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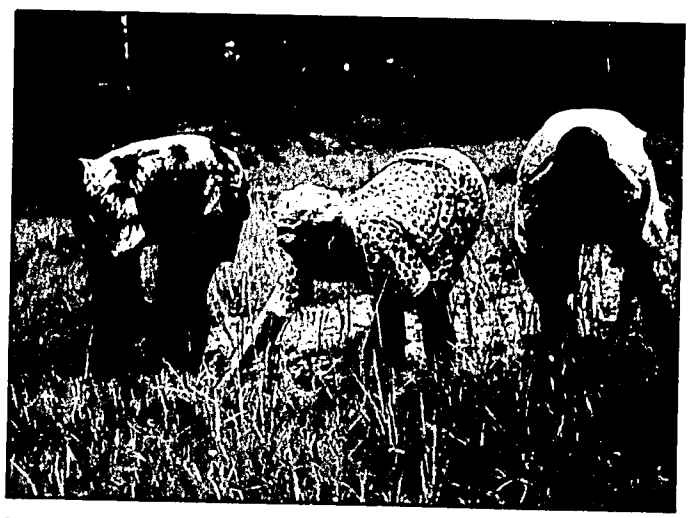
WARDA

ANNUAL REPORT

1989



West Africa
Rice Development Association

The West Africa Rice Development Association (WARDA) was formed in September 1970 by 11 countries with the assistance of the United Nations Development Program (UNDP), the Food and Agriculture Organization of the United Nations (FAO), and the Economic Commission for Africa (ECA). It is a bilingual, inter-governmental organization presently consisting of 16 West African countries: Benin, Burkina Faso, Chad, The Gambia, Ghana, Guinea, Guinea-Bissau, Cote d'Ivoire, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo.

In December 1986, WARDA became a full-fledged member of the Consultative Group on International Agricultural Research (CGIAR), a network of 13 international agricultural research centers. The mandate of WARDA is to assist its member countries in becoming self-sufficient in rice, a staple food of West Africa.

The Association receives funds and assistance in kind from the following:

- *CGIAR funds from the following countries*: Belgium, Canada, France, Federal Republic of Germany, Italy, Japan, The Netherlands, and Sweden,
- *International and regional organizations*: African Development Bank (ADB), European Economic Community (EEC), United Nations Development Program (UNDP), and the World Bank,
- *Member countries*, and
- *International aid agencies of the following countries*: Belgium, Federal Republic of Germany, France, Italy, Japan, The Netherlands, United Kingdom, and the United States of America.

FOREWORD

As WARDA's two year reorganization period drew to a close in 1989, one of the Association's tasks was to systematically document and synthesize the most promising past research results to ensure continuity of its research efforts. In Training and Communications, the major effort was to determine how effectively those two important support services were responding to the needs of the rice scientists in the West African sub-region.

A challenge for WARDA was to consolidate past successes, while preparing to launch its five-year medium term plan in 1990. It was envisaged that WARDA's past progress should guide its current and future directions. At the same time, past weaknesses were to be diagnosed and rectified. Plans were also made in 1989 for a major staff recruitment exercise.

WARDA's rice research program for the continuum ecosystem began field work at its new research farm location at M'be near Bouake, Cote d'Ivoire, during 1989. The major thrust was the characterization of this important rice production environment. The research program for the high rainfall continuum environment was dedicated mostly to iron toxicity studies at Suakoko in Liberia.

The research activities for WARDA's irrigated rice research program continued to be located at Ndiaye in the Senegal River Valley, and at Fanaye in the Delta. The mangrove swamp program was centralized mainly in Rokupr, Sierra Leone.

While WARDA management was consolidating its administrative services in temporary locations in Bouake, training activities continued in Fendall, Liberia.

Planning for the development of WARDA's Main Research Center and Headquarters was in progress in 1989, and the establishment of temporary research facilities took place simultaneously.

This 1989 WARDA Annual Report reflects the accomplishments, progress in long-term activities, and the preliminary results obtained in more recently initiated studies.

The format for the Annual Report of this final year of WARDA's transition reflects the Association's attempt to present the research results of its activities somewhat differently from the past.

Firstly, results of activities which have reached an advanced stage are presented as feature articles. Research by a multidisciplinary team on characterization of rice agro-ecosystems in the upland/inland swamp continuum, at the M'be site of the WARDA Main Research Center and Headquarters, is fully described. Other features presented outline the advances and status of research in developing rice varieties with tolerance to iron toxicity, blast and insect pest resistance, and crab control in mangrove ecologies. A feature article also reviews progress in the use of *Azolla* in rice production in West Africa. Secondly, other research activities undertaken in the various research projects during the year are reported as summaries. Thus, the results which are still preliminary are given as progress reports, reflecting mainly trends and directions of the relevant studies.

The report on training presents progress in the development of new ideas for technical group training, especially in rice research and production techniques. These ideas are to be vigorously pursued in preparation for a new orientation in training whereby WARDA will decentralize its training activities among the Association's member countries.

We believe that WARDA has now taken initiatives in the right direction in full preparation for implementation of the Medium-Term Plan from 1990.

Eugene R. Terry
Director General

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1989 CALENDAR OF EVENTS

JANUARY

11-13	WARDA Council of Ministers Meeting - *Yamoussoukro, Cote d'Ivoire*
30-31	Program Committee Review of the Medium-Term Implementation Plan and 1990 Program and Budget - *The Hague, The Netherlands*

FEBRUARY

1-2	WARDA Board of Trustees Meeting and Review of the Medium-Term Implementation Plan - *The Hague, The Netherlands*
16	Meeting of the Tenders Executive Subcommittee - *Bouake, Cote d'Ivoire*
20-24	Director General's visit to *Senegal*
20 Feb - 14 April	Post Harvest Technology Training Course - *Fendall, Liberia*

MARCH

1-2	Director General's visit to *Gagnoa, Cote d'Ivoire*
2	USAID/REDSO mission visits WARDA - *Bouake, Cote d'Ivoire*
6-8	NARS Manpower Training Conference - *Bouake, Cote d'Ivoire*
9	Full complement, Executive Management Meeting - *Bouake, Cote d'Ivoire*
10-20	TAC 48 - Final presentation of WARDA's Medium-Term Implementation Plan - CIMMYT, *Mexico* - Washington Meetings
23	Quarterly Financial Review
28-31	Meeting of the WARDA Board of Trustees Program Committee - *St. Louis, Senegal*
	In-House Review Meeting - *St. Louis, Senegal*

1989 CALENDAR OF EVENTS

APRIL

2	Meeting of the WARDA Board of Trustees Program Committee, Nominating Committee, and Executive Committee - *St. Louis, Senegal*
3-4	WARDA Board of Trustees Meeting - *St. Louis, Senegal*
5-17	Director General's visits to *Mauritania, Senegal, and The Gambia*
24-26	Annual Rice Review Meeting - *Bouake, Cote d'Ivoire*

MAY

1-3	Director General's visit to Liberian Ministry of Agriculture, WARDA Training Center and Suakoko Research Station -*Monrovia, Fendall and Suakoko, Liberia*
2 May - 6 Oct	Rice Production Specialist Training Course - *Fendall, Liberia*
5	Tenders Committee Meeting - *Bouake, Cote d'Ivoire*
19 May - 6 June	Presentation of WARDA's Medium-Term Implementation Plan to the CGIAR Meeting - *Canberra, Australia*

JUNE

9	Director General's visits to UNDP and embassies of Germany, France, and Italy - *Abidjan, Cote d'Ivoire*
13	Full Complement, Executive Management Meeting - *Bouake, Cote d'Ivoire*
13	Tenders Committee Meeting - *Bouake, Cote d'Ivoire*
16	Director General's visits to embassies of Sweden, The Netherlands, United Kingdom, and Switzerland - *Abidjan, Cote d'Ivoire*
18-22	CGIAR Center Directors Meeting - *Rome, Italy*
27-29	Director General's visits to rice growing areas at *Gagnoa, Man, Odienne, Boundiali, and Korhogo, Cote d'Ivoire*

1989 CALENDAR OF EVENTS

JULY

3-12	Director General's visits to *Guinea, Guinea-Bissau, and Sierra Leone*
17	Quarterly Financial Review
	Tenders Committee Meeting - *Bouake, Cote d'Ivoire*
21-22	Director General's visit to *Kregbe, Cote d'Ivoire*

AUGUST

2-16	UNDP Mission

SEPTEMBER

3-6	Interviews for Director, Training and Communications - *The Hague, The Netherlands*
8	Full Complement, Executive Management Meeting - *Bouake, Cote d'Ivoire*
	Tenders Committee Meeting - *Bouake, Cote d'Ivoire*
11-16	Director General's visits to *Ghana, Togo and Benin*
17-19	Board of Trustees Program Committee members' visit to *Rokupr, Sierra Leone*
18	Interview for Director, Training and Communications - *Bouake, Cote d'Ivoire*
19	Ambassador's Day - *Bouake, Cote d'Ivoire*
25-29	Director General's visit to *Guinea-Bissau*

1989 CALENDAR OF EVENTS

OCTOBER

2-7	Director General's visits to *Mali and Burkina Faso*
16 Oct - 17 Nov	Rice Drying and Storage Training Course - *Fendall, Liberia*
16	Director General's presentation at MacDonald College - *Montreal, Canada*
19	WARDA management visit to International Research Development Centre (IDRC) - *Ottawa, Canada*
20	WARDA management visit to Canadian International Development Agency (CIDA) - *Hull, Canada*

NOVEMBER

20-25	Director General's visit to *Tchad*

DECEMBER

6	General Staff Meeting - *Bouake, Cote d'Ivoire*
11	Ad Hoc Executive Staff Meeting - *Bouake, Cote d'Ivoire*
13	Tenders Committee Meeting - *Bouake, Cote d'Ivoire*
14	Executive Management Committee Meeting - *Bouake, Cote d'Ivoire*

research

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Research Focus on Rice Growing Environments

The constraints to rice production and needs for technical change vary according to the diverse ecosystems and farming systems in which rice is cultivated in West Africa. To allocate its resources efficiently, WARDA has established environmental programs that focus its research on distinct rice farming ecosystems.

Although the differentiation of rice systems requires further research, for operational purposes, WARDA defines the upland/inland swamp continuum, the Sahel, and the mangrove swamp as the rice growing environments in which it will conduct research. Current rice cultivation and future potentials differ considerably across these three major environments.

The upland/inland swamp continuum is a priority in West African rice production because it is the largest in area and farm population, giving it the greatest overall production potential. It is estimated that 70%-80% of the smallholder rice producers in the region cultivate rice on approximately two million hectares of continuum land. With favorable technical and policy conditions, the area devoted to rice production could be expanded considerably across all portions of the continuum.

In the Sahel irrigated environment, rice is grown on approximately 135,000 hectares. The technical potential is substantially larger. An irrigable area of nearly two million hectares is located along the Sahel's major rivers and in the Lake Chad Basin, but only a small percentage of the land is presently under irrigation. The completion of the Diama and Manantali Dams in Senegal and Mali makes a further 375,000 hectares available. Uneconomically high land development costs are likely to restrict exploitation to less than 10% of this potential by the year 2000. Together with projected increases in other Sahelian countries, rice grown under improved irrigation should be about 155,000 hectares by the turn of the century.

Mangrove swamp rice cultivation is currently limited to less than 200,000 hectares of the approximately 1.2 million hectares of mangrove swamps in West Africa. The high cost of clearing and developing this land limits its expansion potential, even though the potential for modest and stable increases in yields are good. In addition, large-scale clearing of mangrove swamp areas may also

threaten the genetic diversity of plant and animal species, especially fish and oyster populations.

TRANSITION RESEARCH ACTIVITIES

As WARDA's transition period ended in 1989, accent was placed on consolidating and completing past research thrusts, while establishing a more solid base through characterization and diagnostics research to undertake the projects set out in WARDA's Medium-Term Implementation Plan for 1990-1994.

In WARDA's continuum program based in Cote d'Ivoire, scientists initiated research activities in 1989 on WARDA's new experimental farm located in the M'be Valley, near Bouake. The major goal was the preliminary characterization of the environment of this new location by an interdisciplinary research team of physical, biological and social scientists. Also, varietal improvement of upland rice cultivars continued and progressed satisfactorily.

In WARDA's Sahel program, major accent was placed on consolidating and synthesizing results from past research thrusts. In mid-1989 the water management project conducted by WARDA in collaboration with researchers from Wageningen University in The Netherlands ended. A seminar held in St. Louis, Senegal on May 17-19 brought together an unusual mix of researchers, development experts, professors, and farmers to discuss the findings and recommendations of the project. Research on *Azolla*, conducted since 1980 in collaboration with the Catholic University of Louvain in Belgium, also ended in 1989. Varietal improvement research was continued.

In the mangrove swamp program, interdisciplinary projects progressed in 1989 in the areas of integrated weed, insect, disease and crab control; management of adverse soils; and varietal improvement.

RESEARCH PROGRAM I:

Upland/Inland Swamp Continuum

The Upland/Inland Swamp Continuum Environment

CHARACTERISTICS

The undulating landscape of West African forest and forest-savanna transition zones creates diverse and continuous ecosystems which WARDA calls the upland/inland swamp continuum. For rice cultivation, the continuum contains two distinct land types: the uplands and the inland valley swamps. A third less defined type, the hydromorphic zone, lies between the other two. Where the hydromorphic zone is narrow and variable, for many research purposes such as breeding, it need not be distinguished from the inland swamp or upland ecosystems. However, where it is broader and somewhat more stable over time, it can be considered a separate ecosystem requiring a specific research focus.

At the upper end of the continuum the potential for impact on yields may be relatively small, but because of the vastness of the area involved, the overall leverage on regional output is large. Even marginally increased areas will translate into large production impacts. Issues of cropping sustainability are most urgent in this portion of the continuum as erosion and soil fertility degradation can be severe under some systems of continuous cultivation. At the lower end of the continuum, the potential for impact on yields is greater, although human health risks pose an important constraint to

rapid development. Continuous rice cropping generally poses fewer problems on soils in this portion of the continuum.

PRODUCTION CONSTRAINTS

The most important constraints within the continuum environment are those associated with the stability and sustainability of rice production. In the upland/hydromorphic ecosystem these include drought stress, low soil fertility, and erosion. In the hydromorphic/swamp ecosystem, a complex of poorly understood adverse soil conditions, including iron, aluminum and manganese toxicity, are often critical. Major biological constraints common to both ecosystems are weeds, the diseases of blast, leaf scald and brown spot, and the stem borer and diopsid insect pests. Rice Yellow Mottle Virus (RYMV), a problem unique to Africa, poses a potentially major threat under hydromorphic/swamp conditions. Although local rice varieties are generally well adapted to low-input cropping systems, yield potential for most of these genotypes is modest and their response to improved inputs poor. Moreover, there is generally high susceptibility to blast, leaf scald and moisture stress among local upland varieties, to RYMV among lowland varieties, and to stem borers among varieties found across the continuum.

SITE CHARACTERIZATION OF RICE AGRO-ECOSYSTEMS IN THE UPLAND/INLAND SWAMP CONTINUUM AT M'BE, COTE D'IVOIRE

E. Akinsola, M. Choudhury, S. Diatta, K. Miezan, V. Nyanteng, and G. Nyoka

WARDA's future Main Research Center and Headquarters is to be situated in the M'be Valley 25 kilometers north of Bouake, Cote d'Ivoire. An initial study aimed at understanding the physical and biological characteristics of the site, as well as the major socio-economic parameters of the cropping systems in the area was begun in 1989. The study had three components: a global survey of the entire M'be Valley; a multidisciplinary field trial designed to rigorously identify factors influencing rice performance across a transect of the upland/inland swamp continuum; and uniformity trials designed to measure the degree of soil micro-variation within future experimental blocks.

Research activities to characterize the site will continue at M'be for several years as the development of the experimental farm advances. Results from such characterization will provide a baseline understanding of the M'be environment to help orient subsequent research. In the context of broader regional characterization studies by WARDA, present results will allow WARDA scientists to determine more precisely how the M'be environment represents rice ecologies and to extrapolate experimental results to the remainder of the sub-region.

FARM SURVEYS AT THE M'BE VALLEY

The land requested by WARDA at M'be includes active farmers' fields, areas under fallow, and extensive uncultivated areas.

Cropping systems were studied by surveying seven villages adjacent to the requested area. Approximately 100 randomly selected farm households from these villages were interviewed. Farmers' fields were visited to observe cropping systems *in situ* and to verify interview data. In collaboration with scientists from the Winand Staring Center in The Netherlands, the entire area was surveyed to determine the morphological and chemical properties of the major soil units and to identify the suitability of the major land classes for rice production.

Farm Households, Land Types and Cropping Systems

The indigenous inhabitants of the M'be Valley are predominantly of the Baoule ethnic group, constituting approximately 90% of the farm population. Household size is relatively large. Nearly half of the sampled farm households contained 10 or more persons. Except for yam cropping, women play key roles in planting most of the upland food crops and vegetables, and in weeding and harvesting. Men clear and prepare yam plots, make yam mounds, plant and harvest yams, and provide most of the labor in swamp rice operations.

Three main land types were identified based on the toposequence position: the upland (totally aerobic); the hydromorphic or colluvial (ground water is within the rooting zone during a major part of the cropping season); and bottomland or swamp (ground water is within the rooting zone throughout the cropping season). Cropping systems vary across these land types.

Upland fields are by far the most important ecosystem for crop production at M'be, comprising 69% of the total areas surveyed. A yam-based mixed cropping system consisting of yam, cassava, okra, pepper and eggplant, dominates the upland zones. All crops are sown almost simultaneously with yams planted on mounds interspersed with cassava and other crops. Although rice is not normally grown by local inhabitants in the upland ecosystem, it is commonly cultivated as a sole crop in the swamps during the main wet season which lasts from May to October. Swamps are located on 12% of the total area. During the dry season, farmers use residual moisture in the valley bottoms to grow vegetables. Hydromorphic zones represent the remaining 19% of land area, and are commonly sown to maize and banana.

Uplands account for 69% of the crop production area found at the M'be research site.

In the upland zone, land preparation for yams is done from February through March. The planting period is April to June, and the yam is harvested from November to January. After yam harvest is completed, fields that still have cassava, okra, pepper and eggplant are prepared for two maize crops planted in the following year. Cassava is subsequently harvested from January to April; maize is harvested during two periods: June-July, and November-December. Vegetables are harvested from August to November. This two-year upland sequence is generally followed at least twice, and at the end of the fourth year the field is abandoned to fallow. The fallow period usually lasts five years, but can extend up to 10 years.

A second important cropping system identified in the upland ecosystem is cotton-maize rotation. However, while only 16% of the households grow cotton, yam and maize are cultivated by 97% and 100% of the households, respectively.

SOILS

Survey Results

The results of the soil surveys showed that approximately 51% of the upland soils of the M'be Valley are highly suitable for rice cultivation. The most suitable uplands are situated on the upper portions of the toposequence where slopes vary between 0%-2%. These areas tend to be sandy-clay to clay, well drained, and often have overlying carapace below 120 cm. Ironstone gravel (30%-60% by weight) may be found throughout the soil profile, but generally begins at a depth of 40-50 cm. The upper 25 cm of most upland soils are rich in organic matter (4%), with sandy-clay loam texture and high carbon and nitrogen content. The exchangeable cations and cation exchange capacity (CEC), as well as cation saturation are good (Table 1).

Fields lower on the toposequence, but above the hydromorphic belt, tend to be

Table 1. Characteristics of different soil units in the topsoil horizons (0-25 cm) at M'be, Cote d'Ivoire, 1989.

Parameter	Plateau Upland (slope 0-2%)	Middle Upland (slope 2-4%)	Hydromorphic Areas (slope 1-4%)	Swamp Areas (slope 0-1%)
pH (water)	6.1-6.5	5.0-6.9	6.0-6.1	5.7-5.8
Clay %	18-30	15-25	6-10	37-42
Silt %	9-21	7-13	3-7	20-27
Sand %	49-73	62-78	83-90	26-38
Gravel %	7-22	0-18	0	0
Carbon %	1.72-3.15	0.72-1.57	0.19-0.55	1.08-3.38
Nitrogen %	1.26-1.90	0.34-0.78	0.34	0.90-2.30
C/N	14-17	13-44	6-13	10-15
Phosphorus (Olsen) ppm	9.1-239	2.6-27	3.0-3.5	9.5-19.1
Exchangeable cations (meq/100 g)	6.66-18.72	2.64-5.45	1.31-1.41	8.55-9.41
Cation Exchange Capacity (meq/100 g)	9.6-16.4	4.0-8.0	2.0-3.0	13-15
Cation Saturation %	67-83	59-78	44-71	59-63

Source: The Winand Staring Center Report No. 22.

Soils found in the swamp areas of the M'be continuum are highly suited to rice production.

shallower with slopes varying between 2%-4%. These areas are only moderately suited to rice cultivation. These middle-slope fields are well drained, sandy-clay to clay or loamy-sand to sandy with depths of between 50-80 cm overlying a carapace at 80-120 cm depth. The upper layers are clayey to sandy-clay with ironstone gravel in the shallower horizons and occasionally throughout the profile. Carbon, nitrogen and phosphorus content are low to medium. Exchangeable cations and CEC are low in comparison with the upper slopes. Cation saturation is moderate.

Hydromorphic areas form a transitional zone between the upland and swamp zones. These areas are usually narrow (20-100 m) with 1%-4% slopes. Their sandy texture and inherent low fertility make these soils poorly suited to upland rice cultivation. Soils are imperfectly to moderately well drained, poor in organic matter, prone to lateral leaching of micro-nutrients, and influenced by ground water. Carbon, nitrogen and phosphorus contents are low, as are the exchangeable cations and CEC. Cation saturation can vary from low to moderately high (Table 1).

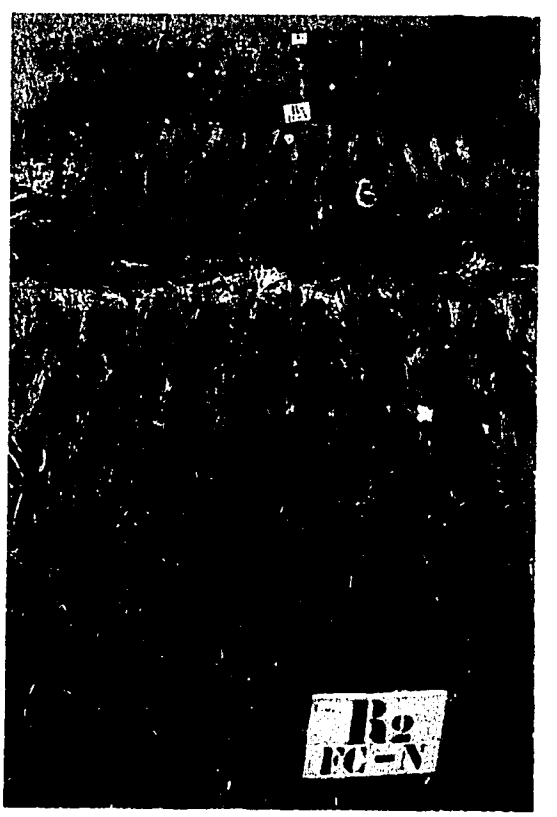
The swamps are flat (slopes 0%-1%) and vary between 20 to 250 m in width at valley bottoms. More than 90% of the soils in this ecosystem are highly suited to swamp rice cultivation. Soils are very poorly drained, deep, sandy-clay loam to clayey in texture, and the upper 50 cm is usually reduced. They are rich in mineral elements washed down from the surrounding upper slopes. Carbon and nitrogen contents, as well as CEC and exchangeable cations are high.

Soils in all these ecosystems are non-acidic, with high pH ratings ranging from 5.0-6.9 (Table 1).

Nutrient Deficiency Experiments

A series of experiments was conducted at four locations (three at upland sites and one at a hydromorphic site) to measure deficiencies of macro and micro elements. Yields for IDSA 6 were taken after applying no fertilizer; a complete fertilizer that contained all the recommended levels of N, P, K, Ca, Mg, and Zn; and six treatments using a complete fertilizer minus one of the nutrient elements.

The results indicated that nitrogen was the only nutrient lacking in all locations during the first cropping year (Table 2). In the upland ecosystem nitrogen deficiency was greatest in the middle portion of the toposequence and less marked towards the plateau. If yields from the full nutrient supply are represented as 100%, deficiency indices (Chaminade Index: 0%-20% = very high; 20%-40% = high; 40%-60% = medium; 60%-80% = low; and 80%-100% = nil) for nitrogen were 33% at the middle slope, 69% at the upper slope, and 41% on the plateau. Nitrogen deficiency was also observed in the hydromorphic zone with an index of 53%. Phosphorus and potassium were not deficient in any of the soils.



Nitrogen deficiency is readily apparent in rice plantings made at M'be where incomplete fertilizers have been applied.

Soil Heterogeneity

The soil survey conducted in the M'be Valley showed a wide range of soil types present across the toposequence. Within these soil types, however, a high degree of heterogeneity or micro-variability was observed. Such heterogeneity is typical of transitional upland soils. The great variability in fertility can be caused by micro-variation in slope, soil composition and depth; variations in earlier land use patterns, management and cultural practices; and the random distribution of numerous large trees and termite mounds. Characterization of such soil heterogeneity is necessary to design methods of reducing it and/or in trial site selection and experimental design.

Methodology

Four blocks were uniformly planted to upland rice varieties without fertilizers: three were located on the plateau and one in the hydromorphic/upland transition zone. Grain yields were taken from a dense matrix of 2.4 m x 2.4 m plots and used to reflect inherent soil productivity differences. The methods used followed those of Gomez, K.A. and Gomez, A.A., 1984 described in chapter 12 of *Statistical*

Treatment	Hydromorphic Zone	Middle Slope	Upland Upper Slope	Plateau
0	751	1089	2658	1158
Complete fertilizer (CF)	1617	2228	4161	2544
CF - N	864	764	2881	1046
CF - P	1210	2422	3720	2767
CF - K	1534	2521	3958	2727
CF - Ca	-	2235	4100	2775
CF - Mg	-	2688	3980	2746
CF - Zn	-	2116	3887	2728
SE	149	188	254	216
CV (%)	38	19	14	19

* No data available

Table 2. Effects of mineral nutrients on rice grain yields (kg ha^{-1}) of IDSA 6 at Mbe, Cote d'Ivoire, 1989.

Procedures for Agricultural Research, with slight modifications: e.g. biomass was measured for each basic unit and later converted to grain yield from systematic sampling data using polynomial regression. Soil productivity contour maps, vertical and horizontal serial correlations, vertical and horizontal mean squares between strips and Smith's Index of soil heterogeneity were used to assess soil heterogeneity in each rectangular block.

Results and Implications

Blocks situated on the plateau show moderate soil heterogeneity. Horizontal serial correlations ranged from 0.30 to 0.44, while the vertical serial correlations ranged from 0.45 to 0.74. The relative size of the horizontal strip mean square to the vertical (ratio) ranged from 2:1 to 1:3. The weighted average Smith's Index was 0.387, ranging from 0.346 to 0.542. Smith's Index of soil heterogeneity is the index b, defined as $b = \frac{\Sigma (\log x)(\log V_x)}{\Sigma (\log x)^2}$ where log x is the variance between plots of one basic unit size (2.4 m x 2.4 m in the present case) and V_x is the variance per unit area for plots of size x.

In the transitional hydromorphic/upland zone, fertility gradients tended to follow the natural slope. This tendency, however, was disturbed by adverse soils, and the productivity was particularly high in the lower and middle portions of the slope where groundwater was near the surface. Soil fertility declined towards the top of the slope and in the opposite direction, by the shading effect of large trees and bronzing from iron-toxic conditions at the bottom of the slope. Smith's Index ranged from 0.258 to 0.823, with an average of 0.376.

For efficient experimentation, soils in each location need to be made more homogeneous prior to the establishment of trials. Data obtained in the uniformity trials provide inputs to calculate several parameters of efficient experimental designs, including optimum plot and block sizes and shapes, block orientation, and number of replications. Soil heterogeneity trials will be set out in the

future on all newly developed areas at M'be to fully characterize the extent of soil micro-variability and to provide guidance for future experiments.

