4	0.9	0.163
478	Manoeroen 1172		2				2			4/10			8.6			0.518
935	Carreon							2		22/9			13.2	22.3	2.4	0.075
801	H5								0	29/9		2.0	11.2	30.3	2.9	0.311
921	Bad Shabbag								0	10/9	0.9	1.1	15.3	31.3	1.0	0.210

TABLE 4 (cont'd)

No.	Varieties	a	b	c	d	e	f	g	h	Date	1	2	3	4	Yield (t/ha)	r
3346	KU 43-2								0	18/9		0.4	0.3			
5	E 425				4					11/9	0.8	0.1	52.3	50.3	3.3	
6	OS 6				2					19/9		0.2	28.3	40.3	2.5	0.128
29	R 75				1					13/9		0.6	0.1	4.3	1.9	
35	RT 1031-69				1					15/9	0.9	28.2	28.3	64.5		0.304
89	Iguape-Cateto				0					19/9	0.5	0.2	9.3	22.3		0.260
120	Moroberekan					0				22/9			3.2	3.3	2.1	
179	63-41				0					15/9	0.3	0.9	0.2	40.3	3.6	
184	63-104				0					15/9	0.4	0.9	7.2	13.3		0.182
334	Blue Bonnet					0				22/9	0.2	7.2	45.3	40.3	3.0	0.238
399	IAC 25					1				16/9	0.6	6.7	7.2	5.3	2.6	0.023
482	Chianan 8					0				15/9		0.4	0.2	7.3	1.1	
606	63-83					0				15/9	0.3	3.2	7.3	14.3	4.6	0.326
1108	Columbia 1						0			24/9			2.2	21.3	1.5	0.442
4315	IRAT 13					0				15/9		0.3	3.2	6.3	2.6	0.098

(a) The epidemic on the leaves was measured on a 1-9 scale of increasing severity at the following intervals: a = 11 Aug.; b = 19 Aug.; c = 28 Aug.; d = 6 Sept.; e = 15 Sept.; f = 19 Sept.; g = 25 Sept.; h = 10 Oct.

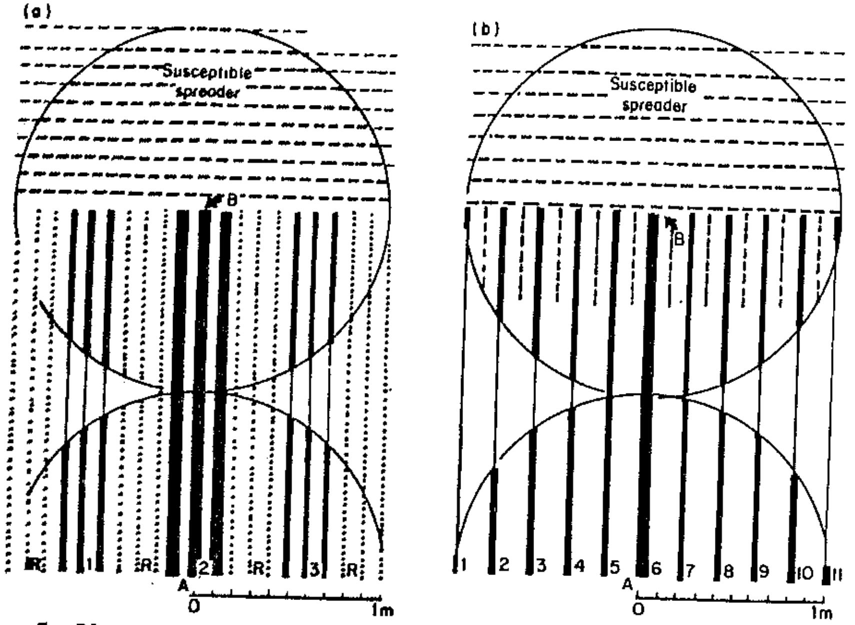

Fig. 3. Blast screening designs from Malagasy (Nottegham, 1976a), (a), and AICRIP, Hyderabad, India (Amin and Buddenhagen, 1972), (b). R = Resistant barrier variety; 1, 2, 3 etc. = test varieties; location A, spore load from auto-infection; location B, spore load from allo-infection.

on spreader and individual test varieties. Differing assumptions of spore dissemination were also considered. It was determined that all designs were equal at location B regardless of differing assumptions of spore production and dissemination. However, the IRRI and CRRI designs offered only a location B situation whereas the Notteghem and AICRIP designs both offered a location A where spore load pressure was essentially from auto-infection (given a hypothesis of slow dissemination) and thus could be a measure of horizontal resistance. It was also determined that at location B in all designs allo-infection would be overwhelmingly present, regardless of which hypothesis is used, precluding any measurement of horizontal resistance. All potential resistance through long latency or weak conidial production is lost.

Actual measurement of disease in many trials in the Ivory Coast confirmed that the design influenced 'resistance ratings' and that short distances from an allo-infection source were sufficient to enable ratings for horizontal resistance and for basing *r* curves which actually represent the level of horizontal resistance. By recording data of disease levels, using a revised scale (Bidaux,

1976), through space and time, following the gradient of disease pressure, *r* curves may be constructed on test varieties.

An amended version of Notteghem's design has been adopted for use in the Ivory Coast, in which the test plots are 3-4 m in length and contain 7 rows grown at recommended spacing for the area. A key element is the presence of a barrier row of a tall resistant variety between every test variety, to reduce bias due to spread of inoculum among test varieties.

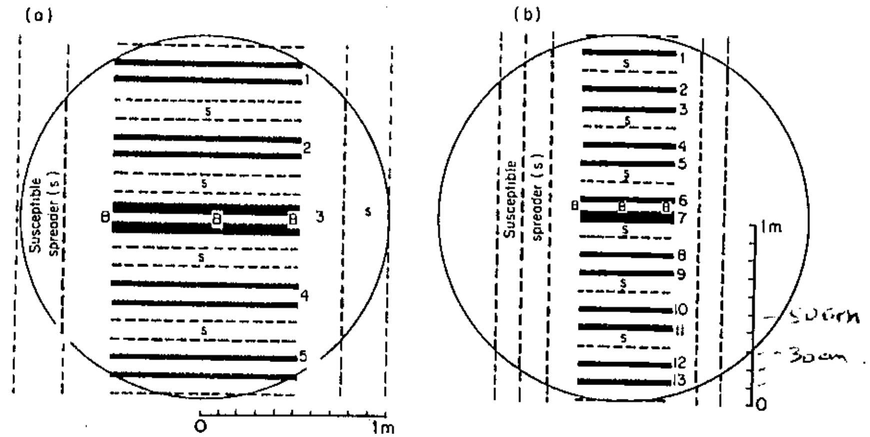

Fig. 4. Blast screening designs from CRRI, Cuttack, India (a) and IUBN, IRRI, Philippines (b). S = susceptible spreader; 1, 2, 3 = test varieties; location B, spore load from allo-infection.

Genetic analysis of horizontal resistance

A diallel analysis of horizontal resistance has been undertaken in Ivory Coast with 9 parents. For leaf blast, there were no differences between reciprocal crosses. The variance of the general combining ability and the specific combining ability was highly significant. Additivity has a predominant influence on genetic expression of resistance. Varieties Moroberekan and 63-83 were found to have good general combining ability (GCA), while IR5 and IR8 had the poorest GCA amongst the 9 parents tested. Although 63-83 had the highest general combining ability, the high variance indicated that, depending on the cross, one might or might not obtain good resistance. Whereas Moroberekan (with a lower GCA) transmitted its resistance more uniformly. The parents' GCA and their phenotype were strongly linked with a correlation coefficient of 0.96. The choice of suitable parents to transmit resistance thus becomes easy. In addition, resistance was highly heritable, ranging from 69 to 90%. Analysis according to the Hayman pattern confirmed the importance of additivity and revealed a partial and significant dominance. Distribution of genes among parents was asymetric.

Ecological Factors

Estimating both resistance and epidemic development depends on and varies with ecological conditions. Although this might seem axiomatic, it is clear from the literature and from many observations, that ill-defined and poorly measured ecological conditions confound much understanding of both blast resistance-susceptibility and of blast epidemics.

The leaf and air moisture levels affecting spore production and leaf infection are fairly well understood. But the effects of soil chemistry and of moisture stress on blast, an apparently typical foliar disease, are both real and not understood. In Ivory Coast, blast epidemics develop on pluvial rice only after a period of drought stress. This observation was explored for varieties IR5, Palawan and IRAT 13, where plants were kept in the greenhouse at either 50 or 100% of evapo-transpiration potential. After inoculation, many more spots appeared at the 50% (stress) treatment than at full watering, and latency was shortened from 10 to 6 days. Thus, drought affected rate of infection and latency, both important components of horizontal resistance.

In Cameroon, blast did not occur at two sites on known susceptible varieties, even with good aerial conditions for disease (Seguy and Delassus, 1976). This observation was followed by moving soil among different sites. Soil plots were 30 cm in depth. Results showed that soil differences were overriding factors in disease development, with 'resistant soil' providing resistance even at sites normally 'blasted' and 'susceptible soil' providing susceptibility even at normally 'non-blastable' sites. Of 5 varieties tested, only variety 63-83 failed to react to the soil difference, having a low level of blast on all soils and sites. All others showed differential reactions to soil source. There was an association of susceptibility with soil of low pH and low cation exchange and low phosphorus.

Obviously more knowledge is needed on ecological-plant-fungal interactions before blast resistance susceptibility and blast epidemiology can be understood in tropical Africa.

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INSECT PESTS AND RICE PRODUCTION IN AFRICA

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Introduction

Although some 60 insect species have been reported as pests of rice throughout Africa (Brenière, 1969; Descamps, 1956; Stephen, 1973), few have been studied in detail. The approach to their control has been largely through adjustment of cultural practices adapted to subsistence-type agriculture. In most cases, little is known regarding actual losses due to insect damage, and only scant information is available for predicting an insect's importance following the introduction of new varieties and intensive agricultural practices. However, it is likely that intensive cultivation and multiple cropping will increase pest populations.

Most insect species causing damage to cultivated rice in Africa are indigenous species different from those found in Asia. Presumably they have been associated with the African rice species, *Oryza longistaminata*, *O.barthii* and *O.glaberrima*. Most of the significant African and Asian rice insect pests are closely related species of the same genera. Some African species are identical to those in Asia, such as the rice caseworm, *Nymphula depunctalis* Guenee, and the rice gall midge, *Pachydiplosis oryzae* Wood-Mason. There have not been sufficient taxonomic studies and collections in Africa to clarify the relationships with insect pests of rice in other continents.

Insect Pests

The stem borers constitute one of the more important groups of injurious insects of rice throughout Africa. All of them are larvae of moths (Lepidoptera; Noctuidae and Pyralidae). Three species are consistently important: the African white borer (*Maliarpha separatella* Rag.), the African striped borer (*Chilo zacconius* Blesz.), and the African pink borer (*Sesamia calamistis* Himps.). The larvae feed inside the rice stems. If the infestation occurs during the vegetative stage, the growing point is killed, giving rise to what is commonly referred to as a 'dead heart'. Larval damage during the flowering period prevents grain filling, a condition called 'white head'. The damage caused by the white stem borer is seldom associated with dead heart and white head formation but more often with necrotic areas at the base of the stem and partial grain filling (Brenière, 1969).

The most important Dipterous pests include the stalk-eyed fly (*Diopsis thoracica* Westwood), the whorl maggot (*Hydrellia* sp.), and the rice gall midge (*P.oryzae*). These pests are often found in areas of high humidity but in areas having from little to moderate or severe dry seasons (Brenière, 1969). The gall midge is always associated with hot and humid conditions, usually in the savanna zone. The larvae invade the terminal and axillary buds at the base of young rice plants, producing tubular galls commonly referred to as silver shoots, or onion shoots (Brenière, 1969).

Most of the information concerning *Diopsis* of rice is based on the excellent studies conducted by Descamps (1957) in northern Cameroon. Larvae of *D.thoracica* feed only on healthy tissue and are capable of feeding on several tillers during their growth. The growing point is cut by the larvae, giving rise to a dead heart which is differentiated from stem borer damage by the absence of frass and presence of holes in the stem. The whorl maggot has recently been reported as a pest of rice in Africa (IITA, 1974). Symptoms typical of *H.philippina* in Asia were observed in rice growing under hydromorphic conditions at IITA. This species has been described as *Hydrellia prosternalis* Deeming (Deeming, 1977). The same type of damage has recently been observed in Sierra Leone, Senegal, and Liberia. The biology and distribution of *H. prosternalis* should be studied further.

Several species of leafhoppers and planthoppers have been found infesting rice in Africa. They usually occur at low levels under present conditions, with minimal damage in farmers' fields but they could become important and they could act as virus vectors if the appropriate viruses were present in Africa. Some of the species recorded include *Nephotettix modulatus* Melichar (Brenière, 1969), *Nilaparvata maeander* Fennah and *Sogatodes cubanus* Crawford (Soto, unpublished data).

Other insect pests which have been reported to damage rice in Africa include: Leaf-feeding beetles, mainly *Trichispa* sp. and *Dicladispa*; the rice caseworm, *Nymphula depunctalis*, and several species of plant bugs which feed on the developing grains (*Stenocoris* sp, *Aspavia* sp.).

Crop Loss Assessment

Under low-level technology of rice cultivation, insect pests are usually only of minor importance. This is not unexpected, considering the low density and rapid rotation under traditional slash and burn farming systems, or the low input, single cropping of low lying areas (Braun, 1973). Traditional farms are small, well separated from each other and uniseasonal so that insect buildup and damage to the rice crop is not as serious as in Asia. The minor importance of various insect species infesting rice has also been attributed to the effect of predators and parasites (Jordan, 1966; van Halteren, 1970). Also, the farmer raises local varieties, long-adapted and selected under his own conditions, without the use of pesticides, which results in a highly balanced system.

It is difficult to determine actual yield losses due to the insect complex associated with rice in Africa. The few reports which are available seldom provide reliable data; losses are often referred to as "serious losses". It is more difficult to relate the significance of a particular rice culture, i.e. irrigated, rainfed, swamp, or boliland. There is a need to define the existing situation for each rice ecosystem, to identify and analyse the significant insect faunas and their impact on rice production. An insect pest which causes serious damage to rice grown under upland (pluvial) rice culture may not be as important on rice grown in lowland conditions. Varietal differences also affect the estimation of yield losses; one variety may be devastated by a particular insect pest while another, due to its inherent resistance, may sustain minor losses.

The continuing expansion of areas under rice, the planting of high yielding, heavy tillering, and nitrogen responsive varieties will introduce major ecological changes in the lowland rice fields of Africa. These changes will bring about a variation in the relative abundance of the insect pests of rice. Pests like stem borers may become more serious, and minor pests, e.g. leafhoppers, planthoppers, leaf folders and rollers may become major pests. Indications that this change is already happening are based on reports from the Ivory Coast where yields of 3 t/ha under intensive monoculture of irrigated rice can be increased by one ton when insecticides are applied (Brenière, 1969). This loss was considered to be related to the increase of the area under cultivation, the prolongation of the growing season, and to other factors which influenced the populations of the various insect pests associated with rice. In Sierra Leone, the use of insecticides for control of stem borers increased yields by 50% (Morgan, 1973).

Investigations have indicated that intensive rice culture and greater use of fertilizers can cause a rapid buildup of a large number of insects, some of which may be of economic importance, either as pests or as agents of biological control (Taylor and Kamara, 1974). Several experiments conducted at IITA have also demonstrated increased yields of 1 t/ha under irrigated and hydromorphic conditions using granular insecticides. Carbofuran was effective in controlling the whorl maggot (*Hydrellia* sp.), *Diopsis*, and the white stem borer (*Maliarpha separatella* Rag). The yield loss in the control was mainly due to the cumulative damage caused by these pests throughout the growth of the rice crop (IITA, 1974).

Discussion and Conclusion

The need for controlling rice insect pests will be increased as the pattern of rice cultivation changes from a low-input to a high-input rice technology. This will be necessary in order to achieve the high yields inherent in the new, improved varieties. It is apparent from reviewing the literature that little detailed research has been done on the various insect pests which affect African rice crops, primarily because there are so few workers in this field in Africa. This research is essential for the development and application of control methods.

It is essential to investigate the biology, ecology and distribution of the various rice insect pests. Emphasis should be on the several species of stem borers, *Diopsis*, gall midge, plant bugs, leafhoppers and planthoppers. The existing situation in farmers' fields in different rice ecosystems should be carefully analyzed to understand and determine the important biotic and abiotic factors, which influence the populations of insect pests. This information will aid in determining species which may assume greater importance with the introduction of new varieties and more intensive practices.

Many effective chemicals are available which can be used in granulated or spray form for field control of rice insect pests. Beyond the immediate benefits of pesticide usage, long-term dependence can result in insecticide resistance, appearance of secondary insects as major pests, insecticide residue problems, and hazards to humans and animals. Unbiased evaluations of judicious insecticide use are essential and should be intensified. Tests conducted by the insecticide industry should be repeated by national researchers with no vested interests in insecticide use, and modified with the purpose of an integrated pest management objective. The decision to use insecticides in farmers' fields should always be compared with the value of the crop yield and the cost of the control measure to determine if the proposed measure is economic.

Varietal resistance is the most practical way of controlling many insect pests. It is essential to establish and maintain in several locations plant nurseries which comprise adapted varieties and segregating populations under high but realistic insect pressures. One of the important needs in this area is wider and more stable varietal resistance to the insect pests and pathogens which operate in combination. Extensive surveys of virus diseases should be conducted throughout the rice growing areas of Africa. The recent findings of pale yellow mottle virus in Sierra Leone, Ivory Coast, and Liberia (Raymundo *et al.*, 1976) clearly demonstrates the need for surveys on other possible virus diseases.

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WEED PROBLEMS OF AFRICAN RICE LANDS

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Introduction

Rice yields in Africa are below the world average partly because of adverse production conditions and partly because more than half the crop is from dryland culture (IITA, 1974; IRRI, 1975). Rice is grown in Africa in a wide range of ecological situations, ranging from dryland through hydromorphic to shallow swamps and flood plains. Consequently, weed infestation is by many different species adapted to the specific ecology in which rice is grown.

Weeds have been man's constant companion in agriculture. The level of agricultural development may be measured by the extent and way in which farmers control losses caused by crop pests, especially weeds. Weeds in African farmlands have been accepted as the natural consequence of land clearing and crop production and because weeds do not appear to damage crops as much as insects and diseases, control measures (if used at all) have largely remained the old method of hand-pulling. Research workers in weed science are scarce in Africa. It is therefore not surprising that weed problems in Africa's farmland have remained conspicuous and information on weeds and their control is fragmentary or absent in many parts of the continent. Work in West Africa has shown that weeds are a major limitation to rice production in dryland areas where adequate moisture and good soils are available (Fagade, 1976; IITA, 1974; Merlier, 1973a, 1973b; Valian, 1967). Weed competition is most severe in those parts of West Africa where broadcast seeding is still practised (Armstrong, 1968; Dogget, 1965). Adoption of improved mechanical and chemical weed control practices in East African rice projects has increased grain yield.

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Weed Problems

Weeds of African ricelands consist of sedges, grasses and broadleaves, and can be broadly classified into two groups according to their adaptation to terrestrial or aquatic habitats. Some of these weeds viz: *Cyperus rotundus*; *Echinochloa* spp.; *Panicum maximum* Jacq.; *Eleusine indica* (L) Gaerth.; and *Imperata cylindrica* (L) Beav. var. *africana* Hubbard have been listed among the world's worst weeds (Holm, 1969; Holm and Herberger, 1969).

Weeds of dryland rice

In dryland areas, rice is planted by direct seeding. In such situations, weeds germinating with the rice plants pose the greatest threat to the establishment and subsequent growth of the rice crop, as they reduce rice yield through competition for moisture, nutrients and light.

Weed problems of dryland rice are similar to those of other upland crops, and the extent to which yield is reduced by weeds will vary with local weed flora, growth characteristics of the rice crop, cultural practices, and environmental factors at the time of crop production. Weed infestation in newly cleared forest lands is known to be mild compared to that of land that has been under cultivation for several years (Merlier, 1973b; Moody, 1973a). Savanna regions and short-term fallows in the forest zones are characterized by heavy weed infestation that increases risk and labour requirements to uneconomic levels (Aryeetey, 1970; Brown, 1969; Cates, 1969; Moody, 1973b; USDA/USAID, 1968).

Although dryland rice is raised in ecological zones from forest through savanna to mid-altitudes, the weed flora in these zones does not appear to vary greatly (Table 1). What does vary is the intensity of infestation and the dominant weed species in a particular habitat. *Rottboellia exaltata* L. may be the major weed limiting rice production in one area while *Echinochloa colonum* L. predominates in another area. *Ageratum conyzoides Tridax procumbens* L. are broadleaved ephemeral annuals that are found in stands of maturing rice plants, as they continue to germinate following dissipation of herbecides or after the last hand-weeding. Such late infestation has little effect on crop yield but it interferes with harvesting and the weeds also harbour rodents. Weeds like *Rottboellia exaltata* L., *Commelina* spp., *Digitaria* spp. and *Echinochloa* spp. are often resistant to a range of commonly available herbicides. If these weeds are not physically removed, competition with rice plants occurs. Frequently, members of Compositae and Commelinaceae become dominant in fields where other weeds have been controlled with preemergence herbicides.

Perennial weeds of drier cleared forest and derived savanna zones include *Cyperus* spp. and *Imperata cylindrica*. The perennating rhizomes of these weeds make them more difficult to control than the annual weeds and control measures involve costly inputs. Infested areas are generally fallowed several years before being returned to cultivation.

Weeds of hydromorphic rice lands

Weed problems on hydromorphic lands are more serious as weed competition is greater than with dryland conditions. In addition to the weeds discussed above, weeds adapted to water-logged conditions like *Fimbrystylis* spp., *Echinochloa* spp., *Alternanthera* spp., and wild rice (*Oryza* spp.) are common problems of hydromorphic rice. At least three timely hand-weedings are necessary to minimize yield losses caused by weed competition. Herbicides that give good weed control in lowland and dryland rice do not persist long enough to give similar weed control in hydromorphic soils (IITA, 1976).

Weed problems of lowland rice

Aquatic weeds predominating in this habitat include sedges, annual and perennial grasses and annual broadleaf plants. Aquatic weeds with wide distributions are *Oryza longistaminata*, *O.breviligulata*, *Cyperus* spp., *Pycreus* spp., *Fimbristylis* spp., *Eleocharis* spp., *Scirpus* spp., *Echinochloa* spp., *Sphenoclea* spp., and *Leptochloa* spp. The aquatic weeds that are most difficult to control include *Oryza* spp. and *Ischaemus rogusum* Salisb.

Yield Reduction Caused by Weeds

One of the most labour requiring operations in rice production is weed control. Hand-weeding in many rice areas has been estimated to be 250 to 780 man hours per hectare, depending on the ecosystem, frequency of weeding and environmental conditions during cropping (Dadey, 1973; De Datta *et al.*, 1973; Kim, 1969; Matsunaka, 1975). Poor land preparation at time of planting is a major factor affecting the severity of weed infestation (Allnut, 1942; Dadey, 1973; Merlier, 1973a; Parry, 1974; Smith, 1970). In lowland rice culture, another important factor is water management. Yield reduction of lowland rice caused by weeds can be minimized by proper water management. Total crop loss can occur where weed infestation is severe or where rhizomatous wild rice varieties are the predominant weeds (Martin and Guegan, 1973). Direct seeded rice is more susceptible to weed infestation than transplanted rice, and losses caused by weeds are affected by the method of crop establishment (Table 2). The absence of water increases the cost of weeding in dryland and hydromorphic

TABLE I

Common weeds of African rice ecosystems

Common weeds of African dryland rice ecosystems	
AMARANTHACEAE	*Alternanthera sessilis* (L.) R. Br. ex Roth
	Amaranthus hybridus L.
	A. spinosus L.
	A. viridis L.
	Celosia spp.
COMMELINACEAE	*Commelina benghalensis* L.
	C. erecta L.
	C. diffusa Burm. f.
COMPOSITAE	*Acanthospermum hispidum* DC
	Ageratum conyzoides L.
	Aspilia spp.
	Bidens pilosa L.
	Chrysenthellum americanum (L.) Vatke.
	Emilia spp.
	Synedrella nodiflora Gaert.
	Tridax procumbens L.
CONVOLVULACEAE	*Ipomoea* spp.
CYPERACEAE	*Cyperus esculentus* L.
	C. rotundus L.
	C. sphacelatus Rottb.
	C. tuberosus Rottb.
	Mariscus spp.
	Fimbrystylis spp.
EUPHORBIACEAE	*Acalypha ciliata* Forsk.
	Croton lobatus L.
	Euphorbia heterophylla L.
	Phyllantus amarus Schum. & Thonn
GRAMINEAE	*Brachiaria* spp.
	Chloris pilosa (L.) Schum.
	Eleusine indica (L.) Gaert.
	Digitaria spp.
	Dactyloctenium aegyptium (L.) Beav.
	Imperata cylindrica (L.) Beav. var. *africana* (Anderss.) C.E. Hubbard
	Panicum maximum Jacq.
	Paspalum orbiculare Forst.
	Rottboellia exaltata L.
	Setaria spp.
	Pennisetum spp.
	Cynodon dactylon (L.) Pegs.
LOGANIACEAE	*Spigelia anthelmia* L.
MALVACEAE	*Hibiscus* spp.
	Sida spp.

TABLE 1 (cont'd)

NYCTAGINACEAE	*Boerhavia diffusa* L.
PAPILIONACEAE	*Desmodium* spp.
	Indigofera spp.
PORTULACACEAE	*Portulaca oleracea* L.
	P. quadrifida L.
	Talinum spp.
RUBIACEAE	*Borreria* spp.
	Oldenlandia spp.
SOLANACEAE	*Physalis* spp.
	Solanum nigrum L.
TILIACEAE	*Corchorus* spp.
	Triumfetta cordifolia A. Rich.
VERBENACEAE	*Stachytarpheta* spp.
URTICACEAE	*Fleurya* spp.
Common weeds of African lowland rice ecosystems	
AMARANTHACEAE	*Alternanthera* spp.
COMMELINACEAE	*Commelina* spp.
CYPERACEAE	*Cyperus difformis* L.
	C. distans L.f.
	C. haspan L.
	C. sphacelatus Rottb.
	Fimbrystylis spp.
	Kyllinga spp.
	Mariscus spp.
	Pycreus spp.
GRAMINEAE	*Brachiaria* spp.
	Cynodon dactylon (L.) Pegs.
	Echinochloa colonum (L.) Link
	E. crus-pavonis Schult.
	E. pyramidalis (Lam.) Hitch & Chase
	Ischaemum rugosum Salisb.
	Leptochloa caerulescens Steud.
	Oryza breviligulata A. Chev. & Roehr
	O. longistaminata A. Chev. & Roehr
	O. punctata Kotschy ex Steud.
	Paspalum spp.
	Sacciolepsis spp.
ONAGRACEAE	*Ludwigia* spp.
PONTEDERIACEAE	*Heteranthera callifolia* Rchb. ex Kunth
POLYGONACEAE	*Polygonum* spp.
RUBIACEAE	*Pentodon pentandrus* (Schum. & Thonn) Vatke
SALVINIACEAE	*Salvinia* spp.
SPHENOCLEACEAE	*Spenoclea zeylanica* Gaert.

areas.

In dryland rice, heavy infestations of *Rottboellia exaltata* L. have been known to cause total crop loss. A yield reduction of 47% has been reported for *Cyperus rotundus* L. and this weed, in association with other weeds, caused a yield reduction of 82% in dryland rice (Moody, 1973b). In direct-seeded lowland rice, yield reduction due to uncontrolled weed growth can be as high as 70 percent (IITA, 1974). In transplanted lowland rice, weeds constitute a serious problem where there is an intermittent supply of water; they are especially severe 20-40 days after transplanting when competition is greatest for light and nutrients (Vega and Punzalan, 1968).

TABLE 2

Average yield reduction due to uncontrolled weed growth

Rice Culture	% Yield reduction	Source
Dryland		
The Gambia	100	(WARDA, 1976)
Ghana	84	(Aryeetey, 1970)
Liberia	39- 87	(Carpenter, 1973; WARDA, 1976)
Nigeria	80-100	(Fagade, 1976; Williams, 1975)
Senegal	48	(WARDA, 1976)
Upper Volta	62	(WARDA, 1976)
Lowland		
(Transplanted)		
Liberia	44- 51	(Carpenter, 1973; WARDA, 1976)
Nigeria	33- 75	(IITA, 1974; Williams, 1975)
Senegal	28	(WARDA, 1976)
(Direct seeded)		
Ghana	28	(Aryeetey, 1970)
Nigeria	46- 84	(Fagade, 1976; IITA, 1976; Williams, 1975)

Control Methods

Increased yields from use of improved rice varieties cannot generally be realized by farmers until weed control practices are improved. There are several methods of reducing weed-related yield losses.

Cultural practices

For irrigated rice, proper land levelling is necessary to ensure a uniform water depth, permitting good growth of rice seedlings. Most aquatic weeds grow best in shallow water (less than 5 cm deep) and are most troublesome in

improperly levelled rice paddies (Smith, 1970). Water depth of at least 10 cm when rice is at the seedling stage helps to control many annual weeds. While the application of nitrogen or phosphate fertilizer directly to rice stimulates growth of many rice weeds, weed competition may be less severe in fertilized than unfertilized fields (Williams, 1975).

Closer spacing, especially in hydromorphic rice, is an important method of increasing the crop's ability to compete with weeds.

Early seedling establishment of direct-seeded dryland and hydromorphic rice is affected by the weed population. No-tillage techniques using paraquat, dalapon or glyphosate can be used to reduce tillage operations in both direct-seeded and transplanted rice cultures (Mittra, 1968; Moomaw *et al.*, 1968). Glyphosate, although costly, has the advantage of being able to control a wider spectrum of weeds than the other preplant herbicides (IITA, 1976).

Hand-weeding

Hand-weeding is common in Africa and although effective, it is tedious and best adapted to small holdings (Aryeetey, 1970). Two weedings are usual for dryland and three for hydromorphic areas. Weeds are allowed to grow until they are tall enough to be pulled out easily. The hoe is a faster and more efficient method, but requires line sowing (Curfs, 1974). The use of improved mechanical methods, like the push type rotary weeder and motorized rotary weeders (Athwal, 1972), is essentially not practised in Africa.

Crop rotation

Each crop has its characteristic weeds, and growing the same crop continuously on the same land tends to increase such weeds. Rotation of lowland rice with an upland crop such as a legume, resulted in reduced infestation of water tolerant weeds in the rice crop in the Philippines and USA (Jereza and De Datta, 1976; Smith, 1967, 1969).

Chemical weed control

Chemical weed control is slowly gaining ground in rice culture in Africa. Herbicides offer the most practical, effective, and, in many situations, the most economical means of reducing crop losses and production costs. In areas where rice is broadcast, chemical weed control is the only alternative to hand or hoe weeding. It should be stressed that herbicides cannot substitute for good land preparation. Use of the right herbicide, applied at the right rate and time, with properly calibrated spray equipment and with the correct nozzles is essential for optimal control. Commonly available herbicides used for weed control in rice include the phenoxyacetic acids, fluorodifen, propanil, molinate, bentazon, cyperquat, butachlor, thiobencarb and formulated mixtures involving two or more of these herbicides (Table 3).

Consideration for herbicide use by African rice farmers

Although herbicides when properly used give good control of weeds in rice, their effectiveness depends partly on environmental factors at the time of application. Several herbicides like oxadiazon, molinate and butachlor have proved effective in Asia and cool climates, but have not been as effective in tropical Africa. Modifications in herbicide formulation are needed to reduce wash-off by rain soon after spraying. The use of granular formulations reduces the need for spraying. A need for wide-spectrum herbicides exists for dryland rice mixed-cropping systems. However, the herbicides recommended must be tolerated by species in the mixed cropping system.

TABLE 3

Common and chemical names of herbicides mentioned in this paper

Common name	Chemical name
bentazon	3-isopropyl-1 H-2,1,3-benzothiadiazon-(4) 3 H-one 2, 2-dioxide
butachlor	N-(butoxymethyl)-2-Chloro-2^{1},6^{1}-diethyl-acetanilide
cyperquat	1-methyl-4-phenylpyridinium
dalapon	2, 2-dichloropropionic acid
fluorodifen	*p*-nitrophenyl α,α,α-trifluoro-2-nitro-*p*-tolyl ether
glyphosate	*N*-(phosphonomethyl)glycine
molinate	*S*-ethyl hexahydro-1 *H*-azepine-1-carbothioate
paraquat	1,1'-dimenthyl-4,4'-bipyridinium ion
propanil	3',4'-dichloropropionanilide
thiobencarb	S-(4-Chlorobenal)-N-N-diethylthiol carbamate
Hormone herbicides:	
2,4-D	(2,4-dichlorophenoxy)acetic acid
2,4,5-T	(2,4,5-trichlorophenoxy)acetic acid
MCPA	((4-chloro-o-tolyl)oxy)acetic acid
silvex	2-(2,4,5-trichlorophenoxy)propionic acid

Benefits of Weed Control

Increase in grain yield

Improved weed control can help increase grain yield. Rice yield in Swaziland was reported to have doubled following introduction of herbicides (Armstrong, 1968). Although better weed control may not be solely responsible for increased crop yield, it can contribute to better utilization of production inputs. Improved weed control facilitates the ease of harvesting, reduces harvesting cost, improves quality, and reduces the incidence of insect problems (Smith and Shaw, 1966).

Reduction in labour

A powered rotary weeder decreases the labour requirement for weeding in rice from 500 man hour/ha for hand-weeding to 35 man hours/ha (Curfs, 1974). In the irrigated rice zones, transplanted rice has an advantage over direct-seeded rice in that the larger transplanted rice seedlings compete better with weeds (Allnut, 1942). Also, the spacing in transplanted rice facilitates inter-row tillage. When weeds are properly controlled, direct-seeded lowland rice yields as well as transplanted rice (De Datta *et al.*, 1968). It therefore follows that direct seeding combined with good chemical weed control should eliminate the labour required to establish the nursery, to transplant, and to weed the transplanted rice.

