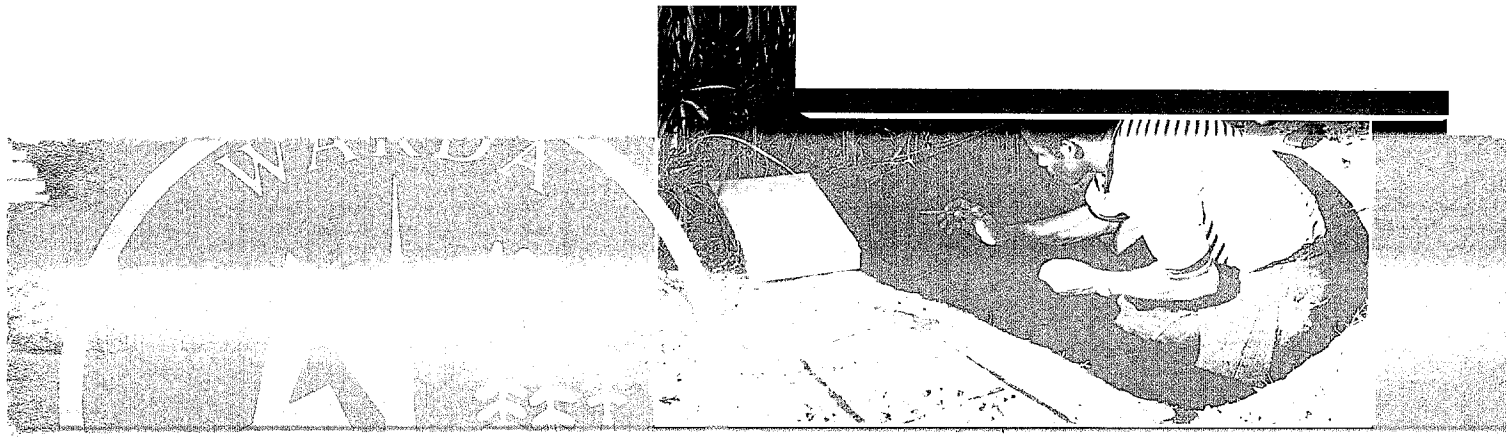
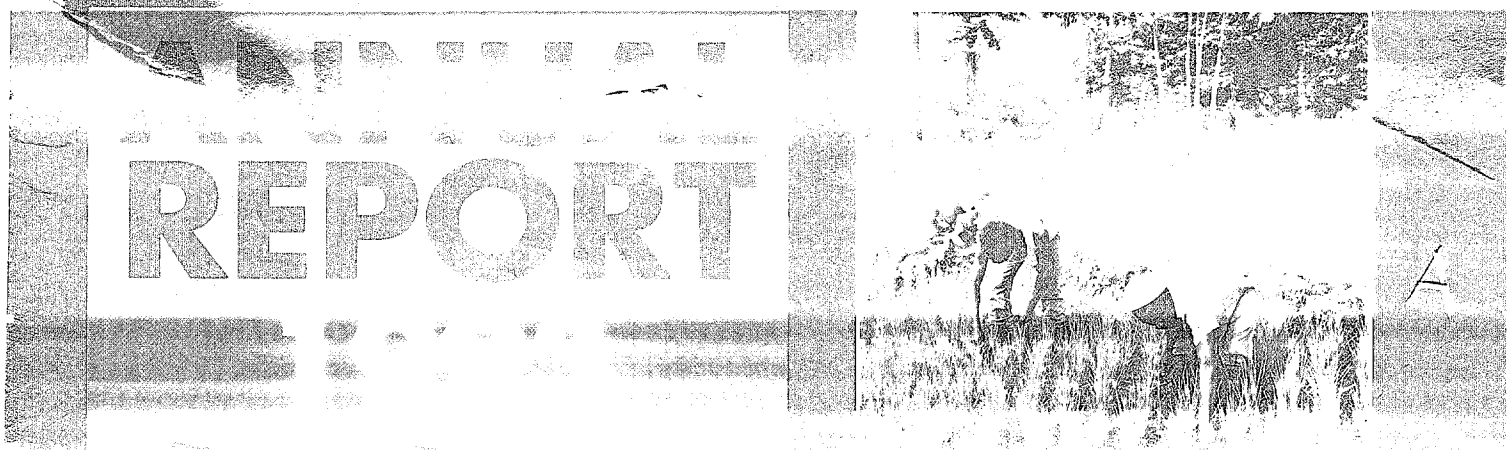


WARDA

West Africa Rice Development Association

REPORT



WARDA
Annual Report

1993

West Africa Rice Development Association

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Foreword

Many countries in sub-Saharan Africa have been severely affected by serious food insecurity. Indeed, within the past decade, these countries have recorded a dramatic decline in per capita food production. This low agricultural productivity is due partly to the limited genetic potential of existing varieties of the commodity food crops. In addition to this constraint, the region has witnessed increasing degradation of its agricultural resource base, as food production shifts from extensive to often inappropriate intensive land-use systems.

To address the resource management and other constraints to increasing food production within sub-Saharan Africa's diverse production systems, research must be location specific. This implies a major role for the national agricultural research system (NARS) scientists, whose ultimate task it is to generate and test improved technologies. The reality, however, is that the current institutional instability of many NARS, caused mainly by declining financial support, has severely constrained their effectiveness. The Consultative Group on International Agricultural Research (CGIAR), to which WARDA belongs, continues to be an effective instrument for international agricultural research. Changing circumstances, however, call for urgent action to optimize the expertise and capacities of the CGIAR's partners in regional and national research systems.

The year 1993 witnessed the start of experimentation with WARDA's 'Open Center' structure and the consolidation of the Task Force approach to regional collaboration. WARDA's Board of Trustees, management and staff are encouraged by the initial results. We believe that these two mechanisms will play a useful role in the implementation of research programs within an ecoregional framework. It is already clear that they will help WARDA and its national partners identify and define research priorities for the region, and generate increased funding for joint WARDA/NARS activities.

With the inauguration of the Main Research Center and Headquarters on 20 August 1993, WARDA now has a permanent and well-equipped institutional facility that will serve as a focal point for the efforts of a range of collaborating institutions working in rice production and related fields. This fulfills one of the requirements of the Open Center structure and marks the achievement of an important strategic goal of the first Medium-Term Plan (1990-94). The inauguration provided an opportunity for the region's policy makers to visit the new facilities and pledge their continued moral and material support for WARDA.

The establishment of six thematic Task Forces in 1992 in partnership with the region's national scientists enhanced WARDA's ability to play a catalytic role in the development of an integrated and interdependent West African regional research system for rice. In 1993, two additional Task Forces were established for collaboration in rice economics and problem soils research. Thus, the full range of research activities envisaged within the eco-regional framework was undertaken in 1993 through the work of eight Task Forces.

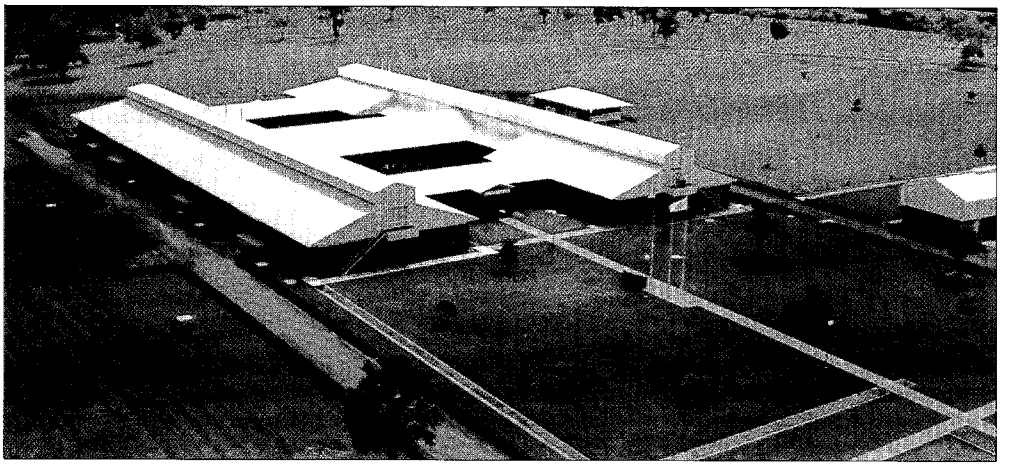
Within the specific interdisciplinary projects on resource management research, high priority was given to the development of improved soil, water and pest management practices that minimize the use of purchased inputs. The results from some of these studies are summarized in this Annual Report. As reported in one of the feature articles, significant progress was made in interspecific hybridization between *Oryza sativa* and *O. glaberrima*. Some of the target traits from these crosses (earliness, seedling vigor and high tillering ability) have appeared in progeny populations. One of the most exciting results from this work is the appearance of the high tillering trait at an early stage of growth, which is important for weed suppression. The second feature article discusses the results of work conducted by WARDA's Sahel Irrigated Rice Program on the

About WARDA

The West Africa Rice Development Association (WARDA) is an intergovernmental research association with a mandate to conduct rice research, training and communications activities for the benefit of the West African region. Formed in 1971 by 11 countries with the assistance of the UNDP, FAO and ECA, WARDA now consists of 17 member countries. The Association is a member of the network of 18 international agricultural research centers supported by funds from donors of the CGIAR.

WARDA's goal is to strengthen West Africa's capability in rice production science, technology and socio-economics. Through these efforts, it hopes to improve the livelihood of small farming families, increase the opportunities for rural employment and enhance the prospects for food security.

The Headquarters of WARDA are in M'bé, Côte d'Ivoire. WARDA maintains regional research sites near St Louis in Senegal and at IITA, Ibadan in Nigeria.



Aerial view of WARDA's MRC & HQ at M'bé, Côte d'Ivoire

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Nigeria
Senegal
Sierra Leone
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Professor Alassane Salif N'Diaye (above), the chairman of the Council of Ministers, cutting the tape at the inauguration of the MRC & HQ on 20 August 1993, and Mme Maikorema Zeinabou Baderi (below), the incoming chairman of the Council of Ministers, looking at the inauguration plaque

characterization of the climatic stresses that contribute to yield instability and constrain double cropping. The physiological simulation model designed for this study has provided a management tool that will enable farmers to target improved germplasm and cropping calendars more accurately.

Significant progress was made in the training and communications programs in 1993. This report provides information on new initiatives implemented in collaboration with other CGIAR centers and regional organizations. An excellent example of this is the leading role being taken by WARDA in a regional project designed to strengthen the dissemination of agricultural information in West Africa.

WARDA is pleased to present its 1993 Annual Report, and hopes that the work reported in this publication will make an important contribution to the wide range of research activities being undertaken by CGIAR centers to improve food security in sub-Saharan Africa.

Eugene R. Terry, PhD (Illinois)
Director General, WARDA

allowed for a comparison of drought resistance at both stages, taking into account drought adaptation, escape, avoidance and recovery. The entries were sown in 1 m rows, with resistant (OS6) and susceptible (IR20) check varieties repeated after every 20 entries. Each entry was rated at 2-weekly intervals for a number of traits, including seedling vigor, plant height, leaf tip burn, and leaf rolling and unfolding ability. The entries were visually scored for drought resistance.