CHARACTERIZATION OF THE UPLAND/INLAND SWAMP TRANSITION ZONE

A team of WARDA scientists conducted an interdisciplinary experiment to measure the physical and biological factors that affect rice growth on a transect of transitional upland and hydromorphic soils in the M'be Valley. Three experimental blocks were established, each 40 m wide and 120 m long, running up the slope of a toposequence. The blocks were situated about 150 m apart on a tributary of the Oundre River. The blocks displayed considerable variation of soil types and hydrology in the upland/inland swamp continuum.

Two upland rice varieties (IAC 164 and IDSA 6) and two lowland varieties (IR 5931-110-1 and Bouake 189) were planted in 10 m x 10 m plots and replicated 12 times vertically along the toposequence. Plots were subsequently subdivided into fertilized and unfertilized sub-plots, with a complete fertilizer (150 kg 10:18:18 ha^{-1}) applied 45 days after seeding (DAS). Urea (46% N) was applied at 100 kg ha^{-1} in a split dose at tillering and booting stages.

Pits were dug at 10 m intervals up the toposequence to study differences in the soil profile, and piezometers were installed at 10 m intervals and at 200 cm depth to observe seasonal variations in the water table. The life cycles and yield components of each test variety were recorded to determine growth behavior and yield performance under varying fertility and soil hydrology conditions. Weed counts were made and biomass of all weed species was determined before bush clearing and at 30-day intervals during the cropping season.

Insects were regularly sampled using sweep nets beginning 30 days after sowing and at two-week intervals until harvest. Stem borer infestations were recorded on one meter row samples from which rice stems were removed for dissection. Finally, before and after sowing, soil samples were removed from the upper 20 cm by scientists from the Laboratoire de Nematologie, IIRSDA Abidjan, to determine the presence of nematodes.

Soils

Soils in each of the three experimental blocks included three distinct zones, namely, sandy-loam, sandy and shallow lateritic zones, located in adjacent belts up the toposequence. The width of each zone varied between the blocks. The sandy-loam and sandy zones occurred in the lower 30 m to 70 m of the toposequence, depending on the experimental block. An impermeable clayey region generally occurred at a depth of 60 to 70 cm in the lower 30 m to 50 m of the toposequence, increasing to over one meter depth towards the top of the slope. At distances of 90 m to 100 m up the toposequence from the swamp zone, the sandy layer became superficial, containing an underlying sandy-clay region at 70 cm to 80 cm depths. At distances of up to 120 m, the soils became lateritic and extremely shallow.

Groundwater levels varied systematically throughout the season and

between blocks (Figures 1, 2 and 3). Using a depth of 80 cm as the baseline below which the roots of rice plants cannot access groundwater, the toposequence of each block was post-stratified into: the upland ecosystem with the water table always below 80 cm depth; hydromorphic ecosystem with a water table above 80 cm for part of the growing season; and the swamp ecosystem with a water table within the rooting zone throughout the growing season. These divisions were subsequently applied to analyze and synthesize data on varietal performance as well as the incidence of insects and weeds.

Varietal Response to Toposequence Position

Results showed important varietal differences in adaptation to various locations on the toposequence. Under fertilized conditions, the lowland rice varieties, Bouake 189 and IR 5931-110-1, produced the highest yields (over 4000 kg ha^{-1}) within the hydromorphic and swamp zones, significantly out yielding the upland test varieties. Grain yields for both lowland varieties, however, were between 1000 and 2000 kg ha^{-1} in locations higher on the toposequence, where they were consistently below the upland test materials. IR 5931-110-1 out yielded Bouake 189 in the upper slope positions, suggesting somewhat greater adaptability to low soil moisture.

Upland varieties showed wider adaptability than either of the lowland varieties with yields varying less across soil types, hydrological conditions and toposequence positions. Under fertilized conditions, yields for the upland varieties ranged between 1000 to 3000 kg ha^{-1} and were highest in hydromorphic areas where IDSA 6 generally performed better than IAC 164. Grain yields were lowest on the shallow and lateritic upper slope soils where IAC 164 performed better than IDSA 6. Among the four varieties tested, IAC 164 showed the best general adaptability across the toposequence.

Grain yield trends for varietal adaptation to different portions of the toposequence were similar on unfertilized plots, but at lower levels. Fertilizer response was highest on hydromorphic soils, with yield increments varying between 1500-2200 kg ha^{-1}. In comparison, grain yield response to fertilizer on upland plots varied from 0 to 1400 kg ha^{-1}.

Plant height and grain yields are the agronomic characteristics which seemed to have been most affected by the conditions in the different sectors of the continuum. For all of the rice varieties tested, plants were taller in the swamp and hydromorphic zones than in upland locations. Life cycles also tended to be shorter at the lower portions of the toposequence.

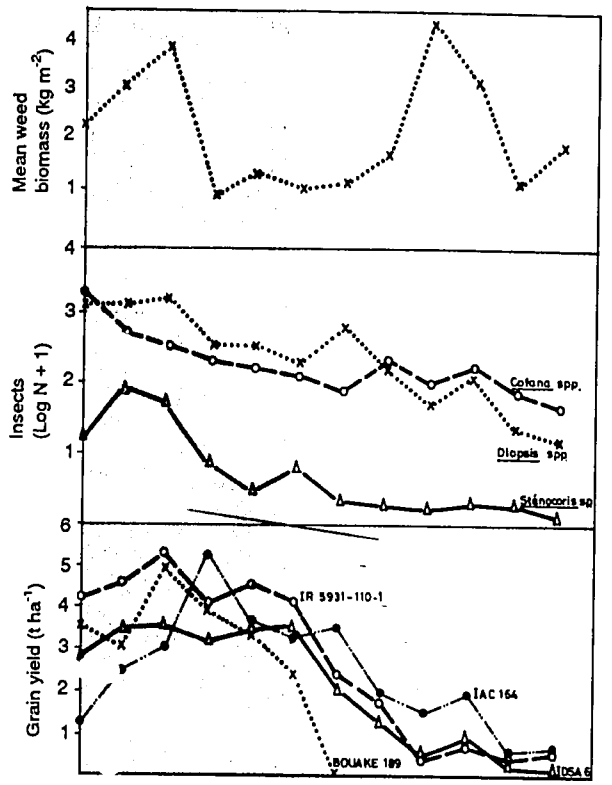
Weeds

Comparative average figures for weed biomass were 5.2 kg dry matter m^{-2} on upland soils, 1.3 kg m^{-2} on hydromorphic soils, and 1.0 kg m^{-2} under swamp conditions. Weed biomass production was consistently greater on upper slope toposequence positions, suggesting that enhanced soil moisture tended to reduce weed infestation.

Sedges, grasses and broadleaf weeds were all found within each block of the characterization experiment. The majority of the sedges occurred along the

The number of weed species found at the M'be site increased following bush clearing, causing greater problems for farmers in the area.

Figure 1. Mean water depth, weed biomass distribution, insect infestation, and grain yield of rice along the upland/inland swamp continuum at Site A, M'be, Cote d'Ivoire, 1989.



Hydromorphic

Upland

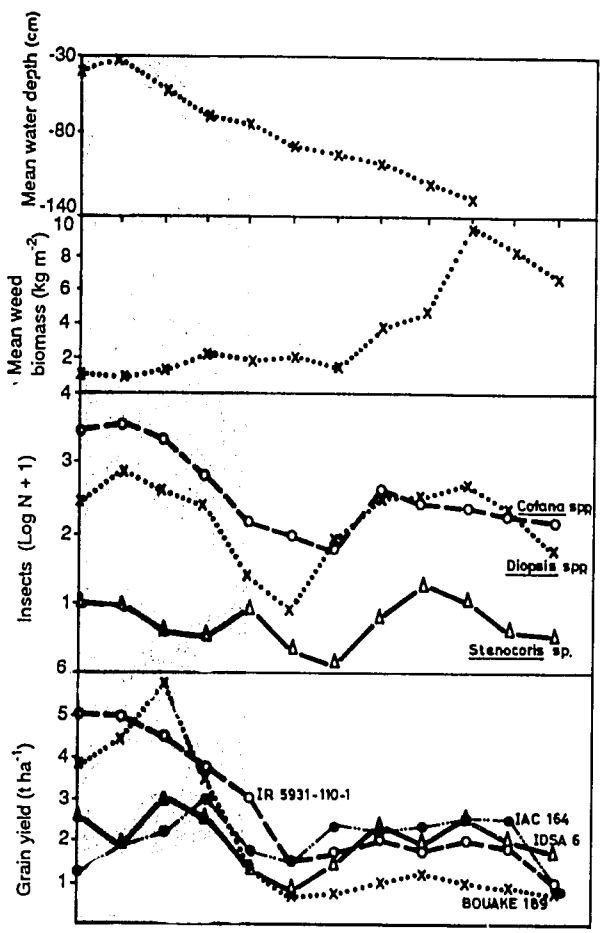
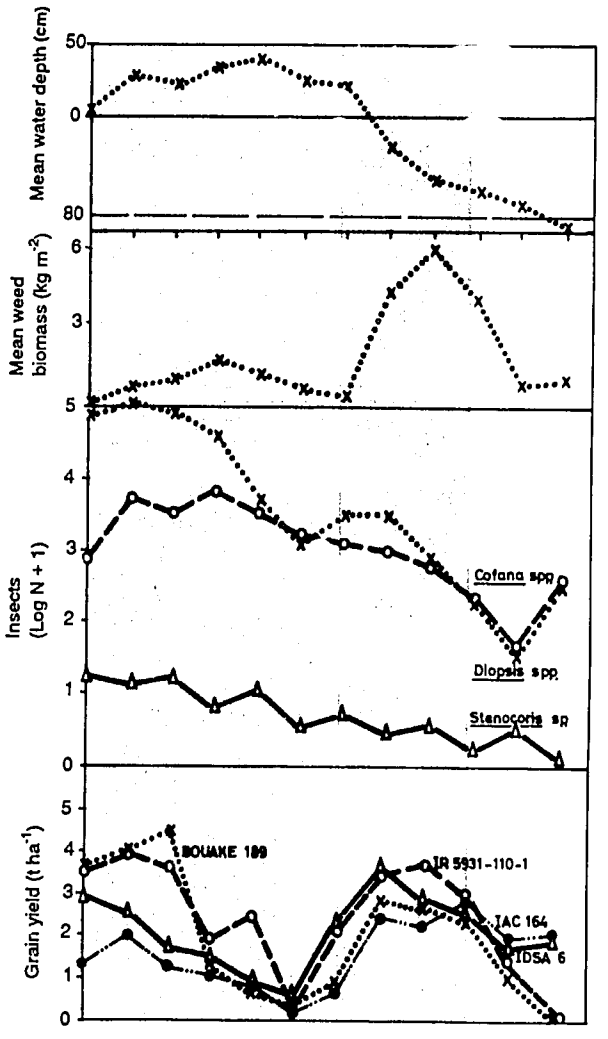


Figure 2. Weed biomass distribution, insect infestation, and grain yield of rice along the upland/inland swamp continuum at Site B, M'be, Cote d'Ivoire, 1989.

Hydromorphic

Upland

Figure 3. Mean water depth, weed biomass distribution, insect infestation, and grain yield of rice along the upland/inland swamp continuum at Site C, M'be, Cote d'Ivoire, 1989.



lower slope, while grasses and broadleaf species tended to occupy any part of the slope but with larger numbers in the upland portion. The number of species observed during the cropping period was higher than before bush clearing, but the species composition before and during the cropping period was similar, according to Jaccard's Similarity Index (IS_j = 0.45). An IS_j value of 0.25 indicates species similarity, and 0.50 indicates very high similarity (Mueller-Doubois D. and H. Ellenberg, 1974, *Aims and Methods of Vegetative Ecology*. New York, John Wiley and Son). Weed species that were restricted to the hydromorphic portion of the continuum were: *Cyperus difformis, C. haspan, Fuirena ciliaris, Rhynchospora corymbosa, Kyllinga pumila, K. squamulata, Leersia hexandra, Ludwigia descurens, L. hyssopifolia* and *Basilicum polystachyon.*

The distribution and intensity of weed species was also dynamic, reflecting changing soil hydrology across the toposequence during the season. As the water table moved closer to the surface, the number of species and densities of hydromorphic weeds increased. Conversely, as the water table receded at the end of the season, dryland weed species invaded lower portions of the continuum.

Insect Infestation

About 30 insect species of importance to the rice crop were collected from the rice plants in the characterization trials. Out of these, the major pests were *Diopsis longicornis, D. apicalis, Chnootriba similis, Cofana unimaculata, C. spectra, Aspavia armigera, Stenocoris elegans, Diaperasticus erythocephalus*, as well as the stem borers *Maliarpha separatella, Sesamia calamistis* and *Chilo zacconius*.

There was an outbreak of the swamp insect leaf miner, *Trichispa sericea*, 40 days after sowing in one of the experimental blocks. Aside from this, the same insect pest species were found at almost all points along the toposequence, although their intensities varied. This pattern was due to the very dynamic nature of insects and the absence, in most species, of strong ecosystem preferences.

The highest populations occurred in the lowland and hydromorphic areas (Figures 1, 2 and 3). *Diopsis, Cofana* and stem borers were consistently more numerous in the lowland. While *Chnootriba* predominated in the upland, *Maliarpha separatella* was the major stem borer species, constituting between 85% and 90% of the stem borers observed. Damage caused by the stem borers during the vegetative stage ranged from 1% to 5% deadhearts, but at crop maturity, infested stems were 15% to 35%.

Soil factors that influenced plant growth also affected the level of insect infestation. Where localized poor soils reduced grain yields, insect infestation also tended to be low as reflected in Figure 1.

Nematodes

Eight ectoparasitic and five endoparasitic nematodes were found at M'be before cropping (Table 3). The most abundant nematode was the ectoparasite, *Helicotylenchus*. The diversity of nematode species seemed to reflect the diverse natural vegetation that had preceded the rice crop. With the initiation of rice cropping in 1989, populations of the rice nematode, *Meloidogyne*, increased during the cropping season, whereas other ecto-parasitic nematode species disappeared. The populations of *Helicotylenchus, Meloidogyne, Pratylenchus*, and *Xiphinema* were higher under upland conditions while *Tylenchorhynchus* and *Rotylenchus* were higher under lowland conditions.

CONCLUSION

The characterization described here confirms that the M'be Valley is extremely heterogenous in land types and suitability for rice production. Survey results indicate that approximately 35% of the surveyed area include upland soils which are highly suitable for rice cultivation. The most suitable uplands are situated on relatively flat areas of the upper portions of the toposequence. A second major ecosystem favorable for rice cultivation is located in swamps that comprise 12% of

Table 3. Nematodes extracted from soils sampled at M'be, Cote d'Ivoire, 1989.

Ectoparasites	Endoparasites
Criconemoides	Heterodera
Helicotylenchus	Meloidogyne
Scutellonema	Pratylenchus
Telotylenchus	Rotylenchus
Trichodorus	Hirschmanniella
Tylenchorhynchus	
Xiphinema	

the total area. More than 90% of these latter soils are highly suited to swamp rice cultivation.

Three 120 m long transects, representing zones of transition between swamp and upland ecosystems, were studied intensively in an interdisciplinary experiment. These blocks varied markedly in their physical and biological characteristics despite their close proximity. The wide heterogeneity within relatively small areas suggests that land type adaptability may be a useful trait of improved rice varieties. The primary factors differentiating the continuum appear to relate to the topography as defined by the nature of slope, soil composition and phreatic water dynamics. These factors influenced performance of rice varieties, weed and insect infestations.

Tests of typical upland and swamp rice varieties showed that upland varieties tend to have greater plasticity as reflected in lower yield variation (1000 to 3000 kg ha^{-1}) across different portions of the toposequence compared to lowland varieties. Lowland varieties are morphologically suited only to swamp and hydromorphic conditions where they achieved the highest grain yields of between 4000 and 5000 kg ha^{-1}. In drier upland ecosystems where the water table remained below the rooting zone, yields for lowland varieties were consistently below 1000 kg ha^{-1}

Weeds and insect pest species were observed in specific portions of the toposequence. Indicator weeds for hydromorphic conditions were identified. True swamp weeds were absent in the study sites and upland weed species displayed wide adaptability as they frequently encroached upon the hydromorphic zone.

Insect pests of rice which have been observed in similar ecological areas elsewhere were absent during the first experimental year at M'be except for the swamp rice pest, *Trichispa sericea*. In old established fields, such pests are likely to be more prevalent and could prove to be useful in distinguishing ecosystem limits.

Characterization studies of the type initiated at M'be in 1989 will be extended to other portions of the M'be Valley in the future. The goal is to achieve a complete *ex ante* physical and biological assessment of the site of WARDA's new Main Research Center and Headquarters before physical development and research activities begin to modify the environment irreversibly.

PROGRESS IN BREEDING RICE FOR TOLERANCE TO IRON TOXICITY

A.O. Abifarin

Iron toxicity is a major constraint of rice production in mangrove swamps with and without tidal effects, in inland swamps, and within irrigated fields where the parent rock or soil is rich in iron. Iron toxic inland swamps can be found throughout West Africa in Liberia, Sierra Leone, Niger, Benin, Cote d'Ivoire, Senegal, Burkina Faso, Guinea-Bissau, Guinea and Togo.

Excessive amounts of ferrous iron are the main cause of iron toxicity. Concentration may be as high as 100-1500 ppm in severely toxic areas, compared to less than 100 ppm in non-toxic areas. The interaction of other soil elements also contributes to the problem. The appearance of brownish-red lesions on the leaves of rice, a condition known as bronzing, is the most common symptom of iron toxicity. Yield losses due to iron toxicity range from 20%-100%, depending on the level of toxicity and the tolerance of the rice cultivar.

Cultural practices can be used to reduce iron toxicity to some extent, but the most cost effective approach is the use of iron toxicity tolerant rice varieties. For this reason, WARDA places considerable emphasis on the development of cultivars that combine high tolerance to iron toxicity with other economically desirable agronomic traits. WARDA's iron toxicity research is conducted at a "hot spot" at the Central Agricultural Research Institute (CARI) in Suakoko, Liberia, on soils which produce excess ferrous iron.

APPROACHES AND PROGRESS

Screening Methods

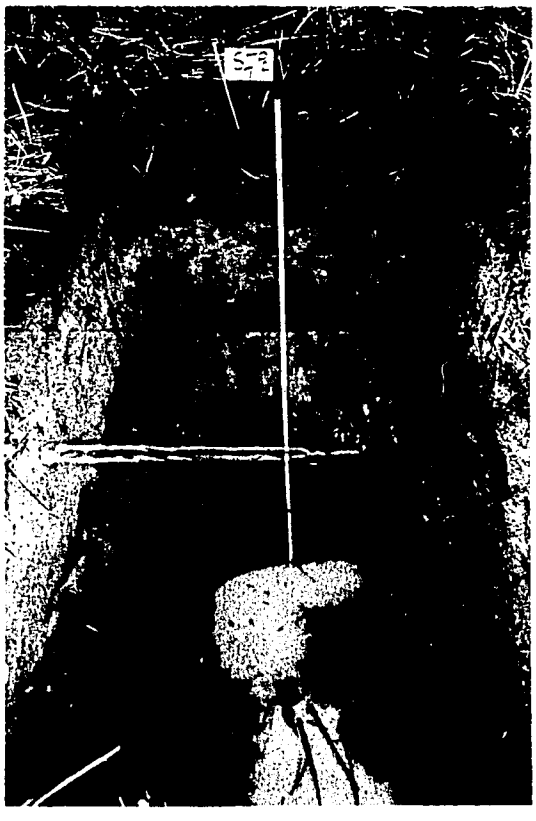
Three screening methods are being used to identify cultivars tolerant to iron toxicity.

Pot Screening

Wet soil from non-toxic sites is collected, thoroughly mixed, placed in 16-liter plastic buckets, and flooded. Three weeks later, 4, 3-week old seedlings that were raised in non-toxic soil are transplanted into the pots, along with one seedling each of a susceptible (IR 26) and a resistant (Suakoko 8) variety. The soil is constantly submerged in water taken from the iron-toxic plots. The test entries and checks are rated according to foliar symptoms of iron toxicity at 4, 6, 8, 10 and 12 weeks after transplanting. The Standard Evaluation System for Rice established by the International Rice Research Institute (IRRI) is used for scoring. The system is set up on a scale of 1-9, with one being extremely tolerant and nine being extremely non-tolerant.

Concrete Bed Screening

Six concrete beds, each measuring 20 meters long, 4 meters wide and 1 meter deep are used in this screening method. The bottom has a concrete floor with sides made of plastered cement blocks. Each bed has a water inlet and outlet. The resulting troughs are filled with soil (50 cm deep) made up of upland laterite soil and top soil in the ratio of two portions of laterite soil to one portion of top soil. These are thoroughly flooded with untreated water. Susceptible and resistant check varieties are planted along the length of the plots or across the plots, one on either side. Both the susceptible and resistant checks, and the test cultivars, are scored by the Standard Evaluation System for Rice.



The presence of high levels of iron in many soils of West Africa becomes apparent as dark brown deposits when the soil profile is exposed.

Field Screening Methods

Blocks of 3 to 4-row plots, 3 meters long, are used for each entry. Susceptible and tolerant check rice varieties are grown alternately after every 5-10 test entries, depending on soil variability and number of entries. In addition, tolerant and susceptible check varieties are grown along the length of the plots, one on either side. Three-week old seedlings raised in non-toxic sites are transplanted at a 20 cm x 20 cm spacing, with 1-3 seedlings per hill. The test entries and the check varieties are scored by the Standard Evaluation System for Rice.

RESULTS

Many rice varieties with varying degrees of tolerance had been identified by IITA and WARDA at CARI in research that began in 1974. Some of these, like Suakoko 8, Mat Candu, CIAT 21528 and C1322-28, have satisfactory levels of tolerance to iron toxicity under West African conditions. However, they do not possess some other desirable traits. These may include appropriate plant-type, suitable maturity, grain quality and tolerance to major diseases and insect pests, and high grain yields.

More information on mode of inheritance for iron toxicity is also needed. WARDA includes this parameter in its research on iron toxicity tolerance in rice.

Screening of Fixed Cultivars

In order to find rice cultivars that are tolerant to iron toxicity and that can be recommended as varieties, or used as parents in hybridization programs,

thousands of cultivars have been screened since 1985.

From 1987-1989, over 4000 materials were screened in pots and concrete beds, in the field, or in combinations of two or three screening conditions. Out of the materials screened, over 400 were identified to have some level of tolerance. Of the 1162 entries screened in 1989, 140 scored 1-4 on the nine point scale of the Standard Evaluation System for Rice. However, because of other undesirable agronomic traits, most of these tolerant fixed cultivars cannot be recommended as varieties.

Yield Trials

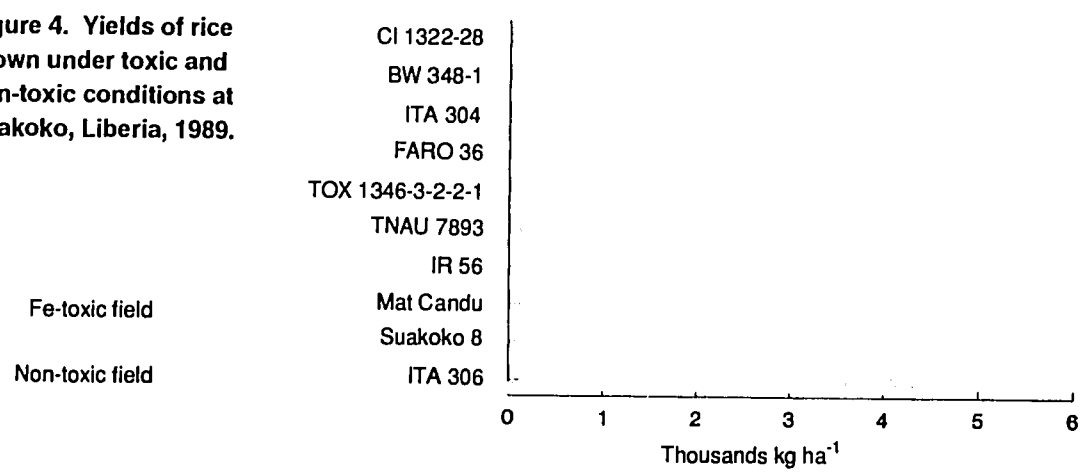
In 1989, two yield trials were conducted at Suakoko. The entries consisted of tolerant cultivars identified in previous trials. In one of the trials, the entries were tested at iron toxic and non-toxic sites. Results showed that tolerant entries produced significantly lower grain yields under toxic than under non-toxic conditions. (Figure 4). Under non-toxic field conditions, grain yields varied from 2700-5300 kg ha^{-1}, but were only 2300-4000 kg ha^{-1} under toxic conditions. The 10 entries with the best iron-toxicity tolerance were cultivars developed at Suakoko. Yields of 4000-5000 kg ha^{-1} for the seven top entries under non-toxic conditions, and the grain yield of over 3000 kg ha^{-1} under toxic conditions for ITA 306, Suakoko 8, Mat Candu and C1322-28, were considered satisfactory. The latter four entries performed close to our goal of 4000-6000 kg ha^{-1} under non-toxic conditions and 3000-5000 kg ha^{-1} under toxic conditions.

For cultivars grown under iron-toxic conditions, there were no significant differences among the grain yields of the three top entries and the control, indicating very limited progress in the development of entries superior to the local varieties. More work is therefore needed to improve the performance of the three top entries used in these trials.

Breeding

Although many rice cultivars and accessions have been identified as iron-toxicity tolerant, they need further

Figure 4. Yields of rice grown under toxic and non-toxic conditions at Suakoko, Liberia, 1989.



improvement before they will be acceptable to farmers. To aid in this effort, some basic information on the genetics of iron toxicity were obtained for several of the tolerant cultivars. Preliminary results showed that some combinations had dominant genes for tolerance whereas other cultivars had recessive genes for tolerance. In some, the genes controlling tolerance are non-allelic. Thus, it will be possible to accumulate genes from diverse sources into new varieties being developed. Through the pyramiding of these genes, it may be possible to produce cultivars with higher levels of tolerance.

Mutation Breeding

Induced mutation is being used to create variability in cultivars without making major alterations to the basic genotype of the varieties. In a collaborative project with the International Atomic Energy Agency (IAEA), three tolerant cultivars: Suakoko 8, Mat Candu and ITA 249, were irradiated. Their seeds were exposed to 20, 25 and 30 kR of Cobalt 60 mutagen. The mutants produced through this process will be screened beginning in 1990.

Hybridization

Many crosses have been made over the past three years to incorporate higher levels of iron toxicity tolerance into promising materials. To accomplish this, a shuttle breeding program was established between IITA and WARDA. Many of the tolerant cultivars identified in Suakoko were crossed with IITA cultivars. F_2 and later generation materials were then sent to Suakoko from IITA and other areas for screening and selection. WARDA screened over 1000, F_3-F_6 lines in 1989. Many promising segregants were identified, some of which have been used as parents in breeding work.

In addition to crosses made at IITA, 24 single crosses were made by WARDA scientists at Suakoko in 1989.

F_3-F_6 Populations

WARDA now has several fixed and segregating lines ready for on-station and on-farm trials. These materials include genotypes of different plant types and different maturity groups that will meet the needs of the national programs.

In 1989, 125 populations were screened and 357 single plant selections made. These will be entered into the observational nurseries in Liberia, Sierra Leone, Guinea, Nigeria and other sites in West Africa. Some of the lines will be nominated for the International Network for Genetic Evaluation of Rice (INGER) trials.

Collaboration

Arrangements have been made with collaborators in Liberia, Nigeria, Sierra Leone and Guinea for improved rice varieties to be field tested in their countries.

Collaboration with IITA

WARDA and IITA continue to cooperate strongly in the shuttle breeding work which has produced many promising cultivars. These cultivars are being tested at Ibadan and Edozhigi in Nigeria. The Ibadan trial will determine

Table 4. Results of preliminary yield trials of iron-toxicity tolerant lines of rice at IITA, Ibadan, Nigeria, 1989.