Improved variety performance

New rice varieties for irrigated systems are usually characterized by early maturity, high yield potential, lodging resistance, and upright leaves (Smith, 1970). These types have greater nitrogen response than the taller, leafier traditional cultivars. The characteristics of these new varieties, such as greater light penetration into canopy and nitrogen response, favour weed growth, hence their dependence on effective weed control (De Datta *et al.*, 1968). The tall, leafier, older varieties, such as OS 6 and LAC 23 compete better with weeds, hence their popularity with African farmers whose weed control efforts are low.

Conclusion

One of the constraints to higher yield of African rice is excessive weed growth. Both annual and perennial weeds are common. Although the farmer may attempt to control the weeds, his timing is often wrong. This is partly because of the farmers' ignorance of when best to weed his crop, and partly because of other labour demands during the appropriate weeding time.

Limited research in a number of rice growing areas in Africa has demonstrated that grain yield can be doubled by improving weed control. This is particularly true in lowland rice cultures, where poor water control, increased use of fertilizer, and improved dwarf varieties stimulate weed growth. Weed control in Africa is presently handicapped by limited knowledge of the biology and importance of the different weeds in the various rice ecosystems.

It is necessary to improve the weed control practices of African farmers in order for them to benefit from other production inputs, such as improved varieties, use of fertilizer, and improved land preparation techniques. Weed control is vital to rice production, and it should be enhanced with minimum drudgery and maximum benefits for the African rice farmer.

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WEED PROBLEMS IN PLUVIAL RICE CULTIVATION IN IVORY COAST

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Introduction

Herbicide trials on pluvial rice in Ivory Coast were commenced by IRAT in 1968. However, the yields in herbicide treatments of these trials, when compared with the corresponding checks with weed infestation were sometimes variable and contradictory. Tropical weed growth in West Africa is characterized by strong emergence, often more than 10,000 seedlings per square metre, and by rapid development; some weeds completing their growth cycle within one month.

It is usually considered that weeding in cereals should be done as early as possible. However, in 1973, a weeding done 15 days late resulted in the best yields, although the rice at that time had been covered with weeds.

Trials were established in 1974-75 to study the behaviour of rice under different durations of weed infestation and to study the effects of *Digitaria horizontalis*, a common weed of pluvial rice fields.

Materials and Methods

The trials were conducted at Bouaké on deep-ploughed soil (25 cm) which had been fertilized with (kg/ha) 40N; 80P_2O_5; 80K_2O. The seedbed was later disc-harrowed. Planting was done mechanically in lines 25 cm apart, using 60 kg seed/ha of rice variety Iguape Cateto. Supplementary nitrogen (20 kg/ha N) was supplied 30 days after planting and again at booting stage.

Treatment plots were 1.25 m x 14 m and were separated by 1.25 m alley-ways. The treatments were replicated six times. After planting on clean soil, the plots were left to natural weed infestation. The first weeding was followed by complete clearing at increasingly later stages. The control plot was not weeded throughout the 130 day cycle. Observations on the weed flora and weight were made at the first weeding. Paddy yield was estimated on the four centre rows for a 12 m length of the plots.

Results

The weed species whose dry weights were greater than 1% of the total weight of weeds at the end of weed infestation period are listed in Table 1. The percentage of each species in the total weight is given as well as the total weight of weeds after the different periods of infestation. The partial and the total weights include the minor weed species not shown in Table 1.

TABLE 1

Percent and total weight of weed dry matter after various infestation periods

Year	1974		1975				
	Duration of weed infestation in days						
	30	60	40	60	80	100	130
Major weed species	Dry weight of weeds as % of total weed weight						
Eleusine indica	66	50	4	4	2	2	-
Digitaria horizontalis	10	20	8	10	12	15	-
Brachiaria lata	5	12	16	18	6	6	-
Dactyloctenium aegyptium	3	5	-	-	-	-	-
Total for *Gramineae*	84%	87%	30%	34%	21%	24%	-
Kyllinga squamulata	4	1					
Celosia argentea	2	4	1	3	4	6	-
Commelina benghalensis	2	2	29	32	43	37	-
Trianthema portulacastrum	-	-	11	13	10	15	-
Tridax procumbens	1	1	9	6	5	5	-
Amaranthus viridis			5	1	1	2	-
Boerhavia diffusa			4	-	-	-	
Sida urens			1	1	3	3	-
Ipomea eriocarpa				-	2	4	-
Total of miscellaneous weeds	16%	13%	70%	66%	79%	76%	-
Total wt (t/ha)	2	7	1	1.4	3.8	4.8	11

The control plot was not weighed in 1974 because of severe lodging. In 1975, the total weight of the control was obtained, but not the weights of individual weed species. The late weighings gave only an estimate of the total weed growth, as they did not include those weeds which had already completed their cycle.

The difference in composition of the weed flora in the

TABLE 2

Rainfall at 10 day intervals, total rainfall (mm) and paddy yield in cleared control plots

Year	Yield (t/ha)	Rainfall in 10 day intervals (mm)													Total (mm)
		1	2	3	4	5	6	7	8	9	10	11	12	13	
1973	2.10	19	10	7	10	6[a]	165	18	41	44	144	43	8	8	523
1974	4.90	27	35	35	5	85	69	19	95	86	44	40	16	3[a]	550
1975	0.80	37[a]	42	21[a]	62	55	2	18[a]	0[a]	40	29	54	75[a]	42	477

a) Rainfall to which one irrigation was added, between 15-20 mm. The total rainfall in 1975 was between 552-577 mm.

two years is due to differences in soil type, the 1974 trial being on soil which was more acidic and gravelly than the 1975 trial soil.

Rainfall during the 1973-1975 growing seasons is shown in Table 2. The 10-day intervals commenced at the date of sowing. In the second half of the cycle the decadal evapotranspiration was 40 mm. The rice showed visible signs of stress when the decadal rainfall was less than 30 mm.

The paddy yield of variety Iguape Cateto and the dry weight of weeds after various periods of infestation are shown in Figure 1. The yields in the 1974 control plot were close to the maximum possible for Iguape Cateto under good conditions. The effects of the duration of weed infestation on yield components (panicle weight and number of panicles per sqm) are shown in Figure 2. These results were obtained by counting and weighing a control row 12 m long.

The damage caused by *Digitaria horizontalis* relative to plant density is shown in Figure 3. Various densities of *Digitaria horizontalis* were obtained by hand weeding. Two treatments consisting of a pure stand of *Digitaria horizontalis* (10,000 plants/m^2 at emergence) and a weedy check, produced no rice yield. These two treatments produced 7 and 15 t/ha dry matter respectively.

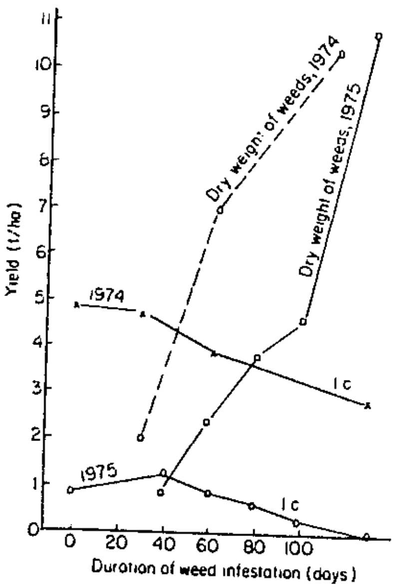

Fig. 1. Yield of variety Iguape Cateto (I.C.) and dry weight of weeds after different periods of infestation.

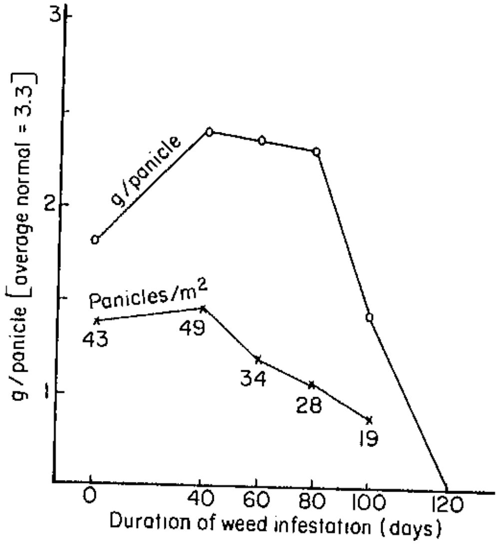

Fig. 2. Influence of the duration of weed infestation on panicle weight (average, normal) and no. panicles/m^2 (average, normal)

Discussion

Fertilization of trials was planned in such a way as not to limit crop yield. However, it was thought that fertilization may have increased weed damage. There were important annual differences in both the composition of the weed flora and the total weight of weeds. Weed damage was insignificant during the first month, although the predominance of *Eleusine indica* in the 1974 season gave cause for alarm.

The increasing duration of weed stress caused moderate and increasing yield reduction (Figure 1). In 1975, however, *Digitaria horizontalis* at 5 plants/m^2 caused 40% harvest loss (Figure 3), which was as great a reduction as was caused by total natural weed infestation in 1974. In all cases, the weed damage could be related to the rainfall and the density of the rice crop.

Recent work on drought resistance has shown that rice is most susceptible to drought in the period following panicle initiation (Reyniers, 1975). For Iguape Cateto, this occurred at 70-73 days after planting. There was a positive correlation between yield and rainfall during the critical period (80-90 days), although the total rainfall in the three years was almost the same (Table 2). Rainfall during this period was more important for final yield than that at the beginning or end of the cycle. This was clearly illustrated in the rainfall and yield patterns for 1973 and 1975.

Dense planting of rice itself can limit yields, as was shown by experiments in which rice was thinned to half density of the control 15 days after planting. The thinned plots yielded 1.8 t/ha, which was double the unthinned control. The control treatments were planted at the same density as those used for weed infestation studies (Merlier, unpublished data).

The effects of weeds on rice yields depended largely on the rainfall during the critical period. If water requirements of the rice were satisfied, weeds were not damaging during the first month of the cycle, irrespective of whether other conditions were optimal for the rice or not. Weed damage only became noticeable when infestation persisted for at least two months. If the water needs of rice during panicle initiation were not supplied, weed competition at this time would increase water shortage and reduce productive tillers of the rice plant. Permanent weed

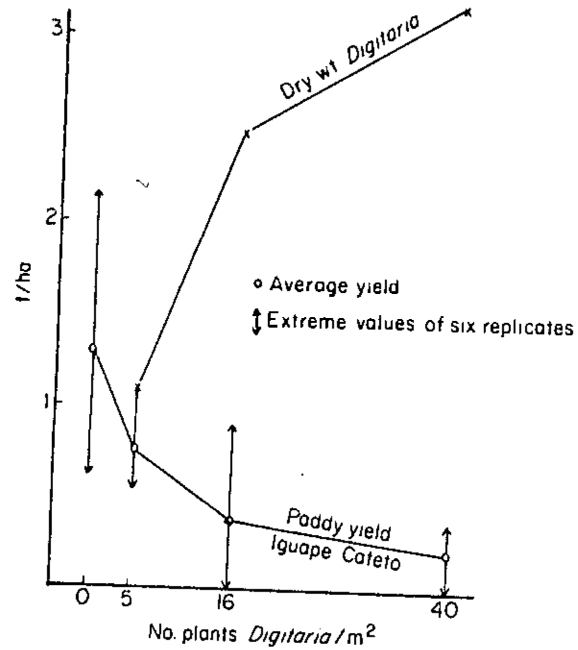

Fig. 3. Specific damage caused by *Digitaria horizontalis* as a function of the no. plants/m^2.

infestation caused total yield loss, especially if *Digitaria* sp. was present.

In conclusion, these trials on weed damage on pluvial rice have shown the importance of plant density to yield. This density, which is used in large-scale cultivation, was originally chosen to guard against stresses at the beginning of cultivation. The plant density chosen also increased the crop's ability to compete with weeds especially as only hand-weeding was possible and labour was in short supply. Weeding is essential, especially for mechanical harvesting, and some suitable chemicals have been identified.

Further work is in progress on the effects of weed infestation in less densely planted rice. Observations during 1976 suggest that lower plant densities will reduce the need for nitrogen fertilizer, which is an important saving in African agriculture.

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WEED CONTROL AND SOIL AND CROP MANAGEMENT IN RAINFED RICE AT IRRI AND OTHER LOCATIONS IN TROPICAL ASIA

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Introduction

For the past four years IRRI has been developing technology for rainfed upland, rainfed lowland and deep water rice in cooperation with some national programmes in Asia. Through IRRI's Genetic Evaluation and Utilization (GEU) programme, progress has been made in recombining drought tolerance, recovery ability from drought stress, a range of maturities, higher yielding ability, tolerance to adverse soils, tolerance to extreme temperatures, and resistance to different pests, to meet specific needs of diverse eco-edaphic environments under which rice is grown in Asia. Many constraints that limit upland rice yields in Asia probably also operate in Africa.

Upland Rice

Competition from weeds

Flooding has been recognized for many years by researchers as an effective weed-control method, a method unavailable under upland rice culture (Cralley and Adair, 1943; De Datta, 1976). More weeds grow under upland than under lowland rice conditions and they may prevent any grain yield in both systems (Vega, 1954; Vega *et al.*, 1967; De Datta, 1972). Potential rice yield losses in upland rice in the Philippines were reported to range from 41 to 100 percent (Madrid *et al.*, 1972). The perennial weed purple nutsedge (*Cyperus rotundus* L.) caused increasing reduction in rice grain yield with increased density. Reduction in the light transmission ratio was greater at higher nitrogen levels during three seasons (Okafor and De Datta, 1976b). Jayasekere and Velmurugu (1964), from Sri Lanka, reported that early competition reduced grain yields by 50 percent.

In West Africa, once land-clearing had been accomplished, weeds were considered the most important problem (USDA/USAID, 1968). In the absence of efficient weed control, other inputs such as high-yielding disease- and insect-resistant varieties and fertilizers were considered useless (Dadey, 1973). Moody (1975) reported that present weed-control methods are unsuitable for continuous or large-scale farming. In shifting-cultivation areas, once weeds become too great a problem, the land is abandoned to forest; that is a cheap and effective means of weed control. Moody further stated that highest priority should be given to research that is aimed at finding chemicals that are economical and effective.

Suitable weed control practices including the use of herbicides would play an important role in increasing rice production in present and potential upland areas.

Minimizing weed infestation

Pande and Bhan (1964) considered that chemical weed control was a remote possibility. Others have considered that chemical and mechanical methods and other cultural practices were the most feasible.

Recent IRRI studies indicate that chemical weed control in upland rice is effective and economical (De Datta, 1974; De Datta *et al.*, 1974a). Hand-weeding often takes from 350 to 600 man-hours per ha. Moreover, several hand-weedings are necessary to remove weeds completely, so chemical weed-control may be essential for successful upland rice cultivation anywhere in the world (De Datta, 1974).

On experiment stations and farmers' fields in the Philippines, the following herbicides were effective as pre-emergence sprays at the rate of 2 kg active ingredient (a.i.)/ha: Butachlor, fluorodifen, benthiocarb, oxadiazon, AC 92553 (a coded compound), dinitramine, and the combination herbicide piperophos plus dimethametryn (C-228) (De Datta, 1976).

Although propanil alone or in combination was found effective in controlling weeds in upland rice in India (Mukhopadhyay *et al.*, 1971), and in West Africa (Aryeetey, 1973), results in the Philippines have been inconsistent (De Datta, 1976). Experiments during the 1976 wet season showed that propanil gave poor weed control at IRRI but fairly good weed control on farmers' fields in Batangas, Philippines, indicating that propanil does not provide consistent weed control under monsoon conditions. Other herbicides in the same trials, such as AC 92553, butralin, dinitramine, and RH 2915, gave yields statistically similar to the 2.5 t/ha grain yield obtained with two hand-weedings.

In a farmer's upland field experiment in Batangas province, Philippines, the predominant weed species were *Echinochloa colonum, Celosia argentia, C.benghalensis, Commelina diffusa, Ageratum conyzoides, Bidens pilosa, Cyperus iria, C.rotundus*, and *Eleusine indica*

In another experiment where new herbicides were tested for the first time with rainfed rice culture in the Philippines, heavy weed-infestation included *E.colonum, C.iria, C.rotundus, Portulaca oleracea, Ipomea triloba* and *C.benghalensis*. SL 55, NTN 6867, and EXP 3316 were promising, giving yields comparable to that of the hand-weeded control (Table 1). EXP 3316 was moderately toxic to rice.

Where nutsedge (*Cyperus rotundus*) is a major problem, mechanical cultivation during land preparation increases the number of infestations by separating dormant tubers and stimulating them to sprout. *C.rotundus* germinates and grows with the rice crop, complicating control (Okafor and De Datta, 1976a). Various attempts to control *C.rotundus* in upland rice have been reported (De Datta, 1974; De Datta *et al.*, 1974a). Recently, Okafor and De Datta (1976a) reported that K-223 /N-(a-a-dimethylbenzyl)-N'-p'-tolyl urea/ gave good control when broadcast sprayed at 8.0 kg a.i./ha in the dry season and at 10 kg a.i./ha in the wet season, immediately mixed into the soil just before drilling.

Other cultural practices, such as land preparation, timely hand or mechanical weedings (Moody, 1975), use of appropriate rice varieties, seeding rates, and fertilizer management complement or may substitute for chemical weed control in upland rice (De Datta, 1976).

Management of N fertilizer

Most upland rices respond to nitrogen fertilization with increased blast and lodging. There seems to be a trade-off between plant-type requirement for drought tolerance and shading of weeds with semi-droopy leaves with that of lodging resistance. Many varieties with intermediate stature and high tillering ability will lodge under heavy rain. On the other hand, such rices fare better than short-strawed varieties under conditions of less favourable moisture, and in weedy areas. Fortunately, loss from lodging is less severe under upland conditions.

Regardless of varietal type, split doses of nitrogen minimize lodging and maximize fertilizer-nitrogen efficiency. Banding fertilizer close to the seed (10 cm deep) greatly increases nitrogen efficiency in upland rice.

In the 1976 wet season at IRRI, an early-maturing intermediate-statured variety (IR9575) and a medium-maturing semidwarf (IR2035-117-3) responded similarly to treatment-combinations of sources, times and methods of N application. Mean grain yield for the two varieties was highest (3.7 t/ha) with ammonium sulfate at 60 or 90 kg N/ha applied in three equal split doses at planting, 30 days after emergence, and at panicle initiation. Sulfur-coated urea (SCU) at 60 or 90 kg N/ha, applied at planting, in

TABLE 1

Effects of liquid herbicides on weed control, yields of rice (BPI 76/9 X Dawn) at IRRI and on farmers' fields 1976 wet season[a]

Treatment	Rate[b] (kg a.i./ha)	Weed weight at IRRI[c] (g/sqm) Grasses	Sedges	Broadleaves	Weed weight farmers' field[c] (g/sqm) Grasses	Sedges	Broadleaves	Yield (t/ha) IRRI	Yield (t/ha) farmers' field
AC 92553	2.0	8	64	4	62	11	56	2.7	2.2
Antor	2.0	74	17	4	29	9	28	1.5	2.9
Butachlor	2.0	86	36	4	21	12	33	1.5	3.2
Butralin	2.0	22	46	2	39	10	43	2.5	3.0
Piperophos/ dimethametryn	2.0	120	7	21	24	5	36	1.7	3.6
Dinitramine	2.0	17	49	4	22	16	42	2.5	3.0
Terbuchlor	1.0	24	40	4	48	14	36	1.8	2.9
Oxadiazon	1.0	73	11	1	54	13	27	2.2	3.1
RH 2915	1.0	37	16	1	5	1	10	2.4	1.2
Propanil	3.0	195	29	0	38	10	38	0	2.8
SL 55	1.0	25	26	17	-	-	-	3.1	-
NTN 6867	2.0	132	16	2	-	-	-	2.6	-
EXP 3316	0.5	6	28	2	-	-	-	2.4	-
X-150	2.0	226	1	0	-	-	-	1.5	-
Hand weeded contr.	-	76	20	2	12	2	14	2.5	3.2
Untreated contr.	-	254	36	0.5	215	5	22	0	0

a) Herbicides applied before crop and weed emergence (2 days after seeding) on rice grown under upland conditions at IRRI and on farmers' fields, Batangas Province, Philippines.
b) kg active ingredient/ha.
c) Taken at heading stage of grasses.

bands, broadcast or incorporated gave lower yield. Urea or ammonium sulfate, which are relatively cheaper than SCU, are equally good sources of N in upland rice if their application is timed properly.

The effect of mulching

Very few studies have been made of the effects of mulching on moisture conservation in upland rice. Studies at the International Institute of Tropical Agriculture, Nigeria, showed that moisture retention was improved by mulching (IITA, 1973). A surface mulch of 4 t/ha was found to be more effective in increasing soil moisture retention than the same organic matter 10 cm deep.

Rainfed Lowland Rice

Competition from weeds and weed control

In Asia, water accumulates in bunded fields as the rice crop grows. The crop starts as an upland crop and finishes as a lowland crop. In other situations, the crop starts as a lowland crop and finishes as an upland crop. With such uncontrolled water conditions, weeds generally occur in larger numbers and with greater diversity of species than with puddled soil under good irrigation.

Each year, IRRI screens herbicides under rainfed bunded conditions to identify safe and effective herbicides for transplanted and direct-seeded rice. During the 1976 wet season, several new herbicides looked promising for transplanted rainfed rice. Of the herbicides tested for the first time, NTN 5810/2,4-D, EXP 3316, and prodotto D75, applied 4 days after transplanting and before weed emergence, gave yields similar to those of a hand-weeded control (Table 2). Prodotto and X-150 also adequately controlled weeds at the 3- to 4-leaf stage. Because there was no standing water in the plots for 20 days after transplanting, granular 2,4-D failed to control the weeds. The important weed species in the test plots were the annuals *E.crus-galli*, *E.crus-pavonis*, *Leptochloa chinensis*, *Fimbrystylis littoralis*, *C.difformis*, *C.iria*, and the perennials *P.distichum* and *S.maritimus*. Infestation of the broadleaved *M.vaginalis* and *S.zeylanica* was low.

Most new herbicides adequately controlled the predominant weeds *E.crus-galli*, *E.crus-pavonis*, *M.vaginalis* and *C.difformis* in a direct-seeded rice experiment. Herbicides X-52/2,4-D, MT-101 and NTN 5810/2,4-D gave high yields compared with the standard controls (Table 3). Prodotto D75, which performed well in transplanted rice, showed promise for application at late post-emergence of weeds in direct-seeded rice. The plots were almost continuously flooded by heavy rains and most of the herbicides were toxic to 7-day-old rice seedlings.

TABLE 2

Effects of promising new herbicides on weed control and yield of transplanted IR26 rice grown under rainfed lowland conditions. IRRI, 1976 wet season

Treatment[a]	Application		Weed weight[d] (g/sqm)			Yields[e] (t/ha)
	Rate[b] (kg a.i./ha)	Time[c] (DT)	Grasses	Sedges	Broadleaves	
NTN 5810/2,4-D IPE (G)	1.4/0.3	4	41	20	0	4.0 A
EXP 3316 (C)	0.5	4	22	42	0	3.5 AB
Prodotto D75 (EC)	4.0	4	97	32	0	3.2 ABC
NTN 6867 (WP)	2.0	4	71	48	0	3.1 BCD
X-150 (G)	3.0	10	180	26	1	2.4 CD
EXP 3391 (G)	0.25	4	44	28	0	2.4 CD
IWD #3051 (EC)	2.0	4	117	9	0	2.3 CD
Oxadiazon (G)	1.0	4	77	30	0	2.3 DE
X-150/2,4-D IPE (G)	1.4/0.5	4	64	40	0	2.1 E
X-150 (G)	3.0	4	128	18	1	2.0 E
NTN 6867/2,4-D IPE (G)	1.4/0.3	4	176	10	0	2.0 E
Benthiocarb/2,4-D IPE[f] (G)	1.0/0.5	4	126	32	0	1.9 E
2,4-D IPE[f] (G)	0.8	4	253	6	0	0 F
Hand weeded control	-	20&40	9	2	0	3.7 AB
Untreated control	-	-	248	39	0	0 F

a) G = granule, C = cream, EC = emulsifiable concentrate, WP = wettable powder. b) a.i. = active ingredient. c) DT = days after transplanting. d) Taken at heading stage of grasses. e) Av. of two replications. Any two means followed by a common letter are not significantly different at the 5% level. f) Standard chemical controls.

TABLE 3

Effects of promising new herbicides on weed control, crop tolerence, and yield of direct-seeded IR26 rice grown under rainfed lowland conditions. IRRI, 1976 wet season

Treatment[a]	Application		Weed weight[d] (g/sqm)			Visual[e] toxicity rating	Yield[f] (t/ha)
	Rate[b] (kg a.i./ha)	Time[c] (DS)	Grasses	Sedges	Broadleaves		
WL 29226[g] (G)	0.75	7	5	0	3	4	4.2 A
X-52/2,4-D IPE (G)	1.4/0.5	7	64	0	0	4	4.1 AB
MT-101 (WP)	2.0	7	68	0	12	4	3.9 ABC
NTN 5810/2,4-D IPE (G)	1.4/0.3	7	26	4	22	5	3.9 ABC
NTN 6867/2,4-D IPE (G)	1.4/0.3	7	22	2	3	7	3.6 BC
NTN 5810 (G)	2.0	7	16	1	65	6	3.5 C
MCPA/TBA (G)	0.8	7	31	0	25	6	3.4 C
Prodotto D75 (EC)	2.0	11	44	0	1	6	3.4 C
Oxadiazon (G)	1.0	7	70	0	2	8	2.5 D
Benthiocarb/2,4-D IPE[g] (G)	1.0/0.5	7	27	0	3	5	4.4 A
Untreated control	-	-	646	26	124	0	0 E

a) G = granule; WP = wettable powder; EC = emulsifiable concentrate. b) a.i. = active ingredient. c) DS = days after seeding. d) Taken at heading stage of grasses. e) Taken at 19 DS. Scale: 1 = no toxicity, 10 = complete kill. f) Av. of two replications. Any two means followed by a common letter are not significantly different at the 5% level. g) Standard chemical controls.

Fertilizer N efficiency

Seldom is more than 30 to 40 percent of applied N recovered in farm rice crops (De Datta, 1974b). The low efficiency of fertilizer nitrogen is more serious with rainfed lowland rice than with irrigated lowland rice. Therefore, the challenges for soil scientists and agronomists lie in better understanding of the fate of fertilizer nitrogen in rainfed lowland rice and in developing improved practices to achieve the maximum rice yields possible with low rates of nitrogen.

Among the basic issues we looked at were the effects of changes in flood water pH on ammonia-volatalization losses from flooded soils. Application of nitrogen in flood water caused an increase in pH (up to 9) and a decrease in the CO_2 concentration (0 ppm), thereby causing an increase in ammonia-volatalization. Deep placement of nitrogen, or broadcast and thoroughly incorporated, greatly minimized the losses of volatile ammonia from flooded N-fertilized rice fields (IRRI, 1977).

During the 1976 wet season, a nitrogen-efficiency trial was conducted under rainfed conditions using the intermediate-maturing variety IR26 and an early-maturing variety IR36. In general, grain yields were similar with different application methods. However, 28 kg N/ha band-placement, using a urea solution, gave significantly higher grain yield (average of 2 varieties) than split application and supergranule placement at the same rate of application (Table 4).

Effects of dry soil mulching on moisture conservation

A field experiment was conducted at the IRRI farm during the 1976 dry and wet seasons to test if soil mulching conserves soil moisture; determine whether soil moisture was conserved because of weed control or the generation of a dry soil mulch; determine if soil nitrogen was also conserved; and to compare the time that might be saved by the early sowing of a dry-seeded rice crop into dry soil mulch over using a transplanted crop following traditional lowland tillage at the beginning of the wet season.

In plots where land preparation was completed at the end of the previous wet season, a dry soil mulch existed from February to the first week of May. The soil-moisture tension under this mulch did not exceed 0.3 bars, even though the water table was below one meter during the whole period. In contrast, soil-moisture tension in weedy, fallowed plots rose to 5 bars and in the weed-free sites to 3 bars. This suggests that by having the site weed-free during the dry season, some moisture is conserved, but not as much as by dry soil mulching; also land-preparation, time and number of tillage operations were halved, and 10 days of growing time were saved. However, the study was

conducted on a deeply cracking clay soil (vertisol with montmorillonite). With a soil type that does not crack, results may be different.

TABLE 4

Effects of different methods of nitrogen application on the grain yield of IR26 and IR36 rices. IRRI, 1976 wet season (rainfed)

Method of nitrogen application	Grain yield[a] (t/ha) IR26	IR36	Mean	
No nitrogen	2.9	1.9	2.4	G
	28 kg N/ha			
Split application, urea[b]	4.6	3.4	4.0	EF
Band placement (urea solution)	4.8	4.5	4.7	BCD
Mudball placement	4.9	4.1	4.5	CDE
Super granule placement	4.3	3.6	3.9	F
Sulfur-coated urea, broadcast and incorporated	4.9	3.6	4.3	DEF
	56 kg N/ha			
Split application, urea[b]	5.3	4.6	5.0	BC
Band placement (urea solution)	5.2	4.9	5.0	B
Mudball placement	4.3	5.3	4.9	BC
Super granule placement	5.0	4.9	5.0	B
Sulfur-coated urea, broadcast and incorporated	5.2	5.0	5.2	B
	80 kg N/ha			
Split application, urea[b]	5.9	5.3	5.6	A

a) In the column, means followed by a common letter are not significantly different at the 5% level. b) 2/3 basal + 1/3 5 to 7 days before panicle initiation.

When the tillage was delayed until June for traditional lowland preparation of puddling, the soil moisture tension values at the end of the dry season rose to 4 bars at depths of both 15 and 30 cm. Further, with transplanted-crop cultivation, at least three weeks of growing time were lost. Yields were similar with the three systems of land preparation (Table 5). The yield from the transplanted rice crop was very low due to poor establishment and subsequent weed competition.

It is apparent that in areas with a distinct dry season, the generation and maintenance of a dry soil mulch would be useful for securing early establishment of the dry-seeded rice crop (Bolton and De Datta, 1976).

TABLE 5

Effect of methods of land preparation and crop establishment on fertilizer response of IR36. IRRI, 1976 wet season

Land preparation and crop establishment method	Grain yield[a] Fertilizer rate (kg/ha N) 20	40	60	80	Tillage mean
3 Rotovations (Feb.) + 1 harrowing (Apr.); dry seeded: 20th Apr. (dry soil mulch)	3.0	3.3	3.7	4.2	3.5 A
3 Rotovations + 1 harrowing (Apr.); dry seeded: 9th May (weedy fallow)	3.3	3.6	3.7	4.1	3.7 A
1 Rotovation + 1 harrowing (Apr.); dry seeded: 30th Apr. (weed-free fallow)	3.4	3.9	4.2	4.5	4.0 A
2 Ploughings + 2 harrowings (June); transplanted: 1st July (transplanted control)	1.1	1.2	1.5	1.4	1.3 B
Fertilizer rate mean	2.7 D	3.0 E	3.3 B	3.5 A	

a) Average of three replicates. Any two means in a row or column followed by the same letter are not significantly different at the 5% level.

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Production-oriented Research

THE RESEARCH PROGRAMME OF THE WEST AFRICAN RICE DEVELOPMENT ASSOCIATION (WARDA)

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Introduction

The West African Rice Development Association (WARDA) was established in 1972 to assist the 13 member countries (Peoples' Republic of Benin, The Gambia, Ghana, Ivory Coast, Liberia, Mauritania, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo and Upper Volta) to attain self-sufficiency in rice. WARDA is headquartered in Monrovia, Liberia, and is currently funded by the United States Agency for International Development (USAID), the Consultative Group on International Agricultural Research (CGIAR) and France, Switzerland, Belgium, Saudi Arabia, Japan and member African countries. This paper outlines the WARDA research programme and the results of coordinated trials.

In West Africa in 1975-76, a record production of approximately 2.5 million tons of paddy was obtained by the 13 WARDA member countries, an increase of five percent above the preceding year but reaching only 77 percent of that required in the region.

It is estimated that there are about 700,000 rice farmers in West Africa, of a population of 120 million. The current production of 2.3 million tons of paddy gives an average yield of 1.4 t/ha from a total area of 1.6 million hectares. Per capita consumption, presently 13.2 kg, is increasing at an average of 4.2 percent per annum, versus population growth of 2.9 percent. In 1974, the deficit created was bridged by a total importation of 550,000 tons, costing US$218 million. In view of the regional per capita Gross Domestic Product of US$54 - $294, it is clear that no effort should be spared in accelerating rice production in the region.

Compared with most Asian countries, rice is a new crop in West Africa, and population density, which to a large extent dictates the intensive rice production methods found in Asia, is much lower in West Africa. The ecological variability in West Africa makes the development of a uniform system of rice production for the whole area difficult. It would appear, both from the socio-economic viewpoint and the low level of West African technology in rice production that capital- and labour-intensive production methods practised in other parts of the world are not yet appropriate. Therefore an indigenous rice technology is needed for the region.

Rice production in the region fluctuates from year to year because the major part of the crop is highly dependent on rainfall. Irrigation water fluctuations and other production stresses also affect production stability.

Ecological Background for Rice Cultivation

The environmental potential for rice growing in West Africa is set primarily by the climate and the soils. The soils themselves reflect the influence of climate. The classification adopted for the various ways in which rice is grown in West Africa is based largely on how water is made available to the crop.

In designing coordinated trials, one should take into account rainfall distribution pattern and evapo-transpiration, solar radiation and temperature pattern, soil types and types of culture, level of management, characteristics of varieties utilized, and incidence of pests and diseases.

The WARDA region can be broadly divided into a) areas of short summer rains (monomodal) as found mainly in the north of the region, often associated with long periods of hot, dry weather and a cold season with long sunshine hours; b) areas of two rainy seasons (bimodal) separated by a short dry spell and a longer dry season during the northern winter; and c) coastal areas of heavy and long periods of rainfall.

Sunshine, rainfall and temperature regimes in more southerly (Rokupr) and northern (Richard-Toll) locations of the West African rice growing region are illustrated in Figure 1. These illustrate the great environmental differences and the potential differences in incidence of pests and diseases and in yields. One of the major objectives of the WARDA programme is to develop varieties that fit within the prevailing ecological situation and to adopt production methods suitable for the existing conditions.