Insect resistance

The African rice hispa, *Trichispa sericea*, and a complex of rice stem borer species are important pests in both upland and lowland rice. Insecticides provide some control of the hispa and stem borers but chemical control is expensive, dangerous to use and destroys the natural enemy complex. Resistant cultivars are needed as a key component in the integrated control of these pests. In 1993, a project was initiated to search for cultivars of *O. glaberrima* which could serve as a source of resistance genes for incorporation into high-yielding rice cultivars.

Field evaluation of 136 *O. glaberrima* materials, previously selected for morphological traits, was conducted at the peak of the hispa population in March 1993 at M'bé. Seedlings were grown in a nursery and transplanted into the field at 21 DAS. Each plot consisted of one 2.5 m test row, bordered on each side by a row of the susceptible check, Bouaké 189. At 40 days after transplanting (DAT), the percentage of damaged leaves of each cultivar and the adjacent check were computed as follows:

$$\text{\% damaged leaves} = \frac{\text{Number of damaged leaves}}{\text{Total leaves examined}} \times 100$$

The percentages were subsequently converted to a new comparative percentage, as follows:

$$\frac{\text{\% damaged leaves in test cultivar}}{\text{\% damaged leaves in adjacent check}} \times 100$$

The comparative percentages were then converted to a 1-9 damage rating scale:

% damaged leaves	*Scale*
0-10	1
11-20	3
21-35	5
36-50	7
51-100	9

To determine the extent of stem borer infestation, all the plants in each row were examined. The total number of tillers present and the number of damaged tillers (deadhearts) were counted at 60 DAT. The comparative percentages were computed and converted to a 1-9 rating scale:

% deadhearts	*Scale*
1-20	1
21-40	3
41-60	5
61-80	7
81-100	9

Disease resistance

The most important disease of rice in West Africa is rice blast, caused by the fungus *Pyricularia oryzae*. Sources of durable resistance to blast have been found in very few landraces of *O. sativa*. To identify new sources, 126 *O. glaberrima* accessions were evaluated for field reaction to the disease at M'bé in 1993. Each entry was sown in single plots (2 x 5 m rows), with the check variety, Moroberekan, replicated after every 20 entries. The entries were scored for blast resistance at 30, 37, 44 and 51 DAS, using a 0-9 scale:

% infected plants	*Scale*
0	0
1-10	1
11-30	3
31-50	5
51-70	7
71-100	9

Resistance to parasitic weeds

The parasitic weed, *Striga* spp., has been observed to affect upland rice in the Sudan and Guinea savanna

TABLE 2: Origin and number of accessions collected of *Oryza sativa* (traditional) and *O. glaberrima*, 1985-90

Country	*O. sativa* No.	*O. sativa* Frequency (%)	*O. glaberrima* No.	*O. glaberrima* Frequency (%)
Burkina Faso	—	—	14	1.2
Cameroon	—	—	20	1.7
Chad	2	0.7	7	0.6
Côte d'Ivoire	138	50.1	28	2.4
Ghana	—	—	18	1.5
Guinea-Bissau	19	7.0	—	—
Guinea	96	35.0	12	1.0
Liberia	—	—	579	51.2
Mali	—	—	84	7.4
Nigeria	—	—	287	25.4
Senegal	10	3.6	51	4.5
Sierra Leone	—	—	23	2.0
Tanzania	10	3.6	—	—
The Gambia	—	—	5	0.4
Total	275	100	1130	100

During the 1992 and 1993 growing seasons, all 1721 accessions were evaluated for a range of morphological and agronomic traits, including seedling vigor, growth duration, plant height, panicle per m^2 and grain shape. The evaluation was conducted at Gagnoa in central-west Côte d'Ivoire. Located in the forest zone at 205 m a.s.l., 05°57'W and 06°08'N, the Gagnoa site is characterized by a bimodal rainfall pattern (March to May, and September to November); the average annual rainfall and temperature are 1500 mm and 26°C, respectively. In the 1992 and 1993 seasons, the soil was prepared with a tractor in February, followed by seed dibbling of each entry at a spacing of 25 x 25 cm in single plots (1 x 5 m). The seeds were sown after a basal application of the compound fertilizer 10-18-18 NPK at a rate of 200 kg ha^{-1}. Urea was applied at a rate of 60 kg N ha^{-1} at 35 and 70 days after sowing (DAS). The herbicide Ronstar was applied 1 DAS at a rate of 4 liters ha^{-1} and hand-weeding was done later as necessary. The morpho-agronomic traits of the test entries were evaluated according to the IRRI Standard Evaluation System for Rice.

Evaluation for resistance to major stresses

Drought resistance

Rice grown in upland and hydromorphic conditions in the humid forest, forest-savanna transition and savanna zones of West Africa may be subjected to varying degrees and durations of drought stress during the crop cycle. This results in yield reduction and sometimes total crop failure. To ensure yield stability, drought resistance is therefore required in upland and hydromorphic rice varieties.

In December 1993, 410 *O. glaberrima* and *O. sativa* accessions, previously identified as resistant to drought, were screened in the field to assess varietal differences in resistance and recovery abilities under drought conditions in the upland and hydromorphic ecosystems at M'bé. Located in the Guinea savanna climatic zone at 5°06'W and 7°52'N, the rainfall pattern at M'bé is bimodal (April to June, and September to October). The average annual rainfall and temperature are 1146 mm and 25°C, respectively.

All materials were screened for response to drought stress during the vegetative and reproductive stages. Two sets of test and check varieties were subjected to 35 days of moisture stress from 15 DAS (vegetative stage) or from 45 DAS (reproductive stage). This

Screening *Oryza glaberrima* and *O. sativa* for resistance to drought during the vegetative stage of growth

management conditions, the yield potential of *O. glaberrima* cultivars can exceed that of *O. sativa*. Landraces of *O. sativa* and *O. glaberrima* are well adapted to local conditions and show resistance/tolerance to major stresses such as drought, soil acidity and blast.

Varietal improvement of *O. glaberrima*

Although *O. glaberrima* has never been subjected to modern varietal improvement, early research showed that this species possesses traits which enable it to withstand certain environmental stresses, including drought, blast and soil acidity. It also has good grain quality properties, such as taste and aroma, and excellent vegetative growth which suppresses weeds (Koffi, 1980). Varieties capable of suppressing weeds are required in West Africa, where 80% of farmers in upland and rainfed lowland areas are unable to ensure timely and complete weeding because of family labor and farm resources constraints. It has also been reported that varieties of *O. glaberrima* compete more effectively with weeds than *O. sativa*, as they tend to produce more tillers (Koffi, 1980).

Unfortunately, *O. glaberrima* has many undesirable traits which result in low yield potential. Its grain shatters easily and has long dormancy. The weak stems lodge easily. Past efforts to transfer useful genes from *O. sativa* into *O. glaberrima* have had limited success, primarily because of sterility problems. In spite of the strong sterility barriers, the gene flow of *O. glaberrima* and *O. sativa* or *O. longistaminata* has been thoroughly analyzed at ORSTOM by Second (1984) and De Kochko (1987), who recommended the exploration of this species as a tool for introducing new variability into upland rice. Although the grain yield of *O. glaberrima* is generally low, the species can be used in hybridization with *O. sativa* to incorporate genes for resistance/tolerance to major stresses, as well as for rapid and vigorous vegetative growth.

WARDA breeders recently initiated research activities to gain a better understanding of the useful traits of *O. glaberrima* germplasm and to exploit it in an applied hybridization program targeting the upland and rainfed lowland ecosystems. The objectives of this work are to:

- determine the genetic variability in the *O. glaberrima* and *O. sativa* collections
- screen available germplasm for morphological and agronomic traits that are important for the breeding program; this work includes studies on resistance to diseases and pests and on adaptation to adverse soil conditions
- compare and broaden the genetic diversity of each varietal type through intraspecific and interspecific hybridization and the use of anther culture as a breeding tool
- explore the possibility of alien gene introgression for increased biomass to suppress weeds, increased grain yield, enhanced drought tolerance and disease and insect pest resistance, and better grain quality

RESEARCH APPROACHES

The WARDA upland rice breeding program at M'bé, Côte d'Ivoire has over 5000 accessions of mainly upland rice germplasm maintained as a working collection in a short-term storage facility. The accessions include donations from IITA, IRAT and IRRI. All accessions have been characterized for morphological traits and screened for resistance to drought, blast and insect pests. Promising selections have been used in the hybridization program.

Morpho-agronomic characterization of *O. glaberrima* and *O. sativa* accessions

The WARDA collection includes 1721 upland accessions (1130 *O. glaberrima*, 316 improved *O. sativa* and 275 traditional *O. sativa*). The *O. glaberrima* and traditional *O. sativa* accessions were collected from 14 African countries between 1985 and 1990 (*see* Table 2).

CHARACTERIZATION AND UTILIZATION OF *ORYZA GLABERRIMA* IN UPLAND RICE IMPROVEMENT

M.P. Jones, E.A. Heinrichs, D.E. Johnson (NRI) and C. Riches (NRI)

Rice is grown under various agro-climatic conditions in West Africa. Grain yields are constrained by unfavorable weather and water and soil conditions, several diseases and some major insect pests. Variability in such traits as resistance/tolerance to drought, soil acidity, rice blast, rice yellow mottle virus (RYMV), stem borers and African rice gall midge is limited in the widely cultivated species, *Oryza sativa*. The species *O. glaberrima* and its wild relatives represent an invaluable reservoir of useful genes for many of these traits.

Since 1991, WARDA breeders have increasingly exploited *O. glaberrima* in applied varietal improvement research. The research has included characterization for morphological traits, screening for resistance to some environmental stresses and hybridization with *O. sativa*.

ORYZA SPECIES IN AFRO-TROPICAL REGIONS

Twenty species of rice have been identified in the genus *Oryza*, of which eight are indigenous to Africa (*see* Table 1). In addition to *O. glaberrima*, the indigenous domesticated species, *O. sativa*, the Asian domesticated species, is also widely grown by African farmers. The wild *Oryza* species indigenous to Africa include *O. barthii*, *O. longistaminata*, *O. punctata*, *O. eichingeri* and *O. brachyantha*. All these species are diploid except *O. punctata*, which is both diploid and tetraploid (Takeoka, 1965; Chang, 1975; Ng *et al.*, 1983). The chromosome number, genome grouping and geographical origin of the cultivated and wild *Oryza* species are given in Table 1.

Origin and cultivation of *O. glaberrima*

The African rice, *O. glaberrima*, is endemic to West Africa. Known to have been selected and cultivated in parts of West Africa more than 3500 years ago (Jacquot, 1977; Carpenter, 1978), it probably developed independently, domesticated from a wild progenitor, *O. barthii* (syn. *O. breviligulata*) (Jacquot, 1977). It is believed to have originated (or been first domesticated) in the upland delta area of the Niger river, whence it spread through the upper Niger valley and delta, and then westwards to the Senegal valley and Casamance (Ng *et al.*, 1991).