Entry	Plant Height (cm)	Maturity (days)	Yield (kg ha^{-1})
TOX 85C-C1-15-WAS 1	124	133	4550
TOX 3113-27-1-1	122	134	4520
TOX 3133-56-1-1	114	128	4450
TOX 85C-C1-16-WAS1	122	136	4330
TOX 3118-6-82-3-2	118	134	4250
TOX 3100-44-1-2-2-2	121	129	4170
TOX 311118-6-82-3-3	122	128	412[illegible]
TOX 3093-4-5-1-1	112	138	4120
TOX 3100-44-1-2-1-2	114	124	4060
TOX 3100-44-1-2-3-3	120	131	3960
TOX 3100-37-3-3-2	119	138	3890
TOX 3100-37-3-3-3-2	123	138	3800
TOX 3118-37-2-2	133	146	3710
TOX 212 (check)	106	126	3670
TOX 85C-C1-17-WAS 2	118	136	3590
ITA 247 (check)	134	147	3560
TOX 85C-C1-10-WAS 8	110	136	3500
TOX 3142-2-1-2	126	146	2860
Suakoko 8 (check)	161	147	2490

the agronomic traits as well as tolerance to blast and Rice Yellow Mottle Virus disease under zero toxicity. Work at Edozhigi is to determine agronomic traits and tolerance to blast and rice gall midge under iron-toxic conditions.

At the Ibadan site, there have been four observational trials involving iron-toxicity tolerant entries. Table 4 shows some of the information collected from one of these trials. A line selected at Suakoko, TOX 85C-C1-15-WAS 1, was the best yielder, producing grain yields significantly higher than the checks, ITA 247 and Suakoko 8. This selection and other promising lines will be further assessed and included in multilocational trials. At the Edozhigi site, IITA had two trials grown under iron-toxic conditions. Observations revealed TOX 85C-C1-16-WAS 1, TOX 3107-56-1-3-2, TOX 3118-2-E2-1-2-3 to be among the most promising entries. In addition to fixed lines, 106 F_3-F_6 lines were sent to IITA for trials.

SUMMARY

Significant progress has been made in solving the problem of iron toxicity in rice through breeding rice varieties tolerant to iron-toxicity. Among those identified by WARDA scientists, Mat Candu compares favorably with Suakoko 8 in producing grain yields with better grain qualities and more tolerance to *Pyricularia* and *Helminthosporium oryzae*. Under non-toxic field conditions, it out yielded Suakoko 8 by about 1000 kg per hectare. Mat Candu is 8-10 days later maturing than Suakoko 8. It is tall (125-135 cm) and is low tillering (9-12 tillers). It is a good replace-

ment for Gissi 27 in toxic and non-toxic sites where a long duration cultivar is desirable. Mat Candu will be included in future multilocational trials in West Africa. Other cultivars that yielded satisfactorily under iron-toxic conditions include C1322-28 and ITA 306. CIAT 21528 is a very early maturing tolerant cultivar, but is lower yielding than the medium and late duration tolerant cultivars.

Several advanced generation lines now exist for testing in multilocational sites. Some of these will be given to cooperators and collaborators in and outside West Africa beginning in 1990.

It is encouraging to note that cultivars and lines selected by WARDA, such as TOX 85C-C1-16-WAS 1, and TOX 85C-C1-15-WAS 1, performed well in preliminary yield trials in Liberia and Nigeria. The considerable progress which has been made will be improved upon in the future through lines that are now being developed.

RESEARCH ACTIVITY SUMMARIES

The Development of Improved Soil Fertility Techniques

Adverse soil conditions constitute a major constraint within the continuum environment in West Africa. In the upland/hydromorphic ecosystem, these problems include low and declining fertility, poor water retention, and erosion. In the hydromorphic/swamp ecosystem, adverse soil conditions are mainly related to low soil fertility (in terms of nutrient deficiency), and toxicities related to iron, aluminum and manganese. Although chemical fertilizers and natural phosphates may improve soil fertility, economically optimum fertilizer formulas and doses targeted to specific portions of the continuum under different ecological conditions are yet to be determined. More economical and efficient techniques need to be developed to improve soil productivity on a sustainable basis. The diversity of the continuum environments in the region must be considered in developing these techniques. In this context, a number of activities related to soil fertility were conducted in 1989 in the upland/inland swamp continuum program.

Five activities were conducted under this project; three represent the consolidation of activities initiated earlier within the upland rice research program. These include the study of soil nutrient deficiency in Cote d'-Ivoire, the effect of dolomite on acid soils for upland rice cultivation, and a study of the effect of three sources of phosphorus on upland rice. The remaining two activities aim at understanding the soil status of the M'be Valley, a new environment where upland and hydromorphic rice are being grown for the first time. These studies include the effect of inorganic fertilizers on upland rice and the dynamics of the water table in an upland/hydromorphic transition zone in the M'be Valley.

STUDY OF SOIL MINERAL DEFICIENCY IN COTE D'IVOIRE

S. Diatta

A trial was undertaken to determine the state of mineral reserves in upland soils in different ecological zones of Cote d'Ivoire. The trial was conducted during 1987, 1988 and 1989 at locations in Odienne, Bouake, M'be, and Man, Cote d'Ivoire with two short duration varieties, IAC 164 and WABC 165, and two medium duration varieties, IDSA 6 and WABZI. The method used was the Chaminade technique of determining mineral deficiencies for nitrogen,

Table 5. Mineral deficiency of plateau soils and soils in the hydromorphic zone of M'be. Grain yield in kg ha^{-1} and index of mineral deficiency (%).

	Hydromorphic zone		Mid slope		Upper slope		Plateau	
	Grain yield	Deficiency index (%)	Grain yield	Deficiency index (%)	Grain yield	Deficiency index (%)	Grain yield	Deficiency index (%)
O	751	-	1089	-	2658	-	1158	-
CF	1617	100	2228	100	4161	100	2544	100
CF - N	864	53	764	34	2881	69	1046	41
CF - P	1210	75	2422	108	3720	89	2767	108
CF - K	1534	95	2521	113	3958	95	2727	107
CF - Ca	-	-	2235	100	4100	98	2775	109
CF - Mg	-	-	2688	120	3980	95	2746	108
CF - ZN	-	-	2116	95	3887	93	2728	107
SE	149		188		254		216	
CV (%)	38		19		14		19	

CF = Complete fertilizer

phosphorus, potassium, calcium, magnesium and zinc.

These trials were terminated in 1989. The results show that at Man, Bouake and Odienne, nitrogen and phosphorus are the most deficient elements. Phosphorus was more deficient in the humid forest zone (Man) than in the other zones (savannah and the forest - savannah transition zone). The opposite is true of nitrogen. At M'be (Table 5), only nitrogen was deficient, and the degree of deficiency varied according to topo-sequence position. The absence of phosphorus deficiency at M'be was confirmed by the results of the isotopic dilution of 32_P undertaken on the soils. The analysis showed that upland soils in particular contain a fairly high level of assimilable phosphorus. In the hydromorphic zone, nitrogen is also deficient while there is a secondary deficiency of phosphorus. As suggested by previous studies, nitrogen and phosphorus constitute the two main limiting factors of the soils studied. Methods of improving the absorbing complex of these soils, need to be studied.

EFFECT OF THREE PHOSPHORUS SOURCES ON YIELDS OF UPLAND RICE

S. Diatta

Due to the high cost of chemical phosphorus, African small-scale farmers are unable to use them; there is need therefore to identify efficient and cheap phosphorus sources. Rock phosphates abound in the West African sub-region and constitute a viable alternative to chemical fertilizers.

Three sources of phosphorus (calcium phosphate, 34% P_2O_5; aluminum phosphate, 35% P_2O_5; and simple superphosphate, 18% P_2O_5) were each tested at the rate of 0, 15, 30, 45, 60, 75, 90 and 105 kg ha^{-1} on two medium duration upland rice varieties: IDSA 6 (improved variety) and WABZI (traditional variety). The experimental design was a split-plot with four replications, with fertilizer in the main plot and variety in the sub plots. The trial, now in its second year, was conducted in the humid forest zone in Man, Cote d'Ivoire.

The results obtained showed a highly significant phosphorus effect on grain yields, although there was no significant difference between phosphorus rates. Among the three phosphorus sources, aluminum phosphate and simple superphosphate performed similarly, with calcium phosphate performing poorly. The performance of aluminum phosphate seems to be related to its fine size. Results obtained in the second year were similar to those obtained in 1988 except calcium phosphate which produced a sharp drop in yield (Table 6).

There was no cumulative effect after two successive years of phosphorus application. This result is confirmed by the soil analysis which showed that the soil was not enriched despite the application of phosphorus for two continuous years. The phosphorus applied through fertilizer application is solidly fixed by the soil which has a high fixing potential.

These results show that low phosphorus rates may be adequate to improve soil phosphorus content.

EFFECT OF DOLOMITE ON ACID SOILS FOR UPLAND RICE CULTIVATION

S. Diatta

Tropical African plateau soils are generally acidic with pH ranging from 4 to 6. Several trials have been conducted annually since 1987 to assess methods to

Table 6. Effect of three sources of phosphorus on the grain yield (kg ha^{-1}) of upland rice at Man, Cote d'Ivoire. Average of two varieties (WABZI and IDSA 6), 1988 and 1989.

Rates of P_2O_5 (kg ha^{-1})	Calcium phosphate		Aluminum phosphate		Simple superphosphate	
	1988	1989	1988	1989	1988	1989
0	1610	1110	1510	1010	1710	1310
15	2020	1670	2070	1810	2230	2290
30	2070	1840	2230	2150	2240	2510
45	2080	1920	2490	2470	2290	2390
60	2180	2010	2450	2470	2370	2490
75	2390	2160	2140	2400	2440	2570
90	2230	2010	2460	2700	2680	2710
105	2390	2070	2250	2520		
SE	153	99	133	126	140	115
CV (%)	20	16	17	12	18	8

raise the pH level. The purpose of this trial was to evaluate the role of dolomite.

The trial was conducted at Man in the humid forest zone of Cote d'Ivoire with the following treatments: 0 (check without fertilizer), NPK alone, NPK + 100 kg ha^{-1} of dolomite, NPK + 300 kg ha^{-1} of dolomite, NPK + 500 kg ha^{-1} of dolomite, NPK + 700 kg ha^{-1} of dolomite, NPK + 1400 kg ha^{-1} of dolomite, and NPK + 2800 kg ha^{-1} of dolomite. Two medium duration varieties were used, IDSA 6 and WABZI. The experimental design was a split-plot with four replications involving dolomite in the main plot and the variety in the sub plots.

There was a highly significant effect of the first 100 kg of dolomite, but no significant difference between the dolomite doses with regard to either grain or straw yields (Table 7).

As the trial was being conducted for the third year, ongoing soil analysis will make it possible to monitor the effects of dolomite on the evolution of the soil pH over time.

Table 7. Effect of dolomite on the improvement of an acid soil for the cultivation of upland rice (Grain and straw yield in kg ha^{-1}).

Dolomite rates (kg ha^{-1})	Grain yield	Straw yield
0	630	1390
NPK	1500	3830
NPK + 100	1760	4650
NPK + 300	1580	4320
NPK + 500	1500	4040
NPK + 700	1530	4020
NPK + 1400	1640	3900
NPK + 2800	1440	4100
SE	113	161
CV (%)	24	14

WATER TABLE DYNAMICS IN THE HYDROMORPHIC ZONE OF THE M'BE VALLEY CONTINUUM

S. Diatta

Studies of the dynamics of the water table in relation to water requirements of the rice plant have shown that yields are generally higher as the underground water is closer to the soil surface. Trials conducted in the M'be Valley in 1989 studied fluctuations in the water table in relation to the rice plant's water requirements in the upland/hydromorphic transition zone of a continuum.

Piezometers were installed at 10 m intervals to a depth of 2 m to measure the level of the groundwater table. Measurements were taken thrice weekly for eight months from July 1989 to February 1990.

A study of the soils in the upland/hydromorphic zone distinguished three main sections: (1) a lower section with loam to sandy-loam soils; (2) a middle section where the soils are sandy to coarse sandy; and (3) an upper section where the soils are clayey-sandy. In the lower section, the water table began to rise as early as July to reach its peak level in September - October (18-19 cm from the soil surface). During three months, from mid-August to end of October, the underground water supplied to rice plants in this section was adequate since it was continuously above the rooting depth of 80 cm. In the middle section, the underground water began to rise in mid-August and reached its peak

level between late August and the end of September. During this period, the rice plant received additional water from the water table. In the upland section, the underground water level rose abruptly in mid-August as in the lower slope positions. However, it remained at a depth of 80-90 cm, which is below the rooting zone of rice. This profile of the dynamics of the water table made it possible to distinguish limits for the hydromorphic zone where rice receives water from the water table in addition to rainwater, and for the plateau zone where the only source of water to the rice plant was rain water infiltration. These delimitations were subsequently used to interpret data obtained in an interdisciplinary characterization experiment on the same site.

Fluctuations in the water table are an important consideration in the fixing of cropping calendars on sandy soils. It will be necessary to undertake studies on the rooting capacity of the rice plant, soil moisture and the dynamics of soil mineral elements in relation to the water table. Similar characterization studies will be undertaken at additional points along the M'be Valley and its main tributaries to delineate distinct ecosystems within the continuum for experimentation purposes.

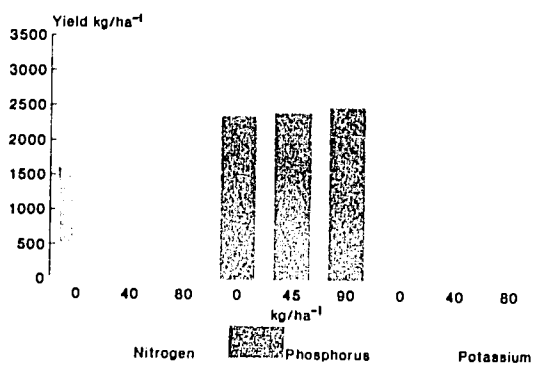


Figure 5. Yield response of ITA 257 to nitrogen, phosphorus, and potassium.

EFFECT OF CHEMICAL FERTILIZER ON UPLAND/ HYDROMORPHIC RICE IN THE M'BE VALLEY

S. Diatta

Although previous studies indicate that nitrogen and phosphorus are the limiting elements for rice production in much of West Africa, the diversity of soils in upland ecosystems does not permit the development of a single optimal chemical fertilizer formula for all locations.

A trial was conducted to study the separate effect and interactions of the major soil nutrients (N,P,K) on the yield of an upland rice variety grown on soils recently cleared following a five-year fallow period. Three doses of the nutrients: nitrogen (N: 0, 40, 80 kg ha^{-1}), phosphorus (P: 0, 45, 90 kg ha^{-1}), and potassium (K: 0, 40, 80 kg ha^{-1}) were applied to a short duration upland rice variety, ITA 257, in a randomized complete block design with four replications. The trial was conducted at the M'be Valley in Cote d'Ivoire.

The results showed that only nitrogen has a significant effect on rice yields. No significant response was observed to either phosphorus or potassium application (Figure 5). There was also no significant interaction between the three elements. These results indicate that after a long fallow period, nitrogen becomes the main deficient nutrient under upland conditions, at least during the first year of cultivation. Phosphorus and potas-

sium need not be applied during that period.

It is necessary to monitor the changes in nutrient content which may occur in the soil after several years of cultivation following a long fallow period. There is also a need to develop a response curve for each nutrient to identify the optimum formula and doses to be applied.

Development of Sustainable Cropping Systems

Upland/hydromorphic rice in West Africa is generally grown either in relay cropping or in mixture with other crops. Traditionally, farmers grow rice in mixture with maize, sorghum, yam, millet and banana in the strictly upland conditions. Under hydromorphic conditions, rice is often mixed with cassava, maize and less frequently with yam. In either ecosystem, the proportion and geometry of the different components of the system vary and the rationale for the various systems are not always well known. It is therefore necessary to learn more about existing cropping patterns and mixtures, and to develop alternative systems which are more efficient and sustainable.

Under this project, only one activity was conducted in 1989, as a component of a larger characterization study that will cover the entire West African region. The activity was aimed at developing a broad picture of the socio-economic environment of M'be Valley and its relationship with cropping systems in the area.

A SURVEY OF EXISTING CROPPING SYSTEMS IN THE M'BE VALLEY

V. Nyanteng

A pilot survey to identify and characterize existing cropping systems at the site of WARDA's new Main Research Center and Headquarters in the M'be Valley was conducted in 1989, as part of WARDA's broader effort to characterize the West African rice growing environment.

The survey was conducted through interviews and field visits with approximately 100 farmer households in seven villages near the M'be Valley.

Farmers distinguished two main crop growing ecosystems in the M'be Valley: the upland (including hydromorphic) and swamp. Yam-based and cotton-based mixed cropping dominates in the upland. The yam-based cropping system usually incorporates cassava and vegetables. Following clearing, yam and the associated crops are cultivated in the first and third years. Two maize crops per year are grown in the second and fourth years in association with the previous year's cassava and vegetables. After the fourth year, the land is again left to fallow for a period of 5 to 7 years. In the yam-based cropping system, men are responsible for land clearing, making mounds, and planting and harvesting yams. Women plant and harvest other crops as well as weed the farms. The male dominated cotton-based cropping system generally includes maize grown in rotation. In this system, land is

continuously cultivated using chemical fertilizers to maintain productivity. A rice-based cropping system is found in the swamp with most activities performed by men. Swamp rice is grown as a sole crop only in the wet season. Productivity is maintained by application of chemical fertilizers. Very few farmers grow vegetables in the swamp lands during the dry season, otherwise the land is left uncultivated.

Rice is not currently grown on upland soils by farmers in the M'be Valley despite the fact that agroclimatic conditions can support successful upland rice cultivation. Trials in 1989 produced upland rice yields of up to 4000 kg ha^{-1}. Reasons for non-inclusion of rice in local upland cropping systems are now being investigated.

Development of Rice Varieties for Upland and Inland Swamp Ecosystems

The lack of improved rice varieties in most farmers' fields in West Africa is striking. Mostly traditional varieties and a few introduced varieties from Latin America and Asia remain the most widely cultivated, despite the development of improved varieties by various research institutions within the region. The principal factors constraining adoption of improved varieties have been: poor tolerance to drought and adverse soil conditions in upland types, limited tolerance to soil problems such as iron, aluminum and manganese toxicities in lowland types, and generally poor grain quality of the improved and introduced varieties for both ecosystems. Social and economic factors also constrain the adoption of newly developed varieties at farm level; these include poor morphological and cooking characteristics and palatability.

WARDA breeders in the continuum program have been conducting varietal improvement trials since 1984 using African germplasm as the main source of newly developed varieties. They have also continued the evaluation of exotic materials to find sources of high yield potential and stress tolerance/resistance.

Two breeding projects, focused respectively on the lowland and upland ecosystems, are currently implemented through closely related research activities. A common breeding program is currently conducted for upland/hydromorphic and hydromorphic/inland swamp ecosystems for early generations (up to F_3/F_4). Advanced generations are split for specific adaptation to the different ecosystems. This approach will be modified in 1991 when IITA's rice breeding program, which concentrated on the lowland ecosystems, is transferred to WARDA. Apart from WARDA's breeding and selection activities, INGER trials, and trials of traditional African cultivars were also conducted in 1989.

DEVELOPMENT OF IMPROVED RICE VARIETIES

M. Choudhury

In 1989, the varietal development activities for the continuum program involved crosses, early generation

Variety	Plant Height (cm)	Maturity (days)	Grain Yield (kg ha^{-1})	Disease Resistance 0-9				Panicle Exertion (cm)	Soil Acid. Tolerance (0-9)
				Leaf Blast	Neck Blast	Brown Spot	Leaf Scald		
WAB 56-125	119	105	2750	1	1	2	2	8.5	1
WAB 56-104	103	101	2740	1	1	2	2	6.8	1
WAB 56-57	102	103	2620	1	1	1	1	6.3	1
WAB 56-50	105	103	2480	1	1	1	1	6.3	1
IDSA 10	104	108	2430	2	2	1	2	4.5	1
IRAT 144 (check)	101	105	2370	2	1	1	2	4.8	4
IDSA 46	91	107	2180	2	2	3	2	4.3	3
WAB 32-80	124	108	2170	3	1	2	2	8.1	3
IDSA 27	109	109	2030	3	1	2	2	8.5	3
WABC 165	111	108	1930	2	2	2	2	3.1	1
SE			148						

Table 8. Characteristics of entries in the upland variety trial, Cote d'Ivoire, 1989 (mean of three sites and two fertilizer treatments).

testings, pedigree nurseries, screening tests, observational trials and varietal trials for upland and hydromorphic ecosystems. The objectives of the program are to develop appropriate varieties for the continuum and to maintain a continuous flow of superior genetic materials.

Crosses and early generation tests were conducted at Bouake only. Other activities were conducted at the M'be Valley, Man, and Odienne in Cote d'Ivoire, and in Suakoko, Liberia, and at the IITA main research station in Ibadan, Nigeria.

The following work was carried out:

- Hybridization: 77 crosses were made and F_2 seeds from 48 crosses were retained.

- Early generation screening: Selections were made from F_2 and F_3 populations, to identify very early to early maturing, medium maturing and late maturing plants. A generation has been advanced to F_4 for 10 rice x sorghum hybrids received from IRRI. The sterility was high.

- Pedigree nurseries: F_4 and F_5 pedigree lines for upland and hydromorphic ecosystems were selected for advancement.

- Screening tests: From 134 strains tested at M'be, Man and Odienne, 18 performed well at all sites. From 205 advanced breeding lines received from CIAT, 27 were chosen for further tests.

- Observational trial: Out of 13 lines tested at M'be, Man and Odienne, four were selected.

- Preliminary variety trial: Four entries, namely WAB 32-133, WAB 33-25, WAB 33-19 and WAB 30-24 were found to be

superior to IRAT 144 and IAC 164 which served as checks. These were also found to have a satisfactory level of blast resistance.

- Advanced yield trial: Considering mean yield as a criterion for evaluating yield potential, WAB 56-125 and WAB 56-104 were found to be superior to others (Table 8). Four WARDA and one IDESSA varieties were found to be superior to IRAT 144, the check variety.

Performance of superior varieties identified in the 1989 advanced yield trial will be confirmed in multilocational trials in 1990, and several will be nominated for inclusion in INGER trials.

COLLABORATIVE INGER TRIALS

M. Choudhury and A. Abifarin

The International Network for Genetic Evaluation of Rice (INGER), formerly IRTP, is a collaborative program between IRRI, IITA, CIAT and WARDA. It provides rice scientists around the world with a mechanism through which their breeding lines can be tested under a wide range of agro-climatic conditions, and at the same time, allow them to have access to a wide spectrum of varietal diversity. The program helps national programs to identify better genetic materials for their growing conditions and to share their own materials with others. WARDA has been participating actively in INGER-Africa since its inception. In 1989, four different trials were conducted in the upland/inland swamp program.

African Upland Rice Preliminary Screening Set (AURPSS).

The objective of the trial is to identify adaptable upland rice varieties for advancement to observational nurseries. Two rows of 5 m were planted at Suakoko for each of the 150 entries. From 150 entries, 11 promising lines were identified based on plant type, disease resistance and yield potential. These include IRAT 112, ITA 175, Col. 1 x N312A, CR 155-5029-21, IRAT 251 and TOX 955-208-2-102.

African Upland Rice Observational Nursery (AURON)

The objective is to identify superior entries for subsequent variety trials. One hundred entries were tested at M'be, Man, Odienne and Suakoko. Each entry was planted in an unreplicated 5 m row plot. The best performing entries selected at three trial locations were: B 36239-TB-49, ITA 183, TOX 1010-6-3-5 and IR 14632-2-3. Entries selected at any two sites were: IR 5931-113-1, TOX 1857-3-2-201-1 and TOX 891-212-1-201-1. Entries selected at any one site were: B 2997 C-TB-60-3-3, IRAT 110, IR 10068-11-1, B 2992 B-TB-73-4-2-3-3-3-2, IR 9202-5-2-2-2, TOX 1739-101-4-2, TOX 1768-3-1-1-101-1, TOX 17680-7-1-201-1, TOX 1857-3-102-2-1, TOX 1871-53-1 and TOX 957-109-2-1.

African Upland Rice Advanced Variety Trial (AURAVT)

The objective of this trial is to identify fixed varieties that are superior to the best varieties currently being cultivated. Twelve entries were tested at Bouake, Man and Suakoko on 20 m^2 replicated unit plots. At Bouake and Man, no test

entry was found to be superior. Problems included short stature, disease susceptibility and short panicles. At Suakoko, IRAT 144, IRAT 147 and ITA 321 were found to be good.

African Rice Blast Nursery (ARBN)

This trial is aimed at identifying varieties with satisfactory levels of blast resistance. One hundred and fifty entries were densely planted at Suakoko, Liberia with spreader rows on all sides. Among the 150 entries, 20 were classed as moderately to highly resistant. The following highly resistant entries were identified: Ex-Shendam, Kataktara DA 2, Dular, ITA 116, ITA 212, ITA 257, IRAT 41 and ITA 123.

VARIETY TRIALS AT SUAKOKO, LIBERIA

A. Abifarin

Irrigated Yield Trials

Two replicated yield trials were completed in 1989 using elite rice materials developed at IITA. The main objective was to measure grain yields in the humid-forest zone at Suakoko.

In the first trial, MASS, TOX 3118-6-EZ-1-2-2-2 and TOX 3133-56-1-3 yielded 2300, 2200 and 2200 kg ha^{-1}, respectively, while the check variety yielded 1800 kg ha^{-1}.

Soil fertility problems depressed the yields of the second trial to levels of 1500-3000 kg ha^{-1}. ITA 320 produced the highest yield with 3020 kg ha^{-1} compared to 2360 kg ha^{-1} for Suakoko 8, the check variety. ITA 320 matured in 130 days, had a plant height of 103 cm, and was in the satisfactory range for iron toxicity tolerance. ITA 328 was the second highest yielding variety with 2660 kg ha^{-1}, but was not significantly higher than Suakoko 8. ITA 320 could be an alternative to Suakoko 8 if its tolerance to pests and diseases, and its grain quality are acceptable.

All three of the varieties were recommended for inclusion in the INGER yield trials and for use in multilocational trials within national programs.

A promising variety must undergo a series of rigorous screenings before it is released as a recommended variety to the national programs in West Africa.

Collaborative Upland Yield Trials

Three upland rice experiments were jointly conducted by WARDA and IITA during 1989 to evaluate the performance of rice materials developed by IITA under Suakoko conditions.

Seven promising entries were identified from the 51 tested in the Observational Nursery Trials. These were TOX

1870-40-101-1-1-1-1, TOX 1870-47-103-3-2-1-1, TOX 56-WAS 1-101-2-2-3, TOX 1870-24-102-2-1-3, TOX 1889-7-104-1-3-1, TOX 3156-6-7-2 and TOX 1870-30-101-3-2.

Two advanced yield trials were conducted. The first contained 11 IITA elite lines and OS 6 and LAC 23 as local checks. All the entries were shorter than normal and the test varieties were much shorter than the local checks. Grain yields were low due to low soil fertility and heterogeneity. There were no significant differences between the yields of the control and the best entries.

There were 14 entries in the second trial. LAC 23 was the check variety. Grain yields in all the test entries were lower than the check. The top four test entries (1800-2100 kg ha^{-1}) did not differ significantly when compared to the check (2600 kg ha^{-1}). ITA 257 produced almost 2000 kg ha^{-1} after only 86 days of growth.

The trials will be repeated in 1990 to further evaluate yield potential on fertile soils.

Preliminary Yield Trials of WARDA Lines

Fourteen WARDA bred upland lines were planted along with four other entries and LAC 23 as the local check. Yields were generally low (940-1310 kg ha^{-1}) due to low soil fertility on the site and extensive termite damage.

Although the best lines yielded lower than the local check variety, these lines were considered good when evaluated on the basis of days to maturity. The trial will be repeated in 1990 to further evaluate the best eight entries.