WARDA Research

The aims of WARDA research and development are:

a) Improvement of rice quality;
b) Encouragement of production and use of varieties suited to West Africa;
c) Development, introduction and extension of production methods adapted to the prevailing conditions;
d) Promotion and implementation of measures for effective phytosanitary controls;

e) Encouraging, coordinating, and undertaking basic and applied research programmes in the scientific, technical, economic and sociological fields;
f) Collecting, analysing and disseminating information on methods, experience, and results obtained both within and outside West Africa;
g) Organizing conferences, seminars and training facilities, securing of fellowships and establishing, or assisting in the establishment of advisory services and training and extension facilities;
h) Providing appropriate regional rice research and development facilities;
i) Promoting any measures at the regional or the national level, as determined by the Governing Council, for the purpose of developing rice production and marketing in West Africa.

WARDA attempts to approach these aims by organizing coordinated variety and crop protection trials at a network of locations; by developing special research projects on variety improvement, soil fertility and crop protection, in

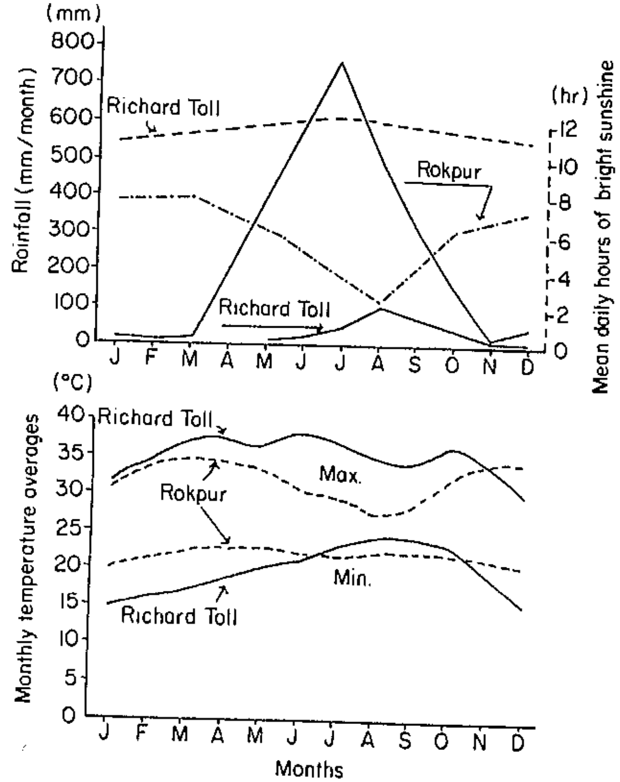

Fig. 1. Climatic data for Rokupr, Sierra Leone (Lat. 9°01N) and Richard Toll, Senegal (Lat. 16°27N).

collaboration with national programmes or international institutes; and by conducting research training in seed processing, plant protection and production.

Research coordination and support

Many research stations in the region are poorly staffed and equipped, and national boundaries and language problems often limit free flow of information and experimental results. It is WARDA's task to overcome these problems and make maximum use of existing manpower and facilities. Use is made of the infrastructure available at national centres such as Bouaké (Ivory Coast), Richard-Toll (Senegal), Mopti (Mali) and Rokupr (Sierra Leone) and of international organizations like IRAT and IITA.

WARDA conducts an annual research review meeting which gives scientists and delegates an opportunity to review critically the overall programme. It has been proposed that all research activities on rice in the member countries should be published annually after the meeting. Seminars on specific topics are held during the year.

Coordinated trials are designed to obtain rapid and reliable results on varietal performance and plant protection measures under various rice-growing conditions. The first coordinated trials on varieties and fertilizers were conducted in 1973 at 27 locations.

Initial evaluation tests enabling screening of a wide range of lines are now conducted at fourteen locations representing different agro-climatic zones of West Africa (Table 1). Promising materials are advanced to the second stage. The initial evaluation is now being conducted in association with the International Rice Testing Programme (IRTP) of IRRI.

Coordinated variety trials are classified according to the needs of the region: Upland, irrigated, deep water/mangrove and floating conditions. The trials are further classified into short, medium and long duration trials. From 77 to 90 such trials were conducted during the main season of each year from 1974 to 1976. Average yields for 1975 main season variety trials were (kg/ha) 2200 for mangrove, 2800 for rainfed, 4500 for deep flooded and 4600 for irrigated. The better varieties for rainfed, short duration were I Kong Pao, SE302G and IR442-2-58; for rainfed medium duration, ROK 1 and ROK 2; for irrigated short duration IR1529-677, IR630-27, IR20, I Kong Pao and CICA 4; for irrigated medium duration IR1529-680-3, IR269-3-3-3, IR5, Vijaya, Jaya and IR442. The best variety for yield and adaptability was IR1529-680-3. However, most varieties had a narrow spectrum of adaptability.

Insecticides and herbicides are tested at 13 locations. Furadan produced significant yield increases under irrigated conditions at several locations.

Recently, WARDA has decentralized its coordinated prog-

TABLE 1

Recommended stations for initial evaluation tests (IET)

Station	Latitude (°N)	Rainfall	Cultivation type	Problems	
				Soil	Others[a]
Richard-Toll, Senegal	16.27	Very short monomodal	Irrigated	Salinity various def.[b]	Cold photoper.
Kaedi, Mauritania	16.09	Very short monomodal	Irrigated	Various def.	Cold photoper.
Mopti, Mali	14.50	Very short monomodal	Deep water	Various def.	Deep water
Sapu, The Gambia	13.20	Very short monomodal	Upland/Irrigated	Various def.	Cold photoper.
Djibelor, Senegal	13.18	Very short monomodal	Deepflooded Deepflooded/ Irrigated	Various def.	Cold photoper.
Farakoba, Upper Volta	11.0	Short monomodal	Upland	Various def.	Drought
Nyankpala, Ghana	9.25	Short monomodal	Upland	Various def.	Drought
Rokupr, Sierra Leone	9.01	Long monomodal	Upland Mangrove Deep water	Fe toxicity Al toxicity Salinity	Deep water
Badeggi, Nigeria	9.00	-	Irrigated	Various def.	-
Bouaké, Ivory Coast	7.40	Bimodal	Upland	Various def.	Drought
IITA, Nigeria	7.30	Bimodal	Upland/Irrigated	Various def.	Drought
Moor Plantation, Nigeria	7.20	Bimodal	Upland	Various def.	Drought
Suakoko, Liberia	6.58	Long monomodal	Upland/Irrigated	Fe toxicity	-
Kpong, Ghana	6.05	Short monomodal	Irrigated	Various def.	Drought

a) Diseases and insects at all locations. b) Deficiencies.

ramme and divided the region into five sub-zones, in each of which will be posted a trial coordinator.

WARDA's efforts towards improving national research programmes and their participation in regional research programmes presently takes the following forms: Training of national research personnel; providing relevant equipment for national research activities with particular emphasis on the WARDA trial points; conducting trials on farmers' fields; and assisting in developing plans for national research programmes.

Special research projects

Plans are being developed for special research projects in variety improvement at Mopti (Mali) for deep water and floating rice, at Rokupr (Sierra Leone) for mangrove swamp rice, and at Richard-Toll/Fanaye in Senegal for irrigated rice. Research on insect pests, diseases and weeds is conducted in conjunction with varietal improvement at these locations. Data and lines from these locations are to feed into the coordinated testing programme

Seed storage

The WARDA seed storage and processing laboratories receive, treat and distribute rice seeds for WARDA variety trials. It has facilities for testing for purity, germination, insects and diseases and includes seed cleaners, fumigators, drying and quality testing equipment.

Strict plant quarantine regulations in West Africa and the limited facilities at the Regional Plant Quarantine Station at Ibadan, Nigeria have hampered WARDA's programme on variety improvement. To overcome this difficulty and to ease the introduction of foreign rice materials into the region, the plant quarantine facilities at Ibadan have been expanded by WARDA to enable it to cope with the additional materials introduced.

A nursery farm has been started at the Suakoko Experimental Station in Liberia for first stage study of introduced varieties and for preliminary variety tests and variety demonstration plots. Seed multiplication for coordinated trials and maintenance of seed stocks for the germplasm bank and seed laboratory are also functions of WARDA's Suakoko nursery. In addition, it is utilized for training purposes for production specialists and field assistants.

Training

Field assistant training is conducted mainly in support of the coordinated trials. Additionally, there is training of senior research personnel for special research projects or for national research needs. A training centre has been established at Johnsonville, Liberia and training is conducted in French and/or English, with interpretation.

Management practices

Problem soils in the region, such as halomorphic coastal soils (Senegal, The Gambia and Nigeria) and those with iron or aluminium toxicity problems (Liberia, Sierra Leone and Ivory Coast) need good management particularly with regard to proper water control, and the use of resistant varieties. Soils on which rainfed rice is produced are the least productive mainly due to poor nutrient status and their vulnerability to drought conditions. This type of cultivation is also vulnerable to pest and disease attack. Coordinated fertilizer trials are attempting to solve some of these problems.

Deep water or floating rice cultivation is characterized by uncertainties of flood waters as related to planting time, damage due to heavy floods and loss of grain during harvest.

Management practices often reflect the historical development of rice culture in the countries. In most parts, rice cultivation is primitive and intensive rice cultivation, either with irrigation projects or large-scale land preparation by machines, is new.

Support to national research

There is no doubt that the WARDA regional coordinated trials will only have lasting impact in the region if the national research programmes are strong enough to support the trials properly and absorb relevant results obtained. Increased level of support to the coordinated trial sites will help in some ways to raise research capabilities of member states.

The assessment of the research needs of member states and how to overcome those needs is an important area of activity. A method for relaying research results from regional research activities such as the coordinated trials and special research projects to national rice production activities, needs to be established.

As part of the future activities at the international level, more cooperation with the international centres will be expected in the collection of African rice germplasm; in the conduct of IRRI-IRTP; in joint monitoring tours and in the training of senior research staff for national programmes.

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RICE RESEARCH IN SIERRA LEONE

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Rice Research Station, Rokupr, Sierra Leone

Introduction

The rice research station at Rokupr, Sierra Leone, was established in 1934 and is the oldest rice research station in West Africa. In 1953, it was expanded in order to deal with rice research for all the British West Africa colonies. Since 1962, however, it has concentrated its efforts on rice improvement in Sierra Leone.

As a result of adaptive research at various ecological sites in Sierra Leone, nine varieties were released by the Rice Research Station between 1971 and 1974. These are BD 2 and CP 4 (Will, 1971) and ROK 1, through ROK 7 (Will and Janakiram, 1975; Jones *et al.*, 1976a).

Varietal Improvement

Rainfed upland cultivation

ROK 1, ROK 2 and ROK 3 yielded as much as Anethoda, the former recommended variety (Table 1). However, the latter was susceptible to lodging and had red grains, in contrast to the lodging-resistant, white grained ROK varieties.

These three varieties have shown yield stability within Sierra Leone (Janakiram, 1975), although ROK 1 can be damaged by pale yellow mottle virus (Raymundo *et al.*, 1976).

The adaptability of ROK 1 and ROK 2 to the West African region has been reported recently by Das Gupta and Will (1976). Diarra (1976) identified ROK 1 and ROK 2 as the most promising varieties for upland cultivation under conditions in Mali, both yielding approximately 2500 kg/ha.

Mangrove swamp

Varieties ROK 4 (3877 kg/ha) and ROK 5 (4179 kg/ha) consistently out-yielded the standard variety, BD 2 (3758 kg/ha) and the local variety, Pa Bunch (2124 kg/ha) over four years. BD 2 and ROK 4, however, are susceptible to lodging. In terms of adaptability to the West African region, BD 2 and ROK 5 have been ranked the best two varieties for mangrove swamp cultivation

Inland valley swamp

Better varieties for the inland swamps when fertilized with $N_{67}P_{45}K_0$ were ROK 5 (4665 kg/ha) and RH 2 (4425 kg/ha), and the Rokupr hybrids C13.H.3, CJ.5.2, AASA.

Performance of varieties on farmers' fields

The value of a variety released by a research station is finally judged by its performance on farmers' fields. A series of farmers' field trials were conducted between 1973-1976. ROK 1, 2 and 3 on upland averaged from 1950 to 2160 kg/ha, which ranged from 35-50% above the local check. Farm trial yields were less than experiment station yields by approximately 15%.

Hybridization

In an effort to improve growth duration, grain yield, blast and pale yellow mottle virus resistance, a series of crosses was made in 1974. In terms of blast and pale yellow mottle resistance, the following crosses were made: Fossagbe x CP 4, OS 6 x ROK 1, Fossagbe x ROK 7, LAC 23 x Mange 2, Moroberekan x Mange 2, Gbongay x Mange 2, Dorado Precoce x Mange 2 and Juma 1 x Mange 2.

TABLE 1

Mean grain yield (kg/ha) and % response of some upland rice varieties to fertilizer applications at different locations after four years cultivation in Sierra Leone

Variety	Yield[a] Fertilized[b]	Yield[a] Unfertilized	Mean response	% response
ROK 1	2372	1424	948	66
ROK 2	2266	1441	825	57
ROK 3	2436	1549	854	55
IR20 (paddy type)	1382	764	618	80
Anethoda	2371	1663	708	42
Gbengbeh (local)	1131	955	374	39

a) kg/ha; b) Fertilizer: $N_{67}P_{45}K_0$

Crop Protection

Yield of improved varieties is adversely affected by the vagaries of the weather, and disease or insect attack. Since the weather cannot be controlled, intensified efforts

have been made to control disease and pest attack.

Plant pathology

Results obtained over the past three years show that of 1526 lines or varieties screened for leaf blast, 30% were classed as resistant. Based on multi-locational disease testing, the following conclusions have been drawn:

a) ROK 7, a station bred variety, has good resistance to leaf and neck blast; ROK 2 has good resistance to neck blast. Among the promising varieties, Ebandioulaye, G.C.23, G.C.28 and U 4 have general resistance to leaf blast; LAC 23, Fossagbe and Gbongay (a local variety) have general resistance to neck blast.
b) All station-recommended and promising varieties have intermediate to susceptible reactions to leaf scald.
c) Of 1180 introductions and collections, 161 were selected as promising on the basis of disease reaction, good plant type, desirable agronomic traits and yield potential (Anon, 1977a).
d) A previously unrecognized rice virus disease was described and named pale yellow mottle (Raymundo and Buddenhagen, 1976; Raymundo *et al.*, 1976); proof of its beetle - and mechanical - transmissibility were demonstrated; limited information on the properties of the virus, which is probably identical to RYMV described from Kenya, are now known (Anon, 1977a; Raymundo *et al.*, 1976).
e) A reliable method has been developed to screen for resistance to pale yellow mottle. By this method, 21 varieties or lines have been rated resistant or moderately resistant.
f) It has been confirmed that potassium deficiency is involved in the brown spot-akiochi complex on upland soils (Anon, 1977b).
g) A suspected virus disease, designated "crinkle", has been observed and investigated. Its cause is not yet determined (Anon, 1977a).

Entomology

Recent surveys indicate that *Stenocoris* spp., grasshoppers, *Diopsis* spp. and *Locris* spp. are the most widely distributed rice pests; *Chaetocnema* spp., *Aspavia* spp. and *Epilachna* spp. are less common. *Epilachna* spp. caused much damage at certain locations; this was also true for the caseworm. The beetle, *Chaetocnema* spp., is a vector of the newly described pale yellow mottle virus disease.

Preliminary findings indicate that Gantang and G.C. 14.3 appear to be more resistant to rice bug damage (*Stenocoris* spp.) than BP 24 and Nachin 11. CP 4, Faro 7, C.J.5.2, G.C. 23, Colombia 2 and Jaya appear to be more resistant to stem borer (*Diopsis* spp.) damage than Nachin 11, Par Com

En, RH 2, Ratna and TOS 2405. IR442 was found to be particularly susceptible to the rice bug. ROK 6 was observed to be quite susceptible to caseworm. The local variety, Flajueh, was found to be particularly susceptible to the army worm. Juma I, ROK 7, CP 4 and Mange 2 were found to be more resistant to *Locris* spp. than H.T. Moro, LAC 23, OS 6 and Moroberekan.

Preliminary results indicate that groundnut oil is superior to palm kernel oil, palm oil and coconut oil in controlling rice storage pests. Furadan was effective in controlling *Diopsis* spp. and borer damage.

Agronomy

Upland rice in Sierra Leone is grown on different types of terrain, including sloping land. Under the latter condition, erosion of soil is quite common. In 1976 an experiment was conducted to determine the effects of soil and water conservation measures on the yield of upland rice variety ROK 1 grown on sloping terrain. The soil and water conservation methods were bunding of plots, stumping and deep tillage. The data in Table 2 show that these soil and water conservation measures increased the yield of rice in the order of 280%.

Inland swamp rice production is severely hampered by iron toxicity. While recognizing the fact that a permanent solution to this problem may rest on varieties resistant to iron toxicity, interim measures must be found. In this regard, a series of experiments was conducted at Kenema and Magbolontor to observe the effects of soil amendments on the yield of two susceptible varieties.

TABLE 2

Grain yield (kg/ha) of ROK 1 as influenced by soil and water conservation measures adopted under upland conditions, 1976

Treatments	With soil & water conservation methods		Without soil & water conservation methods	
	Yield	% increase over control	Yield	% increase over control
$N_0P_0K_0$	695	-	222	-
N_{40}	945	36	269	21
$N_{40}P_{20}$	1316	89	401	81
$N_{40}P_{40}K_{20}$	1399	101	525	136
N_{80}	1310	89	586	164
$N_{80}P_{40}$	1563	125	518	133
$N_{80}P_{40}K_{40}$	1877	170	705	218

Liming improved yield (Table 3); the effect was more pronounced during the wet season at Magbolontor in soil where straw was removed; in contrast, the best yield response at Kenema was obtained with soils in which straw was burned.

Fertilizer application at $N_{80}P_{40}K_{40}$ in the presence of lime gave the best results at both sites. Of the three types of straw treatments, straw ploughed gave the lowest response in the presence of $N_{80}P_{40}K_{40}$. Application of balanced fertilizer (NPK) in the presence of lime would improve rice yields from inland swamps during the wet season.

In an accompanying pot experiment, the effect of various water regimes and fertilizers on iron toxicity was investigated. The results showed that waterlogging reduced yield markedly, whether or not phosphorus was applied.

TABLE 3

Mean response of rice to soil amendments (straw and liming) and fertilizer treatments, under inland valley swamp conditions

Treatment	Straw removed		Straw ploughed		Straw burned	
	L_0*	L_1	L_0	L_1	L_0	L_1
$N_0P_0K_0$	1497	1878	1465	1851	1598	2117
N_{80}	1671	2163	1534	2392	2076	2502
$N_{80}P_{40}$	1891	2426	2319	2371	2296	2603
$N_{80}P_{40}K_{40}$	2182	3121	2472	2624	2489	2965
Mean	1810	2397	1948	2296	2115	2547

*L_0 = without lime, L_1 = with lime.

Sources and levels of phosphorus fertilizer

Combined results of experiments in 1975 and 1976 at different locations for each agro-ecological condition showed that yield return from application of 22.5 kg/ha P_2O_5 was not different from that obtained from twice that level (with the exception of basic slag and Christmas Island rock phosphate in mangrove swamps). It is therefore concluded that, on continuously cultivated soils, a level of not more than 25 kg/ha P_2O_5 may be applied (Jones, 1976a). The data also suggest that all sources of phosphorus are equally good. Because of their soil ameliorating properties and cheaper prices, it is recommended that rock phosphates and/or basic slag replace the currently used single super-phosphate for rice cultivation.

Sources and levels of nitrogen fertilizer

Nitrogen sources having different dissolution rates were compared: Watersoluble ammonium sulphate (AS), urea (U), and four slow-release sulphur coated urea (SCU) mixtures. The trials were conducted on all agro-ecological rice

TABLE 4

Grain yield (kg/ha) in relation to source and level of nitrogen on inland valley swamps and bolilands

Ecology	Source[a]	Level of nitrogen (kg/ha) 34	67	134	Mean
Inland Valley	AS[b]	2140	1850	1480	1920
	U[b]	2500	2220	2520	2410
	SCU-10	2270	2660	2920	2620
	SCU-16	2580	2560	2440	2530
	SCU-20	2580	2550	2770	2630
	SCU-32	2730	2680	2520	2640
Mean		2470	2420	2600	
Bolilands	AS[b]	2020	1780	1700	1830
	U[b]	1750	1830	1690	1760
	SCU-10	2540	3160	2390	2700
	SCU-16	2270	2230	2250	2250
	SCU-20	2210	2340	2530	2360
	SCU-32	1890	1900	2260	2020
Mean		2110	2200	2140	

a) AS, Ammonium Sulphate; U, Urea; SCU, Sulphur-coated urea.
b) AS and U were applied in three split doses; all other were applied basally.

situations occurring in Sierra Leone. The results of inland swamp and boliland trials are shown in Table 4.

These results show that for inland valley swamps, ammonium sulfate is not as effective as the other sources of N. Among the slow release sources, there is no apparent difference. However, SCU-32 gave the highest mean yield (2643 kg/ha).

On the bolilands, the slow release nitrogen sources contributed to yield more efficiently than the soluble nitrogen sources. Among the SCU's, SCU-10 produced the highest yield at 67 kg N/ha.

The above results indicate that SCU could have a promising future in inland swamp and boliland rice cultivation. SCU, however, is about 20% more expensive than the conventional water-soluble nitrogen sources and studies on longer term residual effects would be required before it could be judged to be economical.

To date, SCU has not been as effective as ammonium sulfate or urea on the uplands. Results in the mangrove swamps have been inconclusive.

Micronutrient studies

To date, no significant responses have been obtained to S, Cu, Mn or Zn applied at various levels (Jones, 1976b).

However, Zn deficiency has been observed at an upland site cultivated for three consecutive years. Application of Zn at 5 kg/ha relieved this deficiency within a week.

Weed control

A major factor depressing rice yield is weed infestation; weed control trials have centred around the screening of herbicides since hand-weeding is time-consuming and costly. Weeds are particularly damaging to rice on bolilands and inland swamps. Weed control trials conducted in 1976 at Kenema inland swamp showed that application at 2-8 days after transplanting, of Propanil (1.2 kg a.i./ha) and Piperidine plus Triazine (0.6 kg a.i./ha) have yields of approximately 2800 and 2500 kg/ha, compared with 2300 from hand-weeded plots and 1800 kg/ha from unweeded plots. An ultra-low volume sprayer was used, enabling the dose to be reduced to 25% of that recommended.

Weeds common in rice fields are:

Mangrove swamp
Paspalum vaginatum
Imperata cylindrica (marginal)
Cyperus iria
Sphenoclea sp.

Inland swamp
Digitaria longiflora
Cyperus spp.
Pennisetum subangustum
Cyperus articularis

Upland
Ageratum conyzoides
Paspalum scorbiculatum
Panicum luxum
Eleusine indica
Pennisetum sp.

Boliland
Pennisetum subangastum
Cyperus articularis
Imperata cylindrica

Dry season cultivation of mangrove swamps

In an attempt to grow a dry season crop of rice on mangrove swamps, six-week old seedlings of salt-resistant varieties BD 2, ROK 4 and ROK 7 were transplanted on seven occasions, at two week intervals, commencing January 6, 1976. Chloride and pH values were determined throughout the experiment. Seedlings transplanted on January 6 and 20 respectively flowered and produced grains. Seedlings of BD 2 and ROK 4 transplanted on February 3 flowered but produced empty grains because the salt concentration was high at that time. Seedlings of all varieties transplanted after February 3 were severely affected by the salt concentration and many died. For successful cultivation of a dry season crop on mangrove swamps, seedlings must be transplanted before the third week of January. There are about 12,000 hectares of mangrove swamps in Sierra Leone. Thus, if all were double cropped, an extra 24,500 metric tons of paddy could be realized (Jones *et al.*, 1976b).

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TECHNOLOGY TRANSFER IN NIGERIA AND SIERRA LEONE

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Introduction

Although Nigeria and Sierra Leone are among the major rice producers in West Africa, they are not self-sufficient in rice and both countries import substantial tonnages. Rice is grown by 85% of Sierra Leonean farmers and it is the most important staple food (Anon, 1972). Demand presently exceeds supply and an annual growth rate of 6.5% in production has been suggested in order to achieve self-sufficiency (Anon, 1974a). In Nigeria, rice is the ninth-ranked food crop, but demand is increasing and it has been suggested that production should be increased by 11% to satisfy future needs (Anon, 1974b).

To overcome the widening gap between anticipated rates of growth in production and demand, Nigeria and Sierra Leone have initiated projects aimed at developing a field-tested, economically viable package of practices for raising rice yields.

The major constraints to high rice yields in Nigeria and Sierra Leone are:

1. Poor soils and poor management of fertilizer;
2. Poor weed management;
3. Poor water control under lowland conditions;
4. High labour requirement limiting all good crop husbandry;
5. Low availability of inputs such as fertilizers, pesticides, and credit;
6. Inadequate land preparation in swamps;
7. Minor element toxicities and deficiencies;
8. Low plant population due to wide spacing, low seed rate, and scattered or random planting;

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9. Diseases and insect pests;
10. Low yield potential of locally adapted varieties.

The National Accelerated Food Production Programme (NAFPP) in Nigeria is assisted by IITA, earlier under US/AID financing and now with Nigerian financing. It is divided into two phases. During the *pilot phase* improved varieties and cultural practices are tested on farmers' fields, and agencies to supply the required production inputs, storage and marketing facilities are developed. The *implementation phase* begins with an accelerated production campaign, during which seeds of high-yielding varieties, fertilizers, pesticides, and credit are made available to farmers.

In Sierra Leone, the "All Sierra Leone Coordinated Agronomic Trials on Farmers Fields" began in 1975 under the joint auspices of the IITA/Sierra Leone Rice Project and the Ministry of Agriculture and Natural Resources (MANR). The parent project is financed by UNDP/FAO. The objectives are to test recommended varieties against the local varieties under traditional and improved methods of cultivation and to develop fertilizer recommendations for various rice ecosystems. Also, the profitability of the traditional versus recommended methods of rice cultivation are being compared.

Unique Features of the Two Projects

Two important features distinguish the Nigerian and Sierra Leonean approaches from the conventional approach to research and extension. These features are an effective feedback of information linking researchers, extension workers and farmers through farm-level testing of varieties and other practices, and a crop-oriented training component for participating staff.

In both countries, the trials are supervised by extension agents from the Ministry of Agriculture and Natural Resources who have received intensive training in improved methods of rice production. On-farm trials provide researchers with a direct view of the practicability of their research, as a guide to future research, and for the adaptation of practices to meet the requirements of specific locations.

The main difference between the programmes of the two countries is that in Nigeria the on-farm work both tests a package and at the same time promotes it, whereas, in Sierra Leone, the on-farm testing is primarily research-oriented, with no organized promotional component. Thus, in Nigeria, packages are developed on experiment stations and taken directly into farm minikits and production kits* in a two-step process. In Sierra Leone there are three steps to the process, which are: 1) experiment station research; 2) on-farm research; and 3) promotion of on-farm tested research findings.

There are advantages to both approaches, but where experiment stations do not represent the farm situation, the danger is that promotional attempts are made with packages which are not sufficiently superior at the farm level. This has happened in the case of "improved" dryland packages in Nigeria. Also, in Sierra Leone the on-farm trials are revealing that no simple package is good for all areas and that considerably more on-farm research testing is required. The finding that experiment-station dryland rice research recommendations are not appropriate for ready use at the farm level has resulted in the development of new applied research activities aimed at solving the newly identified problems limiting dryland rice farm yields.

For irrigated and swamp rice, in Nigeria, however, the packages of practices were found superior to and more profitable than farmers' practices under farm conditions and they are generating considerable farmer interest.

Nigeria

The Nigerian NAFPP rice programme has completed three years of activities which included:

1. Testing of varieties, fertilizer levels, plant spacing or method of planting, and herbicide application through minikit trials in 15 states;
2. Testing for optimum profitable yield of selected minikit varieties in production kit plots;
3. Training of extension workers and farmers;
4. Providing feedback and direction for new applied research needs;
5. Establishing and guiding State steering committees;
6. Reviewing the results of the NAFPP trials at the end of the crop season and assisting the states in planning their programmes;
7. Multiplying seeds of minikit varieties;
8. Organizing an agro-service centre system to support the accelerated production campaign.

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*(opposite page) Minikit trials are simple, non-replicated trials conducted by farmers on their own farms. In the variety minikit trials, five varieties are compared to farmers' best variety under a set of recommended practices. Plot size for each variety is 10m x 5m. All inputs are provided free-of-charge to farmers. Varieties and practices found superior in minikits are tested in production kit plots (1,000 sqm size) which are expected to demonstrate to farmers the optimum yield they can obtain. The inputs are sold to farmers at a minimal cost.

Swamp rice

Varieties. The results of 340 swamp rice variety minikit trials conducted in 1975 and 1976 showed that four swamp rice varieties, TOS 78, IR8, TOS 42, and FARO 15, were superior in most locations to the standard variety SML 140/10. The trials were conducted under irrigated and non-irrigated shallow flooded swamps in four States: Benue, Plateau, Kwara and Niger. Earlier, in 1974-75 dry season, IR8 and TOS 78 out-yielded SML 140/10 while in the 1975-76 dry season, IR8 and IR20 (TOS 490) out-yielded the standard variety in one of two locations.

Of eight varieties tested under deep-flooded swamp conditions in 1976, FARO 15 out-yielded the standard variety FARO 8 (MAS 2401) in seven locations in one riverine State in the south.

The first 20 production kit trials conducted in 1975 generated great enthusiasm among farmers, convincing them of the economic superiority of the improved package of practices. Farmers obtained average paddy yields ranging from 3.8 t/ha (TOS 78) to 4.5 t/ha (TOS 42). The average gross margins obtained per hectare were ₦823 (US$1316) for TOS 78 and ₦1030 (US$1648) for TOS 42.

The 1976 results from 44 production kit trials conducted in three States under irrigated and non-irrigated shallow-flooded fadamas confirmed the profitability of the NAFPP swamp rice package of technology, with yields averaging 3.9 to 5.2 t/ha in two irrigation schemes and 2.5 to 5.6 t/ha in non-irrigated fadamas.

Fertilizer trials. The two varieties tested in the fertilizer minikit, TOS 78 and FARO 15, showed positive response to increasing nitrogen fertilizer levels up to 120 kg N/ha (Table 1). The currently recommended fertilizer rate is 80-30-30.

TABLE 1

Grain yields (kg/ha) of two varieties in 16 swamp rice fertilizer minikit trials in three States, Nigeria, 1976

		No. of	Fertilizer level (N-P-K) kg/ha			
State	Varieties	trials	0-0-0	40-30-30	80-30-30	120-30-30
Plateau	TOS 78	5	2315	3092	3318	4652
Benue	TOS 78	5	3466	4838	5321	6459
Gongola	FARO 15	6	2437	2788	3697	4113

Method of planting. Farmers compared the traditional method of dribbling seeds at random against dribbling in straight rows and against transplanting seedlings. Higher yields were obtained by using the two new methods of planting; 3.8 t/ha with transplanting, 3.3 t/ha with dribbling seeds in straight rows. Traditional dribbling at random gave 2.3 t/ha yield. Evaluation of the economics of the different methods is still needed.

The high yields which can be attained by growing rice on hydromorphic soils were shown during 1974 when IR20 averaged 5.9 t/ha and SML 140/10 averaged 3.3 t/ha in ten locations in western Nigeria. A great potential exists for increasing rice production in Nigeria by bringing under cultivation large tracts of unused hydromorphic lands (Moormann, Perez and Veldkamp, 1976).

Upland rice

Varieties. Results from 298 upland variety minikit trials conducted between 1974 and 1977, in seven Nigerian states showed that the standard variety OS 6 remained the best and most stable variety. However, in a few locations, FAROX 56/30, TOS 2300, TOS 2583, TOS 4020 and TOS 2578 gave higher yields than OS 6. OS 6 came originally from Zaire and is a cross between a Malagasy variety and a local variety from Zaire.

Fertilizer trials. Results of four upland rice fertilizer minikits conducted in 1976 in two States, Benue and Bendel, showed that the highest yields were obtained with the medium fertilizer level tested of 40-20-20, for varieties TOS 4030 and TOS 4019.

Plant spacing. In the rainforest zone of Nigeria, the plant-spacing recommended for OS 6 is 30cm x 30cm. Results from five spacing minikits conducted in Benue, Ogun and Ondo State confirmed that this spacing was optimum for OS 6 in the two States, Ogun and Ondo, which are situated in the rainforest zone. However, in Benue State under savanna and hydromorphic conditions, yields were increased by 400 kg/ha with a closer spacing of 25cm x 25cm.

Herbicides. Limited tests suggested that Propanil (STAM F-34) effectively controls weeds in upland rice in Nigeria.

Training/Communication

Rice production specialists were trained at IITA in Ibadan, at the National Cereals Research Institute, also in Ibadan, at the West African Rice Development Association, Liberia and at IRRI, Philippines. State extension specialists were trained in the new production technology. Farmers were introduced to the new varieties and techniques through a series of field days.

Special record books for each type of minikit and production kit trial were developed and printed. These record books contain simple, step-by-step instructions on how to conduct the trials and what data to record.

Research workers were encouraged to visit NAFPP trials to discuss yield constraints and identify areas for further research. Annual workshops were held at the end of each cropping season to review the results of NAFPP trials throughout Nigeria and to discuss research findings which may result in additional or amended recommendations for the NAFPP production kits.

Sierra Leone

In order to test the performance of varieties and suitability of production technology developed at the Rice Research Station at Rokupr on farmers' fields, four basic types of experiments were conducted in 1975 and 1976 in all 13 districts of Sierra Leone. These were:

1. Varietal trials to study the relative performance of recommended rice varieties under traditional and improved methods of cultivation;
2. Fertilizer trials to study the response of rice to nitrogen at optimum level of phosphorus and potassium;
3. Fertilizer trials to study the response of rice to potassium at optimum level of nitrogen, and
4. Fertilizer trials to study the response of rice to nitrogen, phosphorus and potassium in combination.