Oryza glaberrima is cultivated across a wide range of ecosystems in West Africa: in deep water, shallow water, mangrove swamps, hydromorphic conditions and upland conditions. Studies of its genetic diversity indicate that there are two major groups, the floating type and the upland type. In some areas in West Africa, farmers still grow mixed proportions of *O. glaberrima* and *O. sativa* (approximately 15-20% of the total rice area), while in other areas *O. glaberrima* is grown alone (10-15%). Under poor

TABLE 1: The species of *Oryza* in Africa

Species	2n	Genome	Origin
O. sativa cultivated	24	AA	Asia
O. glaberrima cultivated	24	A^gA^g	West Africa
O. stapfii (weed species)	24	A^gA^g	West Africa
O. barthii	24	A^gA^g	West Africa
O. longistaminata	24	A^1A^1	Tropical Africa
O. brachyantha	24	FF	West and Central Africa
O. eichingeri	24	CC	East and Central Africa
	48	BBCC	
O. punctata	24	BB	Tropical Africa
	48	BBCC	
O. schwein furthiana	48	BBC	Tropical Africa

Source: Adapted from Ng *et al.* (1983), Takeoka (1965)

Physiological studies in the Sahel Irrigated Rice Program are unravelling the complex climatic and edaphic factors underlying the instability of rice grain yields in the Sahelian zone. These studies are also guiding the development of new breeding strategies and varietal selection criteria. Models based on this work have led to the development of new management tools to help researchers and development workers target varieties to appropriate locations and modify cropping calendars.

Funding for the Mangrove Swamp Rice Network, established in 1990 to consolidate the gains from mangrove swamp rice research and enhance the capacity of national programs to respond to the needs for sustainable increases in rice production in mangrove swamp environments, came to an end in 1993. Consideration is being given to providing facilities for Task Force activities for these environments.

WARDA continues to benefit from close collaboration with partners within and outside West Africa. Two new thematic research Task Forces were formed in 1993: the Rice Economics Task Force, bringing together national social scientists from 15 countries, and the Problem Soils Task Force, involving researchers from 12 countries. Among the existing Task Forces, objectives have now been more clearly defined, the quality of work conducted in collaborative projects has improved, and national scientists are taking a leading role in Task Force activities. The increased level of these activities was made possible through major new support from USAID in 1993, in addition to the support provided by the AfDB, EEC and IDRC for research conducted in partnership with national programs.

Collaboration with advanced research institutes outside the region also grew in 1993. A new joint initiative was launched between WARDA and CAB International on the African rice gall midge, involving the recruitment of an ODA-supported entomologist to work with the WARDA lowland breeder at IITA in Nigeria. A physiologist from the University of Hamburg, Germany joined the Sahel Program to reinforce a GTZ-funded project on rice plant tolerance to salinity, and an NRI weed scientist, with support from ODA, continued with his work for the second year at M'bé.

The number of African research scholars working for higher degrees under the supervision of WARDA scientists increased to 14 in 1993, with nine new students beginning their thesis-related field work. Five students supported by AfDB fellowships are working in economics, two in breeding, and one each in physiology and soil chemistry. Working with these students not only reinforces WARDA's on-going research efforts but also enables us to establish close personal and professional ties with the students' respective national programs.

RESEARCH

OVERVIEW

Peter J. Matlon
Director of Research

WARDA's research activities in 1993 expanded considerably, collaboration with national and international partners became more dynamic and the involvement of young African scholars in the core research programs grew substantially. This report reflects not only the increased pace of our research, but also the significant progress being made.

The need for such progress to help African rice farmers improve their productivity while conserving their resource base for future generations has never been greater or more urgent. The demand for rice continues to grow at almost 5% annually among urban and rural populations and across income groups, including the very poor. Pressure on the land continues to rise, and there is now increasing evidence of severe degradation of fragile upland ecosystems. An effect of the structural adjustment programs introduced in most West African countries has been substantial increases in rice prices and the costs of imported inputs, creating new market opportunities but also new threats to the long-term quality of the resource base.

WARDA scientists, in collaboration with our many partners, are working to respond to these new challenges. Basic studies on soil chemistry in the Upland/Inland Swamp Continuum Program are helping us to gain a better understanding of how soils evolve as production systems intensify, and the results are already pointing towards improved soil management practices. Surveys in farmers' fields, in conjunction with controlled research station experiments, are greatly increasing our knowledge of the dynamics of rice pests and their natural enemies and why farmers use pesticides. Such information is critical for the development of environmentally friendly integrated pest management (IPM) strategies suited to the region's rice farmers.

WARDA plant breeders have made substantial progress in interspecific hybridization, with fertile populations from *Oryza sativa* x *O. glaberrima* crosses now in the F_4 generation after two backcrossings to *O. sativa*. The populations include a significant percentage of intermediate types that combine the earliness, seedling vigor, high tillering and weed suppression traits of *O. glaberrima* with the panicles and grain type characteristic of *O. sativa*. On the basis of this work, we hope to develop materials that are better adapted to the management practices of resource-poor farmers and higher yielding than currently available local germplasm. During the year, encouraging progress was also made in our conventional breeding work. As a result of regional trials and on-farm tests, a new generation of high-yielding and stress-tolerant varieties will soon be released to farmers for upland, lowland and irrigated Sahelian ecosystems.

Calendar of Events in 1993

January

5-25 WARDA External Program/Management Review (EP/MR): Main Phase at WARDA
22 External Audit
24-29 Board of Trustees meeting, M'bé
26 Nominating Committee meeting, M'bé
27 Program Committee meeting, M'bé
28 Executive Committee meeting, M'bé
29-30 Medium-Term Plan (MTP) 1994-98 Working Party meetings, M'bé

February

11-13 Visit to WARDA by Dr M. Jackson (Head of GRU) and Dr K. Alluri (INGER-Africa)
18-19 Soils Task Force meeting, M'bé
22-23 Upland Task Force meeting, M'bé
24-25 Lowland Task Force meeting, M'bé
26-27 IPM Task Force meeting, M'bé

March

1 Program Management Committee meeting, M'bé
1-28 Training course, M'bé: Development of training materials
4 General staff meeting, M'bé
8-9 Mangrove Task Force meeting, Rokupr, Sierra Leone
22 TAC Working Group discussion on WARDA EP/MR, Rome, Italy
25 Presentation of MTP to TAC, Rome, Italy
29-31 Joint Task Force Steering Committee meeting, M'bé

April

1-2 Varietal Improvement Working Group meeting, M'bé
2-3 Crop and Resource Management Working Group meeting, M'bé
5-8 Soils Task Force Steering Committee meeting, M'bé
15-16 Economics Task Force meeting, M'bé
21-22 Visit to WARDA by Abidjan-based African Ambassadors
23 Reception Definitive of MRC & HQ and Tenders Committee meeting, M'bé
27-28 Visit to WARDA by Dr G. Gryseels (Deputy Executive Secretary, TAC) and Dr M. Collinson (Scientific Adviser, CGIAR Secretariat)

May

3-29 Training course, Kumasi, Ghana: Rice research techniques
10-12 Sahel Task Force meeting, St Louis, Senegal
24-28 DG and DR attend CGIAR mid-term meeting, San Juan, Puerto Rico; presentation of MTP

June

7 Program Management Committee meeting, M'bé
8-10 IVC meeting, M'bé
21-24 Training course, M'bé: Rice production and research

July

21-24 IVC Interim Steering Committee meeting, M'bé
22-24 DG attends ECOWAS Heads of State meeting, Cotonou, Benin

August

19 Experts Committee meeting, Council of Ministers
20 Inauguration of WARDA's MRC & HQ and Council of Ministers meeting

September

10 WARDA Open Day for AfDB representatives and Abidjan-based Ambassadors from donor countries
17 WARDA Open Day for Ambassadors from Nordic countries
21 Visit to WARDA by German Ambassador
30 Program Management Committee meeting, M'bé

October

1 WARDA Open Day, attended by representatives of IDESSA and the Ministry of Agriculture and Scientific Research, Côte d'Ivoire
4-6 Economics Task Force Steering Committee meeting, M'bé
4-12 Nov Training course, Garoua, Cameroon: Rice agronomy
6-8 Visit by DG and Board of Trustees chairman to Scandinavian donors
23 Board of Trustees Executive Committee meeting, Washington DC, USA
23 DG and DR attend International Centers Week 1993, Washington DC, USA

November

2-5 DTC attends IARCs Africa Workshop on Training Materials Development and IARCs Africa Training Officers meeting, ICRAF, Kenya
5 Visit to WARDA by DGISP representatives
17-21 DTC attends IFS Symposium and General Assembly, Antananarivo, Madagascar
22-3 Dec Training course, Rokupr, Sierra Leone: Mangrove rice production

December

2-3 Visit to WARDA by officials of the Republic of China (Taiwan)
7-12 DR attends SPAAR Advisory Committee meeting, IITA, Ibadan, Nigeria

Council of Ministers

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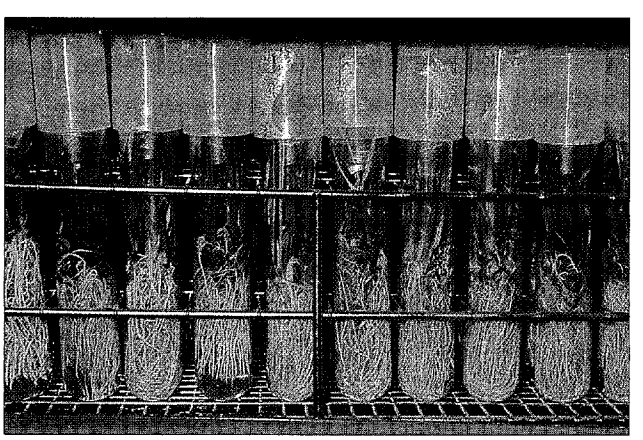
zones of West Africa, and in certain areas causes serious crop losses. To identify sources of host plant resistance, 40 lines of *O. glaberrima* were screened as possible hosts of *S. aspera* and *S. hermonthica* in glasshouse pot experiments at Long Ashton Research Station, UK.

Hybridization

In 1992, we initiated a program of wide crossing between *O. sativa* and *O. glaberrima* to incorporate genes for rapid vegetative growth and drought resistance into improved *O. sativa* varieties. In 1993 we continued the search for new donors of *O. sativa* (*japonica* and *indica*) and *O. glaberrima* origin with desirable traits in order to diversify and broaden the genetic base of new breeding materials.

Fifteen successful single crosses and backcrosses were made to incorporate genes for appropriate plant type to compete with or suppress weeds and for blast, drought and insect resistance. Backcrosses and F_1, F_2 and F_3 populations were grown in the field and modified bulk and pedigree selections were made. Anthers from 15 selected plants from the backcross, F_1, F_2 and F_3 populations were cultured to investigate the high percentage sterility observed. Modified N6 and MS media were used for callus induction and green plant regeneration/rooting.