ADAPTABILITY OF SOME TRADITIONAL AFRICAN RICE CULTIVARS TO THE UPLAND/ HYDROMORPHIC ECOSYSTEM

K. Miezan

Oryza glaberrima and *O. sativa* are the two rice species cultivated in West Africa. Although in farmers' fields the two species are often found occupying the same ecosystems, their relative adaptabilities to the upland and lowland ecosystems are not well known. In order to make the best use of *O. glaberrima* in rice improvement, an understanding of its adaptability to the various rice ecosystems is necessary.

Four *O. sativa* and *O. glaberrima* varieties were line dibbled in 10 m x 5 m plots replicated 12 times along the toposequence of a continuum at the M'be Valley. Spacing was 25 cm within and between rows. Data on tiller number, panicle number, days to heading, height and yield were obtained.

Significant differences between the varieties within each species were found only for height and days to heading. *O. glaberrima* appeared to produce more tillers, more panicles and shorter culms than *O. sativa*. When performance of the two species was plotted against different zones of the continuum, *O. sativa* and *O. glaberrima* showed opposite adaptability patterns for all the traits analyzed. *O. glaberrima* performed better in the wetter zones than in the strictly upland areas. *O. sativa* varieties, on the contrary,

performed better on the upper parts of the continuum than in lowland areas.

These results are very preliminary and indicate that *O. glaberrima* species might be more suitable for use in rice improvement programs targeting lowland ecosystems. There is need, however, for a more detailed study using typical lowland and upland varieties as checks in order to better characterize the test *Oryza glaberrima* and *Oryza sativa* varieties and to gain more precise estimates of their potentials in various ecosystems.

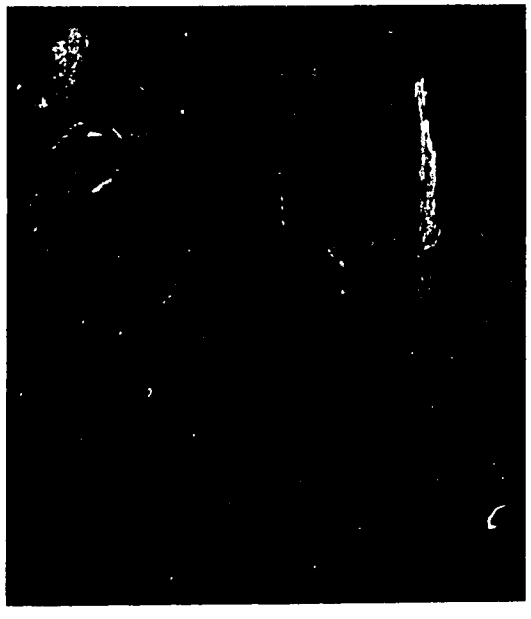
SCREENING RICE VARIETIES FOR RESISTANCE TO INSECT PESTS

E. Akinsola

Insect pests substantially reduce rice yields in West Africa. Among the most common species recorded, stem borers and stalk-eyed flies, *Diopsis longicornis*, constitute the major menace. In the development of pest management strategies that are environmentally safe and technically as well as economically feasible for smallholders, varieties with high levels of resistance to major pest species are indispensable. No variety is yet known to be highly resistant to both *D. longicornis* and the lepidopterous stem borers. This study was undertaken in collaboration with scientists at IITA to identify sources of resistance to *D. longicornis*.

Two hundred and eight advanced lines from IITA's rainfed lowland observational nurseries and some *O. glaberrima* lines were exposed in non-replicated 20-hill single row plots to *Diopsis* infestation in the nethouse at IITA, Ibadan. Suakoko 8, the standard susceptible check, and three other improved varieties, IR 5, ITA 312 and ITA 308, were included and replicated five times. Observations on deadhearts were made at 45 days after transplanting (DAT). Another set of 13 promising varieties/lines from previous unreplicated mass screenings were retested in 20-hill single row plots and replicated four times. Observations on the level of infestation were made 45 and 75 DAT.

Among the 208 advanced lines screened, percentage deadhearts ranged from 22% to 94% (mean 59%). Five entries had between 22%-30% infestation and two had 31%-40%. The least attacked entries were all *O. glaberrima* (Table 9). Suakoko 8 and the improved varieties were heavily attacked with uniformly high mean infestation levels. The 13 promising varieties selected as being moderately resistant from previous mass



The presence of white heads, caused by stem borer attacks on rice, is a common sight in West African rice fields.

screenings also had very high levels of infestation, ranging between 48%-67% at 45 DAT and 40%-60% at 75 DAT. These levels of attack were attributed to high insect pressure within the nethouse indicating that varietal reactions vary with prevailing levels of stress. On the basis of this and previous evaluations, two materials, namely A 21387-2 and TOX 3102-27, were considered superior.

Since the level of resistance available in varieties so far screened is low, future work will explore other germplasm sources including wild rice and additional *Oryza glaberrima* materials.

Table 9. Percent infestation rates of selected materials mass-screened for resistance to the stalk-eyed fly, *Diopsis longicornis*, IITA Ibadan, Nigeria, 1989.

Variety/line	Infestation (%)*
Tog 6399 (*glaberrima*)	22.4
Tog 6529 (*glaberrima*)	23.5
Tog 6343 (*glaberrima*)	29.1
Tog 6486 (*glaberrima*)	29.4
TOX 3118-47-1-2-2-1	30.2
TOX 3084-136-1-3-1-2	38.8
TOX 3052-46-3-3-1	42.8
TOX 3081-36-1-4-1-1	45.3
TOX 3084-137-1-2-4-1	48.3
TOX 3093-4-5-4-2-1	55.0
IR 5	59.8
Suakoko 8	60.5
ITA 308	60.6
ITA 312	61.3
TOX 3107-39-1-2-2-4	67.9
TOX 3069-66-2-3-1	74.6
TOX 3096-52-3-3-3	76.8
TOX 3108-63-5-1-2-3	86.2
TOX 3114-10-1-2-3-3	90.6
TOX 3109-75-4-3-2-2	91.0

* 208 materials screened. Infestation ranged from 22%-94%.

Development of Improved Techniques for Weed Control

In the upland/hydromorphic ecosystem, severe weed infestation is one of the major biological constraints to increased rice production in West Africa. In both traditional and modern rice farming, the lack of appropriate improved weed control techniques, coupled with shortage of labor for weeding, help to explain why shifting cultivation continues to predominate. Although diagnostic research during the past few years has identified some weed control components, these need to be refined and adapted into integrated weed management systems.

Three activities were conducted under this project in 1989. Two were maintained from WARDA's earlier upland rice research program. These are related to the control of Euphorbia heterophylla and weed control in bush-fallow farming. The third reported activity on weed characteristics at M'be Valley was initiated in 1989 within the framework of a general characterization of the M'be Valley environment.

INTEGRATED CONTROL OF *EUPHORBIA HETEROPHYLLA* L.

G. Nyoka

Euphorbia heterophylla L. is one of the most difficult weeds of upland rice to control in West Africa. In experiments conducted from 1986 to 1988, it was found that repeated tillage alone prior to

Euphorbia heterophylla **is a quickly spreading weed that is causing large economic losses for rice farmers in West Africa.**

rice seeding did not eliminate the weed. Good control was achieved however, when repeated tillage was integrated with chemical herbicide application. The herbicide rate used, oxadiazon at 1000 g ha^{-1} applied at rice seeding followed by picloram-2,4-D at 300 g - 700 g ha^{-1} applied four weeks later, nevertheless required one supplementary manual weeding to achieve weed free plots.

In 1989, the experiment was further modified to find out whether maintaining both the tillage methods and the rate of oxadiazon, but doubling the rate of picloram-2,4-D, would eliminate supplementary manual weeding.

Under all three tillage methods tested, the biomass of *E. heterophylla* was reduced to negligible levels with the double dose of picloram-2,4-D. Although rouging of isolated plants of *E. heterophylla* was done, this required little labor. The double herbicide dose had little phytotoxicity effect on the rice crop; and although this dose increased the cost of the herbicide, it was compensated for by the elimination of supplementary manual weeding. The cost of picloram-2,4-D is about 25% that of oxadiazon.

Although the present results are conclusive, they concern only one set of herbicides. To allow farmers a wide choice of control methods, future research will evaluate other herbicide combinations that can control *E. heterophylla* as well as other problem weeds.

WEED CONTROL IN BUSH-FALLOW FARMING

G. Nyoka

In traditional upland rice farming, farmers minimize the weed problem through shifting cultivation. As farmers move from this system to more intensive cropping, weed infestation increases.

This means that farmers either have to adopt cropping systems that significantly reduce weed populations prior to rice seeding or they have to develop methods to effectively control high weed infestation *in situ*. Since the later option is always a problem, research is concentrating on studying cultural practices that can minimize weed populations to the level where direct weeding can be more cost effective.

In a trial conducted in 1988, traditional hand hoe tillage was compared with the power tiller repeated once, twice and thrice at three-week intervals. The use of power tillers was as effective as the hand hoe except when tillage was repeated three times. The trial was repeated in 1989 to confirm the earlier results.

Hand hoe and power tiller methods produced similar effects on the weed flora, weed biomass and rice yields. Tillage frequency had significant effect only during the first four weeks following rice emergence, after which weed biomass accumulation was similar regardless of the tillage method and tillage frequency.

The two-year results indicate that there is no weed control advantage in using the power tiller compared to the use of the traditional hand hoe. However, three tillages at three-week intervals significantly reduce the initial weed infestation. For future work the tillage methods will include tractor tillage and the tillage frequencies will be increased to four-six-week intervals to allow more weed seeds to germinate.

CHARACTERIZING WEED FLORA AND DISTRIBUTION AT M'BE VALLEY

G. Nyoka

Although traditional farming has been practiced for many years at the site of WARDA's new Main Research Center and Headquarters in the M'be Valley, the weed vegetation has never been studied.

The objective of this investigation was to study the weed flora, its distribution and pattern of infestation. The weed flora and distribution were studied by sampling 50 farmers' fields using 10, 1 m x 2 m random quadrats per field. The pattern of weed infestation was studied from three continuum experimental sites laid out along a toposequence.

The weed flora consisted of broadleaf species (67.5%), grasses (20.5%), sedges (8.4%), and other species (3.6%). The most common species were: *Mariscus alternifolius, Commelina banghalensis, Imperata cylindrica, Digitaria horizontalis, Phyllanthus amarus, Solanum nigrum, Cellosia laxa, Mullugo nudifolius, Andropogon gayanus, Andropogon tectorum, Eleusine indica, Rottboellia cochinchinensis,* and *Ageratum conyzoides.* Along the continuum, weed biomass was higher in the dryland areas than in the hydromorphic zone. Individual species were confined to the wetland zone and these could be used to delimit hydromorphic and swamp areas. These include *Leersia hexandra, Ludwigia descurens, Cyperus difformis, Kyllinga squamulata, Fuirena ciliaris,* and *Rhynchospora corymbosa.* Dryland species

tended to occupy both upland and hydromorphic ecosystems. Species infestation also varied with time. Both the wetland and dryland weed species invaded various parts of the toposequence in response to water table movements.

The evaluation of weed infestation patterns in farmers' fields was complicated by lack of information on the farming history of individual fields. Future studies will therefore be closely linked to the study of soil characteristics and cropping pattern histories.

RESEARCH PROGRAM II:

Sahel Irrigated Rice

The Sahel Irrigated Environment

CHARACTERISTICS

The Sahel presents a markedly different environment and set of problems due to its organizational structure, management system, and proximity to the desert. Most rice in the Sahel is produced under governmental development projects on large irrigated areas where it is often the only rainy season crop grown. Nevertheless, individual holdings are generally small and managed by farmers who typically cultivate crops other than rice outside the irrigation scheme during the rainy season.

Access to water control means that potential returns to high levels of variable inputs are greater than in other rice production systems, and the risk of loss less. Water availability permits two rice crops to be grown annually over much of this environment, the first during the rainy season, and the second during the dry season. Temperature extremes and high pest pressures, however, make second season cultivation highly risky with most available rice varieties. In the absence of more suitable rice varieties many farmers currently prefer to grow vegetables or other profitable cash crops during the dry season.

PRODUCTION CONSTRAINTS

A complex of climatic factors combined with poor water management constitute the principal constraints to increased productivity in this ecology. Extremely high temperatures and strong dust laden winds at the vegetative stage of plant growth can severely reduce grain production

stage of plant growth can severely reduce grain production during the hot, dry season and the main rainy season. In addition, low temperatures experienced at the seedling stage during the cold, dry season threaten seedling survival for the second season rice crop. Dry atmospheric conditions can also cause significant post-harvest losses, as brittle grains are more prone to breaking during milling.

Insufficient leveling, poor canal design, and inadequate assessment of water resources lead to inefficient distribution of water. High soil permeability contributes to substantial water loss due to seepage in canal structures, as well as in cultivated fields. Neglect of watershed management (including deforestation) has led to an escalating problem of sedimentation, and inadequate drainage has led to a rapidly increasing problem of salinity. Constraints are not only of a physical nature, however, and are not easily resolved through simple application of well known technical improvements in design and implementation. Rather, important issues of social organization often underpin these problems, greatly complicating the search for appropriate solutions.

Additional biological constraints include pests, especially white flies and spider mites during the second season, and stem borers throughout the year. The principal rice plant diseases are blast and leaf scald. Weed infestation, often associated with poor water management, can cause major yield losses, especially under high fertility conditions.

POTENTIAL USE OF *AZOLLA* FOR RICE PRODUCTION IN WEST AFRICA

H.F. Diara

West African farming systems have generally remained traditional, in part because small-scale farmers have limited access to existing technological innovations. Chemical fertilizers, for example, which can be essential inputs in crop production, are not applied in adequate quantities or on time. These chemicals, especially nitrogen fertilizers, are very expensive and pose a major foreign exchange problem for poor countries of the region which must import them.

Biological nitrogen fixation, which is accomplished by microorganisms living symbiotically with plants, is a promising alternative to chemical sources of nitrogen. One type of symbiosis is represented by the association between the free-floating aquatic pteridophyte *Azolla*, which can fix atmospheric nitrogen, and its partner, the cyanobacterium *Anabaena azollae*.

Azolla has been used as green manure in China and Vietnam for centuries. But it is only recently, in the mid-seventies, that the interest of the scientific world in *Azolla* and its practical uses grew in response to the international oil crisis. In its efforts to increase rice production, the West Africa Rice Development Association (WARDA) launched a research project to evaluate the agronomic value of *Azolla* in the West African environment. From 1980 to 1989 the project conducted multilocational trials, on-station and on-farm trials, and developed collaboration with national and international institutions. Very little scientific information was available on the environmental requirements and methods for *Azolla* cultivation. Despite the fact that most of the well developed irrigated rice schemes are located in the Sahelian zone, this climatic environment seemed to be, *a priori*, inappropriate for *Azolla* culture.

The objectives of the *Azolla* research project were to develop *Azolla* utilization techniques to stabilize and increase natural soil fertility; reduce the use of chemical nitrogen fertilizers; and help control weed infestation in swamp rice farms.

The work plan was regional because of the soil and climatic diversities encountered in West Africa, and because of the exploratory nature of the study. Scientific backstopping was provided by the plant physiology department of

Universite Catholique de Louvain (UCL), in Belgium. Their input was focussed on ecophysiological studies and chemical analysis. Research was undertaken in the following areas:

- creation and development of a reference *Azolla* collection;
- selection of *Azolla* ecotypes adapted to contrasting ecologies in the humid and semi-arid zones of West Africa;
- adaptation of cultural practices to existing rice cropping systems and evaluation of *Azolla* culture on rice production; and introduction of *Azolla* technology into West African farmers' environment.

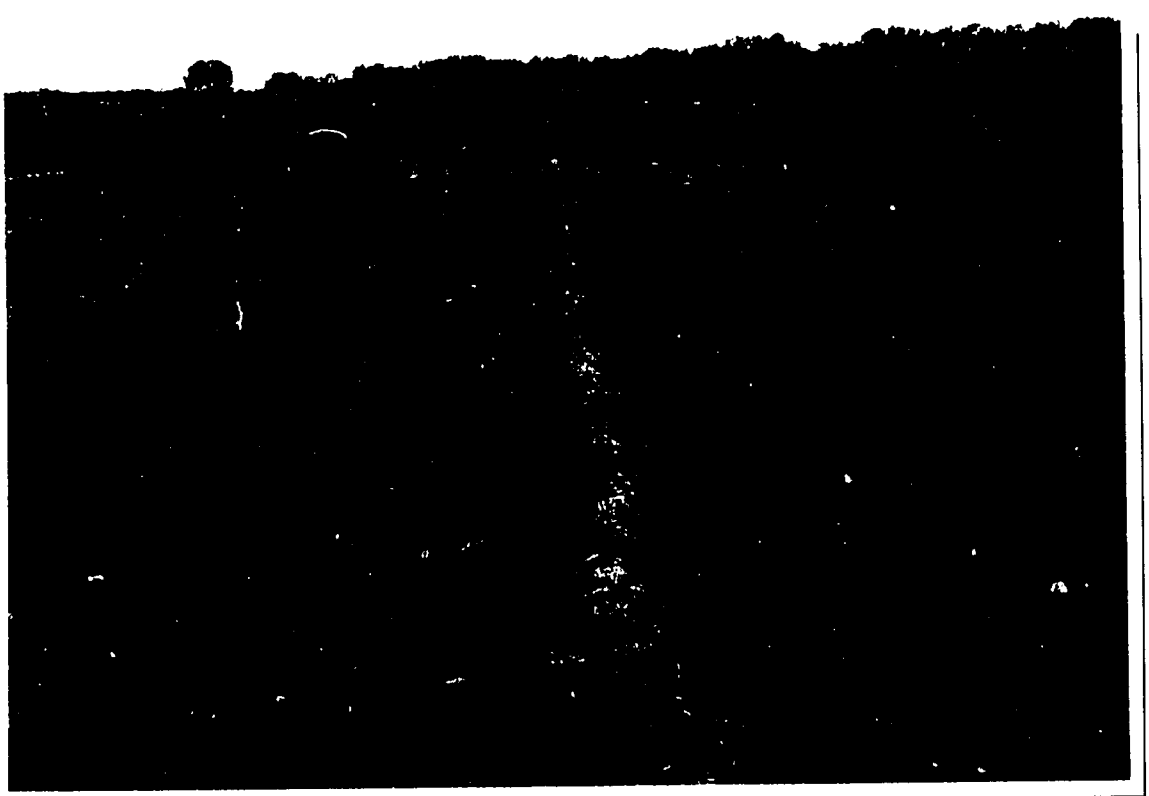
Implementation of this program involved scientists from WARDA regional stations in Senegal and Sierra Leone, and from several national institutes in WARDA member countries.

CREATION OF A REFERENCE COLLECTION

To evaluate a large number of *Azolla* ecotypes in the West African environment, collaborators from all over the world were asked to collect and provide local *Azolla* strains. The plant physiology unit of UCL developed means to maintain the entire collection in controlled and standardized conditions. The most promising accessions were sent to Senegal for adaptive field trials.

SELECTION OF SPECIES AND STRAINS ADAPTED TO THE REGION

Selection criteria and the methods to quantify them have been developed. For each series of experiments, a batch of strains, pre-screened in the labor-



More than 250 *Azolla* ecotypes have been collected and tested by WARDA scientists in an effort to find alternative sources of nitrogen for rice grown in the region.

atory and in adaptive field trials, were tested under natural conditions in different ecosystems. The objectives were to: identify well adapted strains for each environment, and to determine the environmental requirements of *Azolla*.

Like any other diazotroph, it has been observed that *Azolla* has high demand for phosphorus. As a result, phosphorus can be a major limiting factor for *Azolla* growth under field conditions. A series of studies were conducted on the response of several *Azolla* ecotypes to various sources of phosphorus.

EVALUATION OF THE AGRONOMIC VALUE OF *AZOLLA* IN PADDY PRODUCTION

Azolla can be introduced into the cropping system in several ways. It can be grown alone on standing water as a monoculture. After full cover of the water surface, the field is drained and the green matter is incorporated into the soil just before planting rice. *Azolla* can also be intercropped with rice and allowed to grow until it fully covers the open spaces between rice rows. Then, it can be left as top dressing or incorporated one to three times before maturity of the main crop.

These two cultural methods were evaluated and compared with respect to their effect on rice productivity and weed infestation. Combinations of various doses and periods of application, with *Azolla* alone or supplemented with increasing doses of mineral nitrogen, were compared to determine cultural practices that best fit into existing rice cropping systems.

ON-FARM TRIALS

On-farm trials have played a key role in evaluating the potential of *Azolla*. In the first series of on-farm verification trials conducted in the mid-1980's, two treatments were tested and compared to the farmers' practice:

- *Azolla* monocrop incorporated before planting rice; and
- the same treatment + half of the equivalent quantity of nitrogen applied by the farmer.

In 1988 an *Azolla* intercropping treatment was added to evaluate its effect on weed infestation and rice yields.

Prospecting trips and *in situ* adaptive trials were made in Senegal, Mali, Burkina Faso and Sierra Leone. In all locations, on-farm work showed that a permanent source of *Azolla* within the rice schemes was crucial for farmer adoption of *Azolla* technology.

RESEARCH RESULTS

Azolla Collection, Characterization and Selection

More than 250 *Azolla* ecotypes from throughout the world were collected and are presently maintained in the plant physiology unit of UCL. A subcollection of about 50 ecotypes has been maintained in the WARDA regional station in Senegal, and a duplicate of the entire ADUL collection was sent to the International Rice Research Institute (IRRI) in 1987.

Ecophysiological studies conducted on *Azolla* in the laboratory and in the field led to its characterization at the specific and sub-specific levels, although vari-

ability between the ecotypes can be very high for a given factor.

Productivity appeared to be the most important criterion for *Azolla* selection. For this reason, multilocational comparative experiments were conducted in contrasting environments throughout West Africa. Results showed that *Azolla* productivity in semi-arid climatic zones (average + 170 g m^{-2} day) is twice as high as productivity in humid tropic climatic zones due to solar radiation and temperature differences. Tables 10 and 11 give the performance characteristics of *Azolla* species in the Sahel and humid zones in West Africa. Results obtained in West Africa were later confirmed by those obtained at IRRI in the Philippines. Thus, the Sahelian agro-ecological environment was found to be conducive for adaptation of several imported *Azolla* species such as *A. microphylla* from tropical and sub-tropical America, *A. caroliniana* from North and Central America, and *A. pinnata* var. *imbricata* from Asia. Comparatively, *A. pinnata* var. *pinnata* from West Africa is more adapted to the humid tropical environment, which is its natural habitat.

Phosphorus Requirements

Phosphorus deficiency in the medium can depress *Azolla* growth severely. Plant color changes from green to yellow-green, brown or red-brown, depending on the species, and the extent

Table 10. Performance characteristics of some introduced *Azolla* species in the Sahel agro-ecological zone of West Africa.

Azolla Species	Origin*	Growth Rate: Cold Dry Season	Growth Rate: Hot Dry Season	Growth Rate: Hot Wet Season	Maximum Yield ('000 kg ha^{-1})	Phosphorus Growth Requirements	Tolerance to Absence of Standing Water
A. pinnata var. *pinnata*	Oceania	L	M	L	20	L	L
A. pinnata var. *pinnata*	Africa	M	H	M	20	M	N
A. pinnata var. *imbricata*	Asia	M	H	M	20	L	N
A. caroliniana	Tropical America	L	H	M	30-40	H	H
A. microphylla	Tropical America	L	H	M	30-40	H	H
A. filiculoides	America	M	M	L	n.a.	n.a.	M

* After Lumpkin, T.A. and D.L. Plucknett (1982). *Azolla* as a green manure: use and management in crop production. Westview Tropic. Agric. Series No. 5, Westview Press.

N = Nil; L = Low; M = Medium; H = High; n.a. = not applicable

Table 11. Performance characteristics of some introduced *Azolla* species in humid tropical agro-ecological zones of West Africa.

Azolla Species	Origin	Growth Rate: Wet Season	Growth Rate: Dry Season	Maximum Yield ('000 kg ha^{-1})	Phosphorus Growth Requirement	Tolerance to Absence of Standing Water
A. pinnata var. *pinnata*	Oceania	H	M	20	L	L
A. pinnata var. *pinnata*	Africa	M	L	20	M	N
A. pinnata var. *imbricata*	Asia	H	L	20	L	N
A. caroliniana	Tropical America	L	L	15	H	H
A. filiculoides	America	L	L	n.a.	n.a.	M

* After Lumpkin, T.A. and D.L. Plucknett (1982). *Azolla* as a green manure: use and management in crop production. Westview Tropic. Agric. Series No. 5. Westview Press.

N = Nil; L = Low; M = Medium; H = High; n.a. = not applicable

of the deficiency. In phosphorus deficient soils, the application of 10 - 15 kg P_2O_5 ha^{-1} to the *Azolla* crop 3 to 7 days before its utilization gives the most cost effective results. Though the response of *Azolla* to soluble fertilizer is greater, trials conducted in 1989 demonstrated that some of the local rock phosphates have good potential to replace costly chemical fertilizers.

Trials conducted in 1989 also showed that the phosphorus requirement of *A. pinnata* is lower than that of *A. microphylla* and *A. caroliniana*. However, the phosphorus accumulation capacity of *A. microphylla* and *A. caroliniana* is much higher when compared to *A. pinnata*.

Effectiveness as Green Manure

The effectiveness of *Azolla* as green manure was evaluated mainly through its impact on rice yields. Its positive contribution to rice as nitrogen fertilizer was assessed in the Sahel and the humid zones of West Africa.

A single *A. pinnata* monocrop, representing a maximum fresh weight of 20000 kg ha^{-1}, incorporated before planting rice is equivalent to the application of 30 kg to 40 kg N ha^{-1} in mineral form.

In several years of tests in the Sahelian zone, this dosage has been shown to generate an average rice yield of 4000 kg ha^{-1} (range 3700 - 4300) corresponding to an average incremental rice yield (IRY) of 49% (range 30%-54%). Incorporating two monocrops is equivalent to the application of 60 kg N ha^{-1} and generates an average rice yield of 5200 kg ha^{-1}, corresponding to an IRY of 70%.

Incorporation of intercropped *Azolla* was less efficient than *Azolla* monocrop

incorporation. This is due partly to the delayed application of nitrogen which, as a consequence, deprives the young rice seedlings at the tillering stage. A further contributing factor is the development of the rice canopy which reduces the space and light required for optimum *Azolla* biomass production.

The combination of an *Azolla* monocrop and subsequent intercrop incorporated successively can be an alternative to increase its efficiency as green manure when *Azolla* is the only source of nitrogen available. Otherwise, complementing the incorporation of one or two *Azolla* monocrops with 30 to 60 kg N ha^{-1} in urea form is the easiest and most efficient way to satisfy rice's overall nitrogen requirements. Generally speaking, the complementary use of organic and inorganic nitrogen sources has a better effect on rice yield than when they are applied separately. Complementing one *Azolla* monocrop with 30 to 60 kg N ha^{-1} as urea gives an average IRY of 60% to 100%, respectively; with two monocrops and urea, the average IRY rises to 105% and 120%, respectively, giving rice yields equivalent to the maximum.

Results obtained in the tropical humid zone show that when *Azolla* is the sole source of nitrogen, the maximum benefit is obtained by successive incorporation of one monocrop and one intercrop two weeks after transplanting rice. Doing so, the average IRY is 64%, instead of 50% and 55%, respectively, with one and two monocrops.

Experiments to evaluate composted and dry *Azolla* materials compared to fresh *Azolla* materials led to the conclusion that the agronomic effect of fresh *Azolla* is superior. Other materials can be used only as an alternative when fresh *Azolla* cannot be used.

Effectiveness in Weed Control

A mature *Azolla* population forms a thick mat on the water surface, preventing sunlight from reaching below the water. As a consequence, the germination and growth of some weed species is inhibited.

An *Azolla* cover in an unweeded rice field reduces the population of weeds by 40%-80% and, as a result, can increase rice yields up to 40% compared to yields without weeding and without *Azolla*. Results in 1989 confirmed not only the yield benefit, but the weed control benefits to unincorporated *Azolla*. Efficiency can be improved by 15% by combining *Azolla* intercropping with one hand weeding three weeks after transplanting rice. However, this positive effect of *Azolla* requires good water control and rapid vegetative multiplication to cover the water surface before weeds emerge. *Azolla* intercropping is also facilitated when rice is transplanted or seeded in lines.