Upland rice

Cultivation methods. Newly recommended high yielding varieties were tested under improved and traditional cultivation practices in farmers' fields. The improved practices consisted of line sowing, application of uniform dose of 60-40-40 NPK and plant protection.

At a site near Rokupr, in the rainforest zone, the average yields in two years under improved practice were much higher than those under traditional practice (Table 2). The variety OS 6 out-yielded all others, and in the first year showed a four-fold increase in yield under the improved practices. In the second year, there was a reduction in yield of all the varieties under both practices. This may have been due to depletion in soil fertility and greater weed, pest and disease problems. Traditional practices in the second year resulted in very low yields, magnifying the comparative increase with improved technology.

Fertilizer trials. Response of upland rice to nitrogen: Various N levels were applied at individual sites for two years. Without N application the yield levels declined in the second year by about 33%. Responses to nitrogen application in the first year ranged between 658 kg/ha for 20 kg/ha N and 1331 kg/ha for 100 kg/ha N.

Responses to corresponding levels of nitrogen in the second year were less than half of those in the first year, with diseases influencing and compounding direct effects. Higher N levels were necessary to maintain productivity in successive years. Under bush fallow-rice, a response of 9 to 16 kg of grain per kg of N was obtained for levels ranging from 20 to 60 kg/ha N. Under rice-rice systems, although the average yield without nitrogen declined by 43%, responses to nitrogen were higher, ranging from 11 to 17 kg grain per kg of N applied at 20 to 80 kg/ha N.

TABLE 2

Yield (kg/ha) of upland rice varieties under local and improved methods of cultivation grown on the same site for one or two successive years, Sierra Leone

Variety	Bush Fallow-Rice 1975		Rice-Rice 1976	
	Traditional practice	Improved practice	Traditional practice	Improved practice
ROK 1	682	2465	153	700
ROK 2	1079	2788	198	1557
ROK 3	403	1945	-	-
OS 6	771	3256	188	787
LAC-23	-	-	148	1489
A X BG7.3	1015	2955	196	1033

Response of upland rice to balanced application of N, P and K: The results for bush fallow-rice, rice-rice, and rice-rice-rice cropping systems showed that although yield of unfertilized plots declined in the second year, fertilizer applications continued to give yield response. For example, responses to 80-40-0, 80-80-0, 80-40-40 and 80-80-80 fertilizer levels were higher by about 400 kg/ha or more in the second year compared to the first year. With third year rice, responses to different fertilizer levels declined somewhat. Further research is needed if rice productivity is to be maintained year after year on upland soils.

Inland swamps

The average yields of almost all varieties showed that fertilizers and close spacing raised yields significantly. Yields of CP 4 ranged from 1800 to 6000 kg/ha depending on location. RH 2, ROK 4 and ROK 6 also yielded well at more than one site. Generally, NPK at 40-40-0 or 40-40-40 gave as good a yield as 80-40-0. Higher levels of N, without also providing K, were not effective.

Boliland

All the varieties tested at three sites gave significantly higher yields under improved methods of cultivations than under traditional methods. The difference in average yields under local and improved practices for different varieties varied from 700 to 1300 kg/ha in Kenema from 2100 to 2900 kg/ha in Kono and from 1150 to 1450 kg/ha in Tonkolili. The local variety was as good as some of the improved varieties under both practices.

No significant differential response between 80-0-0 and 40-40-0 was observed in any district. In two districts application of 40-40-40 was found beneficial over that of 80-40-0. Potassium applied with higher levels of N and P enhanced the yields significantly at four sites. The application of N alone at 40 kg/ha showed significant responses in one district only. However, when N was increased to 80 kg/ha, significant responses were observed in four districts.

Mangrove swamp

All the varieties tried in Mayamba district gave higher yields under improved cultural practices than under traditional practices. The additional yield was approximately 1000 kg/ha for the local and ROK 5 varieties while SR-26 and ROK 4 recorded incremental yields of about 1400 kg/ha.

Significant differences in responses to NPK at 80-0-0 and 40-40-0 were not obtained. Addition of potassium to nitrogen and phosphorus enhanced yields significantly. A dose of 40 kg/ha K added to 80-80-0 increased yield by about 1100 kg/ha, while 80 kg/ha K added, increased yield by about 2000 kg/ha. Interestingly, there were no significant responses when nitrogen was applied alone at 40 and 80 kg/ha.

Economics

Economics of improved practices of rice cultivation. A rapid way to increase rice production is by adoption of improved agronomic techniques, especially fertilizer application to responsive varieties. However, it should be ensured that by adoption of improved techniques the farmer gets profitable returns on his investment. It is considered that a minimum benefit cost ratio (BCR) of two would be required before an African farmer might adopt improved measures. An economic study of data collected from on-farm trials is reported here. For calculating the benefit-cost ratio, the price of one kg each of N, P_2O_5 and K_2O was taken as 40 Leone cents, 50 cents and 25 cents, respectively. The price of one kg of rice paddy was taken as 20 cents, which is the average procurement price of rice by the Rice Corporation in Sierra Leone. The cost of inputs of fertilizers was deducted from the gross return (in the form of extra paddy) to obtain the incremental gross return.

The results presented in Table 3 show that under bush fallow-rice as well as under rice-rice cropping systems,

TABLE 3

Economics of improved technological practices over traditional practices under bush fallow-rice and rice-rice cropping systems, Sierra Leone, 1976

Variety	Bush Fallow-Rice			Rice-Rice		
	Extra yield (kg/ha)	IGR[a] Leones[c]	BCR[b]	Extra yield (kg/ha)	IGR Leones	BCR
Local	732	104	2.4	739	106	2.5
ROK 1	736	105	2.5	1244	207	4.9
ROK 2	857	129	3.0	1549	268	6.3
ROK 3	1180	194	4.6	1179	194	4.6
LAC-23	1358	230	5.4	1187	195	4.6

a) Incremental gross return; b) Benefit/cost ratio;
c) One Leone = US$0.85.

the farmer obtained a benefit cost ratio ranging from 2.4 to 6.3 by adopting improved methods of cultivation. The ratio increased with the use of improved recommended varieties. Results also clearly indicated that it was highly profitable to grow a crop of rice in the subsequent year. Indeed, if expenditure in clearing the bush in the first year were taken into account, the comparative return in the second year under rice-rice cropping system should be even higher than that obtained in the first year. Among the cultivars, LAC-23 showed the highest benefit cost of ratio of 5.4 Leones for every Leone invested in the first year.

Economics of nitrogen application. Under the present price structure, even a small dose of 20 kg/ha N applied in any one of the three cropping systems enabled the farmer to obtain a net return of five Leones and above for every Leone invested in nitrogen. The net return with higher levels was 8.6 for 40 kg/ha N, and it ranged from 3 to 7 for 80 kg/ha N and from 1 to 6 for 100 kg/ha N. In conclusion, it can be said that farmers can get a profitable return on improved recommended practices even if rice is grown successively for two years under upland conditions and even with as small a dose as 20 kg/ha N.

Economics of balanced application of N, P and K. The results obtained under upland conditions with different levels of N, P and K applied alone and in combination showed that nitrogen alone gave an incremental cost benefit ratio of 8.7 under rice-rice system as compared to 5.3 under bush fallow-rice system in the Rokupr area. The dose of 40-40-0 NPK was as good as 80 kg/ha N except in rice-rice-rice system. Application of 40-40-40 NPK gave a minimum benefit cost ratio (BCR) of 2.0; 80-40-0 gave less than 2.0 in the first and third year. With other fertilizer levels, BCR was comparatively low, although response was high. The most suitable fertilizer doses to give at least a minimum BCR of 2.0 are 40 kg/ha N where P and K are not deficient; a dose of 40-40-0 NPK where K is not deficient; and a dose of 40-40-40 NPK where all three are deficient.

Discussion

The Nigerian NAFPP rice project has completed three years of activity while the Sierra Leone Co-ordinated Agronomic Trials have been conducted for two years. During the initial testing phase, important information has been obtained which may be relevant to countries in tropical Africa contemplating similar agricultural projects.

1. On-farm trials are essential to test the practicability of research findings and to identify economically viable package of practices. The results should enable governments to decide whether or not to launch accelerated production campaigns, based on available knowledge and expertise.
2. On-farm trials provide researchers with feedback to influence their research priorities. This is probably one of the most valuable aspects of the on-farm testing and promotion conducted to date. These trials effectively link researchers, extension workers, and farmers.
3. Progressive farmers are provided opportunities to test on their farms the recommended cultural practices developed at research stations. In turn they themselves serve as agents of change in disseminating to other farmers field-proven cultural practices.
4. To assure the success of farm trials at many sites, there is a need for good planning, organizational and budget support, and above all, political support and commitment.
5. On-farm testing research should be developed, financed and controlled by a research organization and not be dependent upon multi-organizational agreements and committees.
6. The degree of success in obtaining accurate results depends upon the agricultural extension workers being well-trained and dedicated, and upon close supervision by the state and national staff. In addition, extension workers must be able to devote full attention to the project. As was experienced, most extension workers were not assigned on a full-time basis and most were responsible for many projects. Thus, trials were often poorly supervised.
7. Intensive crop-oriented courses are a necessary component of on-farm trials. They must include some theory as well as practical details of how to conduct trials and record data.

With these provisions, a successful programme which will result in higher national rice production and higher yields per hectare becomes a feasible proposition.

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FLOATING RICE IN MALI

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Introduction

Today rice is second in importance to sorghum and millet in Mali, in both tonnage and value. Approximately 195,000 ha are cultivated, of which 150,000 ha are floating rice in the central Niger delta in the Sahel. In order to increase the average yield of floating rice, better land management is required. The aim is to increase yields from 0.9 t/ha to 1.9 t/ha by 1982. A project with this objective has been undertaken in the Mopti area, where approximately 25,000 ha have been developed since 1972, and it is planned to develop a further 6000 ha by 1982. The highest and lowest flooded areas where successful cultivation is possible have been established.

Methods for Floating Rice Cultivation

The traditional methods for cultivating floating rice are hazardous because of their dependence on natural conditions, especially regular rainfall at the beginning of the season and flooding conditions with appropriate arrival, flow rate, magnitude and departure of flood waters. Farmers cultivate many plots at different sites to minimize the effects of these topographic irregularities.

Ploughing is a common practice, having first been introduced into the Mopti area about 1930. Ploughs were essentially the only equipment used prior to the Mopti Rice Project in 1972. Ploughing is done from early April to late July. *O.glaberrima* is broadcast in late June in low lying areas. In higher areas, where *O.sativa* (variety Indochine blanc) is found, sowing continues until early August. Bird damage is severe at this time; the seed is not completely covered.

The floods usually commence in August in the low lying areas. The water level continues to rise until October-November, with the maximum level being reached between

October 15 and November 15.

A single hand weeding is usually done before flooding and large weeds are again removed after flooding. The major weeds are the indigenous rices, *O.breviligulata* and *O.longistaminata*. Because of these rapidly growing weeds most fields must either be abandoned after several years or cleared of the wild rices.

In low lying areas, harvesting is done from a canoe or is delayed until after the floods recede. In the latter case, the yield is reduced because *O.glaberrima* is susceptible to shedding. Threshing is done in December-January in the high areas and up to March in the low lying areas, where it is necessary to wait until the soil is dry.

There are a number of factors which limit yield under these conditions. They include climatic factors (e.g. late rains combined with early flooding); damage by herds of animals, rice-eating fish, birds and rats; insect damage by borers (*Maliarpha separatella* and *Chilo zacconius*) and leaf-feeding bugs (*Brachmia* sp.); fungal diseases, especially blast, caused by *Pyricularia oryzae*, bacterial streak, caused by *Xanthomonas translucens* f. sp. *oryzicola*, weeds, particularly the wild rices *O.longistaminata* and *O. breviligulata*, and poor land management. Also, the traditional *O.glaberrima* varieties are low-yielding and do not respond well to nitrogen fertilizers. However, they do have good drought resistance and elongate rapidly during flooding. Their average yield is 800 kg/ha.

The flooding of the Niger and Bani Rivers is controlled by embankments to isolate the river from the plain, and by devices to delay the arrival of the flood into the rice fields. Flow is regulated to rise 5 cm/day, to a predetermined level and its fall is delayed later in the season.

Improvement Programme

Agronomic research has played an important role in devising techniques to improve floating rice cultivation. A research station to deal with floating rice was established at Ibetemi, near Mopti, in 1952. In 1962, IRAT-Mali commenced its research programme. Its aims were to restore the purity of seed for multiplication; select white-grained, high-yielding varieties adapted to floating conditions, and conserve a collection of floating species of *O.glaberrima* for further crossing. Projects which were added in 1971 were for improving cultural practices and identifying insect pests.

Varietal improvement

Varieties of *O.sativa* suitable for flooded conditions have been introduced since 1962 from Thailand, Vietnam, Pakistan, and more recently from Philippines (IRRI),

Nigeria (IITA) and Liberia (WARDA). After further tests at Mopti, a series of varieties adapted to various flooded areas in the delta have been identified. Their characteristics and yield potential are given in Table 1.

Crosses have been made between erect and floating types, such as D52-37 x Malobadian and Mali sawn x Phar Com En. The hybrids obtained have retained their floating characteristics, grain quality and the productivity of their parents.

Recently, varieties which have been grown since 1962, such as Malobadian, Nang kieu, Khao gaew, and Mali sawn, have been attacked by blast disease and borers in the Mopti basin. Resistance to these two factors is necessary for increased productivity since varieties already exist which yield well (4-5 t/ha) under good climatic conditions and fertilization.

Cultural techniques

Tillage is usually inadequate and this can significantly depress yield. Soil tillage may be done at the beginning or end of the crop season. The best results are obtained with tillage at the end of the crop, as soon as possible after harvest. This gives good control of *O.longistaminata*, the rhizome-forming wild rice, and allows the first rains in the following season to be conserved in the soil. This tilling may be supplemented by a second one at the beginning of the next season. Alternatively, all the tilling may be done after the first rains, just before planting. This is acceptable in areas without *O.longistaminata*.

A rough seed-bed is preferable to a fine one because it reduces the rate of overland flow and thus gives better water retention at a critical period. Shallow seeding (2 cm) is best on clayey soils. Depth of seeding is not as important on sandy soils. Hoe-weeding may be done prior to flooding in August. Weeding in water at the heading stage of wild rice, in October-November, is also desirable. Various machines for ploughing, seed-bed preparation, tilling, planting, hoeing and threshing have been compared and desirable modifications made. A Canadian-designed harrow was particularly useful.

Production Systems

Labour

The average family size in the Mopti area is ten members. More than 60% of the families have only one single couple. Thirty percent of the families have only one man. Since women are not involved in rice cultivation and children only help with tilling, the working population (men from 15-59 years of age) is 26% of the total. Many of the farmers are in the 40-70 age-group, and are somewhat

TABLE 1

Recommended floating rice varieties for Mopti area, Mali

Variety	Cycle (days)	Origin	Yield potential (t/ha)	Susceptibility Blast	Susceptibility Borer
very early					
Malobadian	145	Guinea	3.5-4.0 M[a]	H S[b]	1[c]
Maliong		Thailand	3.0-3.5 D	H S	1
early					
Malirat DM 16	150-155	Mali	2.0-2.5 SH	M S	2
(IRAT 17)			4.0-4.5 M	H S	2
Malirat DM 17			2.5-3.5 D		
medium					
Cula	155-165	Vietnam	3.5-4.5 M-D	S	2
Indochine blanc		Vietnam	4.0-4.5 M-D	M S	1
FRRS 43/3		WARDA	3.5-4.0 M	S	2
T 442 90		Thailand	3.0-3.5 SH	S	2
T 442 36			4.0-4.5 D	S	2
late					
Malirat MSP 10	165-175	Mali	2.0-2.5 SH	S	2
Malirat MSP 11		Mali sawn x	3.5-4.0 M	S	2
(or IRAT 16)		Phar Com En	2.5-3.0 D	S	2
Khao gaew		Thailand	4.0-4.5 M-D	S	2
Nang kieu		Vietnam	4.0-4.5 M-D	S	2
Neang kheaw		Thailand	3.5-4.0 M-D		
Puang N'Gern		Thailand	3.0-3.5 D		
			3.5-4.4 SH	M S	2
very late					
Mali sawn	175-185	Thailand	4.0-4.5 D	S	2
Khaq nahng nuey		Thailand	3.0-3.5 D	M S	2

resistant to change. Extra labour is employed for harvesting and threshing. However, there is a labour shortage, which makes it difficult to obtain adequate weed control.

Production factors

A socio-economic survey in 1975 characterized the existing system. The average farm size was 2.8 ha with 1.2 ha dry cropped. About 50% of the farms had ploughs, 6% had harrows. Mopti South had larger farms and lower yields than Mopti North. Equipment for seed-bed preparation is not widely used. The calendar of cultural operations in the Mopti area is given in Table 2.

Detailed studies of the number of man-days required for various tasks were made to compare different production systems. In the traditional system, the only equipment used was a plough, all other work was done by hand. In Mopti South, the average farm size of 4.0 ha was too large for the two men who worked on it. The time spent on various operations was: Tillage, 22 days (often done by children); weeding, 52 days (poorly done without extra labour); harvesting and threshing, 121 days (with extra labour). In Mopti North, the farms were smaller, but weeding was inadequate and invasion by wild rices was a problem.

Alternative systems

Two systems had previously been recommended in the area. In System 1, double tillage, with one tilling late in the season was recommended to control wild rices. Two harrowings were recommended, one before and one after planting. Harvesting and threshing were mechanized. Extra labour was required for tilling and harvesting.

In System 2, mechanical sowing was done, which eliminated one harrowing. Two weedings were made and urea fertilizer was added. However, farmers found it difficult to complete the recommended two weedings and still have sufficient time for harvesting and other operations.

The system recommended by the Research Station reduced the number of working days by replacing the second tillage with a harrowing, using a Canadian-designed harrow and by the introduction of mechanized hoeing which gave better control of wild rices. However, even with this system, the farm size in Mopti South was still too large to enable all

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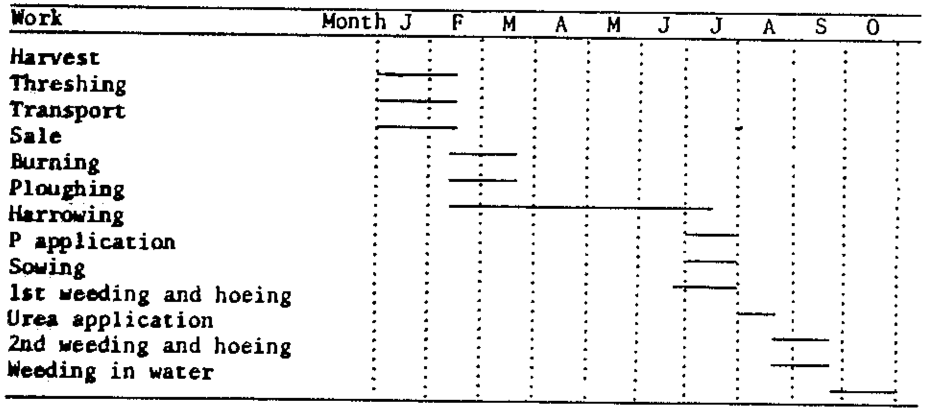
Footnote to Table 1 (opposite)
a) SH = shallow water depth (less than 40 cm), M = medium (40-80 cm), D = deep (80-150 cm); b) HS, S, MS = highly susceptible, susceptible and moderately susceptible; c) Borer, 1 = slight, 2 = moderately susceptible.

TABLE 2

Calendar of cultural operations in Mopti area



operations to be conducted at the appropriate time. It was recommended that the farm size should be reduced for greater efficiency. The system was practical for Mopti North, with the addition of extra labour at the end of the season for ploughing, harvesting and threshing.

Conclusion

Floating rice cultivation is important in Mali both in terms of the area under cultivation and the development work in progress. Suitable varieties have been provided for farmers. Various production schemes have been devised to utilize the available labour to best advantage. The major constraints are labour shortage and competition with weeds, mainly wild rices. The systems which incorporate two ploughings and hand-weeding are time-consuming and are unlikely to be widely adopted. The wider adoption of simple equipment, such as the Canadian-designed harrow, should give better weed control and so increase yields to the level of 2.0 t/ha planned for 1982.

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RICE CULTIVATION UNDER HYDROMORPHIC CONDITIONS ON THE SANDY GREY SOILS OF THE LOWER SLOPES IN SENEGAL

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Introduction

The grey soils of the lower slopes in Casamance, Senegal have unfavourable physical and chemical properties, such as coarse texture and low nutrient status, which seemingly offer severe restraints for rice cultivation. Neverthe-less, rice is traditionally cultivated on these soils in Senegal although yields are generally low. It has been shown, however, that it is possible to obtain relatively high and stable paddy yields on these soils, i.e. from 2-5 t/ha (Bertrand, 1970; Seguy, 1970; Valléhe, 1971). This is related to the presence of temporary shallow ground water at the end of the wet season (Bertrand, 1970, 1973; Bertrand and Forest, 1973; Guillobez, 1973).

Similar hydromorphic grey sandy soils of the depress-ions are common throughout tropical Africa, both in regions dominated by arenaceous sedimentary formations (Senegal, Guinea-Bissau, Mali and Niger), and in Pre-cambrian basement complex regions, dominated by acid and intermediate crystalline rocks, such as granitic gneisses (Ivory Coast, Cameroon, Kenya, etc.).

Hydropedological Characters

The *grey soils* should be defined in the framework of their position in a toposequence, rather than by the study of an isolated soil profile or pedon.

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Pedological characteristics

On the higher parts of the landscape under study, slightly desaturated ferrallitic soils (Ferralsols*) and redish, hydromorphic, ferruginous tropical soils with an argillic horizon (Gleyic, Luvisols) are observed. On the slopes, outcrops of ironstone pans (Petroplintic Regosols) are found, as well as slightly desaturated brown ferrallitic soils (Ferralsols), followed by sandy grey albic soils with deep gley (Gleyic Podzols) and lastly, clayey to loamy hydromorphic soils with gley at shallow depth (Drystric Gleysols).

Soil profiles of the sandy *grey soils* often show the following horizons:

a) Sandy to sandy loam horizon, low in organic matter with signs of reworking due to surface colluviation.
b) Sandy white albic horizon with massive single grained structure, analogous to an A_2 horizon of a Podzol.
c) Sandy, reddish, often discontinuous horizon, similar to a B_{Fe} horizon sometimes passing laterally to a discontinuous iron or iron-humus pan (Placic horizon).
d) Underlying medium textured (coarse to fine loamy), mottled material.

The physio-chemical properties of the soils are:

Bulk density	:	1.4 - 1.5
Real density	:	2.6 - 2.7
Porosity	:	40 - 45%
Clay	:	1 - 15%
CEC	:	0.5 - 2 me/100 g soil
pH	:	4.5 - 6.0
C	:	0.3 - 1.0%
N	:	0.03- 0.11%

Hydrological characteristics

The hydrology of the *grey soils* was studied by series of piezometers at Karcia in Casamance placed along fifteen toposequences. Hydrological profiles were determined, and associated crop test plots were established.

Dynamics and origin of groundwater

The study showed that a strongly oscillating groundwater level existed in the *grey soils*. This level rose abruptly a few days after heavy rains (Figure 1). The study of the hydrological profiles showed that the groundwater rose without being directly fed by the vertical infiltration of rainwater. The groundwater increase may

*Classification according to the FAO/UNESCO soil map of the world; legend is given in brackets.

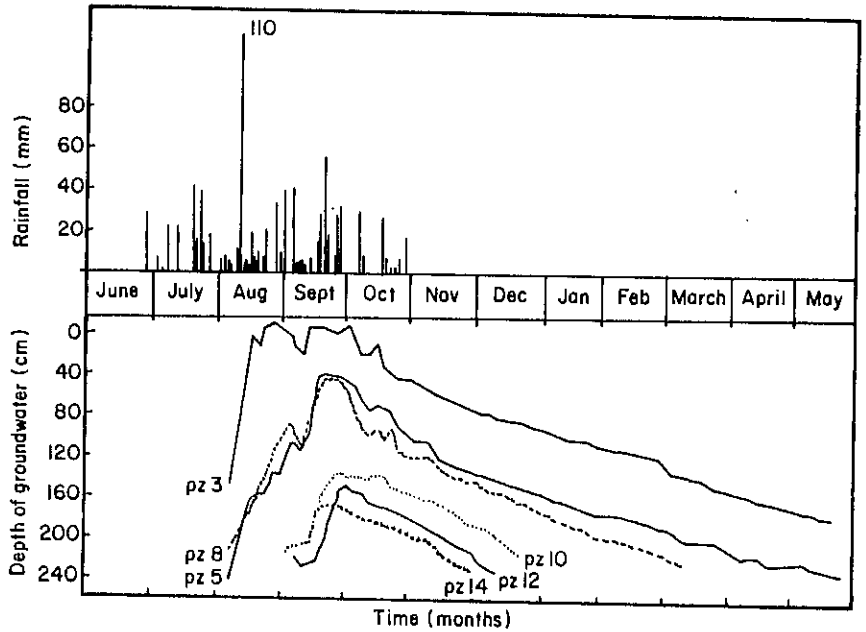

Fig. 1. Rainfall and depth of groundwater at different times and distances from the river at Casamance, Senegal.

reach three times the volume of the rainwater at a time when the wetting front in the higher part of the grey soils was still considerably above the piezometric level. After the end of the rains, the groundwater level fell slowly and regularly at the rate of about 1 cm/day.

This localized rapid rise in the general groundwater level appeared to be fed by an important lateral interflow through permeable horizons of ironstones (petroplinthites) and the B_{Fe} horizons (plinthites) associated with them. The interflow water most likely came from the rapid infiltration of rainwater through the permeable, gravelly horizons of the iron pans situated at the border of the higher plateau.

Dynamics of the groundwater table and rice cultivation

The soil association which, in this paper, is comprised under the term *grey soils* includes from the side of the valley to the valley bottom respectively, the soils named brownish slope soils, the sandy to coarse-loamy grey soils (*sensu stricto*) and the fine loamy to clayey soils which are pleyed throughout. According to the topographic positions in the cross section of the valley, and to the nature of the grassy vegetation (Merlier, 1973), in particular rice, the following zones can be distinguished (Figure 2):

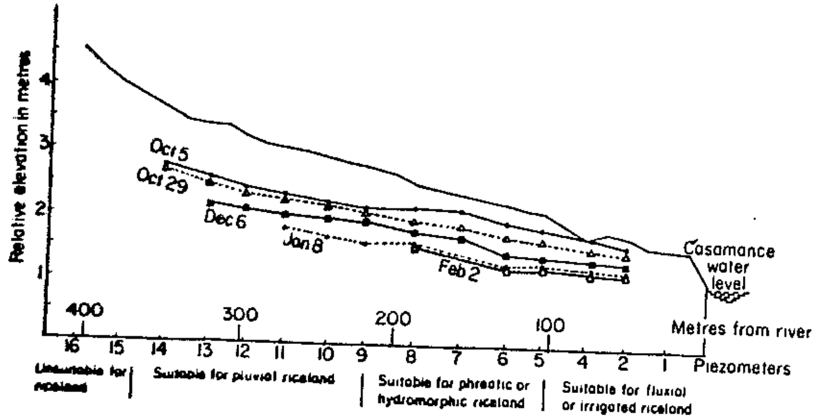

Fig. 2. Dynamics of groundwater levels at Karcia, Senegal (Schematic: Horizontal scale 1:2000, vertical scale 1:50).

- a higher zone, where the groundwater level is always too deep, even during heavy wet seasons, to be within reach of the rice roots. This zone with restricted availability of groundwater is characterized by a plant association with *Andropogon pseudapricus, Loudetia annua, Oldenlandia pinearis, Scleris pergracilis*. Rice cultivation is not advisable;
- an intermediate zone with shallow groundwater in the rainy season, even during dry spells. The effect of capillary water is continuous in the rooting zone and rice is thus not affected by rainless periods towards the end of the growth cycle. This zone of moderate availability of groundwater is characterized by a plant association, comprising *Parahyparrhenia perennis, Schizachirium brevifolium, Sorghum pinnatum, Spilanthes uliginosa*. The zone has a good potential for rice cultivation, giving regular yields;
- a low zone of more clayey soils, where groundwater remains at the surface or at shallow depth from the beginning of the booting stage of the rice, when regular water supply is most essential. Here, no shortage of water occurs and maximum rice yields can be obtained. No submergence occurs in years with a lower than average rainfall, while temporary shallow flooding occurs in wet years, due to rising groundwater. These rice fields with complete water saturation towards the end of the rainy season, can mostly be direct-seeded. The zone of high availability of water is characterized by plant association with *Hyptis spicigera, Ischaemum rugosum, Jussiaea linifolia, Paspalum ascrobiculatum*. The zone has a high potential for rice, with an assured, regular yield.

Agronomic Characteristics and Utilization of the *Grey Soils*

Performance of rice

Traditional rice culture of these soils is very extensive, but in general, the yields are low. However, with good cultural practices, yields in this low zone are higher than those on the neighbouring plateau soils (3-6 t/ha versus 2-3 t/ha).

It has been shown that there was a distinct yield gradient associated with the depth of the groundwater. In the high zones, there was complete crop failure (Bertrand, 1973; Bertrand and Forest, 1973; Guillobez, 1973). The yields were regular in the lower zones in which rice was not subjected to drought stress.

There was high production under favourable hydrological conditions, even without application of fertilizers. Fertilizer responses were, however, significant, as shown in Table 1 (Siband and Diatta, 1974). Undoubtedly there is a distinct interaction between groundwater and soil fertility.

TABLE 1

Relative effect of N, P and K in grey soils and soils of the plateau on rice yields, (in kg/ha at 15% water content of the grain)

Soil area	Response to N		Response to P		Response to K	
	0 N	37.5 N	0 P	$30P_2O_5$	0 K	$30K_2O$
Grey soils	3000	4620	3690	4650	4090	4500
Plateau soils	840	1720	1090	2290	2220	2200

Analysis of agronomic characteristics

The *grey soils* are heterogeneous, but frequently sandy and of too low nutrient status i.e. low in organic matter and mineral reserves and with a low pH (Bertrand, 1973; Siband, 1976). Studies on mineral deficiencies showed them generally to lack P, K, Ca, Mg and minor elements (Siband and Diatta, 1974). They had a low waterholding capacity and a rapid permeability. Under these conditions, the soils tended to behave as an inert growth medium with little power to provide plant nutrients, but with virtually complete availability of introduced water and nutrients.

Undoubtedly, the presence of the groundwater is essential for water supply and possibly also for plant nutrient supply, because it eliminates the hazards at the end of the growth cycle, and it permits the efficient use of absorbed nutrients during the period of maximum need, thus increasing production of vegetative matter and grain (Table 2).

The groundwater also helps to increase the availability of mineral elements, especially K, by improving the solu-

TABLE 2

Comparative efficiency of N, P and K on grey soils and soils of the plateau

Soil area	Production of dry matter per kg of: N	P_2O_5	K_2O
Grey soils	143	396	83
Plateau soils	122	311	85

tion/colloid relationships and the rooting, especially in the thick capillary zone. It can also reduce the hazards of toxicity caused by Al^{3+} and Mn^{2+}, soluble at low pH values.

With the lowering of the redox potential, the conditions approach those in flooded rice fields, which, *inter alia*, explains failures of crops such as maize, susceptible to lack of oxygen in the soils. Manganese uptake is reduced, while non-symbiotic nitrogen fixation in the root zone is enhanced.

Rapid percolation of the groundwater depletes the soil and soluble nutrients are not retained. Thus, for example, there is no residual effect of applied N. However, the same rapid percolation causes an inflow of nutrients from the higher parts of the landscape by interflow and this may explain the satisfactory crop performance even when no fertilizers are applied.

The seasonally variable nature of the groundwater in the root zone creates an environment in which the soil fertility varies during the growing season. *Grey soils* are therefore seasonally fertile, and the agronomic characteristics of the soils as a whole are mainly determined by the groundwater rather than by soil properties *per se*. Crop choice, production constraints, and management aspects, are determined by these hydrological characteristics.

Management and land use on grey soils

Periodic water saturation is the reason why most dryland crops tried on the *grey soils* failed and why monoculture of rice proved to be a superior crop for utilization of this type of land. Soil productivity increases in the years following the establishment of the rice fields. This may be due to an increase of mineralizing organic matter, associated with the establishment of a microflora favourable to rice, and an increase in N fixation (Table 3).

Rice growth is initially dependent on rainfall, until the groundwater has increased, and this can be hazardous. Soil management practices, which can overcome these initial hazards include suitable seedbed preparation, (which however remains to be defined) and the application of organic matter in the surface horizons (Seguy, 1970).

TABLE 3

Rice yields, as related to duration of cultivation (no N applied)

Duration of cultivation	1973 1 year	1973 2 year	1974 1 year	1974 2 year	1975 1 year	1975 2 year
Yield in kg/ha	2345	3940	2045	2810	2000	2300

The beneficial effect of adding straw may be due to the stimulation of biological activity, regularisation of the mineral supply and increase in water holding of the soil. Nevertheless, initial application of N will significantly increase yields.

Early weeding is important in a soil with abundant weeds and low moisture. The second weeding should not be too early, as this would allow further weed growth before the crop can cover the ground. Early planting is less indicated on the freely drained soils of the plateau, because harmful drought stress may occur in the period before the rainfall becomes reliable (Siband, 1976).

The question of split application of N, common in rice cultivation, and K, has been raised in view of the danger of losses and it was shown to be beneficial. However, N application at planting is essential. It appears that the rice, once established, can utilize additional sources of N. Single application of N at planting can give yields from 3.1 to 3.2 t/ha, while split applications can increase yields up to 3.8 t/ha. On the other hand, yields of over 4 t/ha on land, cultivated to rice for 5 years without N fertilization have been observed with a single application at planting of 15 kg N/ha.

As shown by Gouzes (1961), the groundwater in the region contains measurable quantities of nitrates. The NO_3 content may be 150 mg/l, sometimes increasing to 600 mg/l at the end of the rainy season. Under these conditions it might be assumed that, early in the growth cycle, rice roots take up the soil N and the N provided by the early fertilizer application. Once the water table has reached the root zone, nitrogen is taken up directly from the capillary water. The origin of the N in the groundwater is undoubtedly related to N leaching from the soils at a higher elevation, from where the groundwater is fed by interflow.