Anther culture, being used to obtain homozygous lines rapidly in F_1 and F_2 populations of *Oryza sativa* x *O. glaberrima*, *japonica* x *japonica* and *japonica* x *indica* crosses



RESULTS AND DISCUSSION

Diversity of *O. glaberrima* and *O. sativa*

Our characterization work showed that there is very wide variation in important morphological and agronomic traits within both the *O. glaberrima* and the traditional and improved *O. sativa* accessions.

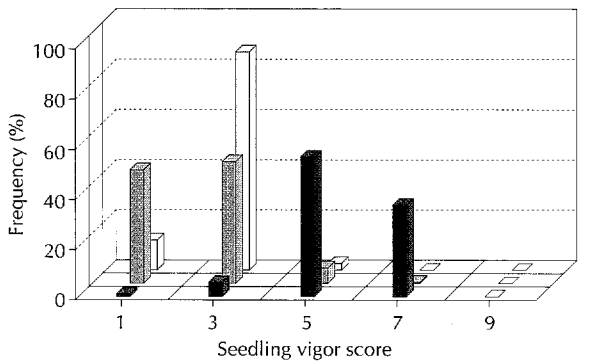
Seedling vigor

Considerable variation in seedling vigor was observed within each varietal group (*see* Figure 1 *overleaf*). However, over 90% of the *O. glaberrima* and traditional *O. sativa* accessions screened scored 3 or less, indicating very high seedling vigor. Among the improved *O. sativa* materials, only 5% scored 3 or less. A few accessions of *O. glaberrima*, such as 1B19 and Biyagero, had very rapid vegetative growth and produced a large number of tillers and droopy lower leaves within 20-30 DAS, resulting in rapid ground cover and good weed suppression. It was also noted that *O. glaberrima* has the ability to compensate for weed competition in the early stages of crop growth by late tillering (30-60 DAS) after the crop has been weeded.

Growth duration

The number of days from planting to maturity for all accessions and the frequency distribution in each varietal type is given in Figure 2 *(overleaf)*. Over 80% of the traditional *O. sativa* accessions had medium to long duration (120-140 days). Among the improved *O. sativa* accessions, the distribution tended to cover a narrow range (most entries 80-120 days). In the *O. glaberrima* accessions there was a much wider range (about 85 days between the minimum and maximum values). We identified several *O. glaberrima* accessions with very early duration (about 75 DAS to maturity); these included Gbondobai, OG7, Zaria(3), 113 90 and UG24(2), all of which will be exploited in the breeding program as donors for earliness. The merit of early-maturing rice varieties is that they may escape drought in drier areas, while in more humid areas they will escape

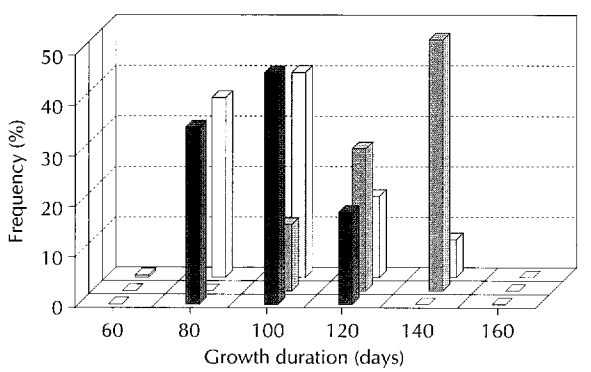
FIGURE 1: Frequency distribution and statistics for seedling vigor of *Oryza glaberrima* and traditional and improved *O. sativa*



Glaberrima	11.0	87.0	2.1	0.0	0.0
Trad. *sativa*	45.0	48.5	6.2	0.4	0.0
Imp. *sativa*	0.6	5.4	56.3	37.6	0.0

- *O. glaberrima* (mean 4.8, max. 1, min. 7, no. 1119)
- Traditional *O. sativa* (mean 2.2, max. 1, min. 7, no. 275)
- Improved *O. sativa* (mean 5.6, max. 1, min. 7, no. 316)

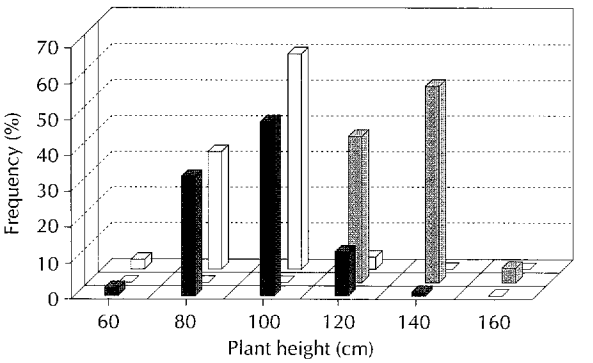
FIGURE 2: Frequency distribution and statistics for growth duration of *Oryza glaberrima* and traditional and improved *O. sativa*



Glaberrima	0.4	35.8	40.8	16.3	6.5	0.1
Trad. *sativa*	0.0	0.0	13.4	38.5	48.0	0.0
Imp. *sativa*	0.0	35.5	46.0	18.4	0.0	0.0

- *O. glaberrima* (mean 107.3, max. 160, min. 75, no. 1096)
- Traditional *O. sativa* (mean 133, max. 150, min. 105, no. 273)
- Improved *O. sativa* (mean 107.7, max. 137, min. 88, no. 315)

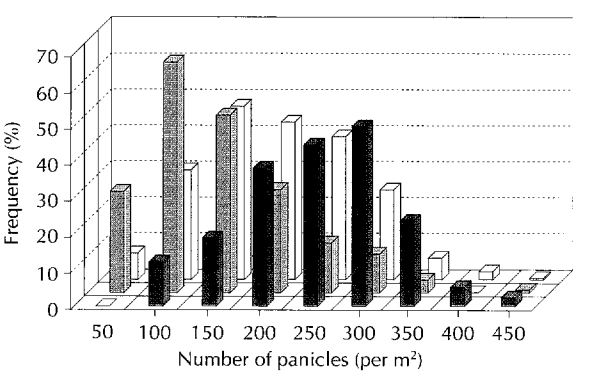
FIGURE 3: Frequency distribution and statistics for plant height of *Oryza glaberrima* and traditional and improved *O. sativa*



Glaberrima	3.0	33.5	59.8	3.6	0.0	0.1
Trad. *sativa*	0.0	0.0	0.0	40.5	55.3	4.2
Imp. *sativa*	2.2	34.3	49.5	13.0	0.9	0.0

- *O. glaberrima* (mean 102.4, max. 138, min. 65, no. 1108)
- Traditional *O. sativa* (mean 141.5, max. 182, min. 80.4, no. 273)
- Improved *O. sativa* (mean 104.9, max. 145.9, min. 72.6, no. 315)

FIGURE 4: Frequency distribution and statistics for number of panicles of *Oryza glaberrima* and traditional and improved *O. sativa*



Glaberrima	3.7	14.8	23.9	21.6	19.8	12.3	2.8	1.0	0.1
Trad. *sativa*	14.7	32.0	24.4	14.7	6.8	5.3	1.9	0.0	0.4
Imp. *sativa*	0.0	6.4	10.0	19.2	22.7	25.5	12.1	2.5	1.6

- *O. glaberrima* (mean 220.7, max. 477, min. 49, no. 1108)
- Traditional *O. sativa* (mean 165.6, max. 476, min. 6, no. 275)
- Improved *O. sativa* (mean 276.6, max. 531, min. 30, no. 315)

late-season fungal diseases such as blast, glume discoloration and sheath rot.

Plant height

The traditional *O. sativa* accessions are generally tall-statured types (over 120 cm) (*see* Figure 3). They can lodge easily, especially under high soil fertility conditions, resulting in a grain loss of 10% to over 50%, depending upon the time at which the crop lodges. Most of the *O. glaberrima* and improved *O. sativa* accessions are intermediate-statured types (80-100 cm). Although it has been shown that most of the improved varieties are resistant or moderately resistant to lodging (Jacquot, 1977), *O. glaberrima* materials have a weak and brittle culm that sometimes causes them to lodge easily during the late vegetative stage of growth. Some *O. glaberrima* materials rated as resistant to lodging, such as Old Ayoma, Fufore-Yola, UG75(1), UG75(2), NG26(3), CG66, Katsina Ala and Shendam, are short to intermediate in stature and have a stiff culm, and could serve as donors for these traits in breeding programs.

Number of panicles

Considerable variability was observed in the number of panicles for each varietal type (*see* Figure 4). Panicle production was highest in improved *O. sativa* accessions (an average of 277 panicles per m^2). The average number in *O. glaberrima* and traditional *O. sativa* was 221 and 166, respectively. However, we identified several *O. glaberrima* and traditional *O. sativa* accessions with a higher number of panicles than in the improved varieties. The accessions Barta Tazo(1), Demsa-Yola, MF13(1), Dan Mauya and Barta(9) all had more than 400 panicles per m^2. We plan to use these materials as donors for this trait.

Evaluation for resistance to major stresses

Drought resistance

Our drought screening trial showed that the *O. glaberrima* and *O. sativa* accessions varied in their response to drought stress imposed during the vegetative stage. There was considerable variation in visual scores for seedling vigor, tillering ability, leaf tip burn and drought resistance among the accessions *(see* Figure 5 *overleaf)*. The resistant check, OS6, gave an average rating of 3 for the visual drought score. There were 32 *O. glaberrima* and 30 *O. sativa* accessions with scores of 0 or 1 (highly resistant), and 217 *O. glaberrima* and 18 *O. sativa* accessions with scores of 2 or 3 (moderately resistant). The remaining entries exhibited low resistance.

For comparative purposes, 15 *O. sativa* varieties currently recommended or recently developed for drought resistance were included in the screening. These varieties were all classified as moderately resistant or susceptible, with visual scores of 3. Several extensively cultivated local varieties, including Lac 23, ROK6, ROK3, Moroberekan and M22, were also classified as moderately resistant.