Tests in Farmers' Fields

The agronomic value of *Azolla*, both as green manure and weed suppressor, was tested in a number of sites in various West African ecosystems. The results previously obtained at experimental stations were confirmed, though at lower yield levels.

It was observed that the establishment and year-round maintenance of an *Azolla* pond is a major constraint to adoption, especially in environments where there is a single cropping season. As a

result, in areas like the Senegal River Valley, the potential of *Azolla* use as green manure by the local farmers seems to be low, primarily because water is costly and because urea is generally available in adequate quantities and at a subsidized price.

An additional limiting factor is the cost of labor for *Azolla* incorporation. In the absence of motorized implements the use of oxen-drawn plows, like those used by the Office du Niger (Mali), may be a solution for a large-scale incorporation of an *Azolla* monocrop.

Farmers in all locations were impressed by the use of an *Azolla* intercrop to control weeds, and appreciated the time and labor savings compared to the use of herbicides and hand weedings.

Finally, adaptive tests of various *Azolla* ecotypes in very different ecosystems in West Africa have confirmed that *A. pinnata* var. *pinnata* strain ADUL 138 pp is more tolerant to iron toxicity and phosphorus deficiency compared to *A. microphylla* strains.

IMPLICATIONS AND FUTURE DIRECTIONS

It has been proven that *Azolla* cultivation is technically feasible in the major part of the West African sub-region. The average productivity, obtained with imported strains, is good - and sometimes exceptional - when compared with performance in Asia.

When adequate biomass production is achieved, *Azolla's* nitrogen contribution to rice can help reduce the quantity of chemical fertilizer applied to produce optimum yields. Intercropping *Azolla* with rice can also significantly reduce weed infestation.

The greatest potential for *Azolla* use in West Africa is within a broad belt located, roughly, between the latitudes 9° and 13° North, where average rainfall is 800-1200 mm annually, and where there is a reasonable mean daily hours of sunshine (7-8 hours). Most lowland rice producing areas of Mali, Burkina Faso, the South of Senegal, the north of Cote d'Ivoire, and Nigeria are included in this intermediate zone.

The lack of adequate water control in the majority of rice schemes is a major technical constraint for the full utilization of *Azolla*. For this reason, emphasis was put on adapting the cultural practices to the existing farming systems and selecting *Azolla* ecotypes already well adapted to various ecosystems. From multilocational studies conducted on-station and on-farm, a set of *Azolla* strains highly productive and tolerant to adverse conditions such as iron toxicity, phosphorus deficient soils, and intermittent drying of the field was selected. Recommendations concerning *Azolla's* practical utilization were developed.

From the experience acquired, the necessity to diversify *Azolla* use seems to be the best approach for future research and extension activities in West Africa. Several *Azolla* potentials, such as green manure for rice and other crops, food for humans or animals, and material for biogas production, can be integrated in rice-based farming systems. Successful examples exist in China, Thailand and the Cote d'Ivoire.

Considering past activities of the WARDA *Azolla* project, future *Azolla* ac-

tivities should be more oriented to pre-extension and extension work with greater involvement of national development agencies and non-governmental organizations. International institutes such as WARDA and the Food and Agriculture Organization of the United Nations (FAO) may play an important role in this respect. Research activities could also continue on the selection of *Azolla* ecotypes, spore production, large-scale utilization, and determination of *Azolla* feeding value. Considerable emphasis should be placed on an evaluation of the integrated use of *Azolla* and the economies of alternative uses.

Finally, as a pioneer institution in *Azolla* work, WARDA should be able to play a role as consulting agency for the national programs in their future *Azolla* activities; ensuring exchange of information among scientists within and outside of the region; organizing and participating in training workshops and seminars within the region.

RESEARCH ACTIVITY SUMMARIES

Development of More Productive and SustainableWater and Weed Management Practices

The completion of dams in Senegal and Mali has increased the potential demand for irrigation water for the cultivation of rice and other crops. Research conducted by WARDA, in close collaboration with Wageningen University in The Netherlands since 1982, has shown that early attempts to develop irrigation systems in many portions of the Senegal River Valley were done without appropriate designs. Smaller village-level irrigation perimeters were generally technically and economically more efficient than large schemes. Poor designs often led to inadequate water management, degraded physical structures, and the need for rehabilitation. Poor water management also contributes to inadequate control of weeds, a major cause of rice yield losses in the Sahelian environment. Studies also concluded that the extension of uniform irrigation approaches across different village settings often failed because they did not consider crucial differences in the micro-environment and social institutions. Two sets of activities were carried out in 1989 to address these issues.

DESIGN OF SMALL AND INTERMEDIATE SCALE IRRIGATION SYSTEMS

G.E. Fenstra

Criteria for the design of irrigation schemes are generally technical. While they always consider aspects of terrain, they often ignore the socio-economic context of the cultivators. This is thought to be an important contributing factor for the disappointing results of many irrigation schemes in the Sahel. Although farmers are continuously engaged in the improvement of their schemes, success of the introduction of irrigation in the Bakel region of Senegal is only partial. In the rainy season, only 53% of the surface of the schemes is actually irrigated, and in the dry season only 10%.

The aim of a village-level study in the Bakel region was to find more appropriate criteria for the design of irrigation schemes, taking into account current farming systems and farmers' organizational capacities. Methods included studies of how to design, in close collaboration with farmers' groups,

new schemes through which farmers could choose among design alternatives.

Work was initiated in 1989 in two villages. One village was considering construction of a new small-scale irrigation system, while the second was considering alternative approaches to rehabilitate a scheme that had been seriously degraded. Results show that as a function of their organizational and technical skills, level of market orientation, and former experiences with irrigation, farmers tend to choose either designs that are more technically advanced, labor and water efficient, but risk prone, or simpler designs with less risk of total failure. Since these factors differ between neighboring villages, it is not possible to develop irrigation designs that are generally applicable for all village situations. The current research is terminating in early 1990. Further results will contribute to WARDA's planning for future research on water management in the Sahel.

Good canal design and construction is critical to the success of irrigation schemes for rice found in the Sahel.

DEVELOPMENT OF INTEGRATED WEED CONTROL PRACTICES FOR IRRIGATED RICE IN THE SAHEL

A. Moctar Diop

Weeds are a major constraint to rice cropping under irrigated conditions in the Sahel. Poor land levelling and inadequate water control render water management methods of weed control ineffective in most Sahelian irrigated schemes. As a result, farmers commonly rely on chemical herbicides. High and rising costs of herbicides, poor input delivery systems, and increasing concerns about the impact of chemicals on human health and the environment, however, have questioned this approach. Economically integrated weed management approaches that use a range of weed control methods to minimize reliance on herbicides are now considered essential. A range of experiments was conducted in 1989 to examine the individual and combined effects of several weed control methods. These included various land preparation methods, water control, *Azolla* intercropping, hand and mechanical weedings, and a range of doses and timings of pre- and post-emergence chemical herbicides. The work was exploratory and not intended to test optimal packages.

Results showed that a no-tillage system in which gramoxone was applied before seeding was extremely effective in controlling annual weeds, but was inef-

fective against perennial weeds. Perennial weeds were also less affected by the combined use of *Azolla* and water control, although the combination significantly reduced most annuals. The timing of water control measures was crucial. Submergence at the beginning of the season to reduce weed seed germination was considerably more effective than submergence after weed growth was initiated. Useful information on weed response to a range of doses and timings for application of garil (propanil + trichlopyr butoxyethyl ester) were also obtained.

Considerably more work is needed to determine optimal levels and combinations of weed control methods that are effective and well adapted to farmers' circumstances. Economic evaluations of techniques need to be made at earlier stages to guide technology development for appropriate solutions.

Development of Improved Soil Fertility Management Practices

Soils in the Sahel are characterized by low organic matter, low phosphorus, and medium to high potassium content. Nitrogen and phosphorus are the main limiting nutrients. The high cost and unavailability of chemical fertilizers has led to research examining alternative sources of nitrogen for more intensive rice cultivation. Research has shown that the nitrogen fixing (blue-green) alga (Anabaena azollae) and Sesbania rostrata are good alternative sources. However, nitrogen from these sources becomes available to the rice plant only after the organic materials are incorporated into the soil. Incorporation constitutes a major constraint for farmers because of the lack of manpower and it is time consuming.

Research activities in 1989 focused on various methods of Azolla incorporation and the agronomic value of cultural practices involving Sesbania rostrata.

EVALUATION OF *AZOLLA* MANAGEMENT METHODS ON THE INCIDENCE OF WEED INFESTATION AND RICE YIELD

H.F. Diara

It is recognized that effective nitrogen contribution to rice by *Azolla* is obtained only after the fern has been incorporated into the soil. However, the labor required to incorporate *Azolla* in large areas restricts the use of *Azolla* by West African farmers. In 1988, WARDA scientists found that maintaining an *Azolla* cover on the soil surface without incorporation before transplanting rice, followed by an *Azolla*-rice intercrop, produced rice yields as high as when *Azolla* was incorporated. This promising result needed confirmation. The trial was modified and conducted for a second year during the dry and wet seasons of 1989.

The objective of this work was to evaluate the effect of the *Azolla* non-incorporation method on rice yields compared to more classical methods. An experiment was conducted using a split-plot design with five replications. The main plot factor was weeding and the subplot factor was *Azolla* management. Half of the plots

received two hand weedings at 20 and 40 days after transplanting (DAT); the other half was unweeded. *Azolla* management included the inoculation of 0.3 kg m^{-2} of fresh *Azolla microphylla*, along with the application of 10 kg P_2O_5 ha^{-1} as triple superphosphate (TSP). After full cover of the field, the *Azolla* mat was either (a) incorporated two days before transplanting (DBT) by trampling the soil with feet, (b) incorporated using the IRRI designed (locally made) rotary conoweeder, or (c) left unincorporated on the drained soil for 2 and 4 DBT. The check treatment received the recommended dose of 120 kg N ha^{-1} in urea form (1/2 basal application, 1/4 at tillering stage, and 1/4 at panicle initiation) and 60 kg P_2O_5 ha^{-1} as TSP before rice transplanting. The *Azolla* treatments received another 50 kg P_2O_5 ha^{-1} 2 DBT and were complemented with 60 kg K_2O ha^{-1} as potassium chloride and 1 kg active ingredients of Furadan 3G ha^{-1} at 2,4, and 6 weeks after transplanting. The variety I Kong Pao was planted at 20 x 20 cm spacings.

Table 12. Effect of *Azolla* management methods on rice yields and weed infestation during the dry season. Fanaye, Senegal, 1989.

Treatment	Weed Dry Weight 40 DAT ($g\ m^{-2}$)		Rice Grain Yield ($kg\ ha^{-1}$)	
	Weeded twice	Unweeded	Weeded twice	Unweeded
N 120 (urea only)	109	307	5710	3160
32000 kg ha^{-1} fresh *Azolla* incorporated 2 DBT by trampling + 60 kg N ha^{-1} (urea)	82	405	6870	3610
32000 kg ha^{-1} fresh *Azolla* incorporated 2 DBT using the IRRI rotary conoweeder + 60 kg N ha^{-1} (urea)	157	358	7340	4070
32000 kg ha^{-1} fresh *Azolla* unincorporated & left without standing water for 2 DBT + 60 kg N ha^{-1} (urea)	34	97	6810	5460
32000 kg ha^{-1} fresh *Azolla* unincorporated & left without standing water for 4 DBT + 60 kg N ha^{-1} (urea)	65	166	7830	5770
CV (weeding) (%)	89		11	
CV (*Azolla*) (%)	67		14	

DBT = days before transplanting; DAT = days after transplanting

Azolla is still incorporated manually into rice fields, a process which is labor intensive.

Results obtained during the dry season are shown in Table 12. *Azolla* left free on the field without standing water for two days before rice transplanting provided better weed control than two hand weedings with either chemical nitrogen or the *Azolla* treatment incorporated by means of the rotary conoweeder. The weed control benefits of not incorporating *Azolla* are reduced if the unincorporated *Azolla* is left on the field without standing water for four days before transplanting rice. The highest rice yields were consistently obtained on hand weeded plots. Nevertheless, the yield benefits of not incorporating *Azolla* were clear, particularly on the unweeded plots. Without weeding, unincorporated *Azolla* provided a yield increase of 34%-82% compared to treatments where *Azolla* was incorporated or where only chemical nitrogen was applied. Insect damage, compounded with the trial treatments, rendered the yield data unreliable for the 1989 rainy season trial. Grasshoppers used unincorporated *Azolla* mats as support, and concentrated their attack on the intercropped seedlings which suffered significantly greater damage compared to the other treatments.

Labor costs that would otherwise be expended for *Azolla* incorporation and weeding could potentially be saved if an appropriate non-incorporation method could be devised. Results in 1989 confirmed earlier results of the yield benefits due to unincorporated *Azolla*. Adaptive research should continue at the farm level to develop techniques for integrating unincorporated *Azolla* into Sahelian rice cropping systems. It is now clear, however, that the method can be risky if water control is inadequate and grasshopper infestation increases.

THE EFFECT OF FOUR SOURCES OF PHOSPHORUS ON THE GROWTH OF FOUR *AZOLLA* STRAINS

H.F. Diara

It is well known that phosphorus is essential for rice and *Azolla* production. Phosphorus assimilated by *Azolla* contributes significantly to the subsequent rice crop after the incorporation and decay of the green manure in the soil. Thus, availability of a source of phosphorus, as efficient on *Azolla* as on rice, is an important factor in future *Azolla* activities within the region. Results obtained from 1983 to 1987 at various experimental sites in the Sahel, and in 1988 at Rokupr, Sierra Leone, in the humid zone, showed that some rock phosphates, such as Senegalese aluminum phosphate (Phospal) and Morocco rock phosphate, could significantly improve *Azolla* growth. It was not clear, however, whether responses to phosphorus in general, and to rock phos-

phates in particular, varied with *Azolla* species.

In 1989 an experiment was established to determine the effects of various sources of phosphates on the growth of different species of *Azolla*. The trial compared four sources of phosphorus on four *Azolla* species/varieties. The experimental design was split-plot in which the main plot, replicated three times, was represented by the source of phosphorus and the subplot by the *Azolla* species/varieties. Phosphorus sources included: soluble triple superphosphate (TSP: 45% P_2O_5), Senegalese aluminum rock phosphate (Phospal: 32% P_2O_5), *phosphate naturel de Tilemsi* from Mali (PNT: 26% P_2O_5), and Morocco rock phosphate (MRP: 34% P_2O_5). The *Azolla* varieties were *A. pinnata* var. *imbricata* (strain ADUL 7 Pi), *A. microphylla* (ADUL 69 Mi), *A. pinnata* (ADUL 138 PP), and a hybrid strain (IRRI 4028 HYB) resulting from a cross between an *A. microphylla* strain and an *A. filiculoides* strain. *Azolla* inoculum was placed in phosphorus deficient conditions for three weeks before 0.5 kg was sown in a circular floating net of 0.5 m^2. Phosphorus was applied only once, the day of *Azolla* inoculation, at a rate of 15 kg P_2O_5 ha^{-1}. Fresh and dry weights of *Azolla* were recorded every week for four weeks from mid-November to mid-December.

Results showed that phosphorus requirements of *A. pinnata* are far lower than those of *A. microphylla* and the hybrid IRRI 4028, both of which are highly productive only with TSP applied. The effect of soluble phosphate lasts for two weeks after application. The trial also showed that rock phosphates are better assimilated by *A. pinnata* which uses their solubilized fractions by sequences.

The high phosphorus requirements of *A. microphylla* and the hybrid IRRI 4028 are a major constraint for large-scale use by farmers. Although phosphorus fertilizers may sometimes be available, the maintenance and multiplication of *Azolla* on phosphorus deficient soils during the dry-season remains a problem. The adaptability of various *A. pinnata* strains in farmers' environments, as observed earlier at several sites, is consistent with the results of this trial. Research should continue to select alternative sources of phosphorus and appropriate cultural practices to optimize phosphorus assimilation by *Azolla* and the rice crop.

EFFECT OF USING *SESBANIA ROSTRATA* ON THE DEVELOPMENT AND YIELD OF IRRIGATED RICE

H. Diara

Sesbania rostrata is a wild legume commonly found in the Senegal River Valley. It has a high nitrogen-fixing potential due to its dual nodulation capacity on roots and stems. Experiments conducted in Asia and Africa have proved that *S. rostrata* can be an efficient source of nitrogen in rice cultivation. However, under natural conditions, its maximum biomass production and N content is obtained only after 6 to 8 weeks of growth, which does not fit well into most farming calendars. The mass production of seeds and the necessity to break their dormancy before sowing are other problems linked with the practical use of *S. rostrata*.

The objectives of a trial conducted during the rainy season of 1989 at WARDA's Fanaye station were to compare the usual seeding method with vegetative propagation methods to find a way of significantly reducing the land occupation period, and to reduce the amount of seeds needed to produce maximum green biomass.

The experimental design was split-plot with phosphorus source as the main plot, replicated three times. The *Sesbania* planting pattern was the subplot, and the *Sesbania* planting method was the sub-subplot. In the main plot, 40 kg P_2O_5 ha^{-1} as triple superphosphate (TSP: 45% P_2O_5) or aluminum rock phosphate from Senegal (Phospal: 32% P_2O_5) was applied just before preparing the land. In the subplots, *Sesbania* was planted in lines at 50 x 50 cm spacing or at random. The sub-subplots represented several *S. rostrata* management methods: (a) seeding of 40 kg ha^{-1} *Sesbania* seeds scarified in concentrated sulfuric acid for 30 minutes; after a first ratoon cycle of six weeks the plants were cut down to 30 cm and the green matter applied to the soil surface without incorporation; after a second ratooning cycle of four weeks, the entire plant was cut down and incorporated into the soil; (b) cuttings of *Sesbania* stems, 30 cm in length, were grown in an adjacent plot and transplanted four weeks before their incorporation; and (c) *Sesbania* seeds were sown (same rate and method as above) four weeks before their incorporation into the soil of the rice field. One week after *Sesbania* incorporation in the sub-subplots, the rice variety Sri Malaysia was transplanted uniformly at 20 x 20 cm spacings. All the plots were hand weeded at 3 and 6 weeks after rice transplanting.

The results are presented in Table 13. The *Sesbania* planting method had a highly

Table 13. Effect of various practices on *Sesbania rostrata* biomass production and irrigated rice variety Sri Malaysia development and yield, Fanaye, Senegal, rainy season, 1989.

Treatment		*Sesbania* Biomass (kg ha^{-1})	Rice Grain Yield (kg ha^{-1})	Rice Straw Yield (kg ha^{-1})	Number Fertile Tillers (m^{-2})
Source of phosphorus (A)	TSP	12260	5610	4220	461
	Phospal	9780	5150	3690	409
Sesbania planting pattern (B)	Randomly	11430	5500	4070	445
	In lines	10610	5260	3830	425
Sesbania planting method (C)	Direct seeding	520	5110	3680	405
	Ratooning	31640	6280	5040	481
	Cuttings	900	4750	3050	419
SE (A)		1338	159	234	10.9
SE (B)		1653	158	189	6.8
SE (C)		1682	158	158	11.4
CV (%)		53	10	14	9

significant effect on *Sesbania* biomass production and irrigated rice development and yield. Source of phosphorus and the green manure planting pattern had no effect. Two ratoon cycles of *Sesbania* produced 35 and 62 times more green manure than transplantation of cuttings and direct seeding, respectively. The incorporation of this green manure lead to 32% and 23% incremental rice grain yields.

The ratooning ability of *S. rostrata* is high and seems to be a good cultural practice to produce more biomass from a single crop within or outside of the rice field. This excess biomass could also be partly used for cattle or other animals. Further adaptive research should be conducted to refine the most appropriate cultural practices for farmers' cropping systems.

The use of *Sesbania rostrata* as a green manure produced yield increases of 23% to 32% in rice tested.

Development of Improved Varieties for the Sahel Irrigated Environment

In the past, large numbers of high yielding, input-responsive Asian rice varieties had been screened for the main wet season, but none have shown broad adaptability or stable performance. Susceptibility to stem borers and blast, and poor consumer acceptance are important problems for many of these lines. Although recent lines from IRRI show promising tolerance to stem borers, spider mites, and white flies, these need to be confirmed using more reliable screening techniques. Most high yielding Asian varieties are also poorly adapted to the large diurnal temperature fluctuations and to the dust laden winds of the dry season. Some progress has been made earlier to identify lines with cold tolerance, but there is need to screen for multiple tolerance to cold at the seedling stage and to heat and dust at the vegetative and reproductive stages if practical advances are to be achieved in second season cultivars. Improved tolerance to saline conditions is also required for varieties sown in both seasons.

During 1989, varietal improvement research continued in screening, identifying, and developing new varieties tolerant to these major stresses.

PERFORMANCE OF LOCAL RICE GERMPLASM FROM MALI AND SIERRA LEONE

J.O. Olufowote

High yielding varieties selected from introduced material often have problems of adaptability to the severe Sahelian environment. Local West African germplasm possesses agronomic potential that has been inadequately examined

for application to the Sahelian environment. Better knowledge of local germplasm may help solve some of the numerous problems in irrigated rice in the Sahel. Stem borers constitute a major constraint to wet season rice cropping. Local germplasm from Senegal, Madagascar, Liberia, Guinea, Guinea-Bissau and The Gambia have been successfully screened for stem borer tolerance.

In 1989, cultivars from Mali and Sierra Leone being held in a germplasm bank were screened to identify those resistant to stem borers, in order to evaluate entries for desirable traits. The entries included 118 from Sierra Leone and 25 from Mali. They were transplanted in unreplicated 5-row plots, with a plot size of 1 m x 5 m. A basal treatment of N, P_2O_5 and K_2O at 60 kg ha^{-1} was applied after land preparation and just before transplanting. Also, 60 kg ha^{-1} of N was applied as top dressing in two equal splits at 3 and 6 weeks after transplanting. There was no pesticide application, and the trial was kept free of weeds, rats and birds. All screening was done in the field.

Some entries (all of Sierra Leonian origin) exhibited high yield potentials. Varieties showing particular promise included PA KAPARIKENKEN, PA BUNDU, and MESS MESS. Some of the entries in the trial also showed resistance to stem borers. Two of the entries (MO-95 and TE-44, both from Mali) had no dead heart symptoms, while 16 of the entries had no white head symptoms. Three of these (MO-95, TE-30 and G12) were Malian entries. Five entries had low (0-5) percentage of tillers with borers. These were all Malian entries (MO-95, TE-57 and TE-44).

Entries with low borer infestation will be re-tested to confirm resistance, while high yielders will be further evaluated for complementary attributes compared to the current varieties, I Kong Pao and Jaya.

SELECTIONS IN F_3 FAMILIES OF THREE CROSSES FOR THE MAIN CROPPING SEASON

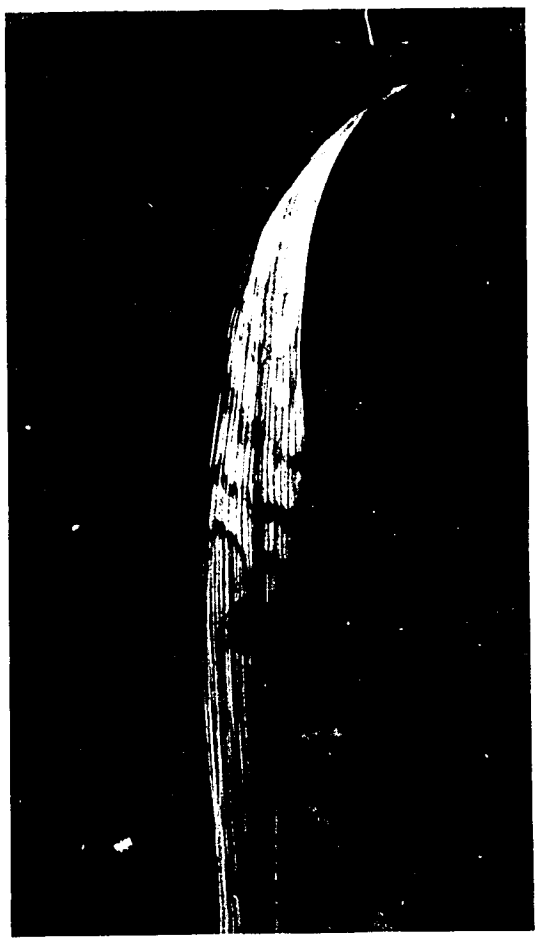
J.O. Olufowote

WARDA's Sahelian rice breeding program was initiated in 1987 with only three crosses involving exotic materials and one cultivar commonly grown in the region. I Kong Pao, the local cultivar, was crossed with two elite cultivars, IR 64 and IR 28228-12-3-1-1-2. IR 64 has superior grain quality conditioned by intermediate amylose content and intermediate gelatinization temperature. It also has excellent lodging resistance, high yield potential, tolerance to blast, bacterial leaf blight, and moderate tolerance to stem borers. IR 28228-12-3-1-1-2 has medium-long translucent grains with high amylose content and intermediate gelatinization temperature. It has tolerance to blast, excellent lodging resistance and high yield potential. The third cross involved IR 54 and IR 39323-182-2-3-3-2. The latter has tolerance to blast disease and good plant type. Apart from being a high yielding variety, IR 54 is highly tolerant to stem borer attack and bacterial leaf blight, has superior medium grains with intermediate amylose content, low gelatinization temperature and hard gel consistency.

In 1988, the F_2 populations of the three crosses were grown at Fanaye, and 30 plant selections were made. These plant selections were advanced to F_3 pedigree rows for further selection.

The objective of the progeny selection in 1989 was to identify families with acceptable plant type, maturity, grain type and tolerance to stem borers, and other stresses. Scientists grew 429 F_3 pedigree rows of the three crosses in 5 m rows at 30 x 20 cm spacing. Management and cultural practices normally used for trials at Fanaye were adopted - the only difference being that one seedling was transplanted per hill.

Fifty-two plant selections were made from the three crosses. The selected plants combined desired early maturity with good plant and grain type, high tillering and tolerance to stem borers. Progeny selection will continue in 1990 and thereafter to develop fixed varieties with improved agronomic and consumer traits.



The harsh, dry climate of the Sahel ecosystem is subject to rapid changes in temperature and wind, creating many problems for rice, including leaf scald.

SCREENING LOCAL RICE CULTIVARS FOR TOLERANCE TO DRY SEASON CONSTRAINTS

J.O. Olufowote

Major constraints to the rice crop during the dry season in the Sahel include cold stress at the seedling stage, excess heat at the vegetative and reproductive stages, and infestation by spider mites and white flies. Evaluation of local germplasm from several African countries has identified some sources of tolerance to some of these stresses and these have been used in WARDA's hybridization program.

In 1989, additional germplasm from Mali, Sierra Leone, Madagascar and Senegal were screened to identify further sources of tolerance for use as parents. A total of 208 local germplasm were evaluated - 25 from Mali, 124 from Sierra Leone, 34 from Senegal and 25 from Madagascar. They were planted in unreplicated 4-row plots, 5 m long, with a plot size of 0.6 m x 5 m, with hills spaced 20 x 20 cm.

Forty-one of the entries had tolerance to cold at the seedling stage. Of these five were from Mali, 16 from Sierra Leone,

one from Madagascar and 19 were from Senegal. Seventeen of the entries matured in less than 110 days. Thirteen of these were from Mali, and two each were from Sierra Leone and Madagascar. Among the entries that flowered during the dry season, five from Senegal were highly fertile. However, none of the Malian, Sierra Leonian or Madagascar cultivars showed high fertility. Only two of the entries, both from Sierra Leone, had less than 5% of their tillers infested with borers. All entries had high infestation by spider mites, while only nine had moderate tolerance to white flies. The grain yield of all the entries was extremely low compared to those of the check varieties, I Kong Pao and Jaya.

Results indicate that none of the screened materials have adequate adaptability to the full range of stresses encountered in dry season cropping in the Sahel. Materials showing resistance or tolerance to one or more of the major stresses may be used as parents in subsequent crosses. However, as these results were obtained under natural field pressure in only one location, they need to be confirmed under conditions where pressure is more assured.