A further study of the different sources of N should be carried out, i.e. N provided by groundwater, N available in the soil (very restricted) and N provided by fixation which is dependent on the organic matter status and the microflora of those soils.

In 1976, it was found that a split application of K gave an increase of approximately 1 t/ha over a single application at planting. No significant differences were found between several methods of split applications.

The agronomic constraints of the *grey soils* are different, but less severe than those of the freely drained soils of the Casamance plateau. On the *grey soils*, possibilities exist for the introduction of high-yielding varieties, adapted to better soil water availability and to the dynamics of *N* supply.

Nevertheless, various production determinants remain to be studied, such as long-term development of nutrient deficiencies, increase of weed growth, use of herbicides in seedbed preparation, etc. Cultivation of the *grey soils* has now been continuous for eight years and apparently has not had major deleterious effects.

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CHEMISTRY OF FLOODED SOIL IN MARINE ALLUVIUM OF THE CASAMANCE, SENEGAL, AND ITS RELATION TO RICE GROWTH

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Introduction

This paper describes the chemistry of soils in the coastal plain of the lower Casamance river estuary in Senegal. Previous studies (Vieillefon, 1974) have revealed close relationships between chemical characteristics of the soils and their location in the landscape. Two variables, hydromorphism and salinity, are of great importance for a better understanding of soil conditions, and consequently for the introduction of improved agricultural management techniques. Lack of knowledge of the edaphic environment has led to serious failures in land development, especially for rice. The present paper analyses the variations in physical and chemical soil conditions due to seasonal flooding and the importance of these variations for the growth of rice.

Materials and Methods

The studies were carried out by means of pot experiments, using the 0-20 cm soil layer from selected soil sites, according to the landscape (Figure 1). This figure summarizes the various landunits which together form the landscape of the area studied.

In the toposequence, profile site Dj 1 represents a well drained soil on Plio-Pleistocene terrace sediments (continental terminal); it is outside of the recent alluvial plains.

Profile site Dj 2 is situated on the transition between the plateau and the valley; this soil is developed on old alluvial and colluvial sediments. The soil is somewhat hydromorphic.

The profile sites Dj 3 to 7 are situated in the recent alluvial plains, in which two vegetation *facies* can be distinguished, i.e. a saltflat (*tanne*)* facies, high in

*We use the word "*tanne*" for this physiographic unit throughout this paper.

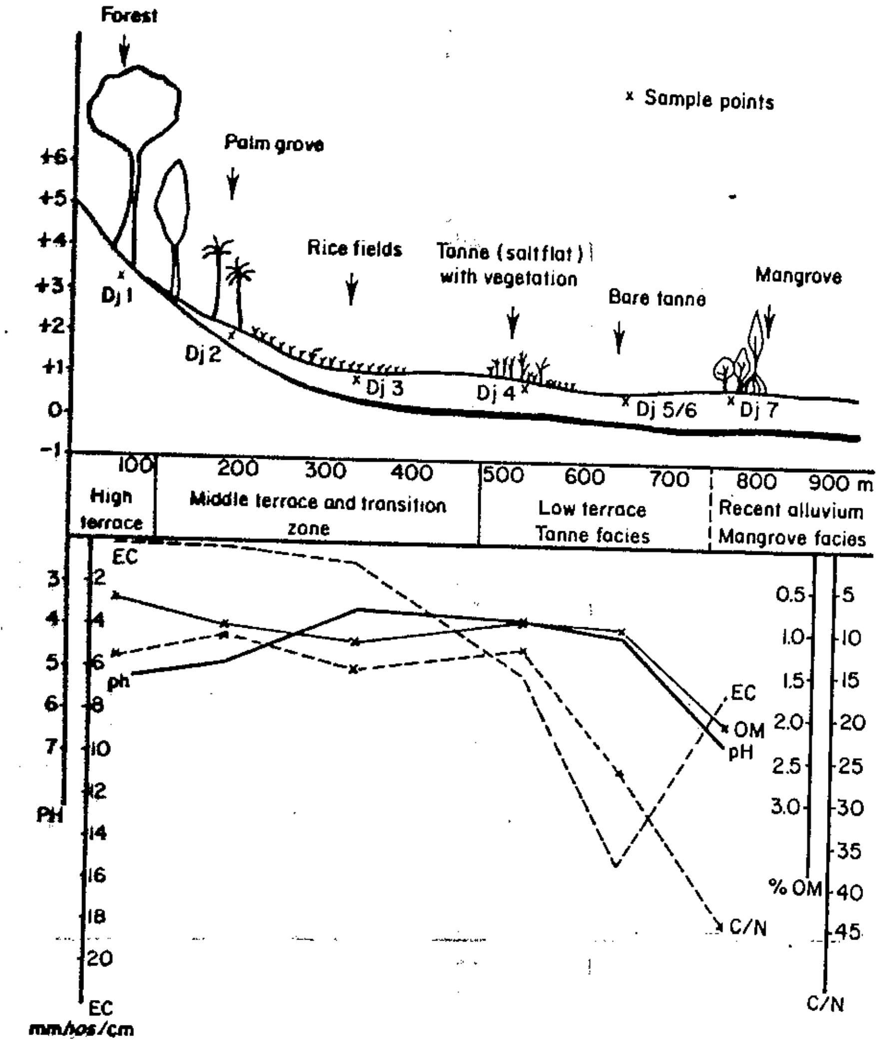

Fig. 1. Schematic cross-section of the landscape.

salinity and strongly acid, and a mangrove facies.

Profile site Dj 3 represents the higher and oldest part of the *tanne*, presently in use for riceland. Soils are strongly acid and retain some salinity.

Profile site Dj 4 is on a transitional type of *tanne*, with a vegetation of Cyperaceae and Graminae. Soils are acid sulphate soils, with a high NaCl content.

Profile sites Dj 5 and Dj 6 are on bare *tanne*. In order to evaluate the influence of rains on the level of salinity, samples were taken at the beginning and end of

the rainy season (samples Dj 5 and Dj 6 respectively). The soils are characterized by a very high NaCl content, but under field conditions, they are less acid than the soils at site 4, and have a lower sulphate content.

Profile site Dj 7 is representative for the mangrove *facies*; in the particular site, *Avicenia nitita* is dominant. The *in-situ* soil is only slightly acidified, while the salinity is distinctly lower than in the adjacent bare *tanne* area. These soils are hydromorphic and predominantly sandy.

Analytical data of the sampled soils, except Dj 6, are given in Table 1; it should be noted that the drying of the samples has led to a certain degree of acidification and a change in salinity, as compared to field conditions. Soil analysis on the samples were carried out, using conventional methods (Black *et al.*, 1975; IRRI, 1973). Ten kilograms of each sampled soil were placed in plastic pots which were provided with a drainage tube, from which samples of the soil solution were obtained under a nitrogen atmosphere at regular intervals. Pots were submerged with demineralized water and placed in a waterbath to maintain a constant ambient temperature for all soils. Each pot received a fertilizer treatment, equivalent to 100 ppm N, P, and K, while additional doses of 30 ppm N were applied, one month after planting and at booting state. The pots were planted with 21 days old seedlings of IR8.

Analyses of the soil solution included:

- pH and Eh under N atmosphere with a Pousel pH meter
- EC, measured simultaneously, with a CENCO conductivity bridge
- Iron, manganese and zinc by atomic absorption spectrophotometry (P.E. 304)
- Aluminium by colorimetry (Eriochrome method)
- Oxidizable and reducing substances by the American Public Health association method, modified by Ponnamperuma *et al.* (1966)
- Bicarbonates and organic acid by titration
- Sulphates and phosphates by turbidometry and colorimetry (spectro-photocolorimeter stand)
- Total and ammoniacal nitrogen
- Silica by colorimetry, modified ORSTOM method. Plant tissue analyses of the flag leaf at booting and 50% flowering were carried out, determining Fe, Zn, N, P, and Si according to Yoshida *et al.* (1971). The same determinations were made on straw and grains at harvesting.

Results and Discussion

Kinetics of electrochemical properties under flooding pH. In general, submersion leads to an increased pH with time, (Figure 2b). The least increase upon flodding is noted for the soils on old alluvium and colluvium (Dj 1 and

TABLE 1

Analytical properties of the soils

Landscape position	pH	EC m ohms/ cm	%OM	%C	%N	C/N	Soil properties % Granulometry clay	fine salt	v.fine sand	fine sand	coarse sand	% soluble salts $SO_4^=$	Cl^-	Na^+	K^+	HCO_3^-
Dj 1	5.4	0.1	0.7	4.0	0.3	14.2	9.1	4.4	7.1	46.5	32.8	0.06	0.56	0.52	0.02	0.24
Dj 2	4.9	0.1	1.0	5.6	1.0	6.4	19.7	21.4	6.5	25.5	26.8	0.06	0.25	0.56	0.02	0.12
Dj 3	3.6	1.2	1.2	6.8	0.4	14.9	11.1	8.3	19.3	42.4	17.4	0.06	2.25	4.56	0.02	0.24
Dj 4	3.9	6.0	0.9	5.2	0.4	12.5	23.4	7.0	6.0	33.3	30.2	0.75	9.91	26.95	0.25	0.30
Dj 5	4.6	12.8	1.0	5.6	0.2	26.6	12.1	8.3	13.9	27.0	38.7	0.40	25.80	60.0	0.78	0.24
Dj 7	3.2	15.0	2.1	12.2	0.3	43.5	9.6	2.1	0.7	41.4	45.5	5.24	10.73	28.69	0.11	0.25

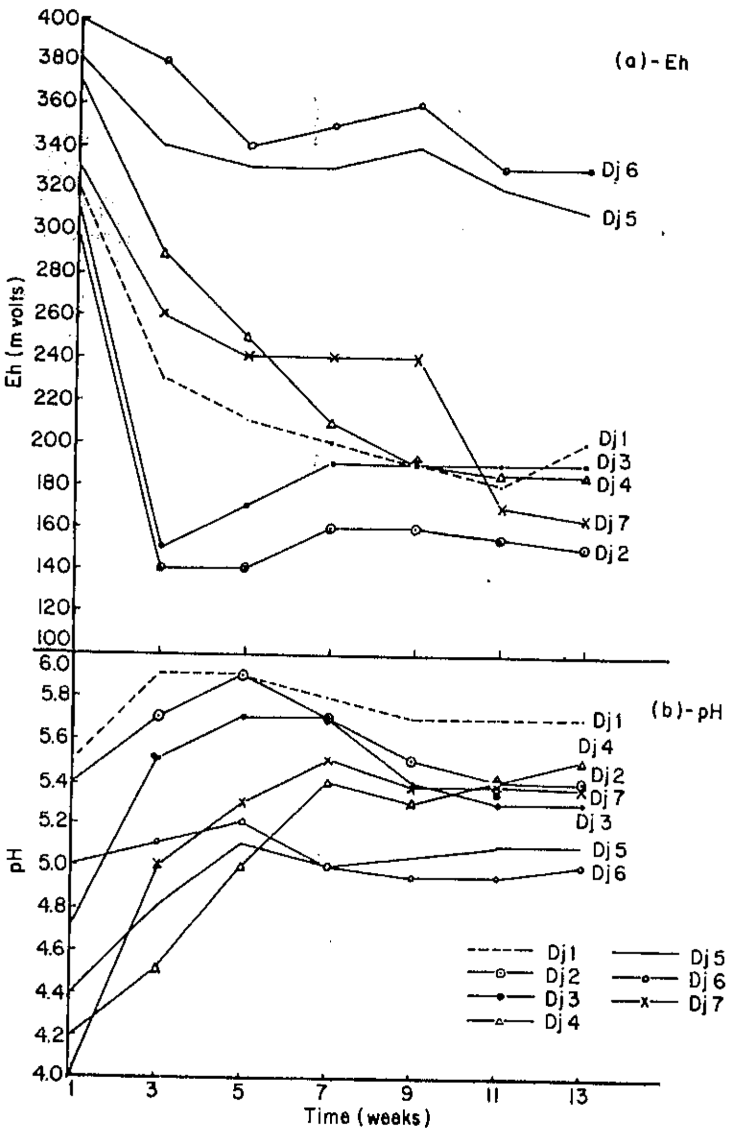

Fig. 2. Evolution of redox potential (E, m volts) (a) and pH (b) against time (weeks) at different sites (Dj 1-7).

Dj 2), and, at a lower pH level, for the soils from bare "*tanne*" (Dj 5 and Dj 6). In the group with a strong increase the pH goes up most rapidly in mangrove soil (Dj 7). For this pyrite (FeS_2) containing soil, the initial drop in pH upon drying was strongest due to oxidation and hydrolysis of the pyrites. The processes involved were described extensively by van Breeman (1976). pH levels in samples Dj 5 and Dj 6 remain reasonably constant after flooding because of the stabilizing influence of compounds such as jarosite and aluminium sulphate. In the more developed soils of the *tanne* (Dj 3 and Dj 4), the kinetics of the pH is transitional to those of the older soils (Dj 1 and Dj 2) which corresponds with data from the literature (e.g. Ponnamperuma, 1955). The soils on old sediments (Dj 1 and Dj 2) are less acid because of absence of acidifying compounds such as FeS_2.

Redox potential. Generally, the redox potential shows a considerable drop after flooding (Figure 2a). The initial drop is rapid, reaching its lowest level within 2 weeks for the Dj 2 and Dj 3 samples, and is least pronounced on the two samples of the bare *tanne* (Dj 5 and Dj 6). Various mechanisms for the differential behaviour of the Eh in the different soil samples should be considered; one of the more important is the variation in micro-biological processes and the difference in initial levels of ferric oxides and organic matter.

A significant negative correlation exists between pH and Eh values, except for sample Dj 6.

EC. Under field conditions, the EC increases from the plateau soil (Dj 1) to reach a maximum in the bare *tanne* sample (Dj 5), taken before the beginning of the rainy season. The range is from 2.5-5 m ohms/cm at 25° (samples Dj 1 and Dj 2) to 120-136 for the bare *tanne* (Dj 5) with a slight drop to 105-120 in the mangrove (Dj 7). Under submergence, a distinct lowering of the EC values takes place in all soils. The decrease in EC values is gradual in the not or slightly saline soils (Dj 1, Dj 2, Dj 3). For most soils, a significant positive correlation exists between EC values, and Eh. However, the correlation coefficient was not significant for sample Dj 6.

From the data on the physio-chemical soil properties and their kinetics, the division of the area into two different zones is clear. Interpretation of the data on electric conductivity allows separation into a non-saline zone with soils on older sediments and a saline zone with soils on recent marine or fluvio-marine sediments. The area where rice is grown at present is largely limited to the non-saline zone, and extends in the landscape only to the point where neither salinity or soil acidification are severe environmental constraints.

Reduction and development of toxicities

Evolution of sulphates: Sulphates are present in the lower part of the landscape, starting with profile site Dj 3. Evolution over time in the experiment are given in Figure 3; in all cases an initial increase of sulphate concen-

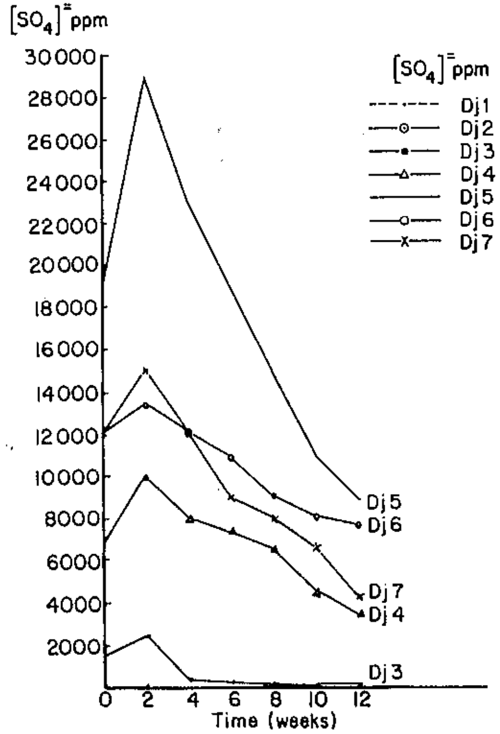

Fig. 3. Evolution of sulphates (ppm) with time, at different sites (Dj 1-7).

tration in the soil solution is followed by a more gradual decrease. The decrease is partly due to uptake by plants, precipitation and absorption, and partly to reduction of sulphates to sulphide compounds. The latter is pronounced in the mangrove soil, Dj 7 (Vieillefon, 1974); simultaneously the bicarbonate content of this soil increases.

Reduction of iron and manganese: The evolution of the Fe^{2+} content in the soil solution over time is presented in Figure 4.

Two types of curves occur. In one, the increase of Fe^{2+} is gradual and continuous, but remains at a low level (samples are Dj 1 and Dj 2 from the oxidized older formation, and sample Dj 6, from the bare *tanne*). In this latter case, the majority of the iron is present in the compound jarosite (van Breemen, 1976). The soils near the plateau are low in free iron, which is related to the fact that Eh values in these soils remain relatively high during the whole submersion period (Figure 2b).

The second type of curves, valid for all other samples, shows an initial increase of Fe^{2+} which is most pronounced for the samples Dj 4 and Dj 3, from *tanne* with a *gramineae-cyperaceae* vegetation and from a *tanne* in use for rice fields. The increase is followed by a decrease. The behaviour over time of Fe^{2+} in the soil solution in the samples of the second type follows the model described by Ponnamperuma (1955) and Ponnamperuma *et al.* (1966).

Soluble manganese in the soil solution was negligible for all samples, except those from the bare *tanne*, but even here, values did not exceed 17 ppm initially after flooding, with a marked tendency to decrease with time.

From a practical point of view, it can be concluded that the chemical composition of the soil solution is favourable for the growth of rice for the higher soils of the sequence. In the younger alluvial portion of the sequence, the soil solution is much less favourable because of high ionic charge and because of reducible products, competing with the roots for oxygen.

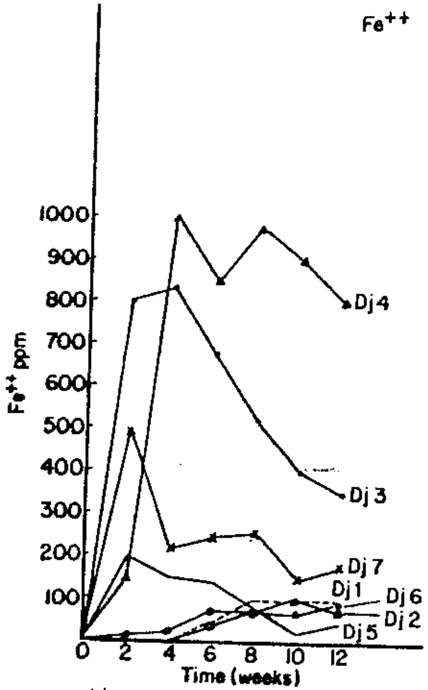

Fig. 4. Evolution of Fe^{++} (ppm) with time at different sites (Dj 1-7)

Evolution of plant nutrients

Nitrogen: The evolution of the total mineral N content under flooding is given in Figure 5(a). Under flooded conditions, N is mainly present in the ammoniacal form. Due to a higher microbial activity the initial increase in N is highest in the non- or slightly saline soils (Dj 1, Dj 2 and Dj 3), but the subsequent decrease is most marked in the same soils. This strong decrease may be related to NH_4 volatilization or to denitrification. The low N mineralization rate in the bare *tanne* soil (Dj 5 and Dj 6) is to a large extent related to the high acidity and the high content of soluble salts, which suppress the microbial activity. In this respect, it was found (Tusneem and Patrick, 1971) that a high sodium content slows the mineralization of organic matter and, consequently of organic nitrogen.

Soluble phosphorus: In general the P level in the soil solution is low, which agrees with the overall lack of available phosphorus in the various parts of the landscape, as determined by field experiments. Highest initial levels were found in the least saline soils (Dj 1 and Dj 2), under cultivation. The decrease of the P content in those soils is, however, more rapid due to removal by crops. The mangrove soil (Dj 7) is the only one in the sequence that maintains a relatively high soluble P content during flooding; this is probably related to slow release from decomposing organic matter.

Soluble potassium: The evolution over time of K^+ in the soil solution is given in Figure 5(b). The decrease over time is clearly related to the generally sandy texture and the low cation exchange capacity (CEC) of the soils. The sandy soils in the higher aspects of the sequence (Dj 1, Dj 2 and Dj 3) have the lowest initial contents, while the bare *tanne* soils and the mangrove soil (Dj 5, Dj 6 and Dj 7) are richest. This may be explained by the presence, in the younger soils on recent alluvium, of K-rich components, notably jarosite $(K[Fe_2(SO_4)_3](OH)_6$ (van Breemen, 1976), which produce K^+ upon hydrolysis. In terms of rice cultivation, the higher soils of the sequence are poor in available K, while the lower ones are not deficient in this element.

Soluble silica: The evolution of silica in the soil solution is given in Figure 5(c). Lowest contents, and greatest decrease over time are noted for the higher members of the sequence (Dj 1, Dj 2 and Dj 3). The consistently higher values in the soils on more recent alluvium may be related to hydrolysis of quartz and kaolinite. The latter may be dominant in soils with high acidity (van Breemen, 1976).

Soluble zinc: No definite relationship could be established between Zn^{2+} in the soil solution as compared to time of flooding and location. After 6 weeks of submersion, low values (less than 1 ppm) were measured for all samples. It is possible that under prolonged flooding, Zn deficiency may occur.

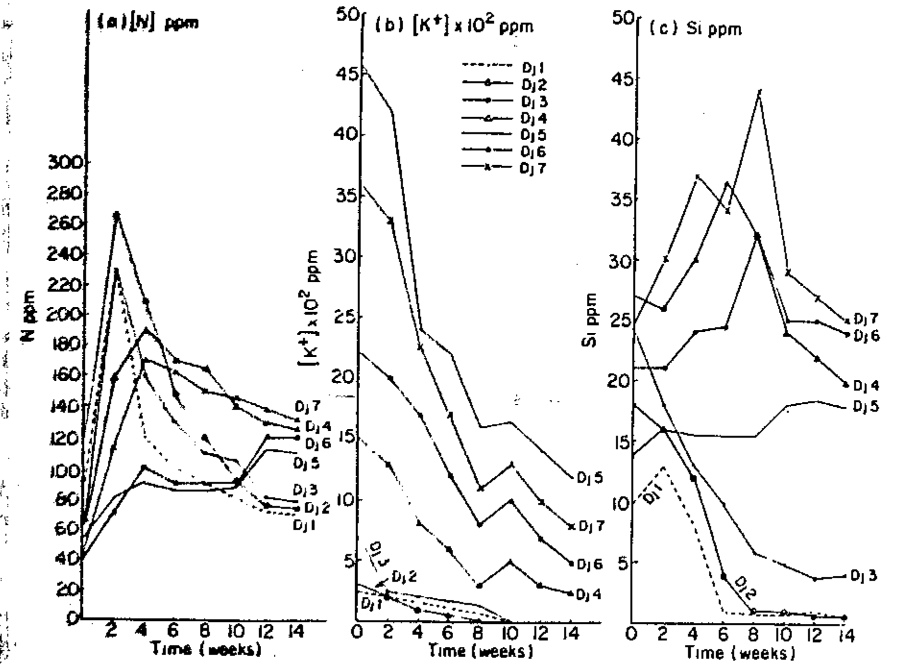

Fig. 5. Evolution of total mineral nitrogen (a), soluble potassium (b) and silicates (c) at different sites (Dj 1-7).

In conclusion, it can be observed that of all the elements studied, nitrogen as provided by mineralization of organic matter seems most closely related to microbial activity, and hence seems to vary most with the dynamics of soil acidity and salinity of each particular soil. The very low phosphorus contents are related to the minute quantities of soluble phosphates in the parent materials of the soils. The inherent or natural fertility of all soils is low, and a further lowering of this level may be expected under the influence of cultivation and, probably, of leaching.

Potentials and Constraints for Rice

A review of the data from the present experiments and information previously collected *in situ* (Beye, 1972; Marius, 1976; Vieillefon, 1974), permits the following generalisations regarding the suitability of the various landscape for rice cultivation.

Ripened mangrove soils: These soils are relatively rich in plant nutrients, but they are subject to rapid acidification when reclaimed and drained. Use for rice requires

the availability of non-saline water for irrigation, suppression of salinity and avoidance of acidification.

Bare tanne soils: Because of natural drainage and oxidation, these soils have become very acid while, at the same time, their salinity is the highest of all soils of the sequence. Under flooding, these soils maintained high levels of acidity, while the toxicity level of sulphate remained too high for rice growth. Irrigation with fresh water in sufficient quantities, and liming to counteract actual and potential acidity would be required if these soils are to be used for rice.

Tanne soils with vegetation: High salinity and acidity are still unfavourable and a restraint for rice production. Flooding improves conditions, but not sufficiently for optimum production. As in the case of the bare *tanne* soils, drainage, irrigation and liming are required if rice cultivation is to be introduced.

Tanne soils with rice cultivation: These soils in their present stage are cultivable, but do not present an optimum environment for rice. Flooding in the presence of sulphates may lead to Fe toxicity. Improvement of hydrological conditions and appropriate cultural techniques, including incorporation of organic matter such as straw are required for improved production.

Hydromorphic soils of the transition zone: These are the best soils of the sequence for improved rice production, since they are without toxic conditions. In view of a low inherent fertility, the main requirement is for appropriate fertilization.

Well drained soils of the slopes (Ferruginous tropical soils - Alfisols): The chemical characteristics of these soils are almost identical to those of the higher plateau soils. The inherent fertility level is low and fertilization is required, including the use of organic manures. These soils are suitable for pluvial (upland) rice cultivation.

Experimental results

The results of a pot experiment, using IR8 as an indicator variety emphasizes the land evaluation conditions, outlined above. Plant growth was completely impeded, and no maturity of the crop was reached in all lower soils of the sequence. For the three upper members, the following results can be noted:

- on the Dj 1 soils, crop growth in the experiment was normal, but signs of early senescence and of N and K deficiencies were noted;

- on the Dj 2 soils, plant development was generally better, but tillering was less and ripening was later;
- on the Dj 3 soils, initial plant establishment was difficult because of salinity and acidity during the early growth stage. Excess salinity is indicated by the light colour of the centre and tips of the leaves which disappeared readily, and was replaced by a light degree of bronzing. Tillering was best, indicating the transient character of the constraints.

Foliar analysis at different stages of plant growth revealed that little correlation existed between these analytical data and the indications provided by the chemical and physio-chemical analysis of the soil solution.

Conclusion

The present study of the chemical and physio-chemical kinetics of the soil solution, have led to a better understanding of the potentials and restraints of the different land types in the landscape of the marine plain and the adjacent uplands. In respect to rice cultivation, the higher soils (Dj 1 and Dj 2) are suitable for rice cultivation, with appropriate soil fertility management. The part of the *tanne* with cultivation and vegetation (Dj 3 and Dj 4) shows restraints due to excessive salinity and acidity. Elimination of these restraints is possible, with the availability of non-saline irrigation water, drainage and liming. Similarly for the acid halomorphic soils of the bare *tanne* (Dj 5 and Dj 6), but investments for their amelioration would be considerably higher. The amelioration of the mangrove zone, submitted to tidal influences is difficult without complete and expensive water control and subsequent soil improvement.

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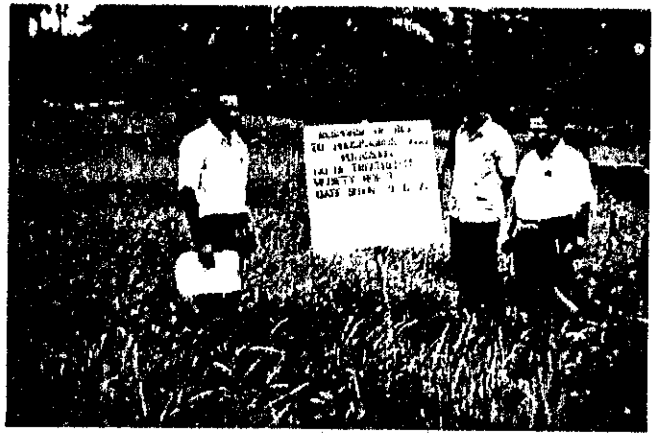

Plate 20. On-farm fertilizer trial in 'slash and burn' dryland rice in oil palm rainforest, Sierra Leone.

Plate 21. Pre-germinated rice seed, ready for broadcasting into paddy, Nigeria.

Plate 22. Uneven stand of broadcast rice with variable water depth from uneven land preparation mechanized culture, Nigeria.

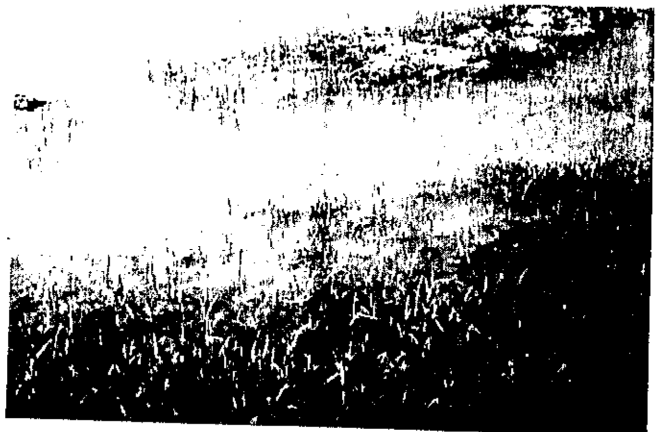

Plate 23. Drought-damaged rice on the flood plain of the Niger River in central Nigeria.

Short Research Communications

EVALUATION OF RICE VARIETIES FOR DROUGHT AVOIDANCE AND DROUGHT ESCAPE MECHANISMS

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Introduction

Upland rice soils of West Africa may be divided into two major categories, according to the nature of the water supply. They are either freely-drained soils where rice is entirely dependent on direct rainfall, or soils with 'hydromorphic' characteristics which also receive water from outside sources.

The distribution of hydromorphic soils is related mainly to topographical features of the land and/or impeded drainage. The determining factor for hydromorphism is the groundwater table, which is either at a shallow depth or at the surface during part of the year.

Sequential-testing along a toposequence from hydromorphic to dryland conditions has indicated a strong correlation between depth of groundwater and rice yield (Moormann and Veldkamp, 1978). Comparisons of rice varieties indicated that typical upland types (OS 6) showed more drought tolerance than lowland types such as IR20. Upland rice varieties with thick and deep root systems, can exploit water supplies in the deeper soil horizons and thus are better fitted to survive or avoid drought than shallow-rooted varieties. This is especially important in West Africa, where many upland soils have water holding capacities of only 3 to 5 cm/30 cm depth (Moormann *et al.*, 1975). Short growth-duration varieties escape drought by completing their growth cycle before the rains stop.

The phenomenon of drought "resistance" is not clearly understood. The situation is particularly complex for rice where drought avoidance, recovery from drought effects, and drought tolerance, all of which contribute to drought resistance, appear to be associated with different 'types' of rices. Low tillering, traditional upland types with a larger proportion of long and thick roots avoid drought (Chang and Vergara, 1975); high tillering, improved semidwarf, lowland types have better ability to recover from drought (Alluri, 1975); and seedling drought-tolerance is more commonly observed in deep water rice varieties. It is to be hoped that innovative varietal improvement efforts can combine characteristics of avoidance, escape, recovery, and physiological tolerance *per se*.

Field screening for varietal performance in upland conditions is difficult since site and seasonal variabilities are usually high and experiment station conditions often do not adequately reflect the farmers' field situation. Previous screening for adaptability to upland conditions has given confusing results since dryland and hydromorphic conditions were not distinguished, confounding the evaluation.

Methods

Evaluation of rice varieties for drought avoidance was conducted using a transect screening technique in which single plots ranged linearly in a continuous function from dryland to hydromorphic conditions. Time of planting for different growth-duration varieties was adjusted such that drought stress occurred during both the seedling and post-flowering growth stages. Seventeen rice varieties were sown across the transect in rows 30 cm apart. The rice was under drought stress for four weeks shortly after sowing, and again between 80 and 100 days after sowing. The transect was divided into dry, semi-dry, semi-wet and wet zones, on the basis of drought symptoms. Towards the end of the second dry period, soil moisture contents at 10-20 cm, were 2%, 3-5%, 13-21%, and 26-41% respectively, for the four zones from dry to wet. Severe drought stress symptoms were apparent only in the upper dry portion of the transect.

Results and Discussion

Significant varietal x zone interaction in growth performance was observed, according to the location along the transect in relation to groundwater and soil moisture. Except for the early-duration variety, IAC 25, from Brazil, which escaped the most severe second drought, virtually no yield was obtained for the varieties in the dry portion (Figure 1). IAC 25 also had a large proportion of long and thick roots. Thus, in severe drought conditions, escape and avoidance through use of early varieties and a long root system with thick roots appear to be necessary. Panicle number was severely reduced in the dry zone in all varieties except IAC 25. However, there was no consistent relationship between panicle number and yield. Reduction in straw weight and plant height in response to drought were highly correlated with reduction in grain yield.