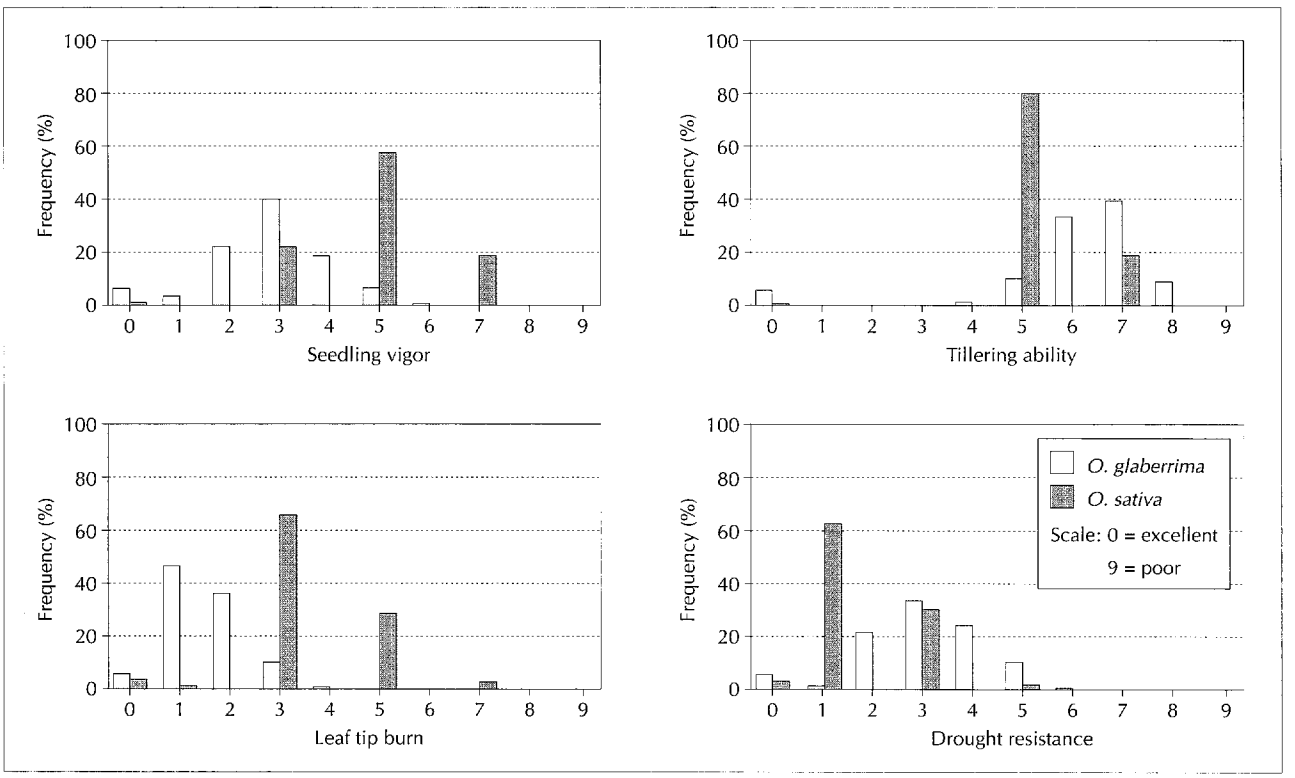
The results for seedling vigor, tillering ability and leaf tip burn showed that most upland improved and traditional rice varieties of *O. sativa* origin have low or moderate drought resistance. The finding that *O. glaberrima* accessions had higher levels of resistance than some of the best improved *O. sativa* varieties indicates the potential for producing improved varieties with better resistance through hybridization, using *O. glaberrima* as a parent.

Insect resistance

The African rice hispa can devastate rice plants during the vegetative stage in hydromorphic and lowland rice conditions. Of 136 *O. glaberrima* accessions screened, 13 had a high level of resistance, with at least one replication having a rating of 3 or less. These accessions were TOG5477, TOG5749, TOG6219, TOG6374, TOG6383, TOG6530, TOG6589, TOG6594, TOG6683, TOG6687, TOG6693, TOG6725 and TOG7137; accession TOG6383 had the lowest damage rating. These accessions, and additional *O. glaberrima* accessions, will be evaluated in 1994.

In the stem borer test, 61% of the *O. glaberrima* accessions had a rating of 1 in at least one replication; of

FIGURE 5: Frequency distribution of various traits for *Oryza glaberrima* and *O. sativa* after 35 days of exposure to drought stress during the vegetative growth stage



these accessions, 28 were resistant or moderately resistant in all four replications, and will undergo further evaluation in 1994 to confirm the resistance. Studies to identify new sources of resistance from *O. glaberrima* and *O. sativa* will continue in 1994.

Disease resistance

Leaf and neck rice blast occurs in most rice-growing areas in West Africa. Of the 123 *O. glaberrima* entries screened, 14 were rated as resistant, 46 moderately resistant and 63 susceptible. Several resistant entries, including TOG6701, TOG7264, TOG6690 and TOG7386, had symptoms similar to those in *O. sativa* landraces (OS6, Moroberekan, Lac 23 and 63-83) classed as having durable resistance to blast. In extensive studies conducted by Bidaux (1978) in Côte d'Ivoire, it was concluded that many traditional *O. sativa* upland varieties have non-specific and polygenic resistance similar to horizontal resistance. This resistance was different from the race-specific monogenic or vertical resistance found in most improved *O. sativa* materials. Studies in 1994 will assess whether horizontal (durable) or vertical blast resistance characterizes the resistant and moderately resistant *O. glaberrima* entries identified.

Resistance to parasitic weeds

Three months after sowing 40 lines of *O. glaberrima* and *O. sativa* check varieties in the experiment to screen for hosts of the parasitic weeds *Striga aspera* and *S. hermonthica*, the *O. sativa* lines were highly infested with both species. However, 18 *O. glaberrima* lines remained free of *S. aspera* and three appeared to be resistant to *S. hermonthica*. Further screening of *O. glaberrima* and *O. sativa* lines will be conducted in Côte d'Ivoire and the UK in 1994.

Interspecific hybridization

Since 1992, 48 crosses have been made involving *O. glaberrima* and *O. sativa*. Seventeen of these crosses were successful and, after two backrosses, F_4 progenies have been monitored.

Interspecific hybridization for plant improvement is complicated by the presence of some incompatibility barriers, such as hybrid inviability. These barriers hinder heterogenetic recombination. We have observed that crosses involving *O. sativa* and *O. glaberrima* have very high sterility (90-95%) in the F_1 and early generations. However, fertility (1-5%) was obtained in F_1 hybrids, from which the following *O. glaberrima* accessions were used as one of the parents: CG14, CG20, T2, YG230 and YG170. Fertility was retained and improved (5-95%) after two backcrossings. The following tendencies were observed among the populations in advanced generations:

- the distribution of genotypes was strongly skewed towards the parental types; this shift was considerably accelerated when backcrossing was made with the recurrent parent
- although true intermediates were generally rare, their occurrence in some populations, such as WAB449 and WAB450, was as high as 30%
- seed shattering in the intermediates was high and occurred very early during the ripening stage of growth
- the fertility of true intermediates was generally low, suggesting a gradual elimination of heterozygotes and thus a gradual reduction of recombination; however, for a few crosses, such as WAB449 and WAB450, fertility tended to increase with each generation
- desirable morphological traits introgressed from *O. glaberrima* into 74 populations included early maturity (75-100 days), rapid seedling growth and high tillering; fixed populations with these desirable traits have been selected for yield trials
- most progenies, including some of the intermediates, were characterized by a weak culm
- high callus efficiency, plantlets and plants were obtained by applying anther culture to select individuals from backcross, F_1 and F_2 populations of *O. sativa* and *O. glaberrima* (that is, WAB56-50 x SG329)

Progenies of *Oryza sativa* and *O. glaberrima*, showing important traits for weed suppression (rapid vegetative growth, lower droopy leaves and high tillering)

FUTURE PROSPECTS

In these studies, 1130 accessions of *O. glaberrima* and 5912 accessions of *O. sativa* were characterized for 43 morphological traits. A number of accessions with resistance to stresses such as drought, blast and stem borers have been identified and are now being used in the breeding program. Interspecific hybridization of *O. sativa* and *O. glaberrima* is showing some success.

Oryza glaberrima is a rich source of useful genes for a range of economically important characters. Interspecific hybridization between *O. sativa* and *O. glaberrima* has great potential for broadening the

genetic base of cultivated germplasm for the subsequent development of improved varieties. It is likely that *O. glaberrima* could serve as a source of increased biomass and grain yield, improved grain quality and resistance/tolerance to major stresses, including blast and drought. To exploit the potential of this species, it is necessary to conduct further evaluation of available germplasm for a number of important morpho-agronomic traits and for resistance/tolerance to major stresses. A better understanding of the physiology and ecology of the material is also required for more successful inter-specific breeding. It will also be necessary to characterize alien gene introgression through isozyme analysis and to examine the crossability, genetic homoeology and nuclear stability of hybrid progenies. The possibilities of alien gene transfer through tissue culture of wide hybrids should be further explored.

In the immediate future our work will focus on :

- identifying useful variability in the *O. sativa* and *O. glaberrima* species for tolerance/resistance to major biotic and abiotic stresses such as blast, drought and acidity

- producing additional hybrids between the breeding lines and *O. glaberrima*, particularly those possessing useful variability for resistance to abiotic stresses, RYMV and gall midge; priority will be given to incorporating genes for drought resistance/tolerance into improved rice varieties

- tagging introgressed segments with molecular markers, in collaboration with IRRI and advanced laboratories in France and the USA.

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DEVELOPING BETTER ADAPTED AND HIGH-YIELDING RICE VARIETIES FOR THE SAHEL

M. Dingkuhn, K.M. Miézan and F. Asch

Unlike other rice-growing ecosystems in Africa, rice grown under irrigated conditions in the Sahel is based on intensive and technologically advanced production methods. The investment in irrigation infrastructure and maintenance requires high average yields and the sustainable use of the natural resource base. The recent economic reforms in much of West Africa have meant that greater risk now has to be borne by small private producers, and thus high yield stability which provides a steady income for farmers has become particularly important.

Irrigated rice production in the Sahel has no traditional germplasm and practices upon which to build. Most farmers are first- or second-generation rice producers who, until recently, operated within the rigid framework set by parastatals. Germplasm supplied by the parastatals was selected mainly for high yield potential and had a narrow genetic base. Most varieties were medium-duration *indica* types which performed well in the main wet season but had excessively long duration and water consumption in the dry season. This led to serious time constraints under rice-rice double cropping, a system strongly encouraged by parastatals and national development programs but not widely adopted by farmers.

Among the first widely adopted varieties was IR8 which, unlike the situation in monsoonal Asia, was not threatened by Tungro virus and is still present in the Sahelian region. However, the main successors of IR8 in Asia, such as IR20, IR36, IR64 and IR72, are not grown by Sahelian rice farmers. Most currently dominant varieties in the Sahel were selected in regional trials coordinated by WARDA in the 1980s; these include BG90-2 from Sri Lanka, IR1529-680-3, IR28 and IR46 from IRRI, and I Kong Pao (IKP) from Taiwan. The most successful variety in Senegal, Jaya, was introduced from India by a local parastatal. The adoption patterns of these varieties do not appear to reflect the characteristics of ecosystems or

Smallholder farmers harvesting rice in Burkina Faso

production systems. Instead, they tend to follow political boundaries: BG90-2 dominates in Mali (over 90% of the cultivated area), IR46 in Chad and Sahelian Cameroon, IR1529-680-3 in Niger (100%) and, until recently, 4456 in Burkina Faso (it has now been replaced by ITA123 from IITA). Varietal diversity is greatest in the Senegal river delta, where WARDA's Sahel Irrigated Rice Program is based. Important varieties in Senegal are Jaya, IR1529-680-3, IR8 and SIPI6920 (medium duration) and IKP and Aiwu (short duration).

Thus, although WARDA's past varietal improvement project had a strong impact in the Sahel, despite coordinated trials across the region it failed to increase varietal diversity in zones geographically removed from the center of coordination. WARDA's Sahel Program, which was restructured in 1990,

seeks to continue the successful breeding work but with the introduction of four significant changes:

- new research foci on key stresses and constraints to production, with the emphasis on developing morpho-physiological ideotypes to guide breeders
- full integration of breeding activities with physiological, agronomic and ecological research by linking the breeding project to an agro-ecological characterization project for the region
- full regional integration and interaction with national programs through the Task Force mechanism and a new regional network for agro-ecological research at benchmark sites
- the extensive use of systems analysis tools for regional extrapolation of information, yield gap analyses, testing variety x cropping system scenarios, and integrating disciplinary work.