SELECTION OF RICE VARIETIES FOR DRY SEASON CROPPING

J.O. Olufowote

Most high yielding varieties have shown considerable yield instability when cultivated under hot dry season conditions. Only I Kong Pao, which is commonly used as a check, has exhibited consistent stability. Among top yielders in the past have been IR 13240-108-2-2-3, SKL 17-69-11, IR 50, IR 32419-44-2-3-2, and IR 18348-36-3-3 (IR 64). Both IR 13240-108-2-2-3 and IR 18348-36-3-3 are cultivars that fit well into both wet and dry season cropping in the Sahel.

A trial was conducted in 1989 to evaluate promising cultivars for yield performance, agronomic characteristics and reaction to pests under hot, dry season conditions. The trial included 24 entries and the check, I Kong Pao. The experimental design was a randomized complete block design with three replications. The entries were planted in 2-row plots, 5 m long, with a plot size of 5 m x 2 m. Hills were spaced 20 x 20 cm. Harvested area for yield evaluation was 7.36 m^2.

None of the tested varieties yielded significantly more than the local check when grown in the hot dry season and all entries showed high infestation by spider mites. The two top yielders, IR 31787-85-3-3-3-2 (5730 kg ha^{-1}) and IR 39357-133-3-2-2-3 (5520 kg ha^{-1}) were significantly shorter in duration compared to I Kong Pao (5410 kg ha^{-1}), but were not among the highest yielders in previous years.

Grain yield instability across years for most of the high yielding materials was again evident in the 1989 results, with I Kong Pao exhibiting somewhat greater stability as it has in the past. The trial will be repeated in 1990 with an additional site at Richard-Toll, to obtain three years data on all entries.

SELECTIONS FROM F_2 SEGREGATING POPULATIONS UNDER DRY SEASON CONDITIONS

J. Olufowote

Grain yield instability continues to be problematic for dry season cropping of most promising rice varieties. I Kong Pao, a widely grown early duration cultivar, and Jaya, a popular medium duration cultivar, have shown somewhat more stable but modest yields. Attempts are being made to transfer genetic tolerance to dry season constraints exhibited by some cultivars into the I Kong Pao and Jaya backgrounds. Similarly, cultivars that complement each other for tolerance to several constraints of the season are being intercrossed.

In 1988, selections were made from several F_2 populations during the cold dry season, selecting segregants that combined tolerance to cold at the seedling stage with good grain type and high spikelet fertility. But due to the prolonged cold stress (up to time of harvest in 1988) there were severe sterility problems, and only a few fertile panicles were possible in some crosses.

Further selections were made in 1989 from within the remaining F_2 to develop high yielding varieties with cold and heat tolerance and resistance to white flies and spider mites. The F_2 populations and their corresponding parents were grown in Fanaye. Twenty-one day old seedlings were transplanted at a spacing of 30 x 25 cm, with one seedling per hill.

Thirty-two plant selections were made from nine F_2 populations. Selected segregants combined seedling cold tolerance with high spikelet fertility, good grain type, earliness and acceptable plant type.

The plant selections will be advanced to F_3 pedigree rows in the 1990 hot, dry season for further selections.

SELECTION OF ELITE CULTIVARS FOR MAIN SEASON CROPPING

J. Olufowote

The most widely grown varieties currently grown by farmers along the Senegal River Valley are I Kong Pao and Jaya. Evaluations of elite cultivars have identified some promising higher yielding lines, but yield instability has been problematic. A trial was conducted in 1989 to further clarify the performance of elite cultivars in both the short and medium duration variety trials. Many of the entries were tested for the third season in 1989.

Twenty-four cultivars each were evaluated in short and medium duration trials in comparison with appropriate checks (I Kong Pao for the short duration, and Jaya for medium duration). The experimental design was a randomized complete block with three replications. Entries were planted in 14-row plots, 4.2 m long, with a plot size of 4.2 m x 2.8 m. Basal doses of 60 kg ha^{-1} of N, P_2O_5 and K_2O were applied after land preparation, and just before transplanting. Also, 60 kg ha^{-1} N, as top dressing was applied in

Varieties	Grain Yield (kg ha^{-1})	Panicle (m^{-2})	Height (cm)	Duration (days)	Stem Borer Infestation				Stem Borer* (%)
					Deadheart		White Head		
					% hills	% incidence	% hills	% incidence	
TNAU 7893	6105	145	86	117	21.5	6.2	14.1	3.2	10 (5)
ITA 230	6003	254	92	122	20.0	6.4	11.1	2.6	16 (7)
I Kong Pao (check)	5006	318	88	116	24.1	7.6	17.8	3.7	17 (7)
SE	282	22.7	1.76	1.49	1.62	0.67	2.47	1.24	
CV (%)	10	11	4	2	15	21	22	45	
IET 6279	6419	313	192	119	27.7	9.0	4.0	1.0	22 (7)
Jaya (check)	5087	231	88	126	33.5	14.9	12.0	3.9	21 (7)
SE	376	21.38	2.10	1.42	4.26	1.53	1.73	0.63	
CV (%)	12	12	4	2	25	29	24	29	

* Percent tillers with borers at harvest from three random hills per variety per replication on dissection. Figures in brackets are standard evaluation scales (SES).

Table 14. Selected results of short and medium duration variety trials in the main wet season, Fanaye, Senegal, 1989.

two equal splits at 3 and 6 weeks after transplanting. There was no pesticide application, and the trial was kept free of weeds, rats and birds. Grain yields were taken from a net plot size of 9.12 m^2.

Three varieties produced significantly higher grain yields than their respective checks. Two entries in the short duration variety trial, TNAU 7893 and ITA 230, significantly out yielded I Kong Pao. Similarly, in the medium duration variety trial, IET 6279 significantly out yielded Jaya. The three varieties also showed higher tolerance to stem borer infestation compared to their respective checks (Table 14). It is significant to note that in 1988 ITA 230 also showed significant grain superiority over I Kong Pao, and IET 6279 significantly out yielded Jaya. During that same year TNAU 7893 yielded the same as I Kong Pao.

During 1990, these promising cultivars will be evaluated further in station based trials before being advanced to farmers' field tests.

RESEARCH PROGRAM III:

Mangrove Swamp Rice

The Mangrove Swamp Environment

CHARACTERISTICS Mangrove swamps constitute a unique rice growing environment in West Africa. Located on tidal estuaries close to the ocean, most mangrove swamps experience a salt-free period during the rainy season when fresh water floods wash the land and displace tidal flows. The rice growing period is directly related to distance from the ocean, varying from less than four months in the nearest estuaries, to more than six months in those most distant. Soils are generally more fertile than in other environments since they benefit from regular deposits of silt left during annual flooding. Nevertheless, the soils can also be characterized by high salinity and sulphate acidity. As these soils dry, oxidation contributes to the formation of sulfuric acid, with pH levels falling as low as 2.5 during severe dry seasons. With good rains, pH returns to a range of 4.5 to 5.5.

Due to periodic flooding, rice plots in the mangrove swamps are often remote from villages and farmers tend to spread their labor by cultivating rice in adjacent inland swamps and in upland areas. Labor supplied to mangrove swamp rice cultivation is consequently limited, with the result that the areas cultivated by farm families are smaller than in the other rice growing environments. This is further accentuated by the high labor intensity of mangrove swamp rice cultivation.

PRODUCTION CONSTRAINTS

Labor costs and potential environmental problems constitute the major constraints to expansion of cultivated areas. A complex of adverse soil conditions characterized by considerable micro-variation are the major constraints to high rice yield increases. These include: salinity; sulphur acidity; and iron, aluminum, and manganese toxicities. The latter particularly in the non-tidal associated swamps ecosystem. These problems aggravate nitrogen and phosphorous deficiencies by making these nutrients unavailable to plants. Flooding, caused by both tidal movements and rains, present additional problems because rice plants are often lodged and covered by silt.

Among the biological constraints, crabs cause major production losses by eating seedling stems and by destroying earthen bunds built to protect rice plots from brackish water. Losses due to stem borers and rice bugs are also important. Among the diseases, blast, brown spot and dirty panicle syndrome are currently the most important constraints, with Rice Yellow Mottle Virus posing a severe potential threat. In swamps further from the sea, where saline conditions are lower and the season longer, weed infestation is an additional major problem.

SCREENING RICE VARIETIES FOR BLAST RESISTANCE IN MANGROVE SWAMP ECOLOGIES

S.N. Fomba

Blast disease of rice caused by the fungus, *Magnaporthe grisea* (more commonly known by its asexual form, *Pyricularia oryzae*), is the most widespread and economically important disease of rice in most of West Africa. More than 10 races of the blast fungus have been identified at Rokupr using international and Japanese monogenic blast differential varieties. Blast causes damage at the rice seedling, post-tillering, and reproductive stages of growth. It is most noticeable as leaf or panicle blast, but it also attacks rice nodes. The incidence and level of damage depend on the rice cultivar/line, the ecosystem, and cultural practices adopted. Blast is generally more damaging in upland rice than in lowland rice.

In mangrove rice, the most critical time for controlling blast is in the seedling stage in nurseries. Nurseries are usually laid out in drought prone upland sites or on gentle slopes adjacent to swamps. These sites generally have freely drained gravelly soils of low nutrient status. Upland nurseries are often severely blasted, appearing as if scorched. Rice nurseries may also be laid out on hydromorphic soils adjacent to non-tidal, seasonally flooded, or associated mangrove swamps, especially towards the river mouth. Under hydromorphic conditions, the incidence of seedling blast is often negligible.

Blasted or diseased seedlings are more susceptible to crab damage than healthy, more vigorous seedlings when transplanted into crab infested mangrove rice fields. Several effective fungicides such as benomyl, tricyclazole, and kitazin P have been identified for the control of blast, both in Sierra Leone and elsewhere. However, this method of blast disease control is not widespread in the tropics, due partly to socio-economic constraints of rice production on small farm holdings, and partly to environmental and technical considerations. The most pragmatic method of seedling blast control in mangrove rice cultivation is the use of resistant varieties, especially in the context of integrated pest management (IPM).

The use of resistant varieties as a method of rice blast diseases control is, however, often constrained by the highly variable nature of the pathogen. Soon after the release of resistant rice varieties, especially those with vertical or race-specific resistance, the pathogen often evolves new strains or races that can overcome this resistance when these rices are grown on a large scale. This "boom and bust" cycle constitutes a major obstacle to

cultivar improvement programs. An alternative to this approach is to identify rice varieties with partial or horizontal resistance to blast, in order to reduce the selection pressure on the pathogen to evolve more virulent races.

Since 1982, hundreds of promising rice varieties and advanced lines, together with traditional mangrove rice cultivars, have been screened for seedling blast resistance under natural infestation at WARDA-Rokupr. Several land races and improved cultivars have been identified which are believed to have stable horizontal blast resistance. This work was continued in 1989 with trials conducted on hydromorphic and upland soils at Rokupr.

Two types of blast nurseries were established in the 1989 cropping season, a Horizontal Resistance Blast Nursery (HRBN) and a Uniform Blast Nursery (UBN), also known as the International Rice Blast Nursery (IRBN). These are illustrated in Figures 6 and 7. HRBN plots were designed to identify rice species with partial or horizontal resistance to blast, while UBN plots were designed to identify rice species with complete or vertical resistance. The two screening nurseries were located at two separate sites in July and September, 1989.

One hundred entries were tested, including traditional rice cultivars (e.g. Bakoh 108 and Pa Fant), standard mangrove rice varieties (e.g. CP 4, ROK 5 and ROK 10), promising varieties (e.g. WAR 1, Kuatik Kundur and Raden Mas), advanced breeding lines (e.g. WAR 44-50-4-1, WAR 74-11-M3-2-1 and WAR 100-3-2-1), and some land races with presumed horizontal resistance: ROK 16 (Ngovie), ROK 17 (LAC 23 white), and Moroberekan. The nurseries were established on well pulverized soil on raised beds at upland and hydromorphic sites, and oriented in the windward direction to promote the spread of blast inoculum.

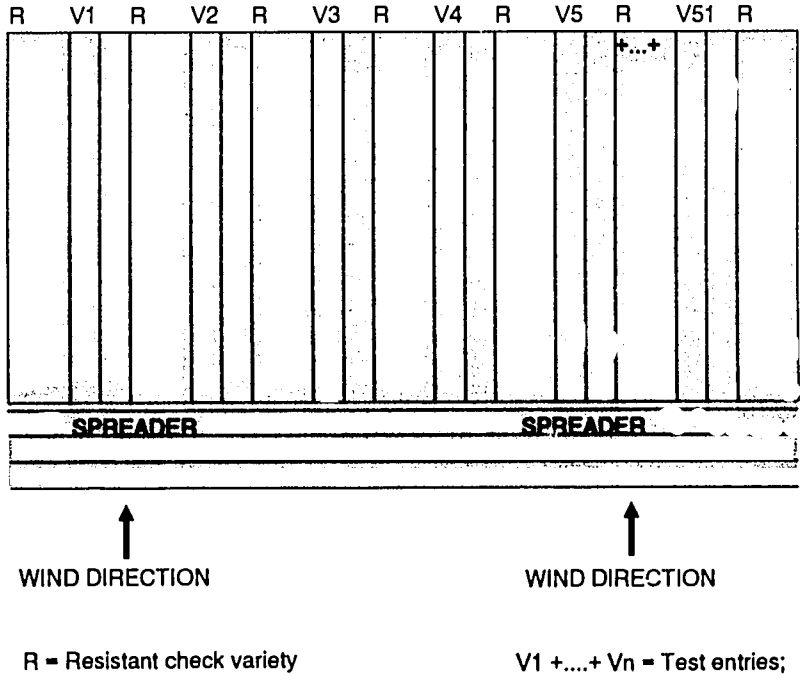


Figure 6. Field plot design for a Horizontal Resistance Blast Nursery at WARDA, Rokupr, Sierra Leone, 1989.

HRBN

Ten grams of seeds were drilled per 2 m long rows using three rows per test entry at 20 cm spacing between rows. Each test entry was separated from the next by two rows of a resistant check variety, e.g. ROK 16. Four to five rows of spreader (a mixture of blast susceptible varieties) were sown at right angles to the test entries two weeks earlier to allow for sufficient blast inoculum to develop before the test entries were seeded (Figure 6). The spreader was densely seeded (100 kg ha^{-1}) and fertilized with urea at the rate of 120 kg N ha^{-1} to promote rapid blast development. The test entries and resistant check variety were fertilized with 15-15-15 (NPK) at the rate of 25 g m^{-2} at seeding, and two weeks thereafter. They also received 40 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}.

Blast incidence was scored on a plot basis when there was sufficient disease incidence on the spreader and on confirmed seedling blast susceptible varieties like ROK 10 and Kuatik Kundur. At least two readings were taken to coincide with the initiation of blast epidemic and thereafter. A weekly or fortnightly interval was allowed between readings depending on the speed of the blast epidemic. The standard International Rice Research Institute (IRRI) evaluation system of 0-9 (with 0 representing no disease, and 9 maximum expression of disease) was used to score test entries. Mean lesion counts per third leaf on each of 10 seedlings per entry were also taken at random within each plot when the test entries were scored; lesion sizes of 10 randomly selected lesions per entry were also recorded.

UBN/IRBN

In this plot layout, no resistant rice variety was interposed between test entries. The test entries were flanked on either side by 3 to 4 rows of spreader, established two weeks prior to seeding of

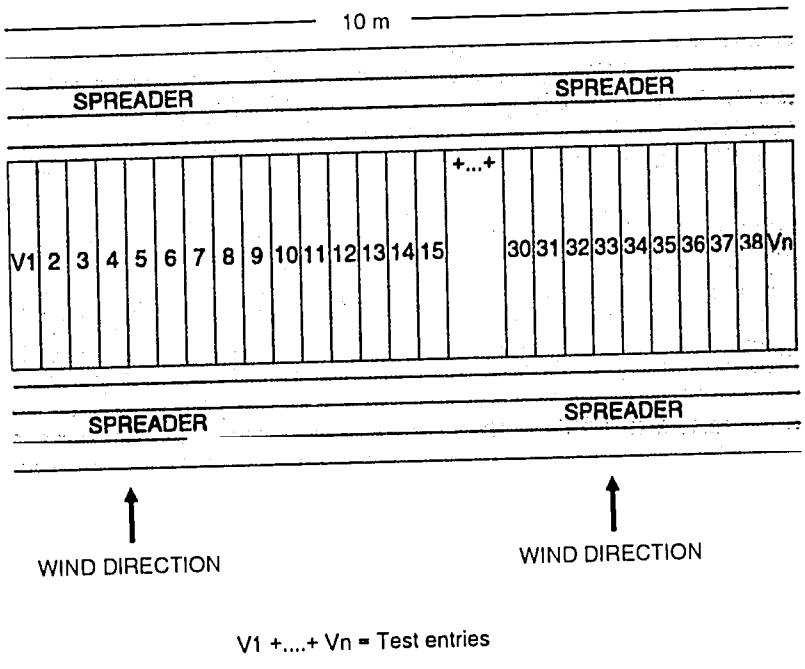


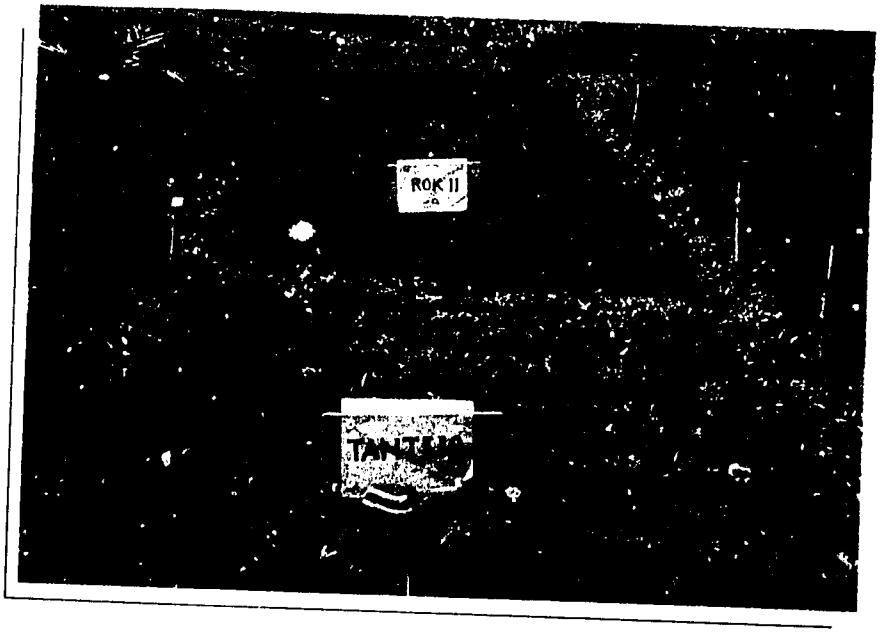
Figure 7. Field plot design for a Uniform Blast Nursery/International Rice Blast Nursery at WARDA, Rokupr, Sierra Leone, 1989.

test materials to provide sufficient blast inoculum and maintain favorable conditions for blast development (Figure 7). Five grams of each test entry were drilled per 50 cm long rows, with 10 cm spacing between rows. Fertilizers were applied at the rate of 120 kg N; 40 kg P_2O_5; and 60 kg K_2O ha^{-1}. Blast incidence was assessed in the same manner as the HBRN plots, except that no lesion sizes were measured.

RESULTS AND DISCUSSION

Some rice accessions that had moderate scores against seedling blast attack under blast conducive environments are indicated in Table 15. Varietal reactions to seedling blast varied with ecosystem as well as with the field plot technique. Generally, higher seedling blast scores were recorded for the upland environment compared to the hydromorphic site in the HRBN and UBN/IRBN tests. Except for Mat Candu and ROK 9, the number of blast lesions per leaf/seedling correlated closely with the plot-based scores in the two rice environments. Higher lesion counts were noted for the upland site than for the hydromorphic site. However, because of coalescence of blast necrotic spots on rice foliage, the values indicated can only be considered approximate. Lesion size measurements showed similar trends on the varieties tested, except ROK 9 and Mat Candu. They had more expanded lesions under hydromorphic conditions than in the upland site. The reason for this was not apparent but was probably due to specific genotype x environment x pathogen interactions peculiar to these two rice varieties.

More than 10 races of blast have been identified at WARDA's Rokupr research station through tests established in nurseries exposed to the blast causing fungus, *Magnaporthe grisea*.



Differences between nurseries may have been due to changes in the racial composition of the blast fungus with time since the two nurseries were not established at both sites simultaneously. Part of the variation could also be attributed to ecological differences, with dry upland conditions being more favorable for seedling blast development than moist hydromorphic environments. The 1989 cropping season was considered a blast favorable year with erratic rainfall, moderate nightly temperatures, and high relative humidity from July to November, when nursery blast screening tests were conducted. Monthly rainfall peaked (752 mm) in August with 29 rainy days, and may have caused water logging on the sites which reduced the level of seedling blast attack at the hydromorphic site by washing off spores before they could germinate.

Rice varieties that showed moderate seedling blast (4-6), and low lesion counts per leaf/seedling in a blast conducive environment during an epidemic, probably possess a high level of horizontal or partial resistance to the disease. The

Accession	Maximum Seedling Blast Score				Lesion Count/Leaf (mm)	
	HRBN		UBN/IRBN		HRBN	
	Upland 11/9/89	Hydromorphic 7/7/89	Upland 11/9/89	Hydromorphic 7/7/89	Upland 11/9/89	Hydromorphic 7/7/89
ROK 9	5	4	6	5	15.2	13.0
ROK 16 (Ngovie)*	5	3	6	3	18.3	10.0
Gissi 27	5	4	6	4	18.1	15.0
Mat Candu	5	4	7**	4	8.5	10.0
Angkata	5	4	7**	5	14.3	13.0
ITA 212	6	3	7**	4	14.4	3.0
Moroberekan	6	3	7**	5	20.0	6.0

Blast score based on 0-9 standardized scale range of the Standard Evaluation System for Rice
HRBN = Horizontal Blast Nursery; UBN/IRBN = Uniform Blast Nursery/International Rice Blast Nursery
* Upland rice cultivar with presumed horizontal or partial resistance to blast.
** Susceptible variety.

Table 15. Rice accessions with moderate seedling blast scores under different ecological and test conditions, Rokupr, Sierra Leone, 1989.

higher seedling blast scores recorded in the UBN/IRBN test on the upland compared to HRBN on the same site were probably due to strong disease pressure exerted on test materials by the additional load of blast spores from the spreader and neighboring susceptible varieties, in addition to the blast inoculum generated from within a planted variety. This strong blast pressure in the UBN/IRBN trial did not allow for the expression of slow blasting phenomena which is indicative of partial or horizontal resistance.

Varieties with low scores (1-3) may possess vertical resistance and/or high levels of horizontal resistance, but this is usually difficult to differentiate under field conditions. Only time and multilocational testing to allow for an encounter between these rices and matching virulent strains of the pathogen can verify if vertical resistance is involved. However, the level of blast attack on the land races, e.g. Moroberekan, ROK 16, ROK 17, IRAT 13, could be used as a guide for selection of potentially blast stable rice accessions.

ADVANCES IN THE CONTROL OF CRAB PESTS OF MANGROVE SWAMP RICE IN WEST AFRICA

M. Agyen-Sampong and S.J. Fannah

Crabs are a major cause of damage to newly transplanted rice seedlings in the tidal mangrove swamps of West Africa. Losses in grain yield ranging from 400 to 600 kg ha^{-1} due to crabs have been recorded in northwest Sierra Leone swamps. Crabs gnaw the stems and leaves of young rice seedlings. Their attack generally starts from areas nearest to bunds and creeks, but can extend to all parts of the rice farm. Areas retransplanted after crab destruction often suffer the same fate. Young seedlings, 40 or less days old, are more susceptible because they are more tender and succulent than older seedlings.

SPATIAL AND TEMPORAL DISTRIBUTION OF CRAB POPULATIONS

Knowledge of the population dynamics and spatial distribution of crabs is essential for the development of effective crab control methods. Reliable information on crab populations in mangrove swamps was lacking until 1978, when WARDA scientists in Rokupr started detailed studies of population changes of crabs along the banks and creeks of the Great Scarcies River from Rokupr to the sea. Weekly hand collection of crabs at four locations (35, 24, 10 and 2 km from the sea) were organized from February to September.

Sesarma huzardi was found to be the most dominant and widely distributed crab species collected, while *S. alberti* was numerous only at distances of 24 kilometers or more from the sea. *Sarmatum curvatum* was numerous at distances of 35 km or more from the sea. The seasonal pattern of occurrence was similar for the three species. Populations were low in February, but gradually built to a peak in September. With a decrease in rainfall during October, the crab numbers declined. Gravid females were common throughout the dry season.

The hand collection method used to sample for crabs in 1978 and 1979 had several limitations. Because small crabs are not easily noticed and usually hidden in burrows, they are not always collected and recorded. It is also not easy to collect all crabs found in the field since they tend to escape, thus making the number of crabs per sampling unit difficult to assess.

During 1989, a quadrat sampling technique was developed to overcome shortcomings of the earlier approaches. Two sampling sites were selected, a bank along the Great Scarcies River, and a creek located along the main Rokupr research station that drains into the main

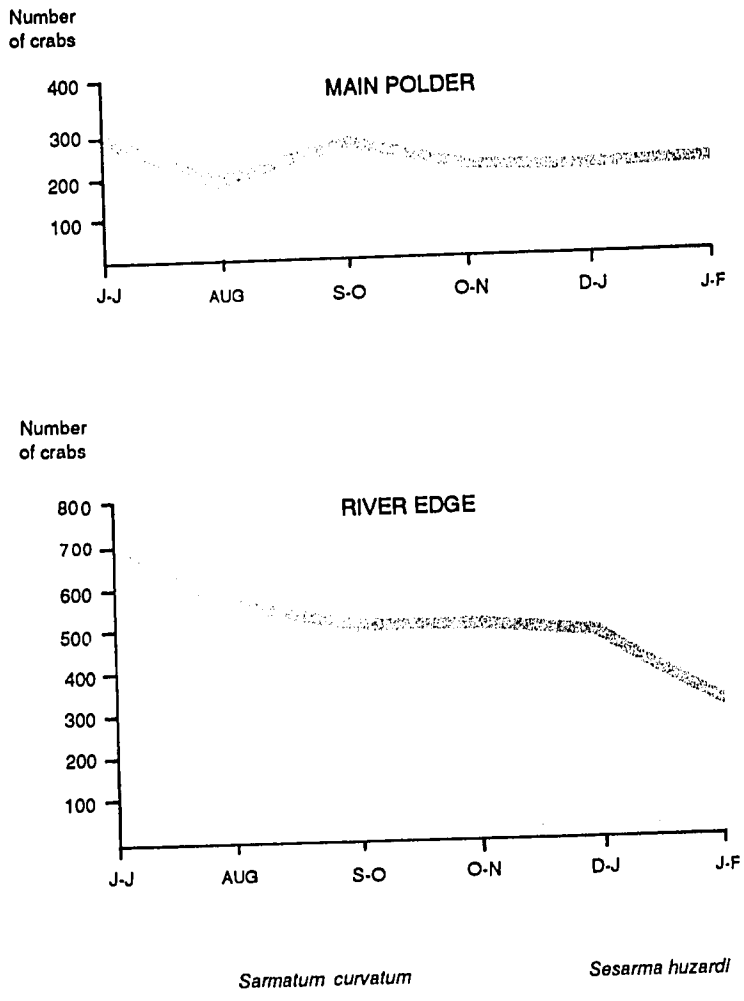


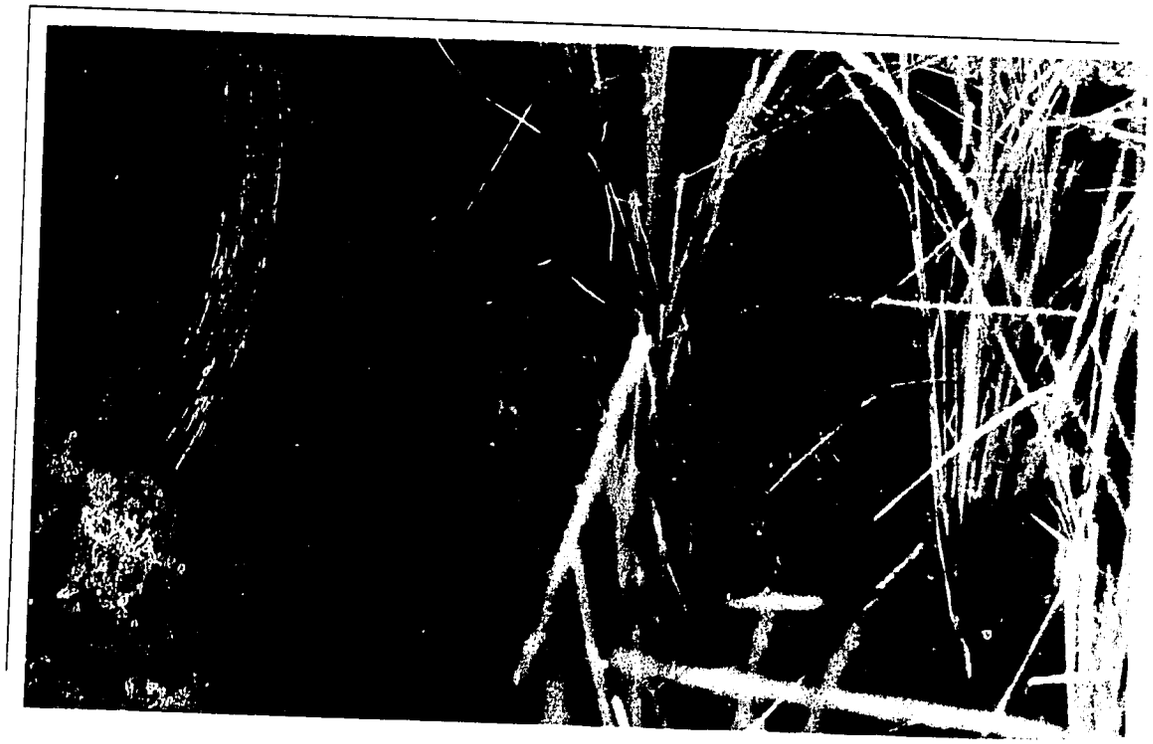
Figure 8. Population changes of two major mangrove swamp crab species around Rokupr, Sierra Leone, June 1989 to February 1990.

river. The sites represent different types of crab habitats. While the river bank is high, muddy and floods only during the high spring tides, the creek is muddier and floods during both spring and neap tides. Collections were made fortnightly at low tide beginning in June, 1989 and are still in progress. At each site, 5, 50 x 50 cm quadrat samples were randomly taken. The substrate within each quadrat was dug to a depth of 25 cm and sieved in 50 x 50 cm wire mesh sieves to capture the crabs. The sex and the reproductive condition of females were recorded. Carapace width of all crabs was measured to the nearest mm using sliding calipers.