Under the more favourable moisture regimes of the lower

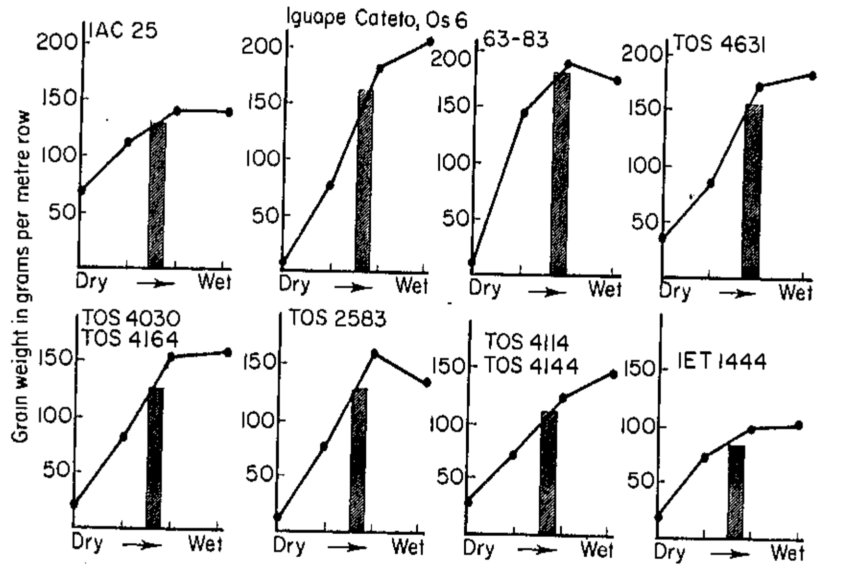

Fig. 1. Performance of different rice varieties across a transect from dry to wet soil conditions, and mean yield (bars) across all conditions.

portions of the toposequence transect, the traditional medium duration varieties, OS 6, 63-83 and Iguape Cateto were higher yielding than the short-duration types, such as IAC 25 and the dwarf IET 1444. The mean yields across all portions of the transect are shown in Figure 1. The major disadvantage of the traditional varieties, however, is their tendency to lodge under good moisture conditions or fertile soils.

The results indicated that reduction in straw weight and plant height are suitable indices of drought stress. The transect toposequence approach provides a simple evaluation of varieties for response over a range of soil moisture conditions for selection of materials with good drought avoidance and escape mechanisms. These can then be combined with good agronomic traits and high yield potential for improving rice for African upland conditions.

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SCREENING RAINFED RICE VARIETIES FOR ROOTING DEPTH BY A P^{32} ABSORPTION TECHNIQUE

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Introduction

One way pluvial rice can avoid drought stress is by having a deep root system which is active in absorption even during flowering and grain filling stages. Our aim was to develop a simple method to measure the effective root zone of varieties, and especially to identify varieties with deep root systems of 50-100 cm. Radioactive P^{32} was chosen as the potential indicator, and techniques of soil application and isotope recovery which would indicate uptake were investigated. Varieties were then screened for deep-uptake.

Methods

The basic method was to place the radioactive tracer around the plant at different depths and to remove either leaves or spikelets after several days and measure their radioactivity. The presence and amount of radioactivity was considered to be indicative of active roots at the depth at which the tracer was placed in the soil.

Holes were made with a steel rod and the tracer was injected through a teflon tube protected by a copper tube. A hypodermic needle was attached to the base of the teflon tube and an automatic distributor to the top. This ensured injection of a constant amount of tracer at a predetermined depth. Entirely hand operated, this equipment enabled two workers to make 125 holes per day up to a depth of one meter in a moist gravelly soil. The holes were arranged in a circle of 10 cm diameter, around the plant, and made to either 40, 60, 80 or 100 cm. The numbers of holes per plant ranged from 1 to 6.

The radioactive solution consisted of 25 millicuries of P^{32} per ml and 500 mg of P per ml, the latter acting as a carrier. Two milliliter of this solution were injected per hole. In different experiments different numbers of holes were used per plant and the depths of injection were varied.

Radioactivity in leaves was measured 11 and 25 days after tracer placement; that in spikelets at 5, 10 and 15 days. A Geiger Muller counter with a mica window was used to count beta radioactivity. The counter's background activity averaged 80 counts/100 seconds. Plants giving an activity higher than that of the background plus three times the value of the standard error were considered to be radioactive.

Results

An initial experiment was conducted with the variety Moroberekan at 120 days after seeding. Different numbers of holes and placements were tested at different depths, and radioactivity was measured in spikelets. It was found that after flowering the spikelets contained the greatest amount of radioactivity but that radioactivity varied among spikelets from different tillers. It was considered adequate to take 10 spikelets from among several panicles. By means of autoradiographs it was found that the volume of radioactive soil induced by the methods of application was a sphere three cm in diameter.

It was found that the percent of radioactive plants increased with the numbers of placements per plant and decreased with deeper placements (Table 1). A similar trend occurred for levels of specific activity. It was concluded from these initial experiments that for screening varieties, five placements per plant would probably be sufficient, ensuring a 60% probability of finding active roots in the deep-rooted varieties.

TABLE 1

Percentage of radioactive Moroberekan and specific activity in counts/100 sec per 10 spikelets in relation to the number and depths of tracer placement

	Number of placements per plant								
	1			3			6		
Depth (cm)	40	60	80	40	60	80	40	60	80
% of radioactive plants	67	50	33	100	50	33	100	83	67
Specific activity	344	115	194	365	102	130	611	269	166

In a second set of preliminary experiments, uptake was determined for three varieties at different growth stages and from different depths of placement. Radioactivity was measured in leaves taken 11 and 25 days after placement, and then dried. It was found that the percentages of radioactive plants among varieties varied but that no consistent difference occurred between plants 63 and 77 days old (Table 2). The percent of radioactive plants ranged from 16 to 100 depending on variety and depth of placement, with higher recovery from 50 cm than from 80 cm. Specific activity increased greatly in leaves taken 25 days after placement compared with those taken after 11 days. From earlier experiments it was found that varietal differences in depth of rooting are expressed at the reproductive stage which is also when the need for water is greatest. Thus, for varietal screening for deep, active root function it was judged best to have plants in the reproductive stage and to measure uptake from 95 cm depth.

Fifty varieties were tested, representing a wide range of variability in origin, morphological type and growth duration. Five of the lines were *Oryza glaberrima*. The varieties ranged in height from 55 to 140 cm and in duration to heading from 72 to 121 days. Tillers per square meter ranged from 100 to 500. The experiment was a thrice replicated Fisher block design with 30 x 15 cm spacing and standard pluvial rice cultural practices. Sowing of individual varieties was staggered to obtain flowering at approximately the same time. Two plants were sampled per variety per replicate and five placements were made per plant. A sample of 10 spikelets was taken from several panicles of 5, 10 and 15 days after placement.

Results showed clearly that varieties differ markedly in presence of functioning roots at 95 cm depth after flowering (Table 3). They differed in both the proportion of plants showing some P^{32} uptake and in the amount taken up as measured by specific activity. Varieties with 5-6 plants of the 6 tested showing uptake were considered 'deep rooted'. The amount of specific activity was considered to reflect either root density or function or both.

Four varieties had activity considerably higher than any others. These were Pratao, LAC 23, IAC 1246 and 63-83. Surprisingly, three varieties with stable pluvial yield, Moroberekan, IRAT 13 and IRAT 8, had low frequencies of recovery of P^{32}. Of the *O.glaberrima* lines, only CG 9 had a high frequency of plants with deep root function, but their activity was low.

Discussion

This method of screening rice varieties for drought tolerance has two main advantages over traditional methods of digging and weighing the root mass. It is a simple technique, hence many varieties may be routinely evaluated under various edaphic conditions. In addition, this method measures only root activity and thus eliminates confounding of non-functioning roots. Studies are also being conducted to correlate phosphorus uptake with root mass and water absorption.

TABLE 2

Percentage of radioactive plants and specific activity in counts/100 mg of dry leaves, according to variety, age and depth of placement

Varieties	IRAT 10				IRAT 13				Moroberekan			
Age of plants (DAS)[a]	63		77		63		77		63		77	
Depth (cm)	50	70	60	80	50	70	60	80	50	70	60	80
% of radioactive plants at:												
11 days	33	0	50	16	33	16	33	16	66	50	66	33
25 days	66	16	66	50	66	66	66	50	100	83	83	66
Specific activity at:												
11 days	77	0	133	38	61	294	45	108	301	76	81	47
25 days	1115	148	1249	56	175	1316	376	201	4635	531	1220	418

a) DAS: Days after seeding.

TABLE 3

Deep root function after flowering of 50 varieties as measured by frequency and amount of P^{32} uptake from 95 cm depth

Variety	Number of radio-active plants[a]	Specific activity[b]
Pratao	6	434
LAC 23	6	422
LAC 1246	6	414
63-83	6	314
P 44	6	188
Mac Fay Dang	6	174
Bete 3	6	164
Chianan 8	5	160
Carreon	5	138
OS 6	6	137
Sixa A	5	136
Iguape Cateto	5	125
Chun 139/2	6	125
Touanlepou	5	109
Pratao Precoce	5	106
H 5	5	69
Blue Bonnet	5	68
I Tame	5	62
2243 73 F	6	62
Palawan	6	55
CG 9 (*O.glaberrima*)	6	31
RT 1031/69	5	20
M 45	4	247
R 75	4	173
Fossa A	4	164
Khao Lay	4	102
Colombia 2	4	98
Batatais	4	75
N 949 m 9/1	4	54
Mandi	3	373
Moroberekan	3	
Kh Chero ATB 13	3	89
Colombia 1	3	84
Mizukata-Mochi	3	81
IRAT 13	3	57
CG 20 (*O.glaberrima*)	3	17
IRAT 9	2	96
J B S	2	69
M 312 A2/2/1	2	46
DS 1	2	39
DG 7 (*O.glaberrima*)	2	21
Tiskou	1	116
Ikon Pao	1	106
E 425	1	79

TABLE 3 (cont'd)

IRAT 8	1	11
IRAT 10	1	11
Zakplae (*O.glaberrima*)	0	
Cas V6	0	
96 (*O.glaberrima*)	0	
TI	0	

a) P^{32} was placed at a depth of 95 cm around 6 plants per variety.
b) Measured 10 days after P^{32} placement in counts per 100 S/10 spikelets.

The technique of placing P^{32} at a given depth in the soil allowed the presence of active roots at that depth to be determined. The technique is simple and useful for classifying rainfed rice varieties according to their depth of rooting and degree of deep-root function. Measurement of radioactivity in the spikelets indicated varietal differences in phosphorus absorption activity of these roots. We acknowledge the support for these studies provided by a grant from the International Atomic Energy Agency, Project IVC 5/05 1976.

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TECHNIQUES FOR SCREENING RICE VARIETIES FOR DROUGHT TOLERANCE

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Introduction

A considerable proportion of rice grown in West Africa is cultivated on upland soils under rainfed conditions (Abifarin *et al.*, 1972). Rice yield under these conditions is unpredictable and low. While suitable soil type for rice cultivation is an important criterion in drought-prone areas the importance of a variety with characteristics to avoid drought cannot be minimized. Chang *et al.* (1972), observed that low tillering potential and slight reduction in leaf area are desirable varietal characteristics for conditions of severe moisture stress. Though the number of leaves and leaf elongation rate may be low, total leaf area of upland varieties has been observed to be high. The ratio of leaf-sheath to leaf-blade length may also be high for certain upland varieties (Hasegawa, 1963). Various researchers have considered lower tillering capacity and deeper root system development to be a desirable characteristic for varieties for upland conditions (De Datta and Beachell, 1972; Hasegawa, 1963; Nicou *et al.*, 1970; Krupp *et al.*, 1972). An important selection criterion for drought tolerance may be the energy status of water in the rice plant relative to the energy status of water in the soil-plant-atmosphere continuum. There is a little information on this aspect of rice. An understanding of the energy concept in a soil-plant-atmosphere continuum may help in selection of rice varieties superior under a range of adverse conditions of drought stress.

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Leaf Water Status in Relation to Drought Stress

Wilting range

Wilting range is defined as the difference in moisture content of the soil between '*wilting point*' and the '*ultimate wilting point*'. Wilting point is the moisture content at which growth ceases, and the ultimate wilting point is the soil moisture content when the plant can no longer maintain life (Arnon, 1972). By analogy, the same concept can be applied to the plants. The difference in the moisture content of the leaves at which they indicate initial rolling from that at which the leaf cannot recover may be an important criterion for screening rice varieties.

Resistance to water flow

The energy status of water in the plant is a more important criterion than the actual amount of water itself. Both the amount and the energy status of water in the plant depend upon many factors (Gardner and Nieman, 1964): a) resistance to water flow from soil to roots; b) resistance to flow from and among other tissues; and c) resistance to flow from the stomata into the atmosphere.

There can be significant varietal differences in terms of these resistances. A variety that offers more resistance to flow from the stomata into the atmosphere has a beneficial trait towards drought tolerance (Kanemasu *et al.*, 1969).

The resistance to vapour flow from stomata into the atmosphere (e.g. leaf diffusive resistance) was measured for IR20 and OS 6 grown at different soil moisture regimes (Table 1).

OS 6 had higher resistance to diffusion than IR20 both with no stress and at all levels of soil moisture stress. The apparent randomness of significant differences in the leaf diffusive resistance among various soil moisture regimes is unexplained. A drawback of this technique is the dependance of the diffusive resistance on leaf temperature, which in turn is a function of atmospheric conditions and transpiration rate. This technique of leaf diffusive resistance can also be used for computing total flux (q_W) of water vapour or the transpiration rate of a leaf in a finite time interval (Δt) according to the equation:

$q_W = (C_2 - C_1)\, v / A\Delta t$. (1) (Slavik, 1974)

C_2 and C_1 are the initial and final vapour concentrations of the air in the cup of the diffusion porometer, v is the total volume of the cup, and A is the leaf area enclosed.

Energy status of water in the rice plant

Total leaf water potential (Ψ_W) is the total specific

free energy of water in the leaf tissue relative to the free water surface. When leaf water potential is expressed in terms of pressure, the numerical value is analogous to the diffusion pressure deficit (DPD). Total leaf water potential is: $\Psi_W = \Psi_S + \Psi_P + \Psi_m$ ------ (2), where osmotic potential is (Ψ_S), the pressure potential is (Ψ_P) and the matric potential is (Ψ_m). Matric potential is the most important component in Eq 2, representing the component of specific free energy of water which is associated with water status on interfacial borders in the leaf tissue.

TABLE 1

Diffusive resistance in IR20 and OS 6 at grain filling stage with different soil moisture regimes

Soil moisture regime	Leaf diffusive resistance (Sec. cm^{-1})	
	IR20	OS 6
Continuous submergence	3.43	4.57
Saturated soil, no submergence	3.53	4.11
Zero suction at 15 cm depth	3.01	4.60
25 cm suction at 15 cm depth	3.26	4.19
50 cm suction at 15 cm depth	3.27	4.27
75 cm suction at 15 cm depth	3.79	4.15
100 cm suction at 15 cm depth	3.93	4.64
250 cm suction at 15 cm depth	4.34	4.29

LSD (.05): Moisture 0.48, Variety 0.64.

A practical method of monitoring the energy status of water is by the use of a 'Pressure chamber technique'. The ambient pressure around an enclosed leaf blade is increased until a pressure is reached at which xylem sap just appears at the cut end of the shoot (Scholander *et al.*, 1964, 1965, 1966; Blum *et al.*, 1973). The pressure applied equals total water potential minus osmotic potential which is at zero when the sap appears at the cut end of the leaf. Leaf water potential of two rice varieties, IR20, a lowland, and OS 6, an upland variety, was tested under different soil moisture regimes. Variety OS 6 maintained higher leaf water potential than IR20 for soil moisture suction ranging from 0 to 250 cm of water at 15 cm soil depth. Generally high Ψ_L is considered to be a desirable trait. However, there have been examples where high Ψ_W has not proven to be advantageous.

Leaf water potential monitored at the grain filling stage was significantly correlated with grain yield and yield components of IR20 and OS 6 (Table 2).

The leaf water potential can be influenced significantly by an interaction between soil moisture stress and the level of nitrogen application, or the fertility status of

TABLE 2

Coefficients of linear correlation between leaf water potential (-bars) at grain filling stage and performance of two rice varieties

Yield Parameter	Correlation coefficient
Grain yield	0.70**
Straw yield	0.71**
Grains/Panicle	0.48*
Panicle weight/plant	0.63**
Unit grain weight	0.70**

*Significant at 0.05 level; **significant at 0.01 level

the soil (Table 3). For a soil water suction of 250 cm, an increase in nitrogen application significantly decreased leaf water potential. For submerged soil it did not, and for 100 cm suction the change was moderate.

TABLE 3

Influence of level of nitrogen on leaf water potential measured at 50% flowering (-bars)

Soil moisture regime	Nitrogen rate (ppm) 100	200	300	400
IR20				
Submerged	20.3	18.4	17.2	20.3
100 cm suction	17.7	20.6	19.3	23.1
250 cm suction	21.5	22.7	24.7	20.6
OS 6				
Submerged	17.0	16.9	16.1	15.2
100 cm suction	15.8	14.5	20.3	18.0
250 cm suction	16.2	19.8	19.1	26.9

A technique for expressing tensiometric results

An improved technique for investigating influence of soil moisture regimes on rice varieties involved monitoring soil moisture suction either by tensiometers or with gypsum blocks. Irrigation is withheld until soil water suction reaches a predetermined value.

A known quantity of water, generally calculated from the information on soil moisture characteristics, is then applied either on the surface or through sub-surface irrigation. No sooner is the irrigation water applied on the soil surface than soil moisture suction approaches zero. The soil moisture suction therefore fluctuates between zero and the predetermined value specified for the given treatment. It is, therefore, difficult to express results in terms of a fixed value of soil moisture suction. Many researchers have attempted to overcome this problem by designing an auto-irrigation system (De Datta *et al.*, 1975). There are many problems involved in this system. One such problem is based on an exponential decline in the hydraulic conductivity with an increase in soil moisture suction. The suction around the source of water is close to zero; the values are much higher farther away. Also, the plant roots cluster around the water source.

This problem may be overcome by integrating the area under the curve of diural changes in soil moisture suction for the entire growth period, obtaining a numerical value for the cumulative soil moisture stress.

Cumulative soil moisture stress (cm-days) can be expressed as

$$S = \int_{t_1}^{t_2} \Psi_{soil}\, dt$$

where t is time (days), dt is the rate of change from t_1 to t_2. This value of soil moisture stress may apply for a given depth.

Weighted mean average soil moisture stress (Sm) can be obtained by integrating the suction values for different depths (z): Weighted mean stress

$$'Sm' = \int_{Z_1}^{Z_2} dZ$$

where dZ is the rate of change from Z_1 to Z_2.

Grain yield of the two varieties was plotted against such weighted means of cumulative soil moisture stress (Figure 1). Different slope gradients between cumulative stress and grain yields were obtained between varieties. At equal levels of cumulative stress OS 6 produced higher levels of grain.

Water use efficiency of rice varieties

Water use efficiency may be expressed in terms of 'energy equivalent' using 4000 cal g^{-1} as an average for different kinds of plant materials (Penman, 1971). According to this system water use efficiency can be expressed as: $QY = CR_I$ where Q is the heat of formation of plant material (4000 cal g^{-1}), Y is the yield in g cm^{-2}, C is a constant, and R_I is the radiation income (in cal g^{-1}). If soil moisture becomes a limiting factor, the evapo-transpiration component can be added: $QY = \beta E_T \lambda$ where E_T is the cumulative potential transpiration for the period in cm, λ is the latent heat of vaporization (590 cal g^{-1}) and β is a constant for a particular variety. By substituting the values for heat of evaporation and heat of formation of plant material, the equation becomes $Y/E_T = 0.1475\ \beta$.

This equation can be used to evaluate rice varieties for their performance under different conditions of evapo-transpiration.

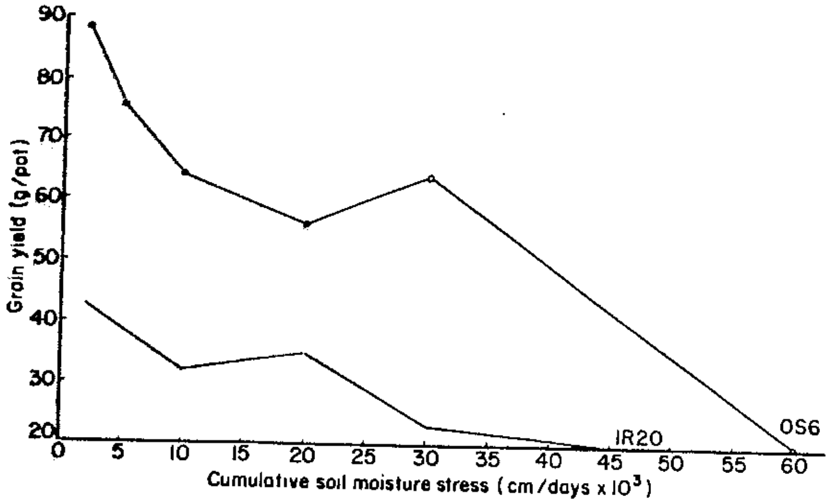

Fig. 1. Effect of cumulative soil moisture stress on grain yield of two varieties.

A technique for screening rice varieties for drought tolerance

A breeder concerned with drought tolerance may wish to have information on potential parents regarding plant-water relationships and water-use efficiency. To obtain reliable information, the techniques employed must not be influenced by soil heterogeneity. It is important that the depth of the active root zone and the distribution of moisture potential from the soil-to-plant-to-atmosphere is precisely determined. The actual evapo-transpiration must also be known. A schematic sketch of an experimental set-up for obtaining useful data on soil plant water relationship is outlined in Figure 2. Uniformly mixed soil is packed at a known density in a circular trench 2-3 metres in diameter and 50 to 75 cm deep. The main soil body is lined with porous blocks, so as to permit free diffusion of water laterally into the soil. Outside of the lining is an open trench of 30 cm width for water. The depth of water in this trench can be regulated. A series of tensiometers and neutron-probe access tubes installed along the radius can be used to monitor soil moisture potential and soil moisture content at different distances from the water source and at different depths. From knowledge of the hydraulic conductivity, and of the potential gradients at steady state, one can calculate the flux at different radial

distances from the water source.

Varieties to be tested for their drought tolerance can be planted along radii in an arc segment. Plant spacing is varied from the periphery to the centre to prevent increased plant competition towards the centre. Plant varieties can be grown to maturity, and new sets of varieties replanted in the same set-up without additional soil disturbance.

In addition to agronomic observations, measurements of the leaf diffusive resistance, leaf water potential, transpiration rate, and water use efficiency, will provide information for selection. Measurement of solar radiation, ambient temperature and humidity should also be done to enable comparison of different sets grown at different times.

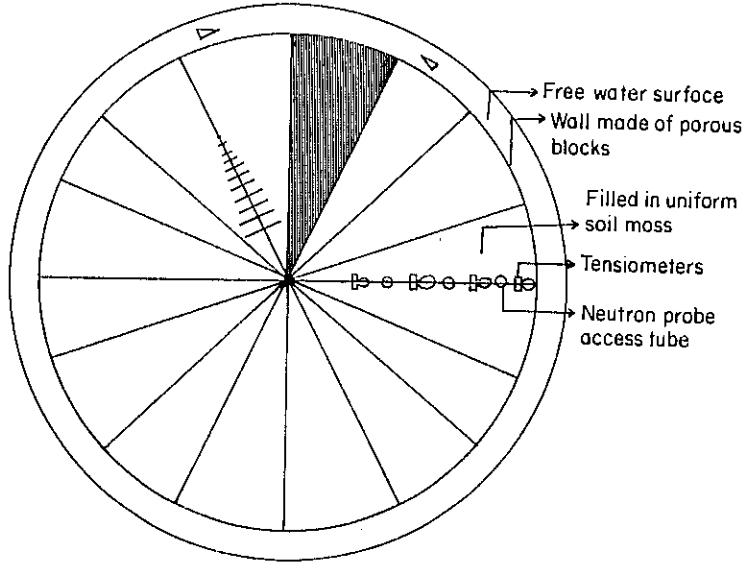

Fig. 2. Technique for screening rice varieties for drought stress.

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TRADITIONAL AND BROADCASTABLE SEEDLINGS IN RELATION TO METHODS OF FERTILIZER APPLICATION

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Introduction

In West Africa in the early 1970's the actual average yield of swamp and flooded rice were about 1.0 t/ha, while upland rice, which remains the major part of the rice production, yielded only some 0.5 t/ha (Abifarin *et al.*, 1972). Although higher grain yields can be obtained with controlled irrigation, labour-intensive operations, especially transplanting, limit expansion of paddy-rice culture in this region. However, the advantages of transplanting over direct sowing are many: Less water is required during seedling stage, as the area for the nursery is usually one twentieth of the main field; the duration of growth in the main field is reduced, which is important for double cropping; the weed problem is less since transplanted rice competes better with post-emergence weeds; and land levelling requirements are less critical. To retain these advantages while also eliminating the tedious process of transplanting, Matsushima (1975) proposed the use of broadcastable seedlings, potted in seedling boxes. In Eastern India where rice is broadcast in rainfed areas, similar but less sophisticated practices are used to redistribute seedlings and achieve better stand uniformity, simply by transplanting seedlings with a lump of soil attached to the roots. Also, in deep water areas, tall seedlings (6-8 weeks old) are uprooted with soil attached and broadcast from boats. In the Matsushima method, seedlings are grown in soil in divided plastic trays and when ready for transplanting the seedlings are easily pulled from the pots with intact roots in a soil-root clump. When the seedlings are thrown onto the paddy field they fall inclined, but with their roots downwards, and quickly become established. Since the seedlings are placed practically on the surface, they are comparable to shallow or surface plantings which results in an easier physical emergence of tillers.

It is apparent that for traditional types of transplanting, deep placement of fertilizer is beneficial because of the proximity of the fertilizer to the roots, with less loss of nitrogen by volatilization. In a rich clay soil with high cation-exchange capacity in the Philippines, deep placement of urea fertilizer at the rate of 60 kg/ha gave a significantly higher yield increase over broadcast and incorporated, top-dressed or foliar-spray application (IRRI, 1975).

Experiments in paddy at Badeggi, Nigeria indicated that run-off and denitrification were the major ways in which fertilizer N is lost from the soil. Deep placement through mud balls or deep incorporation of the fertilizer minimized the N losses and resulted in higher grain yields (Ayotade, 1978).

The fertility of West African soils tends to be low, with generally low levels of clay. Soil organic matter content is also low because of the climate. As a result, the soils have a limited cation-exchange capacity. Amounts of organic nitrogen, phosphorous and sulphur mineralized annually are often well below the requirement for satisfactory crop yields (Jones and Wild, 1975). Thus these soils differ greatly from the paddy soils of Asia. Therefore, the agronomic practices for proper utilization of these soils need to be evaluated carefully for profitable rice production.

Broadcastable seedlings were compared with traditional wet-bed seedlings of cultivar BG 90-2 under three methods of fertilizer application at IITA. The wet-bed seedlings were transplanted at a depth of 4 to 6 cm, while the broadcastable seedlings were placed (not broadcast) on the surface at the same planting density. Basal fertilizer NPK, each at 60 kg/ha, was applied either incorporated with a power tiller for deep incorporation, raked in for shallow incorporation, or applied immediately after transplanting for surface application without incorporation. At the time of panicle initiation, a further 30 kg of N was applied, placed either deep between 4 hills, shallowly incorporated by hand, or applied on the soil surface for the respective fertilizer treatments.

Higher yields were obtained with broadcastable seedlings for all three methods of fertilizer application (Table 1). Panicle number and degree of grain fill were similar for all treatments. The higher grain yield with broadcastable seedlings resulted from a more efficient distribution of dry matter, with a greater number of productive panicles and higher panicle weight.

No effect of fertilizer placement was observed for the traditionally transplanted seedlings. However, for the broadcastable seedlings there was a distinct negative relationship between depth of fertilizer placement and yield. Deep placement of fertilizer resulted in lower yields from broadcastable seedlings. This relationship is

TABLE 1

Comparison of traditionally planted (A) and broadcastable seedlings (B) of rice cultivar BG 90-2 under different fertilizer placement methods

Planting method	Fertilizer placement: Deep A	Deep B	Shallow A	Shallow B	Surface A	Surface B
Grain yield (t/ha)	6.1	6.8	6.1	7.1	5.8	7.4
% productive tillers	79	87	86	92	81	88
Panicle weight (g/hill)	29	33	30	32	28	34

probably due to the broadcastable seedlings having a larger "surface" root system than the traditionally transplanted seedlings. The greater ability of broadcastable seedlings to utilize top-dressed fertilizer (the common and most convenient farmers' methods) points to their advantage, particularly when combined with the labour-saving in avoiding the tedious process of transplanting. An economic evaluation of the method is considered to be merited for African conditions. The author wishes to thank Dr. S. Matsushima for his valuable advice on the method of preparing broadcastable seedlings and for his cooperation in trials during 1976.

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OPTIMAL RATE OF SEEDING FOR PLUVIAL RICE AND NITROGEN UTILIZATION

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Introduction

For each ecological zone, there is an optimal rate of seeding which will result in the highest yield. The aims of the presently described work were to determine the optimal rate of seeding for pluvial rice, growing under good conditions in the Ivory Coast and to determine the relationship between plant density and the use of fertilizer by the plant.

Methods

The variety IRAT 13 was grown at four different seeding densities: Pocket drilling, 30 x 60 cm (6.3 kg seed/ha); Pocket drilling, 30 x 30 cm (12.6 kg seed/ha); Drill seeding, 15 x 15 cm (25 kg seed/ha); Drill seeding 30 x 3 cm (42 kg seed/ha). Each treatment plot was 22.5 m^2 and was replicated four times. Samples were taken periodically to estimate dry matter production at various stages in the growth cycle.

The basal application of fertilizer was 200 kg/ha of 10-18-18 complete fertilizer, supplemented by the addition of urea containing 20 nitrogen units at 30 and 90 days after planting. The seeds were planted on June 17, 1976. Rain and additional irrigation provided optimal water supply.

Data were collected on the growth, ground cover of the vegetation and nitrogen nutrition of the plant. To test the last factor, two seeding rates (30 x 30 cm and 30 x 3 cm) were treated with N^{15} at 5% on a sub-plot basis. This method allowed the actual use of fertilizer at each date of application to be determined.

Results

Grain yields exceeded 5 t/ha in each case, without significant differences among the treatments. Dry matter produced was 10.2 t/ha without a highly significant difference among the treatments. However, the shape of the growth curves differed among the treatments (Figures 1 and 2).

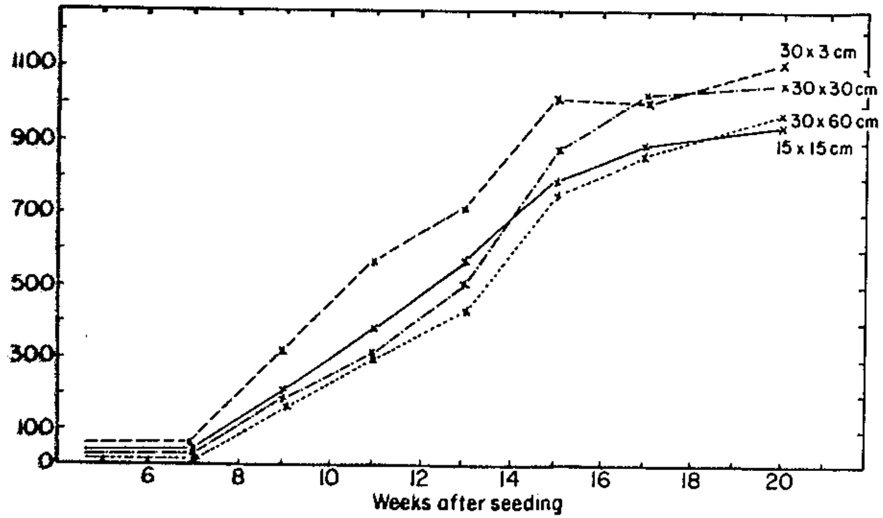

Fig. 1. Dry matter development on variety IRAT 13 in relation to spacing, Bouaké.

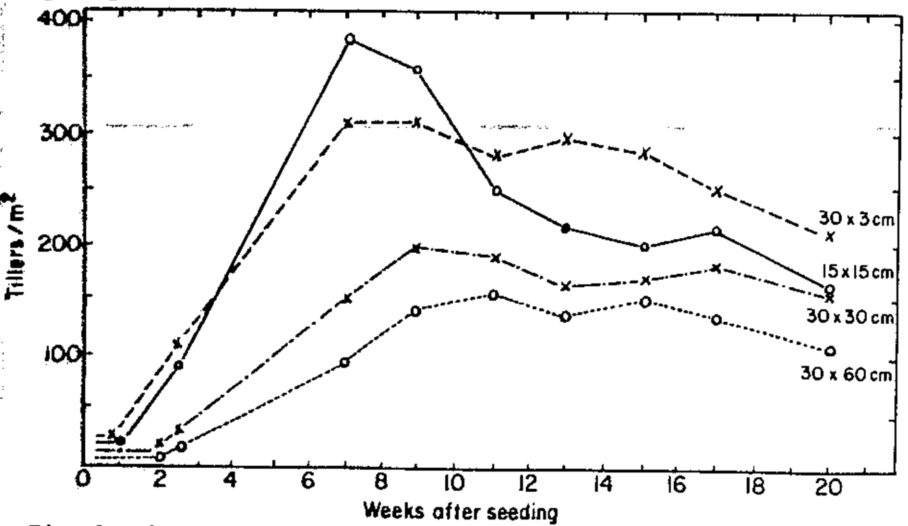

Fig. 2. Tillering density in relation to spacing density and arrangement with time, variety IRAT 13, Bouaké.

With 30 x 3 cm seeding, the rice grew more rapidly, so that the dry matter produced at 60 and 85 days was 50% higher than that of 30 x 30 cm treatment. However, at harvest (140 days), there was little difference between the treatments (1090 g/m^2 for 30 x 3 cm and 1026 g/m^2 for the 30 x 30 cm).

Although growth was slower under the other treatments, it continued and made it possible to obtain maximum yield potential of the variety at harvest. Under good growing conditions and adequate water supply, drill seeding at 30 x 3 cm appeared to be the optimal rate of planting.

The mobilization of N on different treatments was compared, differences similar to those observed for dry matter were noted. Mobilization of N on the 30 x 3 cm treatment was more important during the growing season, but at harvest, there was no significant difference between the 30 x 3 cm and 30 x 30 cm treatments. At harvest, N from fertilizer application accounted for only 15% of total mobilization (120 units) of which 70 units (58%) were mobilized by the grains. The use of the supplementary fertilizer remained low: 33% of the application made at 30 days and 57% of the 90 day application. The second application was used mainly to form grain proteins (Figures 3 and 4).

Discussion

Most of the mobilized nitrogen was provided by the soil. Also, the fertilizer supplied at seeding is less used than that applied later as supplementary fertilizer.