INTEGRATED APPROACH TO VARIETAL IMPROVEMENT

The most important environmental factors limiting rice yields are low temperatures during seedling and reproductive stages, soil salinization or sodification, weed infestation and bird damage (*see* Table 3). These stresses, however, are unevenly distributed across seasons and sites. Cultural factors such as cropping intensity and planting method modulate the intensity of environmental stresses.

Sustaining yields at 5-7 t ha^{-1} requires a high level of crop resistance (avoidance or tolerance) to prevailing stresses or reliable temporal escape mechanisms. An agro-ecological characterization study conducted by WARDA in 1991-93 showed that the most promising way to sustain high yields is to develop appropriate site-specific combinations of cultural methods, cropping calendars and genetic materials.

WARDA's integrated approach to breeding, eco-physiology and cropping systems research is structured as a matrix (*see* Figure 6). The matrix was implemented in 1991 and represents a framework for long-term work. It aims at developing high-yielding genotypes adapted to the cultural practices and the mainly abiotic stresses present in the Sahel. The improved varieties are matched with existing or modified cropping calendars using simulation tools, and on this basis environment-specific technology packages are formulated. Through the Sahel Irrigated Rice Improvement Task Force, national scientists are directly involved in these processes.

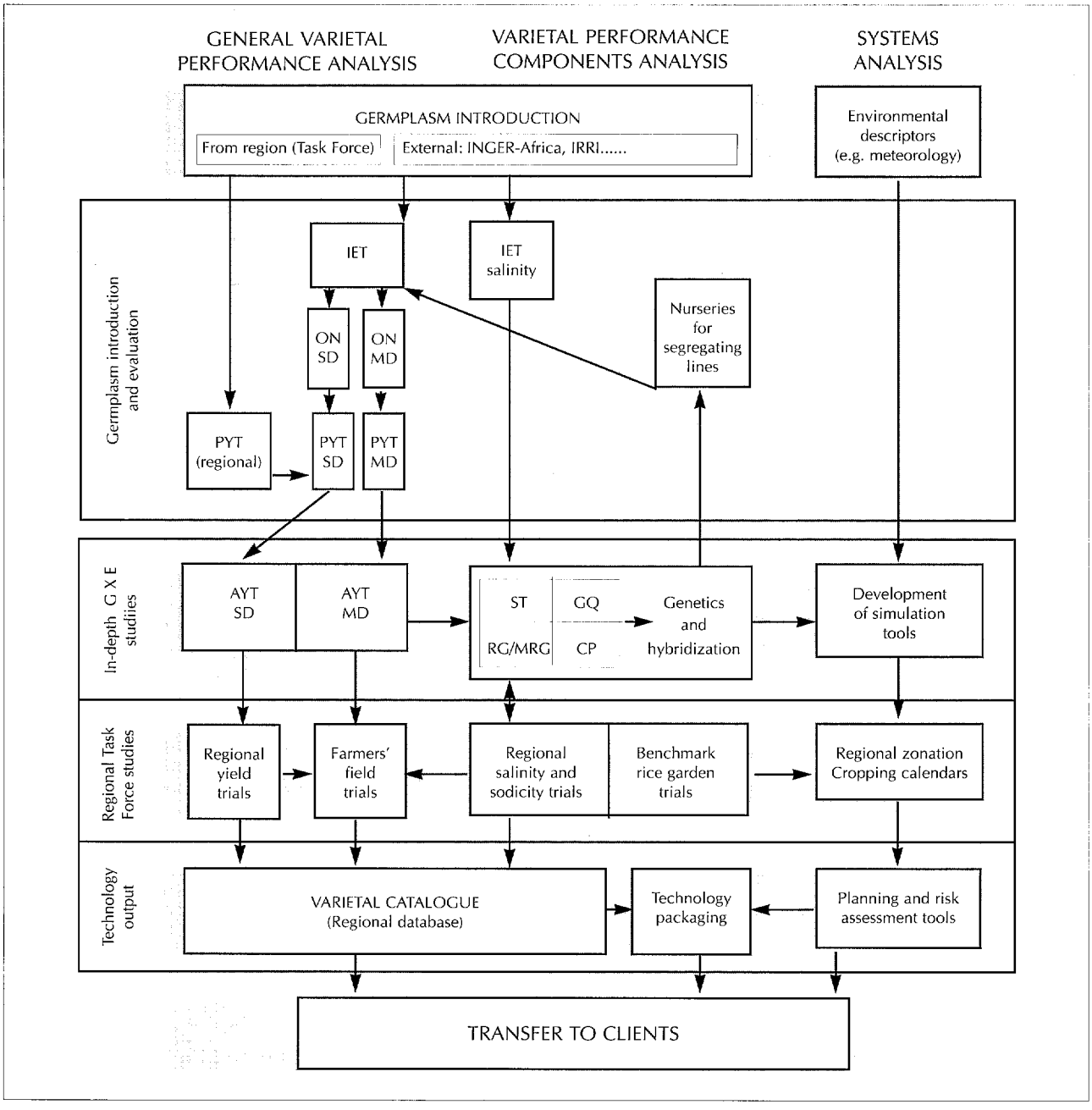
The vertical elements of the matrix represent a sequence of activities: on-station varietal evaluation

TABLE 3: Weighting of some environmental constraints to irrigated rice production in the Sahel as a function of seasonal and cultural factors

	Seasonal problems[a]			Aggravated by[a]			
Stress factor	CDS	HDS	WS	poor WM	long CD	RR	DS
Cold nights (seedling stage)	++[b]	+	0	0	0	++	0
Cold nights (reproductive stage)	+	0	+	0	+++	+++	0
Hot days (reproductive stage)	0	++	0	0	+	+	0
Salinity/sodicity (evaporative residues)	++	++	+	++	0	0	0
Salinity/sodicity (rising groundwater)	++	++	+	++[c]	++[c]	++[c]	0
Weed infestation	+	+	+	+++	0	+	++
Bird damage	++	++	+	0	0	++	++

Note: a CDS = cold-dry season; HDS = hot-dry season; WS = wet season; WM = water management; CD = crop duration; RR = rice-rice double cropping; DS = direct seeding
b 0 = neutral; + = yield reduction; ++ = severe yield reduction likely; +++ = possibility of total crop failure
c Effects with long-term environmental consequences

FIGURE 6: Matrix for the interdisciplinary and regional integration of WARDA's rice research activities for the Sahel



Vertical boxes (colour) = parallel, complementary approaches. Horizontal boxes (clear) = logical sequence of activities, from exploratory research to technology transfer. White boxes = specific activities. Arrows = flow of germplasm and information.

AYT	=	advanced yield trials	ON	=	observational nurseries
CP	=	cultural practice trials	PYT	=	preliminary yield trials
GQ	=	grain quality studies	RG/MRG	=	rice garden/mini-RG trials
IET	=	initial evaluation trials	SD	=	short-duration varieties
MD	=	medium-duration varieties	ST	=	salinity trials

(two sites in Senegal), on-station studies on genotype x environment (G x E) interactions, region-wide experimental and extrapolative studies with national programs, and technology packaging. The horizontal or disciplinary categories of research include general performance-based yield trials, in-depth analyses of components for varietal performance (physiology, agronomy and genetics), and systems approaches. Our research aims to produce:

- a catalogue of genotypes adapted to the Sahelian environment which comprises a comprehensive database on agronomic, physiological and grain quality-related properties
- site-specific technology packages comprising genotype, crop calendar and cultural components
- systems analysis tools to assess climatic risks and the potential performance of site x technology scenarios

About 80% of our experimental activities are multi-annual. This is because varietal selection and eco-physiological characterization trials are based on a continuous flow of germplasm, and the climatic variability of the Sahel is such that one-time observations are unreliable, even if they are replicated.

The main elements of on-station research are a hierarchical sequence of varietal yield trials (for example, advanced yield trials), several trials characterizing the morpho-physiological make-up of advanced selections, and specific trials to develop and calibrate crop models. Advanced materials pass through four eco-physiological experiments: a salinity trial to quantify component traits for salt tolerance, a set of 'rice garden' trials with monthly planting schemes to study responses of crop duration and growth to climatic stresses, a cultural practices trial comparing varietal performance under transplanted and direct-seeded practices, and studies on grain type and quality. Simplified versions of the advanced yield, rice garden and salinity trials are conducted in collaboration with national programs at benchmark sites across the Sahel. These sites are equipped with micro-meteorological monitoring devices. They also serve as nuclei for complementary activities of the Task Force, such as studies on soil degradation under intensive cropping and technologies to regenerate such soils.

An important and innovative element of WARDA's approach is the full integration of systems analysis tools. Models are employed at several levels: to understand morpho-physiological phenomena (for example, salt and water balance of rice plants), to characterize and classify genotypes (for example, genotypic constants governing crop duration) and to extrapolate temporal and spatial results (for example, testing cropping scenarios and regional zonation on the basis of simulated crop parameters). Derivatives of the models are used as risk-assessment and planning tools in rice cultivation.

In this article, we outline the key components of WARDA's varietal research program, and show how the results are aggregated to form technology packages suitable for transfer to rice farmers.

GENERAL VARIETAL PERFORMANCE AND YIELD TRIALS

A succession of varietal evaluation and yield trials forms the core of WARDA's breeding activities, as shown in Figure 6. Starting with the introduction of new materials from INGER-Africa and other sources, the genotypes pass through on-station initial evaluation trials, observational nurseries, and preliminary and advanced replicated yield trials. Each year a new set of materials enters this sequence, resulting in several simultaneous sets of preliminary yield and advanced yield nurseries. From the observational nurseries onwards, the nurseries are separated into two duration groups and tested at two sites (Fanaye and N'Diaye) in Senegal.

Genotypes maintained up to the advanced yield trial stage and the best-performing entries in the preliminary yield trial are characterized in separate experiments for grain quality, tolerance to climatic and edaphic stresses and performance under direct-seeded and transplanted conditions. Based on this characterization, they may or may not be used as parents in hybridization.

Simultaneously with the physiological characterization, selections from the advanced yield trial are tested at the Sahelian benchmark sites managed by the Task Force and in farmers' fields. Key descriptors for the best-performing entries then make up a varietal catalogue from which national programs and development projects and WARDA's external collaborators in research can select germplasm.