Figure 8 shows the population changes of the two prevalent crab species during the sampling period. The maximum density of the crabs was much higher for *S. curvatum* (100 m^{-2}) than *S. huzardi* (20 m^{-2}). *S. curvatum* was the most numerous, constituting about 80% of the crabs collected. *S. huzardi* accounted for about 16% of the collection, *S. alberti* represented 4% and only a few *Uca tangeri* were collected.

At the creek site, there were no clearly defined peaks during the cropping season for either crab species. However, there was a slight decrease in crab numbers during August, followed by an increase in September. For the river bank

During 1989, WARDA scientists devised a new sampling technique to study the population dynamics, distribution, and habitat of crabs, a major economic problem for mangrove swamp rice growers.



site, crab numbers declined steadily throughout the season. These patterns require confirmation.

The young *S. curvatum*, with 2-10 mm wide carapace, formed 60% of the crabs identified at both sites while *S. huzardi* of the same size formed only 11%. These results differ from those obtained during hand collection sampling conducted in previous years when *S. huzardi* was the most numerous crab species recorded. In earlier studies, larger size samples (35 mm) were usually collected compared to the 25 mm samples collected in the 1989-90 sampling. It also appeared that *S. huzardi* tended to move about more freely during the day and between tides, while *S. curvatum* were confined to their burrows and more frequently escaped hand collection.

S. curvatum populations were twice as large on the river edge compared to the creek location. *S. alberti* was similarly distributed at both locations.

Gravid females of all species occurred in low numbers from the beginning of the sampling until December. From December through April, these numbers increased substantially, suggesting that breeding takes place throughout the year, but peaks in the dry season. There may be some correlation between the higher dry season temperatures and breeding activity, since temperature and photoperiod are considered the major environmental factors influencing breeding periods in marine invertebrates.

CONTROL MEASURES

Cultural Control

The role of seedling vigor, fertilizer application, seedling age, seedling number/hill and crop density at transplanting have all been examined to determine their relationship to crab

damage under controlled and field conditions. Experiments conducted at the Rokupr station indicated that vigorous seedlings grown in fertilized nurseries, combined with close hill planting (32 hills m^{-2}) of three seedlings/hill, can effectively minimize crab damage.

In 1986 and 1987 these cultural practices were compared to farmers' practices of planting 10-12 week-old rice seedlings at low plant density (16 hill m^{-2}) with 10-30 weak seedlings/hill. Results of these on-farm trials indicated that the combined package of improved practices was significantly better than the farmers' practices in minimizing crab damage under field situations, boosting yields by 40%-200% over farmers' practices at various sites.

Effect of Nursery Treatment of Rice Seedlings on Crab Damage

Since seedling vigor at transplanting plays such an important role in minimizing subsequent crab damage to the rice crop, it was crucial to explore several ways of producing more robust seedlings. In a 1989 study, a 2 x 3 x 3 factorial experiment involving seedling management in the nursery was established to assess the effect of mulching and fertilizer application on seedling damage by crabs. The nursery was treated with partially decomposed rice husks at rates of 0, 5000, and 10,000 kg ha^{-1}, and with fertilizer (NPK 15-15-15) at 0 and 25 g m^{-2} two weeks after seeding. Six-week old seedlings raised in the nursery were later infested with crabs at densities of 0, 3, and 6 crabs/experimental unit, consisting of a 100 liter barrel filled with mangrove swamp soil. Seedlings were transplanted into each barrel at five seedlings/hill with eight hills/barrel. This is equivalent to 33 hills m^{-2}. This rate was used because the experiment was under controlled conditions with relatively high numbers of crabs per barrel.

Previous experience indicated that when fewer seedlings per hill were planted, seedlings became damaged too quickly, thereby distorting experimental results.

Crab damage was assessed at 2, 4, 6, 8, and 10 days after transplanting. The crabs were removed after the tenth day. The attacked seedlings were counted and expressed as a percentage of the total seedling number.

Results indicated that application of either organic or chemical fertilizer to nursery beds reduced the level of crab damage to transplanted seedlings. It was found that the dose of 25 g m^{-2} of chemical fertilizer provided the same protection as 10,000 kgs of rice husk, with both treatments separately reducing damage from 59% for the control to 47% for either treatment alone (Table 16). Moreover, the effects appear to be additive as the nursery application of chemical fertilizer, together with 10,000 kgs of rice husk, further reduced crab damage of transplanted seedlings to 35%.

Neither husk nor fertilizer application to nurseries affected the grain yield components, percentage filled and unfilled grains or 1000 grain weight. However, the number of productive tillers was significantly reduced by crab damage ($P = 0.01$) and this subsequently affected grain yield.

Chemical Control

The application of chemical agents to reduce crab damage to rice grown along the creeks and river banks of West Africa

Table 16. Percent transplanted seedlings damaged by crabs 10 days after transplanting, Rokupr, Sierra Leone, 1989.

Nursery Treatment	% Crab Damage		Mean
	No Fertilizer	Plus NPK Fertilizer (25 g m^{-2})	
0 Husks	59.2	47.2	53.2
5000 kg husks ha^{-1}	42.5	48.9	45.7
10000 kg husks ha^{-1}	47.2	35.0	41.1
SE	3.90		
Mean	49.6	43.2	
SE	2.28		2.79
CV (%)	25		

was initiated by British researchers at Rokupr in 1935. They used Cyanogas to fumigate crab holes in bunds. This practice was not only expensive, but also proved to be ineffective in reducing crab populations. Between 1953 and 1956, various insecticides, mainly chlorinated hydrocarbons (BHC and DDT) and sodium fluorosilicate, in different formulations and concentrations, were extensively evaluated as poison baits and sprays against crabs. The trials indicated that spraying, especially with BHC, was promising. Routine spraying after high spring tides in the dry season was adopted for control of crabs at the then West African Rice Research Station in Rokupr.

It is now recognized that although the practice of spraying chlorinated hydrocarbons, or other highly persistent non-biodegradable pesticides, on bunds and fields to control crabs can be effective, it is environmentally hazardous. New approaches for the control of crabs with chemicals were therefore initiated in 1977 at WARDA-Rokupr. To minimize the chemical hazards to the environment, different concentrations of organophosphorus compounds and carbofuran were evaluated by immersing the seedling roots in insecticide solution for 24 hours prior to transplanting. Rice seedlings treated with Furadan, Dicarbam or Oftanol were found to be effectively protected from crab damage (Table 17).

Varietal Resistance

Although WARDA's crab control technique of soaking seedlings in pesticide solution before transplanting was promising, the scarcity and high cost of these chemicals poses major obstacles to farmer adoption. The use of rice varieties resistant to crabs may be a more acceptable method of controlling crab damage to rice seedlings.

Since 1981 over 1000 traditional, introduced and advanced rice lines have been screened for their resistance to crabs, especially the prominent crab species, *S. huzardi*. A bucket screening technique and a field screening system have been used.

In the bucket screening trials, 10, 40-day old seedlings of each rice variety were transplanted in three hills using a single bucket, after which six crabs (three male and three female) were placed in the bucket. Each variety was replicated at least twice. Records of crab damage were taken daily for seven days by counting and recording the number of seedlings damaged in each bucket. Dead crabs and damaged seedlings were replaced daily. Ten seedlings from each variety were randomly selected and measurements of plant height, seedling base thickness (flat side), and sheath and leaf length were taken

In the field screening trials, each variety was transplanted at 2 to 3 seedlings per hill in 1 meter rows. The distance between hills was 15 cm and the distance between rows was 30 cm. Two rows of each variety were tested. Weekly measurements of damage were taken for four weeks. At the end of the four-week period, percentage damage was calculated for each variety.

The rice varieties tested showed significant differences in their susceptibility to crab damage. Some of the tolerant varieties tested include Blue Stick 127, Pa Bayo 246, Raden Mas and WAR 77-3-2-2. Heritability was calculated and found to be moderately high (h_b2-61%). It also reflected a fairly large genetic variation in susceptibility of mangrove rice varieties to crab damage which points toward considerable potential in breeding for this trait.

Insecticide 0.1% a.i.	% Mortality (Arcsin trans.)	Seedlings Damaged (Sq. root scale)
Furadan	36.2	1.8
Dicarbam	44.2	2.7
Oftanol	44.2	3.6
Thimet	12.4	6.2
Control	12.4	7.6
LSD 0.01	15.3	1.0
SE	5.0	0.3

Table 17. Effect of soaking rice seedlings in different pesticides on *Sesarma huzardi* and seedling damage over a period of three weeks, Rokupr, Sierra Leone, 1978.

CONCLUSIONS

In the mangrove swamps of West Africa, crabs destroy many newly transplanted rice seedlings through their feeding activities. In some instances, farmers have been known to lose their entire crop due to crab damage, but average losses of 400 to 600 kg ha^{-1} are most common. However, since 1977 WARDA-Rokupr scientists have developed some simple and inexpensive crab control strategies that minimize crab infestation and damage.

A quadrat sampling technique developed in WARDA population studies has proved to be an efficient method of sampling for crab size, frequency, and distribution. More effective sampling techniques should provide a better understanding of population dynamics, distribution and habitat of crabs. This information is a prerequisite for the development of effective crab control strategies.

The production of more vigorous seedlings through fertilizer applications to nursery beds appears to be an extremely promising and economic method of reducing crab damage under farmer conditions. Low labor and cash requirements for these techniques make them particularly appropriate for

resource poor rice farmers in West Africa.

In cultural control studies, WARDA researchers found that 30-day old rice seedlings grown without fertilizers suffered twice as much damage as fertilized seedlings of the same age. Similar observations were noted using 60-day old seedlings. However, 60-day old unfertilized seedlings were significantly less damaged than fertilized 30-day old seedlings used in transplanting.

In other cultural control studies, it was found that transplanting vigorous seedlings at close plant spacings (33 hills m^{-2}) effectively minimized crab infestation, even when transplanted at three seedlings per hill.

Closely monitored on-farm tests of these techniques should be initiated in close cooperation with national research and extension services. With the current scarcity and escalating cost of chemical fertilizers in the region, particular emphasis should be placed on the use of rice husks and other sources of organic fertilizers.

In varietal testing for crab resistance, several tolerant varieties have been identified. Measurements of heritability indicate that this avenue is likely to produce more tolerant varieties in the future.

RESEARCH ACTIVITY SUMMARIES

Development of Rice-Based Cultural Practices That Improve Labor Efficiency

Certain activities in mangrove rice production, such as land preparation, transplanting and harvesting, are time-critical and require large inputs of labor. Unfortunately for mangrove rice farmers who depend on family labor for much of their rice farming, family size is decreasing and other crops grown in the upland areas and inland swamps strongly compete for available labor. Thus, some farming operations are often delayed, leading to improper care for rice crops and subsequent low yields. Another effect of dwindling labor is the decrease in the size of mangrove rice plantings. If this trend continues, it could reduce mangrove swamp rice production and food security for farm families living in this environment.

A primary aim of WARDA research is to develop production techniques that increase labor productivity of mangrove swamp rice farmers. Some of WARDA's research activities during 1989 to accomplish these objectives included the investigation of improved nursery practices that reduce labor requirements, and identification of mechanisms to improve and sustain soil fertility through the use of crop residues and fertilizers, especially phosphorus.

IMPROVING SEEDLING VIGOR

C.A. Dixon

Crop establishment in mangrove swamps requires robust seedlings that are tolerant to tides and resistant to crab damage. Traditionally, mangrove rice farmers try to reduce losses due to tides and crabs by transplanting 12-week old seedlings, and by using high seeding rates (100 kg ha^{-1}). However, these practices substantially reduce potential crop yields. Use of younger (six-week old) seedlings increases the yield potential of mangrove swamp rice, but the younger seedlings are more susceptible to tide and crab damage. To protect the younger seedlings, and allow the rice to reach optimum yield potential, some mechanisms to reduce damage have been tested.

Manuring nurseries with rice husks has been used, although it was not as effective as applying expensive chemical fertilizer (NPK 15-15-15). In order to reduce the costs of fertilizer and increase seedling vigor, tests were established to examine the interaction between mineral fertilizers and manures on seedling vigor.

Experimental nurseries were set up in a factorial design on upland and lowland

hydromorphic sites at Rokupr, Sierra Leone. Rice husks and bran were applied at the rate of 0, 5000 and 10000 kg ha^{-1} to unfertilized and fertilized nurseries. The fertilizer treatments were 25 g and 50 g m^{-2} (NPK 15-15-15).

Seedlings were less responsive to all treatments on lowland areas than on uplands. However, seedling growth was more vigorous in the lowlands. Twice as much fertilizer was required to effect the same seedling vigor in upland nurseries as in lowland nurseries. This suggests inherently higher fertility and suitability of the lowland sites for rice nurseries. No significant interactions were identified. Although manuring improved seedling growth in the upland nurseries, it had no effect on response to NPK application at either site. Rice yields were superior for fertilized seedlings, irrespective of fertilizer source.

Further tests need to be conducted to re-examine rice yield potential and tolerance of older seedlings to crab damage and to evaluate the nutrient supply of manures in nurseries.

Control of Diseases and Insect Pests

The most important diseases affecting mangrove swamp rice are brown spot, seedling blast and dirty panicle disease.

Stem borers, the most economically damaging insect pests of mangrove swamp rice, depress grain yields by as much as 40%. Rice bugs are economically important, but are less severe, especially in associated mangrove swamps.

The main means of suppressing these pests is through effective cultural and integrated pest management practices. Population fluctuations of stem borers, and the biotic and abiotic factors affecting them, have been studied at Rokupr. Varietal selection for tolerance to seedling blast and stem borers remains a viable component of an integrated control system against these diseases and pests. Integrated control strategies against brown spot and stem borers were further studied during 1989.

SCREENING FOR SEEDLING BLAST RESISTANCE

S.N. Fomba

Mangrove rice seedlings are usually grown in upland nurseries and transplanted to the fields. Because upland areas tend to be highly conducive to blast (*Pyricularia oryzae*), infected seedlings are often transplanted and become highly susceptible to subsequent crab damage. Most of the available improved and traditional varieties of mangrove swamp rice lack high levels of stable resistance to seedling blast, particularly under highly fertile conditions. Past efforts to screen promising materials for blast resistance have identified lines that appear to have stable resistance, but results are often inconsistent across locations and over time.

To overcome some of the problems associated with the identification of blast resistant cultivars, two types of screening

nurseries were set up on upland and lowland hydromorphic areas near Rokupr. The Horizontal Resistance Blast Nursery (HRBN) was used to isolate partial or horizontal resistance, and the Uniform Blast Nursery (UBN) to isolate complete or vertical resistance. One hundred accessions were screened in both nurseries.

Reactions of rice varieties tested varied with the ecosystem studied and with the field plot technique used to assess resistance. ROK 9, ROK 16, Gissi 27, Mat Candu, and Angkata had moderate seedling blast scores (4-6) and low lesion counts per leaf for the HRBN test in both environments. This indicates that these materials may have high levels of partial or horizontal resistance to blast. In the UBN test, all of the lines showed moderate to high susceptibility (≥6).

These results indicate that further testing is necessary to establish the presence of blast resistance in these and other cultivars.

IMPACT OF VARIETAL DIVERSITY ON STEM BORER POPULATIONS AND THEIR NATURAL ENEMIES

S. Fannah

Rice farmers in West African mangrove swamp areas often plant different varieties of rice in the same field, mainly as a safety device to guarantee some harvest. Although this practice is known to influence insect pest populations in the field, its significance has never been assessed.

Four rice varieties in contiguous combination plots of a randomized block design were used to assess the impact of combination planting on stem borer populations and their natural enemies. Estimates of insect infestation were made at maximum tillering, milking and harvest stages for each variety planted, alone and in contiguous combination with other rice varieties.

With the exception of ROK 5 and Kuatik Kundur, stem borer infestations were not significantly different when transplanted alone or in combination with other varieties. Numbers of natural enemies tended to be higher on plots with more than one variety per plot, but not significantly so.

Future research should explore varieties with similar photosensitivity on larger field plots to quantify the influence of varietal diversity on the populations of stem borers and their natural enemies.

CULTURAL PRACTICES FOR THE MANAGEMENT OF STEM BORERS

S. Fannah

Close plant spacing, application of rice husks in the nursery, and early transplanting have proven to be effective in reducing losses due to stem borers. The integration of these practices into one package was studied in an experiment in 1989.

Five cultural practice combinations (Table 18) were tested using three dates for transplanting. Cultural practices included: transplanting at two crop

Table 18. Effect of cultural practices on stem borer infestation and grain yields of rice, Rokupr, 1989.

Cultural practice combinations	Stem Borer infestation (%)	Grain yield (kg ha^{-1})	Yield increase (%)	Estimated extra labor required by package (%)
Close spacing (33 hills m^{-2}) Husks (5000 kg ha^{-1}) Insecticide	0.8	2910	17.6	60
Intermediate spacing (25 hills m^{-2}) Husks (5000 kg ha^{-1}) Insecticide	1.4	2890	16.9	50
Close spacing (33 hills m^{-2}) Husks (5000 kg ha^{-1})	20.6	2570	4.0	50
Intermediate spacing (25 hills m^{-2}) Husks (5000 kg ha^{-1})	21.5	2500	1.0	40
Wide spacing (16 hills m^{-2}) No insecticide No husks	26.6	2470		
SE	1.50	85		
CV (%)	31	10		

densities, and the application of rice husks. Both factors were tested with and without the use of granular insecticides and checked against the traditional farmers' practice. The experiment was replicated three times.

When one application of insecticide was made, stem borer infestation was significantly reduced and crop yields increased compared to treatments without the insecticide (Table 18). There was also a significant interaction between date of transplanting and control package combinations. The mid-August transplanted crop responded much more favorably to cultural control packages than rice transplanted in mid-September. Yields increased by as much as 18% with the complete package, although labor inputs also rose. Future research should assess the economics of using the improved package at peak labor periods.

DISTRIBUTION OF RICE BUGS

S.J. Fannah

Rice grain discoloration, or "dirty panicle syndrome", is widespread in West Africa. Grain discoloration implies imperfect rice paddy in the field. This condition can be caused by rice bugs, fungi, bacteria, and adverse abiotic factors. About 21 rice bugs, from three families, are known to be associated with grain discoloration. To determine the intensity and distribution of these pests, weekly surveys of three mangrove rice fields near Rokupr were made during the reproductive phase of the rice crop. Ten sweeps were made at each site four times each sampling day.

Stenocoris spp. and *Aspavia armigera* (Fab.) were the most predominant rice bugs. *Riptortus* spp., *Nezara viridula* (L.) and *Diploxys* spp. were also common. Rice bug populations were higher over a longer period in seasonally flooded swamps than in tidal swamps. These populations gradually increased from the booting stage and reached their peak at the milk/soft dough stage and declined sharply thereafter. The peak of the rice bug populations coincided with the most susceptible phase of the rice crop. Future research will examine the relationships between rice bug populations, grain damage, and the incidence of major rice diseases.

There are 21 rice bugs found in West Africa that are known to contribute to rice grain discoloration, or dirty panicle syndrome.

Increasing Soil Fertility and Minimizing Losses Due to Salinity, Acidity and Weeds

Acid sulphate soils and soil salinity limit rice production, especially in restricted flooding areas of mangrove swamps. Weeds are also an economic problem. They make land preparation difficult and increase production costs.

WARDA scientists have conducted studies on ways to ameliorate soil toxicities and to formulate integrated weed control systems for small farmers in the mangrove swamp areas of West Africa. Soils in the mangrove swamps require regular application of phosphates to improve their fertility, especially in areas prone to drying between spring tides. Organic manuring, using partially decomposed rice husks and bran, has been shown to be beneficial in improving acid sulphate soil conditions.

During 1989, work within this project focused on three activities: evaluating alternative sources of phosphorus, and research on chemical and integrated weed control practices.

EVALUATION OF SOURCES OF PHOSPHATE FERTILIZER

C.A. Dixon

Soils in the associated mangrove swamps are normally acidic, with pH values of 4.0 - 4.4 in the dry season and 5.5 - 6.0 in the wet season. Phosphorus is a limiting element in rice production in these soils. The application of 40 kg ha^{-1} of P_2O_5 increases rice yields by as much as 2100 kg paddy ha^{-1}. However, mangrove rice farmers in West Africa do not have easy access to, or the money to buy chemical fertilizers in many instances. Previous experiments have tried to identify

alternative sources of phosphorus, especially rock phosphates from the region, but the results have been inconsistent with generally low responses.

In 1989, three new rock phosphate sources were tested: Togo phosphate rock, Tahoua phosphate rock, and Togo 50% PAPR in comparison with application of chemical forms of single superphosphate. The experiment was conducted in collaboration with the International Fertilizer Development Center-Africa (IFDC-Africa) on a highly acidic soil (pH 3.9-5.3) during the late tillering stage.

The results from the experiment showed that Tahoua phosphate rock may increase yields slightly (Table 19). However, none of the phosphate sources significantly increased yields. "Phosphorus fixation" associated with soluble soil aluminum and iron is believed to have accounted for the low responses.

Future trials will evaluate methods for alleviating the activity of these elements as a prerequisite for increasing phosphorus use efficiency in mangrove associated swamps.

DEVELOPMENT OF INTEGRATED WEED MANAGEMENT PRACTICES

H. Bernard

Research at WARDA-Rokupr has shown that weeds can reduce rice yields in associated mangrove swamps by as much as 57%. Timely and thorough land preparation, combined with two hand weedings within 40 days after transplanting, can suppress weed growth and substantially increase rice yields.

A trial was conducted in 1989 to evaluate several integrated cultural methods for their effectiveness in controlling weed growth and to measure their impact on rice yields. Five treatments were tested:

- mechanical land preparation (power tiller),
- manual (hoe) land preparation in combination with hand weeding at 30 days after transplanting,
- manual land preparation in combination with herbicide

Table 19. Mean yield (kg ha^{-1}) of CP 4 rice in response to graded levels of phosphate fertilizers in a mangrove associated swamp, Magbolontor, 1989.

Phosphate fertilizers	P_2O_5 applied (kg ha^{-1}) 20	40	80	Mean
Without phosphorus				2010
Togo phosphate rock	1660	2420	2680	2250
Tahoua phosphate rock	2200	2440	2380	2340
Togo 50% PAPR	1800	2540	2120	2150
Single superphosphate	2290	2170	2070	2180
Mean	1990	2390	2310	
SE		156		180
CV (%)		25		

Table 20. Effect of cultivation methods and weed control on total weed weight and rice yield for WAR 1 at three associated mangrove swamps, Rokupr, 1989.*

Treatment**	Total weed weight (g m^{-2})	Yield (kg ha^{-1})
Mechanical plowing & puddling + 1 hw at 30 DAT	3.6	2700
Mechanical plowing & puddling + Stam T-8 (9 l ha^{-1}) at 21 DAT	2.3	3200
Manual plowing & puddling + 1 hw at 30 DAT	2.1	2500
Manual plowing & puddling + weed free	0.0	3500
Plowing & puddling (farmers' practice) + 1 hw at 40 DAT	5.6	2200
SE	0.47	190
CV (%)	60	23

* Average of three locations

** DAT = Days after transplanting; hw = hand weeding

application at 21 days after transplanting,

- manual land preparation kept weed free, and
- farmers' traditional production practices.

Uniform fertilizer treatments of 60 kg P_2O_5 ha^{-1} basally and 60 kg N ha^{-1} in the form of urea at 21 days after transplanting were applied to all plots. Treatments were replicated four times in three locations.

The results, averaged over all locations, showed that all treatments significantly suppressed weed growth and were better than farmers' methods. Mechanical cultivation plus herbicide application gave significantly higher yields than the manually cultivated plots (Table 20).

Irrespective of cultivation method, one hand weeding may not be adequate for effective weed suppression or for maximizing yields in associated mangrove swamps. Further work is needed to develop effective alternative integrated weed control packages and to assess the economics of these alternatives.

EVALUATION OF HERBICIDES FOR WEED CONTROL EFFICIENCY AND SAFETY

H.M. Bernard

Weed infestation is a major economic problem, especially in seasonally flooded associated mangrove swamps. Studies had indicated that herbicides such as Stam F34T (Propanil + Fenoprop) have a broad spectrum of weed control in this ecology and may help to increase rice yields. Although they are effective for controlling weeds, herbicides are

small farmers. They are also highly toxic and can be important health and environmental hazards. Further tests are needed to identify effective, cheap, safe herbicides for use in this environment.

Tests were set up to screen herbicides against a broad spectrum of weeds found in mangrove swamps at Rokupr during 1989. Six-week old seedlings of ROK 5 were transplanted into 5 x 3 m plots at a density of 33 hills m^{-2} with 2-3 plants per hill. All plots received 60 kg P_2O_5 ha^{-1} in a basal application, and urea at 80 kg ha^{-1} three weeks after transplanting. The trial was replicated four times.

All the herbicides tested significantly reduced weed growth compared to the untreated check (Table 21). Basagran PL2 and Stam T-8 at 9 l ha^{-1} gave the best control. Only Goal 2E applied as a foliar spray was toxic to rice, but this did not affect yield. All herbicide treatments, except Machete EC, gave yields significantly higher than the untreated check, and comparable to yields of the hand weeded check.

Herbicides can therefore be effectively used for weed control in mangrove swamp rice. Future work will focus on low dosage treatments that can be used as a last resort option in integrated weed management systems.