Soil provided 100 units N during the growing period, whereas out of 60 units N supplied, only 20 were directly used by the rice, irrespective of the rate of seeding. A

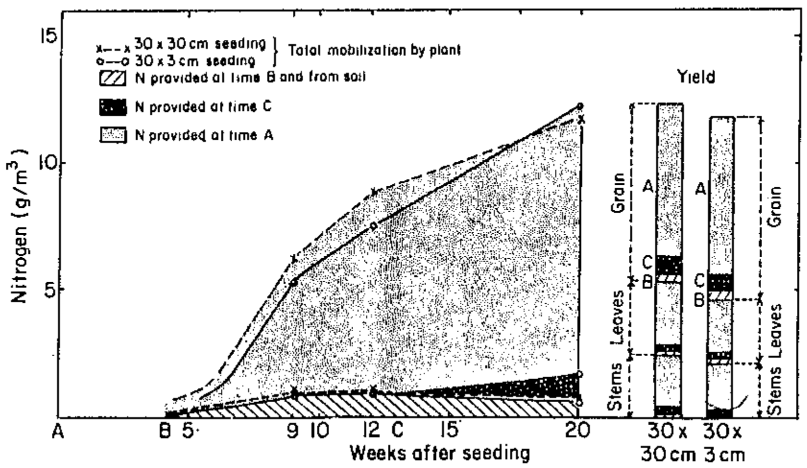

Fig. 3. Mobilization of nitrogen by variety IRAT 13, Bouaké.

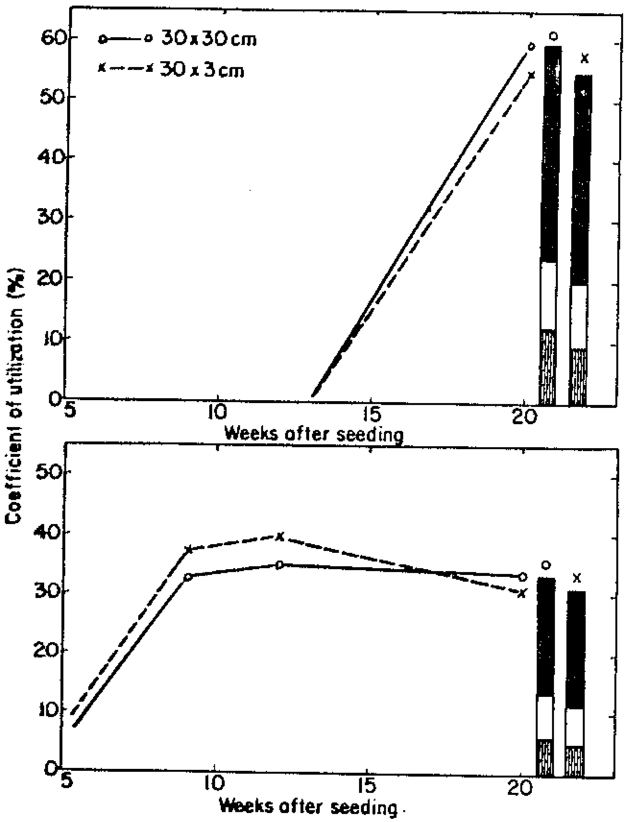

Fig. 4. Coefficient of utilization of nitrogen applied at 30 and 90 days after seeding, variety IRAT 13, Bouaké.

large proportion of the N fertilizer has been reorganized within the organic matter in such a way as to favour mineralization of soil nitrogen. In this way, fertilization plays an indirect role in the nitrogen nutrition of the plant.

The mobilization of the nitrogen by the plant develops in the same way as does the accumulation of dry matter. At heavy planting densities, the amount mobilized is more important to 70 days after planting but it is the same on all treatments at 140 days. There is a slow but continuous absorption of N on treatments with low rates of seeding.

A high rate of seeding (30 x 3 cm) was considered to be the best method under favourable growing conditions because it favoured rapid growth of the plant to allow it to reach maximum yield. At lower seeding rates, similar yields were obtained by slow, continuous growth to maturity. Under unfavourable growing conditions (e.g. poor water supply), a lower rate of seeding (30 x 30 cm) is considered to be preferable since this allows the plant to regulate its growth during the growing cycle and still attain acceptable yields.

Summary

Several plant densities have been tested on an improved variety of rain-fed rice under optimal growth conditions. The highest density (lines of 30 x 3 cm) gave the best results during cultivation because it favoured rapid growth. Lower densities are linked with slower but continuous growth until maturity, which enables the plant to attain the same yield.

For 120 units of N used by the plant, only a small part came from the N-fertilizer, about 20 units, of a total of 60 units applied, N-fertilizer applied at 90 days was most efficiently used by the plant. At maturity, no difference appeared between the treatments (30 x 30 cm) and (30 x 3 cm) concerning the N mobilization, although N mobilization during the cycle was slightly different.

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NITROGEN FERTILIZER UTILIZATION IN A TWO-YEAR ROTATION OF RICE-MAIZE-COTTON IN CENTRAL IVORY COAST

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Introduction

Nitrogenous fertilizers are indispensable for obtaining high rice yields but the factors that control nitrogen efficiency in the African tropics are not understood clearly. The aim of our project was to study the mechanisms of mineralization, the different possible losses of N-fertilizer under upland rice growing conditions and its absorption by plants. N^{15}-labelled fertilizer was used as a tool to trace nitrogen in the soil-plant system and to measure the different transfer flows between the system's compartments.

Methods

Field experiments with N^{15}-labelled urea were conducted in 1973 and 1974 at Bouaké Station on the site where a soil fertility experiment was commenced in 1969, to study the effects of prepeated applications of N and straw on long-term soil fertility and leaching losses.

The soil was a moderately desaturated ferrallitic soil* (B.S. = 50% - CEC 6 meq/100 g soil) derived from acid crystalline formations of the basement complex.

The climate is characterized by a bimodal rainfall of 1200 mm and a mean growing season temperature of 25°C. The biennal rotation was, year 1: rice (June-Oct.), year 2: maize (April-July), cotton (Aug.-Dec.). Upland rice cultivar Iguape Cateto, hybrid maize H507 and cotton cultivar Allen, were used. The experiment was laid out in a randomized complete block design of 6 treatments of 0, 60 and 120 t/ha elemental N (N_0, N_1, N_2) each with (M_1) or with-

*Oxic Paleustalf

out (M_0) an application of 5 t/ha of straw. Nitrogen fertilizers were applied as urea in 2 applications, half at sowing (S) and half at booting (B). Each plot was divided into sub-plots receiving urea or labelled urea. Periodic sampling of both the soils and plants was done to follow the N dynamics in soil and the N absorbed by the plants. Leaching losses were measured, using ten lysimeters with undisturbed soil.

Results

N-fertilizer utilization and N-nutrition of plants

N-fertilization increased N uptake by the plants and slightly increased grain protein content. The nitrogen-supplying power of the unfertilized plots of rice was equivalent to 60 kg/ha during the growing season. The release was fairly slow, reaching a maximum of 1 kg/ha/day during flowering. With fertilizer additions of 60 and 120 kg/ha, total N uptake increased to 100 and 140 kg/ha and 2.8 kg/ha/day, respectively. Total N in the plant was reduced between flowering and maturity, which was correlated with a prolonged dry period.

The apparent utilization coefficients were always higher than the real coefficients; added N favoured mineralization and turn-over. Nitrogen utilization by upland rice was low, ranging from 35-55%, with less at maturation stage. The addition of 5 t/ha of straw had a favourable effect on yields; during one cycle about 15 kg/ha of N (35% of the total N content of the straw) were released. Its action was also important in the K nutrition and on soil saturation. Moreover, straw modified the acidification effects of repeated N-fertilization. Mineral N dynamics in the soil showed the natural N mineralization and the evolution of the N-fertilizer. It was demonstrated that the first N application was available in mineral form for approximately one month and disappeared progressively, while the second application, during the growth stage, disappeared more rapidly. In the no-fertilizer treatments, the mineral N quantities were very low except during the first rains. After cultivation, small quantities of mineral N derived from fertilizer were in the mineral pool. Rice seemed to take up the ammoniacal form preferentially. The buried straw was not shown to have a very clear effect on the N-dynamics and its absorption by the plants.

Leaching losses

Under rice, for 60 kg/ha application, 60 kg/ha were consumed by the plant and less than 1 kg/ha of N-fertilizer was leached. For 120 kg/ha application, 70 kg/ha were consumed and 4 kg/ha of N-fertilizer were leached. The second year, leaching losses of labelled residual nitrogen under N-fertilized maize and cotton were of the same order.

Balance sheet

In establishing a nitrogen balance sheet, with moderate fertilization all the N^{15} was accounted for. With heavy nitrogen additions, up to 30% of the labelled N was lost to the system. It has been shown by computer simulation that chemical denitrification losses can be very important (up to 40% losses) in a tropical acid soil during a drying cycle (Table 1). These conditions were for heavily fertilized soils of pH5.

A phenomenon which seems to be important to these soils is the immobilization of N in the organic matter. The utilization by the microorganisms of the soil was superior to uptake by the plants. There was a preferential incorporation of N into a special hydrolysable fraction corresponding to amide-N equivalent of 50% of N-fertilizer. This indicated that the residual effect of N-fertilization was relatively important to the plant but, on the other hand, leaching losses were of the same order the second year as in the first year of application.

TABLE 1

Balance sheet of N-fertilizer in kg/ha on rice in dryland fields

	1st	2nd	1st	2nd
Application of N	30	30	60	60
Uptake by plant	7	13	11	21
Mobilization soil 0-25	19	15	18	20
Mineral form 0-25 cm	1	1	2	1
Leaching	0.5	0	3	1
Total	27.5	29	34	42.5
Losses %	7%	3%	42%	28%

Summary

In Bouaké, Ivory Coast, field experiments were conducted to study N-fertilization in the tropics in which N^{15} labelled fertilizer was used during two years on a rotation with rice-maize-cotton.

The N-uptake by rice seemed to reach a maximum at flowering. The real utilization coefficients were low and they varied with time and quantity of application. The second application, at booting, was better utilized than the first, at sowing.

In all cases, N-fertilization distinctly increased N-protein content. The storage in organic matter was important. N-fertilizer was transformed to amide-N in the soil,

but a certain quantity of this N source could be re-utilized by the plant. The leaching losses of N-fertilizer were not heavy and N lasted several years. The chemical denitrification losses could be important in the case of acidified soil and prolonged drought. Incorporating the straw is an interesting practice; it had a positive effect on yield and on soil fertility because of its N and K production and of its modifying action on acidification due to N-fertilization. It had no effect on the N mineral dynamics in the soil nor on its absorption by the plants.

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IDENTIFICATION OF RICE YELLOW MOTTLE VIRUS IN IVORY COAST

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Introduction

A virus disease has been found in irrigated rice in several areas of Ivory Coast, notably Gagnoa, Lam-To, Yamoussoukro, Katiola, Odienne and Tabou. The characteristics of the disease and the virus itself were studied in order to identify the disease and assess its importance.

On young leaves, the disease appeared as a yellow and green mottle. Older leaves were yellow at the base and orange at the tip. In an infested field, yellow-orange discolouration of leaves was seen on plants scattered throughout the field, but such plants were more prevalent at field margins. Symptoms occurred at any stage from transplanting to booting. Plants infected at an early stage were stunted. The disease has been observed under irrigated conditions on the varieties IR8 and Jaya, with symptoms more pronounced on IR8.

Transmission and Host Range

The rice yellow mottle virus (RYMV) was successfully transmitted by mechanical inoculation of leaves previously dusted with carborundum. The inoculum was prepared by grinding in a mortar at 0°C, 0.5 cm pieces of infected leaves in 0.1 M phosphate buffer at pH 7.1, containing 0.25% bentonite and 0.35% cysteine hydrochloride. The symptoms after inoculation were similar to those seen in the field. Plants less than 14 days old were killed by the disease. The distribution of the disease in the field suggested that an insect vector may be involved, but this has not been investigated. The disease was not observed in 6000 seedlings grown from seed from infected plants.

The virus was mechanically transmitted, as evidenced by symptoms of a mottle, to 15 varieties of *O. sativa* from the IRAT collection at Bouake: C 463A; Carreon; CICA 4; Iguape Cateto; IR5; IR8; Jaya; LSX 104 x 144 B9;

Moroberekan; Mutant 50; OS 5; OS 6; Tetep; Zenith; and 1487/9/5. The 15 varieties were inoculated mechanically at 15, 30 and 45 days after transplanting. The effect of the virus on growth, development and yield was much greater with earlier infection, and this depended on variety.

The virus was mechanically transmitted to other *Oryza* species (Table 1), but not to the following species: *Chenopodium amaranticolor, Datura innoxia, D.stramonium, Eleusine coracana, E.indica, Nicotiana glutinosa, N.tabacum* v.samsun, *Physalis alkekengii, P.floribunda* and *Zea mays*.

Virus Characterization and Concentration

The characteristics of the virus were investigated using methods described elsewhere (Fauquet and Thouvenel, 1977). Juice extracted from six-week old leaves of variety IR8 which had been infected two weeks previously, or purified preparations, were used. The virus was purified from 30 g samples of frozen IR8 leaves, using the method of Bakker (1974) for rice yellow mottle virus. Using an absorption coefficient of 6.5, yields were obtained of 400-600 mg virus per kg of extracted leaves. The virus was shown to be 28-30 nm in diameter and to be stable (Table 2).

TABLE 1

Symptoms of rice yellow mottle virus on Oryza species

Species	Symptoms
O.sativa (FK 135)	Mosaic, strong mottle
O.sativa (Pacita)	Light mottle, yellow discolouration
O.sativa (TN I)	Apical necrosis
O.alta	Mottle on young leaves
O.australiensis	Chlorosis
O.barthii	Mottle
O.glaberrima	Yellowing
O.latifolia	Slight mottle
O.nivara	Chlorosis
O.rufipogon subsp. balunga	Chlorosis
O.rufipogon subsp. cubensis	Chlorosis
O.rufipogon (Taiwan)	Strong mottle
O.spontanea	Necrosis

Variety IRAT 2 was grown in the greenhouse and inoculated mechanically at weekly intervals from two to six weeks. The virus concentration in the plants was estimated by harvesting the tip of the last leaf and measuring the dilution end-point by inoculating the sample dilutions onto young IR8 plants. It took four weeks for the virus to reach maximum concentration. The virus concentration was much greater in plants infected earlier than later in the season. For IR8, loss in plant weight caused by the virus was estimated at regular intervals and the virus present in the leaves was purified and weighed. The maximum virus concentration occurred 10-14 days after inoculation. The growth was retarded maximally 21 days after inoculation. Virus concentration at the end of the growth cycle was 25% of its maximum value.

TABLE 2

Physical characteristics of rice yellow mottle virus from Ivory Coast

Characteristic	Value
Dilution end-point	10^{-6} (variable with inoculum source)
Thermal inactivation point	70°C
Longevity at 20°C	34 days
Longevity at 4°C	84 days
Particle shape and size in dip preparations	spherical, 28-30 nm diameter
U.V. absorbance	maximum at 260 nm; minimum at 243 nm, which gave the following ratios: E_{260}/E_{280} = 1.46±0.02; E_{max}/E_{min} = 1.29±0.03
Isoelectric point	6.0 ± 0.2
Density in CsCl	1.36 g/cm^3
Molecular weight virus protein subunit	27,000 ± 1000 daltons

Serology

The antiserum produced by this virus reacted specifically with crude sap up to a dilution of 1/1024. It also reacted with RYMV isolated in Kenya by Bakker (1974) up to a dilution of 1/512. RYMV antiserum from Kenya (titre, 1/1024) reacted against the virus from the Ivory Coast up to a dilution of 1/512. The presence of a spur between the two viruses indicated that the isolates were different.

Cross reactions between antisera of RYMV from Ivory Coast and Kenya and comparison of the characteristics of the Kenyan isolate (Bakker, 1975) with that of the Ivory Coast suggest that different strains of the same virus occur in these countries. An identical or similar virus disease has been reported from Nigeria, Sierra Leone and Liberia (Raymundo and Buddenhagen, 1976), so apparently rice yellow mottle virus is widespread in Africa. To date it is the only rice virus which has been isolated and described from Africa.

The provision of a rice yellow mottle virus antiserum by Dr. D. Peters, Virology Laboratory, Agricultural University, Wageningen, The Netherlands, is gratefully acknowledged.

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Plate 24. Recent development of steep paddy culture in the mountains of West Cameroon. 'Slash and burn' upland rice cultivation on the hills in the background.

Plate 25. Inland valley swamp rice of the peasant farmer in the high rainfall area of Liberia.

Plate 26. Testing different paddy varieties in a new, mechanized paddy scheme in a high rainfall area of eastern Liberia.

Plate 27. Recently developed, medium-statured rice for dryland situations in West Africa.

Country Statements

INTRODUCTION TO COUNTRY STATEMENTS

Eighteen country statements follow, from countries where the rice area is as low as 1000 hectares (Rwanda) to as large as 1.1 million (Malagasy). Twenty-seven more countries exist on the African continent, but only nine of them have more than twenty thousand hectares of rice - Sierra Leone, Guinea, Ivory Coast, Mozambique, Gambia, Togo, Angola, Niger and Uganda. Only three of these, Ivory Coast, Sierra Leone and Guinea, have substantial rice areas (300,000 or more hectares). Ivory Coast and Sierra Leone were well represented at the conference and by papers in this volume, but Guinea was absent. This is unfortunate in that it is a country where there is also an ancient rice culture and where there has been a unique centre of diversification of the indigenous rice species *Oryza glaberrima*, in the forested hills.

Since the emphasis was tropical Africa, and our contacts in temperate Africa are minimal, rice in countries along the Mediterranean was not included, apart from Egypt which has extensive rice production and research. Similarly, southern Africa was somewhat under-represented, for various reasons.

Country statements were requested from a participant from each country and most responded in considerable detail, too lengthy for inclusion here, even as edited versions. Hence, we have abstracted the papers, and, hopefully, have included the major points from them.

The Editors.

- 4 JUN 1986
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CAMEROON

J.M. AYUK-TAKEM

The country's ecological conditions are amongst the most diverse in tropical Africa, ranging from mangrove and rain forests to deserts and from sea level to 4000 metres. Soils range from rich, recent volcanics to old leached red laterites, to black cotton soils. Rainfall ranges from 600 mm to more than 3 metres per annum.

Rice production is about 40,000 tons of paddy from both upland and irrigated fields. Irrigation projects exist in the dry north along the Logone River (47% of national production), and in the central-south along the Sanaga River. Irrigated rice is now grown by peasant farmers in small developments in the mountains of the northwest, following introduction of techniques by the Taiwanese. A more recent effort to develop peasant farmer paddy rice is underway in the Ndop plain, at an altitude of about 1000 metres. These peasant farming programmes involve over 8,000 farmers and comprise 20% of the national production. Paddy rice yields average about 2.3 tons/ha.

A large upland rice project has been developed in the Mbo plain on volcanic alluvial soils, where soil conditions range from inundation to hydromorphic to pure dryland. The rest of the upland rice in the country is of the shifting forest agriculture pattern by peasant farmers and it is restricted to a few regions. Upland rice yields are about 0.9 tons/ha under shifting agriculture but over 4 tons/ha have been obtained under dryland conditions in the Mbo project.

Research

Some research dates back to 1953, conducted first by the Ministry of Agriculture then by a commercial development association near Yagoua in the north. In 1967, IRAT assumed responsibility for research on rice and other food crops. In 1974-75, this research was transferred to the Cameroonian organization of IRAF (Institute of Agricultural and Forestry Research) which is under the National Office for Scientific and Technical Research (ONAREST).

Research on rice is as yet in its infancy, but varietal screening and various agronomic trials have been conducted. Agronomic trials have been mostly at commercial projects and have covered fertilizer, rotations, and herbicides.

Varietal screening for commercial upland conditions has been mostly of varieties developed by IRAT in Ivory Coast or of traditional African upland varieties and Brazilian upland types. Several IRAT mutants (M 45, IRAT 13, M 5) and lines from the cross IRAT 13 x Moroberekan, are high yielding and well adapted.

The traditional upland variety 63-83 from Senegal and a Brazilian IAC line were adapted to peasant upland conditions.

Varieties being grown in peasant irrigated areas in mid-altitude sites (up to 1200 metres) are Tainan 5, Mangakeley, and two varieties labelled IR42 and IR288, both of which require clarification for correct designation and origin. In the large northern irrigation scheme, varieties IR8 and IR24 are grown commercially but problems of cold tolerance and blast occur. The peasant farmers grow D-114-4 and Neang Veng under less intensive irrigated conditions in the same area.

The major problems known which require research are blast disease for both paddy and intensive upland culture, and the maintenance of soil fertility for upland conditions. Considerable more varietal screening work or even breeding, could be useful. Intensification of rice culture will require greater research efforts since other pest and disease problems can be expected to increase.

CHAD

M. N'DOUBA

Indigenous rice species, especially *O.breviligulata*, occur around Lake Chad and have been harvested since ancient times. *O.sativa* is more recent, having been first introduced during the colonial period. However, the major expansion of rice cultivation occurred after 1940, with introduction of seeds from Cameroon.

Production

Rice culture over the past 20 years has extended from 8-11^{o}N, in the 1200-800 mm annual rainfall belt. The length and duration of the rains govern the flooding of the rivers and the inundation of the plains and river basins where rice is cultivated. The types of rice culture encountered are:

a) *Pluvial*: On lowlands; requires 1200 mm annual rainfall, from June to October, and occurs in the Moyen-Chari and Mayo-Kebbi regions.
b) *Flooded without water control*: Depends on the depth of the floods in the rivers and streams, occurs in Tandjile and Mayo-Kebbi areas.
c) *Flooded with partial water control*: Semi-pluvial, irrigated by controlling the arrival and departure of the flood waters in Satêgui-Deressia plain.
d) *Irrigated with total water control*: Dams, pumping stations and irrigation canals, in Bongor and Doba regions.

The area of rice cultivation over the past ten years has varied from 30 to 40,000 ha, apart from a peak period of approximately 50,000 ha in 1971-72. The average annual production is 37,000 tons, with a peak of 50,000 t in 1971. Average yield is 0.9 t/ha. Production is insufficient to meet national needs and is supplemented by imported rice.

There are several reasons why production and average yields have not increased in recent years: irregular rains which resulted in reduced flooding along the Logone and Chari Rivers; a severe drought in 1973; poor maintenance of equipment for water control; use of poorly-adapted, long-duration varieties which are low yielding; lack of fertilizers and appropriate cultural techniques. A low official price (25 CFA or US$0.10/kg paddy) encourages farmers to sell in neighbouring countries at a better price, on the black market.

Rice has long been grown in the basins of the Logone and Chari Rivers. It is now extending into the *basfonds* (lowlands) of southern Chad where it is an additional crop to cotton.

There are two major alternatives for future rice development in Chad. One is for large-scale irrigation schemes with complete water control, while the other is for pluvial rice with semi-controlled flooding. The former allows two crops per year and should give increased yields. However, it requires large capital investment and costly irrigation equipment which is difficult to maintain. Because of the cost, most of the potential rice land is unaffected by the schemes. The partial water-control schemes require less management and expense and can reach many more farmers. They should result in a more rapid increase in national rice production.

Research

The first rice research station was established at Bounio in 1952. Stations have subsequently been established at Bongor (1958), Lai-Kelo and Satégui-Deressia (1975). The early work resulted in the release of the varieties Maroua S.M. and Bentoubala B., which are still cultivated in some areas today. Maroua yields 2.5-3.0 t/ha. Of 183 introductions between 1950-69, five (D 52-37, Bentoubala B., Puang Ngeon, Nedng Veng and Dissin 14) were released to farmers. Many varieties have been introduced during the 1970's and some of these, such as IR8, IR20, IR22, and Sintana Diofor out-yielded the older varieties, such as Puang Ngeon, Bentoubala B. and Maroua S.M. by 7 - 30%. Variety D 52-37 and IR24 yielded similarly to the check varieties (2.0-2.5 t/ha), whereas CICA 4 and Tainan 5 yielded less.

Agronomic research has been concerned with devising an appropriate calendar of cultural operations, fertilizer recommendations, and improved cultural techniques. Blast disease occurs on some varieties, as do *Cercospora* and *Helminthosporium* leaf spots. Little is known about insect pests.

Future research could profitably concentrate on the selection of high-yielding varieties adapted to the various zones of rice culture. The establishment of a competitive price for paddy producers is also important for the future development of rice production in Chad.

EGYPT

A.F. EL-AZIZI

Rice in Egypt lies outside the tropics at about 30°N latitude and this, plus the exclusively high water control irrigation in a desert climate, make for a very different situation from rice in tropical Africa. Rice is grown on about 500,000 hectares and it is the country's second export, after cotton. The area under rice has doubled in the last 20 years, mainly due to the Aswan dam. Yields have risen from 3.3 to 5.3 tons/ha, largely due to an improved variety, Nahda (Selection 47), which was locally selected from a Japanese introduction. Rice is a summer crop, in rotation with winter crops and is restricted to the northern half of the delta where a special irrigation regime is guaranteed. Rice occupies approximately 18% of the summer crop land area of the country.

The rice soils are alluvial and are grouped into six classes on the basis of salinity, alkalinity, need for drainage and texture. The soils have deteriorated in general, due to perennial irrigation and poor drainage with concentration of salts, and gypsum formation.

Rice is transplanted, saving seed, water, land area, and decreasing weeds, blast, insect pests, resulting in increased yield. However, broadcasting is done on saline soils. The net profit from rice on an area basis is about double that of either maize or cotton.

Research

Rice research is conducted at four stations administered through the different institutes of the semi-autonomous authority, 'Agricultural Research Center', of the Ministry of Agriculture. The main station is at Sakha in Giza. Research covers varietal improvement, cultural practices, soil and water management, diseases, pests, weeds and economics. It is conducted by 25 PhD level and 20 MSc level scientists along with 40 BSc graduates and 150 supporting staff in engineering and administration and as technicians and labourers. Other research on rice is carried out at the agricultural colleges of the universities. Cooperation with the Egyptian milling organization enables large-scale milling tests of new varieties.

Linkage with IRRI was established in the late 1960s and has resulted in introduction of much germplasm and literature and the training of Egyptian rice scientists and extension men.

Varietal improvement began in 1917 and up to 1954, varieties Yabani 15, Yabani Lolo, Giza 14 and Nahda were released for normal fertile soils. Nahda has remained popular for more than 20 years. For saline soils, Nabatat Asmar, Agami 1, and Giza 159 were released. In 1967 Giza 169 was released to share the major area with Nahda and now Giza 171 and 172 are scheduled for release to replace these. All are *japonica* type.

More than 2000 lines have been introduced from IRRI. Only IR579-48 has been released but for various reasons farmers have not been willing to shift to the *indica* type. Nevertheless, a breeding aim is to develop an *indica* type suitable for Egyptian conditions utilizing IRRI material in the parentage. Many crosses are underway. The *indica* type would be especially useful for the European export market.

Other objectives of the breeding programme are to improve resistance to blast, brown spot, the stem borer *Chilo agamemnon*, and salt tolerance. High milling recovery, grain appearance and nutritional value are other characters of concern - all in varieties of 120-130 day duration. Some induced mutation work is conducted, as well as genetic studies of various traits.

Agronomic research has established optimum seed rates, planting dates and age, spacing, harvesting time and weeding methods. The major weeds are barnyard grass and sedges and most weeding is by hand but Ordram and Stam F34 are recommended for the seedbeds. Optimum fertilizer is usually 50-75 kg N and 36 kg P_2O_5; zinc has been determined to be deficient.

Blast disease is destructive, causing an estimated 5 - 10% or more loss depending on weather, soil conditions and nitrogen levels. Breeding for resistance is pursued but more research is needed to understand how to do this better. Hinosan is recommended for spraying in farmers fields.

Insect pests are mainly *Chilo agamemnon* which may cause up to 10% loss. The variety Nahda is quite resistant. Research on insecticides has been conducted but it is hoped that further studies of overwintering might lead to population control by other means. Bloodworms, a dipterous larva (*Chironomus* sp.) cut and destroy young seedlings in saline and stagnant water. These may be controlled by Diazinon or Sevin or by draining the seedbeds.

Considerable research is conducted on rice quality, nutrition, factors affecting protein levels, cooking behaviour and parboiling methods.

Constraints to research are organizational, in that rice research is carried out within the Ministry of Agriculture in five different institutes. This leads to

isolationism. Another constraint is the slowness of advancing breeding generations by only one per year and the cost and distance of sending seeds to IRRI for this advancement in the off season. A closer site for growing alternate generations is needed. Insufficient work on the genetics of physiological resistance to blast inhibits progress. There are several political and non-technical constraints which inhibit the necessary continuous flow of communication and materials for progressive research accomplishment. Other constraints are insufficient laboratory equipment, transportation and social facilities at most of the experiment stations.

There is a complex structure of extension, and village, district and governorate organization through which useful research results can pass to farmers. On-farm testing is carried out on a 10 acre field in each district. An individual farmer extension field programme also operates, in which a single farmer employs all of the research recommendations for the crop. The increased productivity of such farms has attracted much attention among other farmers, and has led to similar group projects.

The varietal improvement work has played a big role in the development of improved technology in general. A seed programme is geared to supplying farmers with new certified seed every other year. This is produced by growers under contract with the seed board and it follows steps from breeders' seed to foundation seed to registered seed. Certified seed is distributed with a 20% subsidy.

The results of a combination of climate, research and extension in Egypt place it among the top countries of the world in rice yields.

GHANA

W.K. AGBLE and A.G. CARSON

Although possibly of ancient culture in the north, rice received its first government support in Ghana (then the Gold Coast) in 1920, with the provision of a milling facility. Support for rice production was given again during the Second World War but this was not sustained until 1963, when production was about 21,000 tons. By 1974, production was about 70,000 tons on about as many hectares. Rice is raised on a few irrigated schemes in the south, but mostly as upland or hydromorphic rice in the savanna and fadama areas of the central and northern regions.

The government has encouraged production by a guaranteed minimum price; provision of mills; extension services; encouraging bank credit; subsidizing land clearing, fertilizer and seed; encouraging machinery imports. There are many socio-economic constraints to production. Some of these are: Credit problems; distribution difficulties for inputs; marginal land use for rice stimulated by mechanization; diversity of country origin of machinery; labour shortage; bush fires.

The government is attempting to increase land under irrigated rice and this is expected to rise to some 3,000 hectares by 1980.

Research

Rice research is conducted at Nyankpala near Tamale in the savanna region for upland rice and at Kpong in the south for irrigated rice. The research on rice is not extensive, with rice being handled as only one of several crops by various research officers. In the north, the West German Government contributes staff and funds to savanna research, which includes rice. Various types of rice trials are conducted in collaboration with international and regional institutes. Varieties have been released, after screening, such as C4-63, IR5, IR20, IR442, D 52-37, D 99, IRAT 10 and IRAT 13. Several of these have been abandoned, largely due to blast susceptibility or poor milling quality. Agronomic research has established optimum seeding rates, planting dates, fertilizer rates, etc.

Constraints to research accomplishment include lack of a modern research centre with sufficient funding, equipment

and staff to undertake multi-disciplinary research. Remuneration and incentives to researchers are insufficient to prevent a drift to other positions.

The linkage with extension and on-farm testing is provided mainly through the German project in the north. The Grains Development Board and the Extension Services also provide useful services. Meetings are held periodically amongst the various agencies to accelerate research and technology transfer.

GUINEA-BISSAU

C.S. DA SILVA

Rice culture is very important in Guinea-Bissau, being practised by almost all peasant farmers. In some ethnic groups it is the only cultivated crop, and as such, is grown as a cash as well as a food crop.

Production

In 1953, the total area under rice cultivation was 158,000 ha, about 45% of the total arable land. Total production was approximately 100,000 tons, which was a little less than the country's requirements at that time. During the war of liberation, large areas of rice culture were abandoned and irrigation controls were destroyed. As a result, rice imports increased drastically between 1963 and 1974, reaching 30,000 tons per annum. In 1974, the new government introduced measures to increase production rapidly. They included the resettlement of refugees, an increase in the paddy price, distribution of improved seed and appropriate technology including insect control. These resulted in an immediate reduction in rice imports in the following year. Imports in 1976 were 11,000 tons.

The types of rice culture are:

a) *Aquatic:* Occupies 80% of the total rice area (115,000 out of 125,000 ha). Of this, 75% is in mangrove swamps, where salinity and acidity are problems. The remainder is lowland rice on hydromorphic soils. Average yield of mangrove rice is 1.5 t/ha.

b) *Upland*: Approximately 28,000 ha; average yield 300-600 kg/ha.

Some current problems which limit yields are insects, especially borers and leaf-feeding beetles; low-yielding varieties; annual fluctuations in rainfall; high labour requirements for mangrove rice; difficulties of mechanization or animal traction required for upland rice; and the difficulties and expense in reclaiming land from the sea.

Since full independence in 1974, the aim of the Government has been to attain self-sufficiency in rice production as quickly as possible. To this end, the Government has doubled the paddy producer price to 38 CFA (US$0.15)/kg; organized insect control programmes, distributed improved seed of the variety Ikong Pao for lowland culture, and

initiated projects for the reclamation of mangrove swamps and water management along the Geba River basin. A four-year rice improvement scheme has been commenced in co-operation with FAO. In addition, two rice research stations have been established, one for mangrove and one for irrigated and upland rice. A station concerned with mechanization, training and extension has also been established. The staffing of these stations is severely limited by the lack of suitably trained personnel.

Research

The most important problems of mangrove rice are salinity, iron toxicity and low pH. It is necessary to identify varieties and cultural techniques suitable for these adverse conditions. Insects are a severe problem and better control methods are being sought. Seeds of some promising new varieties have been distributed to farmers recently: e.g. Ikong Pao and IR422 for upland and lowland; ROK 5 and RH 2 for mangroves.

Guinea-Bissau is a member of WARDA and receives trials from this organization. There is also exchange of information with the rice research stations at Djibelor and Richard-Toll in Senegal.

The major problems presently limiting the expansion of rice production in Guinea-Bissau are the lack of suitably trained people and appropriate varieties. The solutions to these problems are essential for the future development of rice production in the country.