Table 4 presents the mean yields and some yield components for advanced yield nurseries in 1992 and 1993. Spikelet sterility was consistently higher and panicle number lower at Fanaye than at N'Diaye, due to the more arid climate at Fanaye. This resulted in lower yields at Fanaye, particularly for short-duration materials. Most entries in the medium- and short-duration nurseries for the wet season had higher yields than the local checks, Jaya

TABLE 4: Grain yield at 14% moisture, percentage spikelet sterility, panicle number and 1000-grain-weight as observed in three advanced yield trial nurseries in 1992-93, N'Diaye and Fanaye, Senegal[a]

	Grain yield (t ha^{-1})			% sterility			No. panicles (m^{-2})			1000-grain-weight		
Genotype	ND	FA	Av.	ND	FA	Av.	ND	FA	Av.	ND	FA	Av.
Medium duration WS[b]												
BW293-2	6.9	6.3	6.6	10	21	16	456	314	385	25	24	25
ITA306	6.4	6.7	6.6	16	17	16	371	270	321	28	27	27
ITA222	5.7	6.4	6.1	15	19	17	390	274	332	27	26	26
BG400-1	5.8	6.2	6.0	16	20	18	441	307	374	26	24	25
S449-B28	6.0	6.0	6.0	13	16	14	458	313	386	21	20	20
Jaya	5.7	6.0	5.9	9	23	16	387	259	323	25	27	26
IET279	5.4	6.2	5.8	7	14	11	356	269	313	23	22	23
IR4422-98-3-6-1	5.3	5.9	5.6	13	16	15	398	308	353	24	24	24
Mean	5.9	6.2	6.1	12	18	15	407	289	348	25	24	25
Short duration WS												
IR13240-108-2-2	8.1	6.2	7.1	16	16	16	452	329	391	24	23	23
32XUAN-5C	7.4	5.7	6.6	12	20	16	447	342	395	27	25	26
TNAU7893	7.7	5.4	6.5	12	19	15	474	323	399	24	22	23
RAU2004-6-69-2-1	7.2	5.4	6.3	21	24	22	446	333	390	22	22	22
IR50	7.0	5.5	6.3	12	13	13	620	371	496	22	19	20
ITA230	7.0	5.5	6.2	16	27	22	316	283	300	26	25	25
I Kong Pao	6.9	5.3	6.1	11	20	15	458	301	380	25	23	24
IR31785-58-1-2-3	6.5	5.3	5.9	13	31	22	607	375	491	23	25	24
Mean	7.3	5.6	6.4	14	21	17	471	329	400	24	23	24
Short duration HDS[c]												
IR13240-108-2-2	7.9	5.8	6.8	13	20	16	481	387	434	23	21	22
I Kong Pao	7.3	5.6	6.5	12	17	15	438	398	418	23	23	23
IR50	7.0	5.9	6.4	14	22	18	550	456	503	20	20	20
IR22107-14-2-1	7.0	5.7	6.4	11	20	16	529	461	495	23	23	23
IR39422-75-3-3-3	6.9	5.5	6.2	7	24	15	570	390	480	24	23	23
IR25898-60-2-3	6.6	5.2	5.9	11	16	14	510	416	463	24	23	23
IR39357-133-3-2	6.3	5.5	5.9	16	12	14	550	355	453	24	22	22
IR31785-58-1-2-3	6.0	4.7	5.3	17	20	19	629	445	537	23	24	23
Mean	6.9	5.3	6.2	13	21	17	527	409	468	23	22	22

Note: a ND = N'Diaye; FA = Fanaye
b Wet season
c Hot-dry season

View of WARDA's experimental farm at N'Diaye, Senegal, showing an electronic micro-meteorological station in the foreground and the research station in the background

and IKP, respectively. In the short-duration nursery for the hot-dry season only one selection, IR13240-108-2-2, outyielded IKP. Medium-duration varieties are preferred by farmers in the wet season because of their higher yield potential. However, farmers frequently have to resort to short-duration materials because of time constraints in double cropping schemes or delayed access to inputs.

The results indicate that we have selected varieties which produce higher yields than the local checks in the wet season. Only IR13240-108-2-2 consistently outyielded local checks in both the hot-dry and wet seasons. This was confirmed in trials in farmers' fields in 1993. A major challenge is to identify or breed genotypes with superior performance in both the hot-dry and wet seasons. Farmers prefer such materials because double cropping based on two varieties requires a greater effort to keep the seed base pure and prevent ratoons from infiltrating a subsequent season's crop.

VARIETAL ADAPTATION TO THE SAHELIAN CLIMATE

To evaluate climatic effects on crop performance, it is important to understand the succession of developmental stages (phenology) and its dependence upon weather conditions. This is particularly relevant under the high seasonal and diurnal temperature oscillations in the Sahel: the crop duration of a genotype can vary by up to 2 months, and potential yield, crop calendars and temporal escape from climatic stresses all depend to a large extent upon the crop's development rate which, in turn, is governed by its response to temperature and photoperiod.

A study was conducted in 1990-93 to determine rice genotypic constants governing crop duration in the Sahel, characterize the micro-climate generated by weather and the crop canopy, and develop and validate simulation tools to extrapolate temporal and spatial crop duration information. We adopted and refined the following theory: the crop's development rate is zero at and below a certain genotypic base temperature (T_{base}; 9.5-13°C for most rices grown in the Sahel) and reaches a plateau at a certain optimum temperature (T_{opt}; 23-31°C). The intermediate response is linear.

Based on the actual weather, T_{base}, T_{opt} and a genotypic number of degree-days or heat units (T_{sum}; 400-1300 degree-days), the observed crop duration can be explained or duration predicted for other weather scenarios. The interaction of photoperiod with temperature-driven development

is complex, but for Sahelian conditions and the relatively photoperiod-insensitive genotypes that are preferred by farmers, a simple model proved accurate. We assumed that photoperiod sensitivity occurs at the end of a genotype-specific basic vegetative phase (BVP; 10-60 days) and that it is characterized by a genotypic slope constant (CPP; 0-20%). If the photoperiod exceeds the optimum (11 hours) by *x* hours, the thermal requirement (T_{sum}) increases by *x* * CPP%.

This simple model, using the five photothermal constants (T_{base}, T_{opt}, T_{sum}, BVP and CPP), explained observed crop duration (except for grain ripening, for which a different model was developed) and accurately predicted duration for other sites and dates. A major difficulty, however, was that air temperatures measured at 2 m, the common reference, were not directly applicable. The growing point of irrigated rice is submerged during much of the season and exposed to the temperature of the water. Floodwater temperature was usually colder than the air temperature and depended upon diurnal air temperature amplitudes, crop cover and insolation. A submodel was developed to simulate the temperature at the growing point as a function of air and water temperature and the stage-specific location of the apex.

To determine genotypic photothermal constants, we subjected the materials to a range of climatic conditions. For model development, key varieties were planted monthly at N'Diaye in a continuous rice garden trial, with observations on crop phenology, growth, yield and micro-climate. The model was calibrated for a wider range of genotypes with the help of a simplified rice garden trial using microplots. It was validated with two data sets, one from a second rice garden trial at Fanaye and the other from the Retail project in Mali.

Forty-nine genotypes were characterized for their photothermal constants (*see* Table 5 *overleaf*). They included nine varieties already adopted by Sahelian farmers, one salt-tolerant genotype specifically selected for the Senegal river delta (IR4630-22-2) and 10 varieties from IRRI, among which IR8 and IR28 are grown by farmers in the Sahel. The remaining 29 genotypes had been selected by WARDA for high and stable yield under Sahelian conditions. According to yields produced in 1988-90, the materials were categorized as short-duration types performing best in the hot-dry season (type I), medium-duration types performing best in the wet season (type II) and short-duration types performing well in both seasons (type III).

The genotypes flowered between 36 and 96 days after sowing (DAS) in the wet season (f min) and between 89 and 149 DAS in the cold-dry season (f max), resulting in a mean seasonal effect on crop duration of 53 days (*see* Table 5). The mean T_{base} was 12.2°C and the mean T_{opt} was 26.4°C. T_{sum} ranged between 416 and 1337 degree-days, and CPP ranged from 0.4 (photoperiod insensitive) to 21.4 (photoperiod sensitive). The genotypes adopted by Sahelian farmers represented a distinct group within the tested spectrum, having a lower T_{base} and CPP and a higher T_{opt} and T_{sum} than the means (*see* Figure 7 *page 22*). Overall, these varieties had a relatively stable crop duration under variable climatic conditions.

Based on a principal component analysis (PCA) for the five photothermal constants, two components (axes 1 and 2 in Figure 8, *page 23*) accounted for 79% of the variance across genotypes. Axis 1 was composed mainly of the thermal constants and distinguished genotypes with high T_{opt} and T_{sum} and low T_{base} (on the right in Figure 8) from those with low T_{opt} and T_{sum} and high T_{base} (on the left). Axis 2 was composed mainly of the photoperiodic constants and distinguished genotypes with high CPP and BVP (at the top of Figure 8) from those with low CPP and BVP (at the bottom).

Four medium-duration varieties accounting for more than 90% of rice production in the Sahel (Jaya, BG90-2, IR8 and IR1529- 680-3) formed a cluster in the scattergram (top-right sector of Figure 8). Local varieties grown mainly in the hot-dry season (IKP, IR28, SIPI6920 and KH998) were located in the center-right area of the scattergram. Of the varieties presently grown in the Sahel, only Aiwu, a recent *japonica* introduction grown mainly in the hot-dry season, was located in the bottom-left sector.

TABLE 5: Photothermal characteristics of rice genotypes, Ndiaye, Senegal, 1991-93

Genotype number and name	f max[a]	f min[b]	T_{opt}[c]	T_{base}[d]	T_{sum}[e]	CPP[f]	BVP[g]	Type[h]
IRRI varieties and lines								
1 IR8	142	84	30.5	10.68	1270	6.12	60	II
2 IR28	120	69	31.5	11.00	1067	2.88	20	
3 IR36	124	65	29.5	12.82	937	6.37	20	
4 IR42	142	85	24.5	12.89	915	13.24	60	
5 IR50	120	62	31.0	11.86	941	6.77	40	III
6 IR54	135	80	25.0	12.74	916	10.17	50	II
7 IR58	110	61	23.5	13.50	651	8.98	40	
8 IR64	120	74	27.5	9..55	1194	6.71	20	III
9 IR66	120	68	29.0	11.39	993	3.97	40	
10 IR72	142	80	30.5	10.77	1266	1.67	10	
11 IR1529-680-3	131	80	30.5	10.49	1198	10.22	50	II
12 IR1561-228A	126	65	26.0	12.69	838	6.77	40	
13 IR4422-98-3-6-1	130	85	25.5	12.75	949	7.26	50	II
14 IR4630-22-2	134	88	25.0	11.74	1048	12.65	60	II
15 IR3941-86-2-2-1	119	73	26.0	11.02	985	7.82	10	III
16 IR9884-54-3-IE-PI	129	86	23.5	11.78	967	10.77	60	II
17 IR13240-108-2-2-3	119	69	26.0	9.66	1149	4.24	40	III
18 IR18348-36-3-3	123	70	23.0	14.03	652	5.64	40	
19 IR21820-154-3-2-2-23	131	80	25.0	12.48	964	6.56	50	
20 IR22107-14-2-1	126	68	23.5	14.54	629	3.93	40	
21 IR25898-60-2-3	122	65	23.0	15.26	508	4.80	40	I
22 IR29725-40-3-2-3	128	62	29.0	13.36	827	7.48	40	I
23 IR31785-58-1-2-3-3	125	65	25.0	13.63	744	2.00	20	III
24 IR35295-82-2-1-3-2	120	68	25.5	11.85	913	7.47	40	
25 IR39357-133-3-2-2-2	113	62	24.0	13.43	691	4.48	40	I
Mean	126	73	26.5	12.24	980	6.76	39	
Σ (n)	8	9	2.6	1.44	217	2.97	15	
Miscellaneous varieties								
26 32XUAN-5C	124	70	27.5	9.75	1191	4.70	10	III
27 Aiwu	115	62	25.0	12.93	776	5.85	40	I
28 B5322-PN-LM-5-1	129	69	25.5	13.31	853	4.04	40	
29 BG90-2 (source Mali)	130	81	26.0	9.66	1337	4.42	60	II
30 BG90-2 (source WARDA)	149	96	26.0	12.75	1121	5.86	60	II
31 BG400-1	130	70	28.0	11.58	1084	11.74	40	II
32 Bouaké 189	129	77	26.0	11.00	1119	9.08	50	II
33 BW293-2	129	81	23.5	12.99	849	9.23	60	II
34 CP3-C2	147	80	30.0	12.28	1107	5.46	50	II
35 China 998	116	61	25.0	13.50	715	6.93	40	
36 IET109-73	89	36	28.5	15.49	416	2.07	10	
37 IET6279	126	86	23.5	13.60	735	21.37	60	II
38 I Kong Pao	122	76	26.0	11.84	1016	0.44	10	I
39 ITA222	130	79	28.5	10.06	1302	7.19	50	II
40 ITA230	130	70	25.5	13.34	813	7.39	40	II
41 ITA306	129	78	24.0	13.32	814	10.18	50	II
42 Jaya	137	81	29.0	11.20	1240	4.44	60	II