Development of Improved Rice Varieties

Most traditional, and some improved, mangrove swamp rice varieties are tall and tend to lodge under high fertility conditions

Table 21. Effect of herbicides on weed growth and yield of ROK 5 in an associated mangrove swamp, Rokupr, 1989.

Treatment*	Application Rate (l ha^{-1})	Time (DAT)**	Weed weight (g m^{-2})	Yield (kg ha^{-1})
Stam T-8	7.0	21	17.7	3800
Stam T-8	8.0	21	12.2	4200
Stam T-8	9.0	21	5.1	4100
Goal 2E (broadcast)	1.5	5	26.7	3700
Goal 2E (foliar spray)	1.5	5	15.6	3900
Ronstar 25 EC	3.0	6	27.4	3600
Ronstar 25 EC	5.0	6	18.2	4100
Basagran PL 2	8.0	20	5.0	4500
Stam 7221	13.0	21	7.6	4000
Machete EC	3.3	10	21.6	3100
Hand weeding	twice	21+35	0.0	4100
Untreated check	-	-	80.9	2500
SE		8.50	290	
CV (%)		86	15	

* All herbicides were liquid formulations

** DAT = days after transplanting; EC = emulsifiable concentrate

tend to lodge under high fertility conditions resulting in grain yield losses. A majority are also susceptible to multiple soil stress encountered in adverse mangrove swamp soils.

Research by WARDA has attempted to develop new varieties that combine desirable agronomic traits such as high and stable yields, lodging resistance, sturdy culms, and tolerance to adverse soil conditions.

Recently, rice varieties WAR 1 and Rohyb 6-WAR-6-3-B-2 were developed that have shorter plant height and stiff culms. These varieties withstand twice daily tidal movements without lodging and give higher grain yields. Some local and advanced lines, such as WAR 77-3-2-2 and WAR 81-2-1-2, have been identified that have tolerance to multiple soil stresses. However, the majority of the traditional rice varieties and most recommended improved varieties for mangrove swamps are susceptible to saline and acid soil conditions. Varietal improvement research continues to select for genetic tolerance to soil stresses and yield potential, along with other desirable agronomic traits.

EVALUATION OF RICE VARIETIES/ADVANCED LINES

M. Agyen-Sampong

Work in 1989 in the varietal improvement program at Rokupr focused on selection from introduced and advanced lines identified in previous years as having high yields, tolerance to major environmental stress, and resistance to lodging, diseases, and insect pests. Selections were made for short and medium duration varieties.

Introduced and advanced rice lines were tested by WARDA-Rokupr scientists during 1989 to identify promising short and medium duration varieties for the mangrove swamp ecosystem.

Among the short duration materials, WAR 100-3-10-1, WAR 100-2-11-1 and WAR 115-1-2 out yielded the best check varieties in an observational yield nursery by 41%, 25% and 15%, respectively. The duration of the selected lines ranged from 120-135 days and plant height varied from 80-100 cm. These selections have potential for use in mangrove swamps where the salt-free period lasts about four months.

For the medium duration varieties (135-155 days), WAR 1, WAR 77-3-2-2 and WAR 87-10-2-3-3 significantly out yielded ROK 5, the check variety, in replicated yield trials. WAR 1 and WAR 77-3-2-2 had yields of over 5000 kg ha^{-1}. These are particularly promising varieties since they have been among the top yielding varieties for the previous two years.

The most promising lines in both maturity groups will be advanced to multilocational and on-farm tests throughout the region to determine adaptability and performance under farmers' management.

POST HARVEST TECHNOLOGY

WARDA's post harvest technology unit provides scientific and technical backstopping for other WARDA research activities involving post harvest technological constraints, grain quality considerations in varietal improvement, crop and resource management and economics. The overall objective of the unit is to improve the quality of rice produced in West Africa through the use of appropriate techniques for handling, processing and storing of rice.

RICE QUALITY

M. Takeda and A. Adewusi

Variations exist in the preferences for specific grain quality attributes related to traditional cooking and eating habits. The post harvest unit studies a number of grain quality characteristics in order to meet consumer demand for specific rice grains. These characteristics include:

- grain size and shape,
- hardness of brown rice,
- milling characteristics,
- color,
- amylose content,
- gel consistency,
- gelatinization temperature,
- protein content,
- water uptake ratio
- volume expansion ratio, and
- cooking time.

Tests for only the first four characteristics are currently being done at WARDA's post harvest unit in Fendall, Liberia. Other tests are done in collaboration with the rice quality laboratory at IITA.

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PERFORMANCE OF THE SATAKE TM-05 TESTING MILL USING SMALL SAMPLE SIZES

M. Takeda

For milling tests, WARDA uses a Satake TM-05 grain testing mill. The machine is designed to handle 200 g samples. However, samples submitted for testing by WARDA scientists are often less than 200 g. Therefore, it was necessary to test the accuracy of the test results from smaller sample sizes. Eight feed sizes (10, 20, 30, 40, 50, 100, 150 and 200 g) of IR-5 rice with five replications were used in the test with the Satake TM-05 mill. Milling time was 1.5 minutes. After milling, the samples were allowed to cool to room temperature, after which head rice yields were calculated. There were no significant differences in head rice yields between the 20, 30, 40, 50 and 150 g samples and the control. Yields from the 100 g samples were significantly higher than the control. Thus, a 100 g sample may give the best indication of potential head rice yield for a variety. Further tests using different rice varieties are needed to establish the optimum sample size.

CONSUMER PREFERENCES FOR RICE IN WEST AFRICA

A. Adewusi, M. Takeda and V. Nyanteng

Data gathered in 1988 and analyzed during 1989 indicated that consumers in Cote d'Ivoire, Senegal and Sierra Leone have a strong preference for local rice with grain characteristics suitable for traditional cooking methods and for use in local rice dishes. There was also a strong preference for soft to medium textured rice. Respondents to the survey questionnaires indicated that they preferred rice grain that was fluffy after cooking, that could be cooked as a whole grain, and had good kernel swelling on cooking. Based on these preliminary results, it seems that WARDA rice breeders should be developing rices which have good head rice recovery after milling, a low number of chalky kernels, intermediate amylose content, medium to soft gel consistency, and good volume expansion upon cooking.

The scope of the field survey work was extended in 1989 to include Mali, Burkina Faso, Ghana, Nigeria and Liberia. Results are now being analyzed.

DEVELOPMENT OF AN IMPROVED STORAGE STRUCTURE

A. Adewusi

Farm families still use traditional storage techniques for paddy and milled rice in West Africa. Qualitative and quantitative losses of rice occur because of ineffective protection against the influence of the environment and attacks from vertebrate and invertebrate pests. An improved storage structure was designed and built from locally available materials during the last part of 1989. It has a capacity of three tonnes and is constructed from clay, wood and raffia palm products. The storage unit is completely lined with bituminized felt that serves as a barrier to water and water vapor movement. Corrugated roofing sheets were fabricated into rat guards outside the storage unit and underneath the floor. Grain stored in this unit is being compared to grain stored in traditional farm units. Moisture content and insect populations are being measured on a monthly basis. Cooking and eating properties, seed germination, and aflatoxin content will be measured at the end of one year's storage.

DEVELOPMENT OF PARBOILING HARDWARE

A. Adewusi

Traditional parboiling practices are used in all WARDA member countries except Mauritania and Senegal. Sierra Leone, Mali, Nigeria and Burkina Faso have commercial parboiling operations. However, much of rice parboiling is still done at the village level. A number of problems are common to village-level parboiling systems, including:

- the development of off flavors and aroma,
- a high proportion of discolored grains,
- the presence of undesirable foreign matter,
- high labor and energy costs, and
- a short life for the hardware used in parboiling.

WARDA scientists have developed a parboiling plant with a capacity of 1.5 tonnes per day incorporating a flat bed dryer. Tests began in late 1989 and the results will give physical, chemical, milling and cooking quality data on each variety used in the parboiling plant.

training and communications

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Training

WARDA's training program plays an important role in the region in strengthening the research capabilities of rice researchers and in transferring new ideas and technology among the national agricultural research programs.

Design and construction of rice storage structures was a major part of the post harvest technology course given by WARDA in 1989.

GROUP TRAINING

In 1989 WARDA held three group training courses at its Training Center in Fendall, Liberia. The Rice Production, Research and Extension Course was given for 22 participants from 12 West African countries (Table 22). The course provided basic experience in rice research, production and extension for scientists, production specialists, and extension personnel, involving hands-on experience in rice cultivation from seedbed preparation to harvesting, including sections on research trials and extension methods. The course was funded by the United Nations Development Program (UNDP).

The second course, Post Harvest Technology, involved 23 participants from 10 West African countries. In this course trainees learned aspects of rice milling, storage, loss prevention, drying, parboiling, economics and technology transfer methods. Participants at this course were mainly post-harvest technicians and trainers. The course was funded by the Japanese government.

Japanese funding was also provided for the third course, namely, Rice Drying and Storage in the Tropics. Participants

Country	Rice Production Research, & Extension	Post Harvest Technology	Rice Drying & Storage
Benin	1	1	1
Burkina Faso	-	-	1
Chad	1	1	-
Cote d'Ivoire	-	2	-
The Gambia	2	1	2
Ghana	2	2	2
Guinea	2	-	2
Guinea-Bissau	1	2	2
Liberia	2	5	4
Mali	2	2	-
Niger	1	-	-
Nigeria	4	1	3
Sierra Leone	3	3	4
Togo	1	2	2
Totals	22	22	23

Table 22. Numbers of participants from WARDA member countries attending WARDA group training courses in 1989.

in this course were persons involved in post-harvest operations of drying and storing rice grain. They studied rice drying and storage principles and methods, structures and equipment.

SPECIAL TRAINING PROGRAMS

A special two-week intensive rice production training course was held for 17 Liberian extension workers, and a 4-day introductory rice production course was given for 15 United States Peace Corps volunteers. The first course was organized and prepared by former trainees of WARDA's Rice Production, Research, and Extension Course as a practice training course. This introductory course was held at the request and funding of the Peace Corps Office in Liberia.

The WARDA-Rokupr Research Station held a one-week course on mangrove rice research and production for research personnel in Sierra Leone, Guinea and Guinea-Bissau.

Communications

PUBLICATIONS

Significant progress was made to establish a functional WARDA publications unit. Policies and procedures for processing documents were drafted, and a style guide is being prepared. A single word processing program has been selected and installed in all WARDA offices to ease the flow of work within the publications unit. Training has been provided to help upgrade staff skills in computer assisted publishing.

WARDA made substantial equipment acquisitions during 1989. This included a complete darkroom unit, graphic arts materials and supplies, typesetting equipment, computers, photography equipment, a computer scanning unit, binding equipment and a low cost duplication unit. It is now possible for WARDA to produce its own newsletters, brochures and reports. Typesetting and layout and design equipment enables WARDA to provide camera-ready materials for full color publications as well.

About 190 publications and papers were produced in English and French: 2 Director General's Newsletters, 2 internal newsletters, the 1988 Research Highlights, the 1988 Annual Report, Proceedings of the WARDA-NARS Manpower Study Conference and the Annual Rice Review, the WARDA Medium-Term Implementation Plan, a Capital Development brochure, and numerous Council of Ministers and Board of Trustees documents.

LIBRARY AND INFORMATION SERVICES

The WARDA library continued to provide documentary services to scientists in the region. Library space was significantly increased with the establishment of a reading room and the installation of new shelving. This attracted more scientists to the library during 1989 and made library services also available to outside users.

Special efforts were made to alert scientists about developments in their respective fields through the regular distribution of major journals and through several information dissemination ser-

vices. Lists of recent acquisitions and tables of contents of current journals were distributed and photocopies of articles were also supplied on request. A number of bibliographic searches were made at the request of WARDA scientists.

Steps were taken to equip the WARDA library with a CD-ROM drive and to install AGRICOLA CD-ROM discs. WARDA also participated in the CGIAR evaluation on the use of CD-ROM discs.

The Documentation Unit also supported WARDA's training activities by increasing the Training Center's library holdings in the supply of more than 400 titles, including all relevant IRRI publications, WARDA brochures on insect pests, weeds, and diseases.

The computerized mailing list was continually revised and now contains over 2500 names and addresses of individuals interested in rice research in West Africa. Special emphasis was placed on increasing the number of recipients of WARDA publications within the WARDA member countries.

There are now 12000 records in WARDA's bibliographic database and 797 records in the serials database. In 1989, the documentation unit added the following materials to the library collection:

- 149 annual reports
- 664 books
- 525 catalogues, brochures, and pamphlets
- 1416 issues of periodicals
- 2376 pages of photocopied articles.

In June, WARDA responded to an invitation from the International Development Research Centre (IDRC) and submitted a proposal for the strengthening and upgrading of WARDA library and information services.

Through the courtesy of WARDA's Board of Trustees Program Committee Chairman, Professor Ronnie Coffman, and Cornell University, WARDA is to receive a major gift of all back issues of several major scientific journals.

TRANSLATION AND INTERPRETATION

WARDA translators translated, edited and proofread official correspondence,

research documents and publications, conference proceedings and various administrative materials in 1989. In all, 87 documents were translated from English to French.

Interpretation was provided for WARDA meetings, conferences and seminars, and meetings between WARDA and Ivorian and other French-speaking officials.

PUBLIC AWARENESS/ INFORMATION

A WARDA public awareness strategy document was prepared in 1989 to help guide future work in this area. Public awareness and information dissemination activities were conducted for the national press in the WARDA research locations and for outside media, including press interviews by WARDA's Director General. Media briefings were given and WARDA took part in the Bouake Agricultural Carnival and field days at Rokupr, Sierra Leone.

international cooperation

In 1989 WARDA continued the consolidation of its collaborative links with its partners in national, international and regional institutions. WARDA initiated a number of conferences, seminars and visits to help strengthen these linkages.

Collaboration with National Institutions

The rice research programs of the WARDA member states are the main recipients of information generated from WARDA's research. NARS scientists and research administrators play a vital role in helping WARDA gather critical information on the needs and programs operating in the region. WARDA has called upon and received vital inputs from NARS within the region that has helped guide the formulation of its research, training and communications activities.

SURVEY OF NARS RICE RESEARCH RESOURCES

The Director of International Cooperation visited the rice research programs of the 16 member countries of WARDA to complete a survey of rice research resources in the region. The results of this survey will be compiled and presented at the 1990 Annual Rice Review.

WARDA-NARS MEETINGS

WARDA-NARS Training Conference

This conference was held to identify training and manpower needs related to

rice production in WARDA member countries; to prioritize and clarify methods of implementing the training programs of WARDA; and to identify areas of strength and weakness in WARDA's previous training efforts.

There were 12 participants from 10 WARDA member countries, along with WARDA directors and members of WARDA's training staff. The ideas and recommendations from the discussions contributed significantly to the development of WARDA's Five-Year Training Plan 1990-1994, which was submitted for review by participants at the 1989 Annual Rice Review.

Annual Rice Review Meeting

WARDA's Annual Rice Review Meeting provides rice researchers in West Africa the opportunity to meet among themselves and with other rice scientists from other parts of the world to exchange ideas on rice research activities.

In 1989, 42 NARS scientists from West Africa, 2 from other parts of Africa and representatives from 11 international organizations attended the Annual Rice Review Meeting.

The theme for the 1989 meeting was on varietal improvement in West Africa. Papers were presented on consumer preferences, technology transfer, and the role of biotechnology in varietal improvement. Participants also discussed the status of varietal improvement research in the three rice growing environments of the continuum, the Sahel and the mangrove swamps of West Africa.

Two specialist groups met during the Annual Rice Review. The first group examined the issue of exchange and testing of rice germplasm in West Africa and ways to improve current systems to better serve NARS varietal improvement programs. A second group addressed training priorities for NARS rice improvement programs in terms of disciplines and approaches to training.

Scientists from four WARDA member countries presented a document on future WARDA-NARS collaboration. The recommendations from the discussion will guide WARDA's thinking in future collaborative activities and agreements.

A paper was presented on the concept of working groups and their objectives. Following a discussion of this paper, a

proposal was accepted to establish three working groups that will provide continuing input into WARDA's planning and evaluation of on-going programs. The working groups are Varietal Improvement, Crop and Resource Management, and Training.

COLLABORATIVE ACTIVITIES WITH NARS

The Institut des Savanes (IDESSA), located in Bouake, Cote d'Ivoire, and members of WARDA's continuum research program met by discipline and planned research activities to be conducted in Cote d'Ivoire in 1990 in order to avoid duplication of effort and increase the complementarity shared between the two organizations.

In Sierra Leone, members of the Crop Protection Department of Njala University College, invited WARDA to assist in enhancing the capabilities of their students through guest lectures, establishing student research projects, providing journal articles and establishing research programs for higher degree students.

The WARDA-Rokupr station conducted a one-week training course in mangrove swamp rice research for technicians and extension staff for each of the NARS in Sierra Leone, Guinea and Guinea-Bissau. Exchange programs were set up for Sierra Leone scientists to visit the Guinean rice research program to exchange ideas and review station and on-farm trials. A reciprocal visit was requested by Guinean scientists.

A similar exchange visit was arranged by WARDA for The Gambian Agricultural Research and Diversification Project (GARD) within the Department of Agricultural Research with the Senegalese Institute of Agriculture Research (ISRA Djibelor).

In Liberia, WARDA set up collaborative on-farm iron toxicity trials in conjunction with the Nimba County Rural Development Project (NCRD) through the help of the Central Agricultural Research Institute (CARI).

WARDA also participated in a review of Liberian research programs in relation to the national agricultural goals. In a related area, and at the request of the Ministry of Planning and Economic Affairs (MPEA) of Liberia, WARDA

reviewed a document on Rice Pricing Policy for Liberia and participated in a discussion of the document.

WARDA's Director General and Director of International Cooperation took part in the in-house review of the research program of The Gambian Department of Agricultural Research.

Collaboration with International and Regional Institutions

In order to effectively serve the rice research needs of the region, WARDA has worked out collaborative agreements with a number of international and regional institutions during 1989.

International Institute of Tropical Agriculture (IITA)

A number of agreements and working arrangements were established between IITA and WARDA during 1989. These include:

- An agreement on the arrangements for the transfer of IITA's rice varietal improvement program to WARDA.
- WARDA use of IITA paddy fields and support facilities required for its lowland rice breeding program and use of facilities for rice entomology research.

Discussions were also held on collaborative work on rice-based cropping systems. A key site in Cote d'Ivoire for lowland rice-based cropping systems was identified. The work there will include surveys, trials and testing of methodologies used by IITA at other locations. WARDA will take the lead in research on upland rice-based cropping

systems with the understanding that all information will be shared between IITA and WARDA scientists.

Lastly, IITA and WARDA will collaborate in characterizing inland valley swamps in Sierra Leone and Nigeria.

International Rice Research Institute (IRRI)

IRRI agreed to make available to WARDA their research station development specialist to assist in WARDA's Main Research Center and Headquarters at M'be, Cote d'Ivoire. An agreement was reached to transfer the International Network for Genetic Evaluation of Rice-Africa (INGER-Africa) activities to WARDA in 1991.

Progress was made on a collaborative agreement among IRRI, WARDA, and Centro Internacional de Agricultura Tropical (CIAT) concerning upland rice improvement. The agreement covers transfer of germplasm and allocation of tasks based on needs and comparative advantages of each center.

IRRI agreed to supply technical assistance to WARDA in its characterization of West African rice growing environments project.

International Food Policy Research Institute (IFPRI)

WARDA has initiated a long-term collaborative research plan with IFPRI on West African rice policy issues. A proposal has been drafted to fund an IFPRI scientist to be posted at WARDA headquarters in Bouake. The scientist will be responsible for the identification and promotion of an informal network with other policy researchers in the region. The IFPRI scientist will work closely with WARDA economists, especially in the area of farming systems.

International Center for Insect Physiology and Ecology (ICIPE)

Scientists from the WARDA and ICIPE exchanged visits in 1989 and established an agenda for collaboration between the two institutions. Special attention was paid to ICIPE's work on bionomics and applied ecology, biological control of insect pests, host plant resistance, and insect mass rearing. Collaboration in the training area was also discussed at the

post doctoral level, post graduate level and in terms of short courses in integrated pest management. Work is continuing between the two centers concerning research on *Maliarpha* and *Chilo* pests.

Another area of collaboration that has been suggested is that of medical vectors research as it relates to human health problems associated with inland swamp and irrigated rice production.

International Irrigation Management Institute (IIMI)

IIMI and WARDA have held talks on collaboration in water management research and on the promotion and coordination of a West African water management research and development network.

International Center for Living Aquatic Resources Management (ICLARM)

Representatives from ICLARM contacted WARDA concerning a collaborative working arrangement on fish farming in rice-based production systems in West Africa.

Food and Agriculture Organization of the United Nations (FAO)

Reciprocal visits were made by WARDA management and FAO staff located in Accra, Ghana to discuss potential areas of collaboration. One FAO project on development of cereals and legumes for Sub-Saharan Africa was briefly discussed. Efforts are also underway to develop reliable statistics on rice production in the region. This information would be shared between WARDA and FAO. A third area discussed with FAO officials concerned the preparation of a project on utilization of wetlands for rice cultivation in West Africa.

World Health Organization (WHO)

The Director General and the Director of International Cooperation visited the Africa regional office of WHO to discuss the possibility of collaboration in research on human health problems for rice producers.

Other Contacts

In addition to the collaborative agreements worked out with many organizations, WARDA representatives took part in meetings concerning regional rice production sponsored by the following groups: Comite Permanent Inter-Etats de Lutte Contre la Secheresse dans le Sahel (CILSS), Conference des Responsables de Recherche Agronomique Africains et Francais (CORAF), Special Program for African Agricultural Research (SPAAR), Sasakawa Global 2000, CIDT, International Rice Testing Program-Africa (IRTP-Africa), West African Farming Systems Research Network, and Autorite du Bassin du Fleuve Niger (ABN).

capital development

The movement of WARDA to Bouake in 1988, necessitated the construction of a new Main Research Center and Headquarters (MRC & HQ). In order to handle this task, a development office was opened to develop land provided by the Ivorian government located 25 km from Bouake in the M'be Valley.

On the recommendation of donors and the Board of Trustees, a three phase development program was agreed on for the farm development and construction of permanent facilities. Consultants were appointed by the WARDA Tenders Committee following an international selection process. The consultants were asked to prepare a complete design in outline and a detailed plan for Phase 1 of the development program.

In 1989, during the initial capital development phase, 100 ha at the Main Research Center were cleared and planted for research purposes in the continuum in 1989. In addition to this, a detailed soil survey of the entire proposed site was prepared by the Winand Staring Center of the Netherlands. The report is based on six weeks of field work conducted jointly by WARDA and Winand Staring scientists. All required field survey work has been

completed and 17 distinct soil units have been identified, described and evaluated in detail, and mapped on a scale of 1:5000. The land suitability of each unit has been assessed for rice and other crops.

In order to house the WARDA scientists, units of prefabricated, demountable, temporary offices and laboratories were constructed on the Main Research Center site. These will be used until the completion of Phase 1 of the overall development plan in which permanent research facilities will be constructed.

Also during Phase 1, which is scheduled to begin in 1990, screen houses, an insectary, the research farm complex, and basic infrastructures, including access roads, water, electricity and sewage disposal will be completed.

Meanwhile, temporary administrative facilities located in Bouake provide adequate space for WARDA's administrative, financial, library and communications activities.

During Phase 2, the communications, training, and documentation facilities will be completed, along with hostels for trainees and guests.

For Phase 3, administrative facilities will be completed, including dining and conference facilities and the remaining physical plant and service areas.

For the entire construction program, WARDA's Development Office is striving for modularity, flexibility, replicability and use of efficient spatial relationships.

PERSONNEL

OFFICE OF THE DIRECTOR GENERAL

Eugene R. Terry, PhD, *Director General*
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S. Camara, MS, *Internal Auditor*

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G. MacNeil, MBA, *Director of Administration & Finance*
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U. Konan, ML, CFB, *Personnel Officer*

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J. Dallard, IA, *Breeder**
R. Diallo, MS, *Extension Agronomist*
S. Diatta, DEA, *Agronomist*
G. Nyoka, PhD, *Weed Scientist*

Suakoko, Liberia

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M. Diop, PhD, *Associate Weed Scientist*
B. Fall, PhD, *Sociologist**
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Fendall, Liberia

A. Adewusi,MS, *Processing Engineer*
M. Takeda, BSc, *Agricultural Engineer***

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R. Ayling, ThD, *Acting Director of Training and Communications*
K. Conteh, MS, MA, *Chief, Training Center*
I. Akintayo, PhD, *Trainer*
A. Maiga, Doctorat, *Trainer*

Communications

T. Asongwed, MA, DEA, *Translator/Interpreter*
A. Diallo, MS, *Documentalist*
D. Hill MSc, *Head of Publications*
C. Soufflet, MA, *Translator*

INTERNATIONAL COOPERATION

D. Sanni, Eng Gr, *Director of International Cooperation*

* Left during the year
** Japanese Cooperant
*** French Cooperant
\+ National program staff based at WARDA

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Akintola Williams & Co

Chartered Accountants

27 March, 1990

COPY

The Director General
West Africa Rice Development
Association
01 B. P. 2551
Bouake
Cote d'Ivoire

Dear Sir,

AUDIT FOR THE YEAR ENDED DECEMBER 31, 1989

We have completed the audit of the West Africa Rice Development Association for the year ended December 31, 1989 and set out in the attached Management Letter matters which we wish to bring to your attention. These matters are in addition to those raised in our interim management letter of February 1, 1990.

As part of our examination, we made a study of the Association's sytem of accounting control to the extent we considered necessary to evaluate the system as required by generally accepted audit standards. The purpose of our study and evaluation was to determine the nature, timing and extent of the auditing procedures necessary for expressing an opinion on the Associxation's final statements. Our audit work would therefore not necessarily disclose all material weaknesses, errors or irregularities in the system which may exist.

The matters in the management letter have been discussed with the Director of Administration and Finance.

We would like to express our sincere appreciation for the cooperation we received from the members of your staff who assisted us in the course of our audit.

Yours faithfully,

Akintola Williams & Co

AKINTOLA WILLIAMS & CO.

Partners: Njoh Litumbe (Chairman), Y. Abioye Oyeleke (Managing), Ike Nwokolo, A. Bolaji Osagie, Muri A. Folami, Victor G. Hammond, Olusegun A. Odubogun, Godwin O. Opurum, Emmanuel A. Avornyotse, Emmanuel O. Ikazoboh, Joseph L. Itie, Frederick K. Lule, Edwin I. Oyinze, Sesby S. Banjoh, William O. Kpere-Daibo, E. Chukwuka Barber, M. Olumuyiwa Osho, Christian N. Akujuaobi, Olaniran Oyebanji,

Offices at: Benin City, Enugu, Kaduna, Kano, Maiduguri, Owerri, Port Harcourt (Nigeria); Douala and Limbe (Cameroon); Abidjan (Ivory Coast); Mbabane (Swaziland).

Touche Ross International

WEST AFRICA
RICE DEVELOPMENT ASSOCIATION

Statement of Financial Position
at 31 December 1989
(Expressed in US Dollars)

	1989	1988
CURRENT ASSETS		
Inventory	66 872	58 341
Accounts Receivable - Donors	272 569	925 342
Accounts Receivable - Others	303 458	348 871
Fixed Deposits	1 143 719	1 262 664
Cash and Bank Balances	449 853	728 773
Total Current Assets	2 236 471	3 323 991
CURRENT LIABILITIES		
Accounts Payable	147 300	84 843
Provisions and Accruals	820 764	1 112 440
Contributions in Advance	514 973	1 426 491
Project Fund Balances	81 438	86 849
Total Current Liabilities	1 564 475	2 710 623
Net Current Assets	671 996	613 368
Property, Plant and Equipment	3 450 194	3 200 684
NET ASSETS	4 122 190	3 814 052
REPRESENTED BY:		
Capital Fund	3 450 194	3 200 684
Training Fund	-	92 801
Working Capital	500 000	400 000
Mbe Development Fund	10 468	-
Operating Fund	161 528	120 567
Fund Balances	4 122 190	3 814 052