KENYA

J.M. MUNYUA

Production

Rice is grown on about 7,000 ha in Kenya, as a transplanted crop in Irrigated Settlement Schemes. These schemes are managed by a National Irrigation Board, a statutory board of the government. Mwea, the oldest (1960), largest (5,600 ha), and most productive scheme (5.6 t/ha) is in central Kenya and the others are in western Kenya near Lake Victoria. By having the bulk of its small rice production in these irrigated, managed schemes, Kenya has the highest average country rice yield in tropical Africa. (A small but unknown amount of upland rice has not reached the statistics.)

The irrigation schemes are at about 4000 feet altitude and on soils ranging in pH from 6.5 to 7.9. Soils around the lake are heavy montmorillonitic vertisols. Large hectarages (40,000) could probably be developed for rice in the future in this region.

Research

Research is conducted at small stations in each rice development scheme. Some of this research has been done by the International Land Development Consultants (ILACO EUROCONSULT) with backing from FAO/UNDP. The research has concentrated on fertilization practices, time of planting and spacing experiments. Nitrogen is generally the only element required, but only at 26-52 kg/ha. In some localities phosphorous and more rarely, potassium, is deficient. Some variety trials have been conducted, especially in the west where blast has necessitated a change of variety three times in the last five years. In central Kenya, however, the 'local' variety, Sindano, has been grown successfully for 15 years. A routine spray programme was developed for controlling the paddy borer, *Maliarpha separatella*. It was in the central Kenyan irrigated rice scheme that the first African rice virus (rice yellow mottle) was first found and studied.

As in most places, research has shown that planting early in the rainy season gives higher yields. In the west, yields dropped if transplanting was in March or

later; in central Kenya, transplanting could be done to mid-April. Low yields with later plantings were attributed to low temperatures and low sunshine towards maturation.

Considerable effort has been made to determine why tenant farmer yields are considerably lower than experiment station yields. Many social and management factors appear to be involved. Little is known about riçe possibilities in the coastal areas of Kenya.

LIBERIA

S.S. VIRMANI, A.F. TUBMAN and P.M. WORZI

Rice is the major food for the country's 1.5 million people and it is grown on 25% of the cultivated area. Rice area has increased by 60% during the last 17 years; per hectare yield has increased 34%, with total production increase being 110%. The major jump in yield since 1965 is due to the increase in area of improved swamp rice culture, a system giving 50-150% higher yield than upland culture.

Liberia is a low-lying coastal country of gently rolling, low-forested hills. The northwest is a low dissected lateritic plateau, now a man-made savanna. The climate is uniform and warm with rainfall of 4,600 to 2000 mm, with a short dry season.

The approximately 200,000 hectares of rice is 95% upland and 5% swamp, the latter of which is either improved with some water control or unimproved. About 120,000 hectares of poorly drained swamps and 4,000 hectares of level alluvial terraces could be developed over time, for rice production. About half the existing rice is produced in the wet forest zone and 40% in the secondary forest zone. Little is produced along the coast.

Upland rice is grown by peasant farmers after cutting and burning the forest on a shifting pattern of only one or two crops before either growing cassava or abandoning to forest. The crop is broadcast, with no inputs; weeding is done by hand. It is a primitive but stable and effective method of food production at a low return per unit area (about 1200 kg/ha) but a high return for investment and effort. Yields are low because of low nutrients (N and P) combined with low populations of the tall, old varieties. Weeds, groundhogs, rats and birds cause losses. Under this system with old, adapted varieties, losses due to insects and diseases appear to be minimal.

Swamp rice culture is either very primitive or modernized to the extent of hand-dug drains and hand construction of small paddies. Land is worked with a hoe. Yields are low due to poor soils of low N, P and K, iron toxicity, diseases of blast, sheath blight, sheath rot and the insects, caseworm and *Diopsis*.

Soils are sandy ferrasols, from yellow to red, which are badly leached, with very low cation exchange capacity. Sunlight during the growing season is low and skies are

overcast much of the time.

Government Policy

Liberia is about 80% self sufficient in rice; self sufficiency would require a minimum of 25% increase of present production. This is a very difficult task requiring motivation and implementation involving many people and organizations. The short-term strategy is to increase land area and yield of upland rice. The long term strategy is to encourage farmers to develop permanent lowland or swamp rice culture.

For upland rice, farmers in project areas are provided with fertilizers and seeds of LAC 23, a locally selected, adapted tall variety. This programme involves 2,500 farmers. In addition, there have been several attempts to develop upland projects with large equipment for use by farmers organized in cooperatives. These have not proved very successful, with soil erosion and deterioration being major problems.

For swamp improvement, teams identify areas suitable for paddy cultivation and some credit and other assistance are provided to farmers. This is slow work, with about 600 hectares added under this programme to date. In addition, a rice corporation has been established (LIRICO) by the government for development of commercial paddy rice in the few areas along rivers where this is feasible. The largest one in progress is along the Cestos River in eastern Liberia. More recently, integrated rural development projects, backed by the World Bank, have begun in various areas, with rice and tree crops as the production base. Social services, health and education are essential aspects. Some 15,000 farm families are involved in the first two projects under development. Much infrastructure is lacking in the country to support a massive change in productivity which would involve thousands of farmers and cover everything from supplies to machines, to credit, to transport, storage, milling and marketing.

Research

Rice research is conducted mostly at the Central Agricultural Experiment at Suakoko, under the Ministry of Agriculture. The major scientific expertise has been provided under FAO/UNDP, USAID, and IITA contracts. Some rice research is conducted by FAO/UNDP experts at the University of Liberia. Chinese projects contribute simple experimentation on fertilizers and on a few varieties. A major problem is coordination of these various rice research activities. There is one full time PhD level researcher (breeder), from an IITA, IDA bank/Government contract on rice research. Two Liberian staff with BSc level training are also assigned full time to rice research. Research facilities are inadequate.

Although the research support is inadequate in consideration of the importance of rice production to the country, considerable progress has been made. Varieties resistant to iron toxicity have been identified. A variety has been developed from Malaysian material and recently released as Suakoko 8 which is adapted to iron toxic swamps. Lines have been identified which are productive in swamps where disease problems, including blast, are severe. IR1416 is one line which has remained blast resistant for several years. For upland rice, a white-grained version of the superior tall, LAC 23 has been identified. Many new breeding lines, developed with IITA liaison, are under final stages of test.

Many agronomic trials have been conducted and these indicate that fertilizer needs on experiment stations and on farmers' fields are different, with rather low 24-40 kg/ha additions of both N and P being worthwhile under farmers' conditions. Standard agronomic trials have been conducted on seeding rate, spacing, time of planting, weed control etc.

Increased research on rice could contribute greatly to the country. A base of five scientists would be required, covering breeding, agronomy, diseases, insects and soils and working as a team under strong leadership. Considering the importance of rice to the country, this should be a viable goal.

MALAGASY

R.J. RAKOTONIRAINY

Rice is the staple food for the Malagasy people, who originally brought rice and rice culture from Indonesia about 2,000 years ago. Rice is cultivated by the bulk of farmers and plays an important role in the economy. Total production, of some 1.8 million tons can be compared with 2.8 million tons for all the rest of tropical Africa. Despite this large production, some 100,000 tons are now imported. The country also depends on quality rice exports to assist in the balance of trade. With a population increase of 3% per year, rice production must be increased by 22,000 tons per year. Government efforts are directed to solve the deficit problem through investment in many activities designed to increase rice production in both irrigated and upland situations. Production increase is no longer the business of a single ministry but of the whole government, through a commission called '*Bataille du Riz*' headed by the Ministry of Rural Development and Land Reform.

The majority (70%) of rice is grown in the second, or rainy season, from November to March. Of this, 70% is irrigated, 9% is upland, and 21% is tavy (burnt upland) rice. About 27% of the total rice land is utilized in the first season from June to September. The yields in the first season average 1.4 tons/ha, and in the second, 2.0 tons. Tavy rice averages 0.8 tons/ha. Irrigated rice is often in terraced paddies in this mountainous island lying at 12°-25°S latitude, 500 kilometres east of the African coast.

Irrigated rice is usually, but not always, transplanted. Upland rice is grown in lowlands of the northwest and especially in the highlands (800 m) of the mid-west of the island.

Constraints to high production are poor water control, inefficient use of fertilizer, diseases (blast, brown spot, seddling rot, nematodes), weeds, borers and other insects and rats. Neither viruses nor bacterial diseases are known.

The government attempts to increase production through improving staff in key positions, maintenance of irrigation infrastructures, integration and control of all rice activities by the state, establishing tractor pools, subsidies for village group projects, road improvement, double cropping, fertilizer production, provision of extension services which include farmer pure seed awareness and seed production.

Research

The National Centre for Applied Research to Rural Development (CENRADERU) has been responsible for agronomic and other research since 1974. French institutes (IRAM, CTFT, IEMUT, etc.) were formerly responsible for research activities. Staff is generally young and in need of further specialized training. Research is in 6 divisions: Agronomy, Genetics, Soil Science, Phytopathology, Entomology, and Technology. There are 30 testing stations for rice trials scattered throughout the island. The only areas excepted are the deep south and regions above 2000 metres.

CENRADERU links with various national institutions and with GERDAT, IRRI, IITA and other centres in Africa, India, Indonesia and China.

Varietal improvement work is detailed elsewhere in this volume by Arraudeau. A great deal of work has been done in this area for many different ecological situations and excellent varieties with high yield have been developed or selected.

Experimental results at four main stations have numbered from 1800 to 4500. A fair number of entries have attained 8-10 tons/ha, with some up to 12 tons. The highest yields have been obtained in the higher altitudes where sunshine is high, temperatures are cooler and the growth duration prolonged. Of interest is that breeding for red grain rices is also conducted since the Malagasy people like such types. In addition to conventional breeding, mutation breeding has been done, with 21 useful mutants produced. A total of 465 new varieties have been produced from 53 parents, from a total of 738 crosses. Work with pluvial rice is being intensified. Line 1490 is now grown on a large scale in the Sakay region of the middle west, where it yields some 4 t/ha.

Many agronomic trials have been conducted in all regions, with emphasis on fertilizers and weed control; studies on resistance to blast are also conducted.

Constraints to research include the few researchers and their inexperience, the diversity of ecological zones, and the modest financing of research.

Extension of research results is carried out by extension centres, and extension trials are conducted by the farmers themselves. Within CENRADERU, a division of field economics evaluates the impact of research on rice producers, through socio-economic and regional agro-economic inventory analysis.

It is considered that reliable progress has been made

which, when more completely utilized, can further increase national production. More efforts are needed on pluvial rice.

MALAWI

A.S. KUMWENDA

Production

Rice is the second major cereal in Malawi, after maize and is largely a cash crop rather than a staple food. Rice was probably introduced during the slave trade period but until 1964 only the variety Faya was grown. Rice is becoming increasingly popular and is grown along the Malawi Lake shore plains at 480 metres, near Lake Chilwa at 600 metres and in the Lower Shire River valley at below 200 metres. These areas, ranging from 10 to 17°S latitude receive 1500 to 800 mm rainfall in the warm, humid, rainy season of November to April. The soils are derived from alluvium and range from heavy vertisols to very light sandy loams.

Rice is grown by over 3,700 smallholders in 14 irrigation schemes, encompassing about 3000 hectares, and as a rainfed crop on possibly 50-60,000 hectares. On the irrigation schemes the variety Blue Bonnet is grown as a transplanted crop, of 125-130 days, mostly in the rainy season (with drying problems at harvest). It is also grown in the dry season where river flow exists. Yields have risen to 3-4 tons/ha, with intensive extension and credit services. Three-fourths of the country's rice is from rainfed crop. The rainfed category includes bunded and non-bunded, dryland and hydromorphic, high-water table conditions, with yields from 0.8 to 2 tons/ha in 155-160 days.

Rice is purchased by the Agricultural Development Marketing Corporation; a network of depots exists and five mills have been erected, some with parboiling plants. Some rice is exported, mostly to nearby countries and the competition dictates long and medium grained *indica* rice of excellent quality, which Malawi has been able to supply.

Research

Research is conducted by the Ministry of Agriculture and Natural Resources on a project basis, and reported at an annual gathering which includes extension staff. The first organized rice trials were conducted in 1967/68, although some records go back to 1935. Current objectives are to improve yields and quality of the local Faya variety and to evaluate new introductions. About 200 varieties have been evaluated as irrigated varieties with the aim of maintaining Blue Bonnet quality but improving on cool-temperature performance, yield and blast and brown spot resistance.

Nilo 11 has been released and others are promising: SML Temerin from Surinam, Nilo 1 from El Salvador, RD 1 from Thailand and Basmati (for quality). Varieties have not been found sufficiently resistant to cool temperatures and to performance above 625 metres.

For rainfed, much selection from Faya, a mixture of types, has been conducted, to stabilize the long grain and aromatic quality with higher leaf spot, lodging and shattering resistance. These latter characteristics have been difficult to find.

Agronomic research has determined an economic range of nitrogen for irrigated Blue Bonnet to be 75-100 kg/ha in split doses and for rainfed Faya, 30-45 kg/ha. Little response has been obtained to P and K. Chemical weed control has not proved practical.

Little work has been conducted on insect pests. Borers and beetles occur in the field but stored product pests seem more damaging at present.

MALI

M.F. TRAORE

Production

In the past, Mali has been the granary of French West Africa, exporting many cereals, including rice, to neighbouring countries and supporting them during drought years. However, in recent years, Mali has been importing rice. Total production is approximately 142,000 tons which is grown on 166,000 ha, giving an average yield of 0.8 t/ha. Since 1965, three government-sponsored schemes involving close-supervision of peasant farmers have been initiated in order to bring the country to self-sufficiency and eventually attain exportation again. These schemes are at Segou, Mopti and Sikasso. They complement the work of the *L'Office du Niger* on the irrigated lands of the inland Niger delta at Niono.

The types of rice culture are irrigated rice; floating rice (inland Niger river delta); and lowland rice (Sikasso; Segou).

Research

Rice research is conducted by the Malian Government and by IRAT. Priorities are determined by the *Comité National de la Recherche Agronomique*. The work at Kogoni station has been concerned with varietal improvement, fertilizers and cultural techniques.

The main objectives of the varietal improvement programme are to identify varieties with high yields, long, translucent grains and resistance to drought and diseases by the evaluation of promising local varieties, foreign varieties and hybrids. Promising irrigated varieties are D52-37, Gambiaka Kokum, BH 2 and DK 3 which have a potential yield of 5-6 t/ha. Some of these have been used as parents in crosses with IR20, IR22 and IR442.

Agronomic trials have shown that the lack of adequate fertilizer is the major limiting factor to yield. Short-strawed varieties such as IR8 require 70-80 kg N/ha, preferably applied as a split dose. The irrigated areas of the inland Niger delta lack phosphorous. Work on cultural techniques has been concerned with labour requirements, optimal rate of seedling and weed, rat and bird

problems.

Suitable varieties and appropriate cultural techniques have been identified for irrigated rice. The major factor is weed control, especially of wild rice. Cold tolerance is also necessary for the Sahel. A more detailed discussion of rice in the Mopti region is presented in this volume by Valee and Vuong-Hu-Hai.

NIGERIA

O.A. ATANDA, K.A. AYOTADE, S.O. FAGADE, V.A. AWODERU, J.O. OLUFOWOTE

Although Nigeria is one of the largest rice producers in West Africa, with production of around 400,000 tons, rice is only the 5th or 6th most important food crop. Estimates of rice area range from 3- to 400,000 ha. In spite of this production, imports were probably over 200,000 tons in 1976. Total production has probably quadrupled since 1960. Rice is raised in scattered locations in all areas of Nigeria, from the dry north to the very wet southeast. Accurate figures are not available but the types of rice culture cover four ecological situations: 1) naturally inundated flood plains or swamps, 2) rainfed upland, either with or without additional groundwater, 3) irrigated with controlled water and 4) mangrove swamps. The flood plains and swamps probably constitute the largest production area and are made up of seasonably flooded fadamas in the drier north where the indigenous *Oryza glaberrima* is a major component and of areas along the Niger and Benue and other smaller rivers in the south and east, where *O.sativa* is grown. In the north the water depth may go above one metre and floating rice types exist. The irrigated rice culture is of recent development, usually on state-backed projects which are run by state agencies or by companies and which sometimes involve small farmers as well. Such areas are small as yet. Upland rice culture of the dryland type is scattered across the forest zone of parts of the south.

The Federal Government is stressing self sufficiency and has projected a target of 1.1 million tons by 1980. This will require much greater development of services and input availability. A major constraint is that nearly all the rice is produced only with the aid of a hoe and a cutlass. Other constraints are land tenure, poor marketing systems, lack of storage facilities, tardy and insufficient credit, lack of water control. Major irrigation projects are to be built in the northern part of the country.

Research

Rice research is conducted under the Federal Department of Agricultural Research at the main rice station at Badeggi in central Nigeria, at Moor Plantation near Ibadan and at several other stations in different parts of the country. The International Institute of Tropical Agriculture also conducts rice research near Ibadan and at other locations. The rice research station at Badeggi was established in 1953. (A more detailed discussion is presented in this volume by Virmani *et al.*)

Up to 1969 the varieties released were varieties introduced from other countries that were evaluated for three years before final selection. Variety OS 6 which came from a breeding programme in Zaire (then the Belgian Congo) has remained the most popular and stable upland variety in the country, and is a base for hybridization.

From 1965 onwards, intensive hybridization was carried out with dwarfs from IRRI and elsewhere and local hardy varieties. Various releases have been made of which Faro 15 (BG 79 x IR8) is most significant. A good parent has been the tall rugged variety Tjina, for both swamp and upland rice.

Many experiments have been conducted on all aspects of agronomic practices and soil fertility. The diverse rice growing situations make accurate generalizations from these experiments difficult. It can be considered, however, that for the experiment station locations the optimum for most of the customary cultural practices has been established, covering spacing, fertilizing, seeding rates, planting time, transplanting age, weeding, mulching, etc. An especially interesting point was the finding that at Badeggi the irrigation water contains sufficient K to provide about 30 kg/ha to the crop. Also, it was determined that *both* July and October plantings yielded best. In each case, ripening and harvesting occur during periods (November and February) of dry weather and high solar radiation. Research has been conducted on blast and brown spot and on the three genera of stem borers. Quality, milling and acceptability tests are also conducted as well as economic studies and some work on mechanization.

Except for the fadama flooded areas in the north, rice is essentially a recent crop in Nigeria. Thus there is a large gap between the conducting of research and the developing of advanced rice culture by the farmers. Much effort is given to extension, through state extension services, the extension and research liaison service of research institutes, and now the NAFPP (National Accelerated Food Production Project). Since there is little backlog of rice experience, however, and since the officers themselves have seldom come from a rice culture, education and training in depth remain major hurdles.

In research itself some major areas remain: a) study of soil-water-plant relations in rainfed and irrigated rice; b) study of complex relations of production factors; c) breeding for salt and cold tolerance; d) herbicide research and e) the development of profitable rice-based cropping systems.

RWANDA

A. MAFURA

Rwanda is situated in Central Africa between 1 and 3° south latitude and the country is of moderate altitude. The total rice area in the country is only 1000 ha, with an average yield of 2.3 t/ha. Rice culture has been known for some time in the southwest, but the present important rice culture began in 1964 following cooperative agreements with countries experienced in rice culture, such as China.

Two crops of irrigated rice are grown per year, with the first season planting in November and the second season planting in June. The traditional varieties are Kihogo and Bungara from Tanzania and Sifara from Zaire. These are of 150-170 days duration, with long, fine grains and they are generally resistant to diseases. Sifara occupies the largest area. Eighty varieties were introduced recently from Taiwan, but, unfortunately, most were susceptible to diseases, except the variety Malgache. More recently, 22 varieties were introduced from the People's Republic of China. Many of these are high yielding and warrant further testing and possible adoption.

There are few serious rice diseases in Rwanda, although there are several of minor importance. These could become more important if the varieties change in the future. Birds are the most important pest. Another problem is low temperature, which can be sufficiently low at flowering to cause sterility.

Future research could profitably deal with the identification of varieties adapted to various ecological zones, with appropriate growth duration, good yield and quality and resistance to pests and diseases.

SENEGAL

M. TOURE

Production

Rice, the third most important cereal crop in the country is grown on approximately 60,000 ha, or 3.5% of the total arable land. An average annual yield of 1.25 tons per hectare is obtained and 90,000 tons is produced, representing 14% of the total cereal production. There was a period of expansion between 1960-67, followed by a decline which was largely due to a period of drought. Importation of rice in recent years has been around 340,000 tons p.a. Government policy is directed towards increasing internal production, decreasing imports, and reorganizing the commercial rice structure. These objectives rely on the development of regional organizations and reclamation projects, incentives for production and enhancing research.

There are three regions of rice cultivation, Casamance in the south with 80% of the total, including the plateau region with pluvial, flooded rice in the southeast, the northern area of irrigated rice along the Senegal river and the central region with marginal production.

The types of rice culture include strictly pluvial in the southeast, with dwarf short cycle varieties, hydromorphic (phreatic) rice in Casamance, aquatic rice with controlled or non-controlled flooding. The major irrigated rice is along the Senegal River but a small amount exists in the central region and in Casamance. Flooded rice and *basfond* rice is mainly in Casamance. Mangrove rice also occurs along the coast in Casamance, on a small scale.

Research

The *Institut Senegalais des Recherches Agricoles* (ISRA) is the agricultural research organization of the country, and it includes three stations where rice research is conducted. The Richard-Toll station in the north deals with irrigated rice and its research is assisted by WARDA staff. In the south are stations at Lafa for pluvial rice and Djibelor for flooded rice, the latter having two breeders, and one each in pedology, chemistry and entomology. Liaison is maintained with other national stations and with various international organizations. ORSTOM conducts research on rice in Senegal in the fields of microbiology and nematology.

Breeding has resulted in early dwarf varieties for upland, such as Se 3026 and Se 314g derived from the cross TN 1 x Tunsart. A line 144B-9 from Bouaké does even better in areas of more erratic rainfall. The Chinese variety, Ikong Pao, is suitable for hydromorphic areas. Good varieties for *basfond* are IR8, Vijaya and IR269, and Apura for the deeper sites. In the acid plains, variety DJ 684D is best. For irrigated rice, tall varieties D52/57, D9/9 and L5-26 are utilized. Where water control is good, IR8, Ikong Pao, TN 1 and IR269 are utilized.

Studies in crop protection have covered various aspects of insect control, herbicide research and blast resistance. The water requirements of different rice cultures have been studied as well as the pedology of different areas. Agrometeorological research and soils research is conducted. (See papers in this volume by Bertrand *et al.* and Toure and Arial.) Considerable research has been conducted on fertilizer dosages and practices.

Socio-economic constraints are land tenure, low paddy producer price, absence of infrastructure for inputs and distribution of production, primitive nature of peasant rice production and the difficulty of changing traditional ways with minimal extension efforts.

SUDAN

G.I. GHOBRIAL

Although rice varieties were introduced into the Sudan in 1905 for possible production in the wetter southern areas, by 1942 rice production was considered to be uneconomic. In 1960 the Ministry of Agriculture planned a mechanized rice project in Bahr El Ghazal but internal political problems interfered until 1973. From 1974, rice was given more attention in the Sudan and it was then first grown on a small scale in the Gezira irrigation project. In 1974 the country produced about 7,000 tons and imported about 10,000 tons of rice.

Rice is now grown in the Gezira irrigation scheme (the largest irrigation scheme in the world) in the north, as swamp rice in the Bahr El Ghazal, and as an upland crop in the equatorial province of the far south. These areas differ greatly in ecological conditions, with 350 mm rainfall in Gezira, 950 in Bahr El Ghazal and 1500 in the equatorial south. Temperatures are lower in the south, with a monthly maximum in June of 30°C versus 40°C for Gezira. In the Gezira, soil is of heavy clay of pH 8.5 and rice is rotated with cotton, wheat and groundnuts.

Research

The Chinese technical team for rice popularization started work at Gezira a few years ago. They demonstrated paddy rice growing techniques and found that the Chinese varieties, Chen Chu Ai 11 and Kuang Chu 15 could yield about 6 tons/ha. The Agricultural Research Corporation at Wad Medani (Gezira) began rice research in 1974 and has found that IR22 and breeding lines such as IR2053-206-1-3-6 yield as well or better. Weed control is essential and the common weeds are in the genera *Brachiaria*, *Dinebra*, *Phyllanthus*, *Ischamum*, *Cyperus*, *Cynodon*, *Ocimum*.

Both nitrogen and phosphorus are required. Although experimental yields are relatively high, expanded and long-term production in the Gezira would require concern for very high temperatures and aridity, very high evapotranspiration and water requirements. In addition, the already high pH with the risk of salting the soil and the integration of rice in a suitable rotation currently dominated by other crops, would be important considerations.

In the Bahr El Ghazal (Aweil area) considerable potential for swamp rice exists but the Dinka tribe are herdsmen who look down upon crop culture. The lack of infrastructure is also a severe limitation. An FAO agronomist conducts some agronomic and varietal trials in this area. Earlier, varieties such as Zenith and C20 were grown. BG 45, BG 110 and IR8 have been shown to rival or surpass the older varieties.

In the upland cultivation in the far south, the local people have learned rice culture from the farmers in the neighbouring countries and little is known about this rice culture.

TANZANIA

J.H. MONYO and Z.L. KANYEKA

About 180,000 metric tons of paddy were produced on 112,000 hectares in Tanzania in 1976. An additional 70,000 tons of rice was imported. Rice is produced in very different ecological situations in the regions of Mbeya, Tabora, Coast, Shinyanga and Mwanza. Most of the crop is peasant-grown, especially along river valleys in the Rufiji basin, the Kilombero valley, the Great Ruaha, and in low lying areas around Lakes Victoria and Malawi. There are a few large irrigation schemes, the most developed being the Mbarali scheme in the southern highland region, developed with the aid of the Chinese. Others are Kilangali and Ruvu. Peasant swamp and flooded rice is transplanted and the rainfed upland rice is broadcast. The large irrigation schemes drill or broadcast the crop. A small amount of upland rice is grown on the eastern slopes of the Uluguru mountains, the Usambara mountains in the northeast and in parts of the southern highlands. In parts of the coastal region, rice is interplanted under coconuts. Rice in this rather arid country occurs essentially where either orographic or coastal rainfall is sufficient for dryland rice culture or where surface flow or groundwater-soil relationships enable hydromorphic, flooded, or irrigated rice to be grown.

The island of Zanzibar is a separate case and rice production is being stimulated by an FAO programme which concerns varietal evaluation for both irrigated and upland rice, and the development of inland valley water resources for irrigated paddy in small peasant-self-help programmes. Zanzibar has sufficient frequent rain to provide good moisture for upland rice in season.

Research

Research on rice has been limited and conducted by staff of the Ministry of Agriculture at Ifakara and Ilonga, by staff at the parastatal irrigation project at Kilombero and by staff at the Faculty of Agriculture, University of Dar Es Salaam, located at Morogoro. Varietal improvement conducted at Morogoro at first involved selection of higher yielding adapted types with long grain of good cooking quality from local strains of Afaa Nwanza, Kihogo, Afaa

Kilombero, and others. Then, exotic germplasm was introduced and dwarf varieties such as IR8 were found to be high yielding under irrigated conditions but lacking in quality. Recently, Tanzania has obtained many new lines from IRRI's international testing programme.

Some mutation breeding has been done with assistance from the International Atomic Energy Agency, with the object of improving on stature and protein of adapted varieties Faya Theresa and Kihogo Red. Hybridization has been done on a limited scale since 1971, between local adapted types and dwarf varieties from IRRI.

Agronomic studies have concentrated on seeding rate, weed control and fertilizer practices.

UPPER VOLTA

C. POISSON

Production

Rice is grown on 41,000 ha with an average yield of 1 t/ha. Production is limited by factors such as erratic rainfall, poor water control, the low paddy producer price and the cost of water control.

Recent demographic changes have resulted in an increase in the urban population; changes in eating habits have increased the demand for rice and attracted Government interest in increasing rice production. In the second development plan (1972-76), the proposed methods to increase rice production included:

a) Expansion of the irrigated area with complete water control;
b) Improvement of traditional rice culture by better management of the lowlands;
c) Establishment of a research station to deal with rice research and with the introduction of pluvial rice;
d) Construction of a rice mill, with two units, each of 7,500 tons annual capacity.

Research

Prior to 1973, all research was done by IRAT. Since then there has also been a UNDP/FAO/CERCI project, involving the national rice research station. Irrigated rice with complete water control is currently limited to 2000 ha but will increase in the future. The first priority is to improve on IR8 which is susceptible to various fungal diseases and of only fair quality. Many varieties have been introduced through WARDA, and IR1529-680-3 and Vijaya appear promising.

Various agronomic trials have been conducted to determine appropriate fertilizer levels and suitable rotations. Several insect problems are serious, including gall midge, *Chilo*, *Diopsis*, *Maliarpha* and *Sesamia*. The systemic insecticide, Furadan, has been used to control these pests.

Strictly pluvial or *basfond* (lowland) rice occupies the largest area of rice culture in the country. For *basfond* with a short moisture period, the three-month variety, C 74, is satisfactory, apart from its susceptibility to neck blast. For *basfond* areas with a longer moisture season, IR1529-680-3 appears satisfactory. For strictly pluvial rice, selection is in progress from 630 lines from 12 crosses made by IRAT in Ivory Coast. IRAT 10 was selected from a cross of 63-104 x Leung Sheng. More recently, lines of IRAT 10 x IRAT 13 appear promising, as do mutants of IAC 25 x 64. The latter mutants appear adapted to drought stress and they resist blast under conditions where most varieties are attacked. It is hoped that this programme will enable a new, superior varietal release before 1980.

ZAIRE

B. RUTEBUKA

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Rice was possibly first introduced into the Congo basin by the Arabs around 1840. The first Zairian rice farmers were the peasants who had contact with them, and they remained the only rice producers until after 1945. A mixed group of varieties was grown, which were of low commercial value, being mainly red-grained and low-yielding.

Rice research was commenced by the Belgium research organization, INEAC, in 1932 with the selection and purification of local varieties. Amongst those released were Y 3 (600 kg/ha), R2 111/1 (1000 kg/ha) and MLE series (1750 kg/ha). Later, crosses were made between local varieties and introductions, resulting in many useful varieties, including R 66 and OS 6, which are still wildly grown. R 66, a medium duration variety (120-135 days) yields on average 2.5 t/ha.

Production

The main areas of rice cultivation are Bumba in equatorial province, Maniema in Kivu, and Sankuru in west Kasai. Total rice area in the country is approximately 250,000 ha, of which most is pluvial rice grown as a peasant crop with little technology. There are 1000 ha of irrigated rice in the Ruzizi Valley, Bumba and Lodja regions. Average annual production is 200,000 tons, with an average yield of 0.8 t/ha.

Production is limited by erratic rainfall, unstable prices to the producers, the high labour input required for land preparation in the forest zones, poor cultural methods including mixed cropping and lack of fertilizers; and a lack of infrastructure in the irrigated areas. The government has recently enlisted Chinese assistance in rice projects.

Research

The years following independence were characterized by chaos, which interfered with agronomic research. The *Institut National pour l'Etude et la Recherche Agronomiques* (INERA) and the Department of Agriculture established a project for rice research in 1975. Four Zairian agriculturalists are employed to work on breeding, plant protection and extension. Initially, they have been purifying seed of varieties previously held in collections. The aims of the varietal improvement programme are to find varieties which are high yielding and have good agronomic characters and resistance to the major diseases, blast and *Helminthosporium* leaf spot. The well established variety R 66 needs to be shorter and to have greater disease resistance. The collection presently contains 80 varieties of irrigated rice, 40 of pluvial rice and 20 of recent introduction from IRAT and Italy.

ZAMBIA

R. CRAUFORD and R.M. LEMBELA

Accurate figures on rice production are not available but estimates are 1,700 tons for 1975-76. Rice imports are controlled and do not reflect real demand. These were about 4,500 tons in 1974 and might have been about double if unrestricted. The third national development plan projects a target of 18,000 tons production by 1983.

Rice is largely confined to the valleys of the Zambesi, Luapula, Luangwa and Chambeshi Rivers. It is also grown on the plateau, but below 1,300 metres. Existing varieties show cold damage at flowering above this altitude. The normal season is October/November to April/May and the bulk of the crop is sown as dambo (swamp) rice. Dambos are flat, treeless areas which collect drainage from the adjacent upland. There is usually a drainage line leading to a river. In a general way they correspond to the bolis of Sierra Leone or the fadamas of northern Nigeria. The dambos vary greatly in soil and water conditions from pure sand to fairly thick peats and from surface dampness to fairly prolonged shallow flooding. This variation influences yield. The main constraint to higher yields appears to be slow adoption of simple practices of row-sowing, weeding and fertilizer use, which can change yields from 1000 to 4000 kg/ha.

Research

Documentation of production exists only for Luapula province where the French organization, SATEC, promoted rice production. Average yields are 1300 kg/ha but 3- to 4000 kg are well within the farmers capability. General recommendations are a basal N:P:K:S (N at 50 kg) plus 34 kg/N top-dressed at 8 weeks. Recent surveys in two areas have shown that farmers under-fertilize. SATEC has introduced one row weeders and two and three row seeders from Malagasy, which have proved useful. Both brown spot and blast occur, but surveys have not been conducted to assess the importance of these or of stemborers.

Varietal improvement has been to find one or two varieties suitable for Zambia as a whole. Existing varieties are three numbered lines brought by SATEC from Malagasy, plus Sindano, from Tanzania. None are considered wholly satisfactory. Cold monthly minimum temperatures of 15°C at flowering in March/April in the higher altitudes cause sterility. The germplasm base of about 50 lines has been too limited. A Chinese team is establishing rice above 1300 metres in the central plateau and they are examining a collection of varieties.

Although rice is a minor crop, the trained research staff is far too limited to cover the range of conditions in the country. There are also many logistic constraints which reduce effective liaison with extension and farmers and limit feedback to research.

The utilization of research results must come from a system which can distribute seed, fertilizer, insecticide etc., and which can provide these and credit on time. All this requires an infrastructure and it must be underpinned by education of the farmers and of all who provide services. Many challenges and much work remain in these areas.

Additionally, much more contact with outside institutions should enhance rice research and production in Zambia.

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