TABLE 5: (contd)

Genotype number and name	f max[a]	f min[b]	T_{opt}[c]	T_{base}[d]	T_{sum}[e]	CPP[f]	BVP[g]	Type[h]
Miscellaneous varieties (contd)								
43 KH998	127	79	28.0	10.14	1253	2.23	40	
44 RAU2004-6-69-13	136	71	26.5	13.74	811	16.86	50	II
45 S499-B28	129	83	26.0	9.98	1257	6.17	60	II
46 SIPI6920	122	75	27.5	10.80	1140	3.77	50	III
47 SKL17-69-11	120	69	25.0	11.65	945	5.91	40	
48 Tatsumi Mochi	111	56	25.0	13.41	698	5.02	30	
49 TOS103	125	69	26.5	13.42	804	11.51	40	II
Mean	126	73	26.3	12.16	980	7.16	40	
Σ (n) n = 24	12	12	1.7	1.53	232	4.58	15	
Mean (all entries)	126	73	26.4	12.20	957	6.94	40	
Σ (n) n = 49	10	10	2.2	1.48	217	3.85	15	
Mean (Sahel)[i]	127	76	28.2	10.97	1147	4.49	43	
Σ (n) n = 9	8	7	2.2	0.91	162	2.62	17	

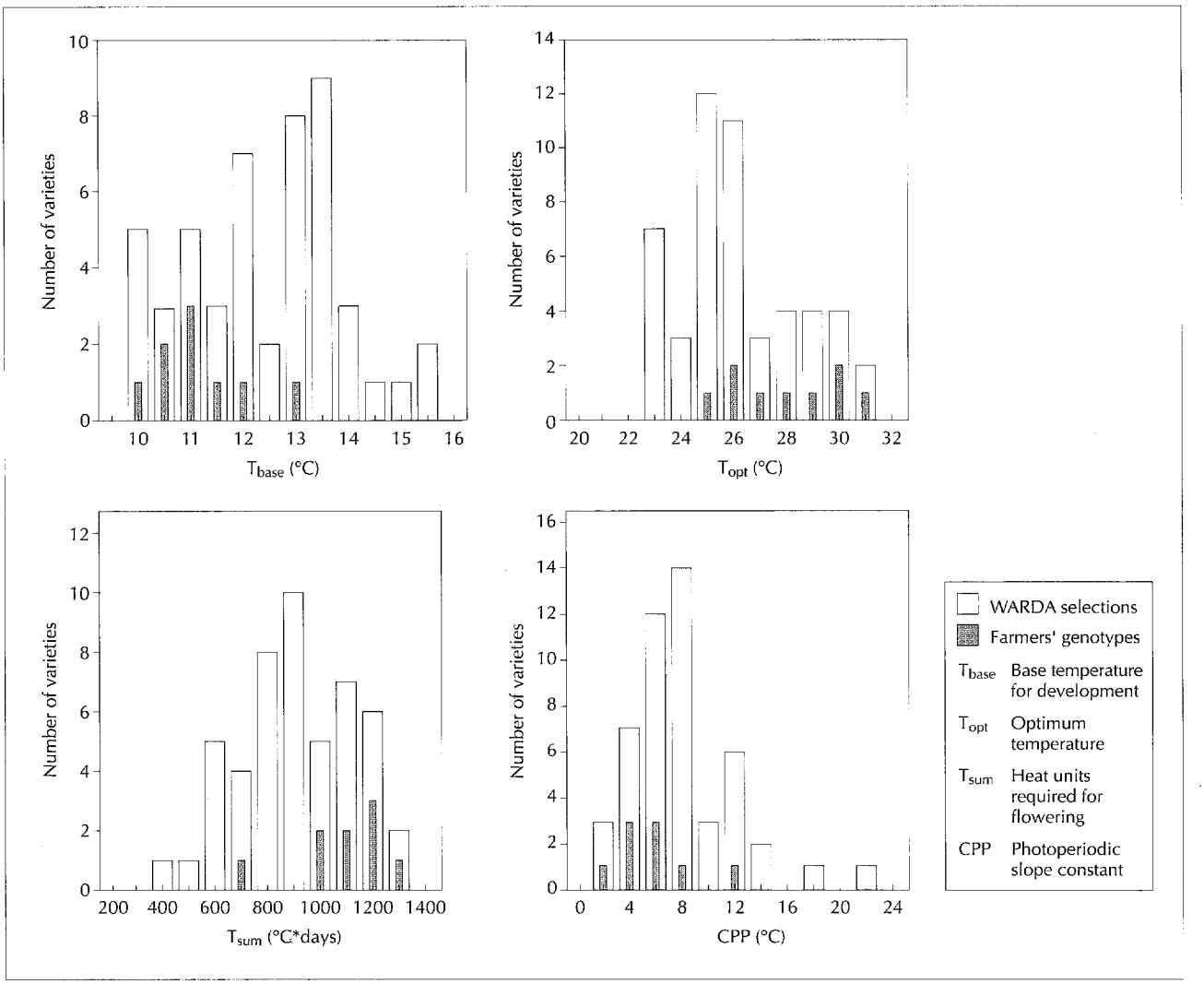
Note:
- a Maximum duration to 50% flowering (f) observed in the field
- b Minimum f observed
- c Optimum temperature for development
- d Base temperature
- e Thermal time required for flowering at 11 hours daylength
- f Photoperiodic constant indicating the increase for T_{sum} as %/hour increase in photothermal environments
- g Estimated mean basic vegetative phase (d) across photothermal environments
- h Seasonal performance: I = good performance in the hot-dry season; II = good performance in the wet season; III = good performance in both seasons
- i Cultivars adopted by Sahelian farmers: numbers 1, 2, 11, 27, 29, 38, 42, 43, 46

The PCA did not provide a complete distinction among duration types, in that photoperiod sensitivity is not strictly linked to duration type, and high heat requirements (T_{sum}) still permit a short duration if the difference between T_{base} and T_{opt} is high, such that many heat units are received per day. Therefore, the distribution of genotypes in Figure 8 was attributable to both absolute crop duration and its plasticity. The resulting groups can be interpreted as ecotypes and in fact corresponded closely with the seasonal performance types I, II and III referred to earlier (*see* Figure 8).

Type I was found mainly in the bottom-left sector of the scattergram and had short but variable duration. It had good yield stability in the hot-dry season, probably because the variable duration provided extra time for growth if temperatures were unusually low. In the wet season, crop duration from sowing to maturity dropped to below 100 days in most type I genotypes and was associated with low yield potential. Only one type 1 genotype, Aiwu, has been adopted by farmers; it is grown exclusively in bi-varietal double cropping systems.

Type II dominated the upper sectors of the scattergram and was composed of two subgroups: type II(1) in the top-left sector, the bulk of WARDA's selections for the wet season (medium-duration with variable duration); and type II(2) in the top-right sector, most of the medium-duration materials already adopted by farmers (comparatively stable duration). Some of WARDA's highest yielding selections for the wet season were type II(1) and had

FIGURE 7: Frequency distribution of genotypic constants for genotypes grown by farmers in the Sahel compared with the varietal spectrum of WARDA's advanced selections for the Sahel

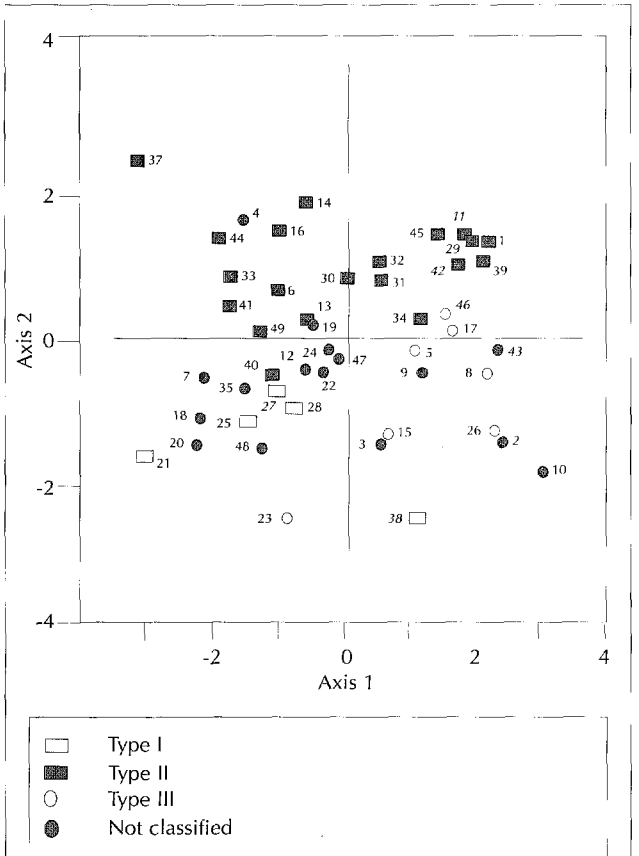


an unacceptably long duration in the dry season; these included ITA306 which will soon be introduced into Burkina Faso, Mauritania and Senegal. By contrast, the locally adopted type II(2) varieties BG90-2 and IR1529-680-3 are used in mono-varietal double cropping systems in Mali and Niger.

Type III was common in the center-right area of the scattergram. Typical examples are IR13240-108-2-2-3 and IR64, whose duration is comparatively temperature insensitive, short enough for the crop to be planted twice a year even in the coastal zone of the Sahel, and long enough in the wet season to ensure the production of high yields.

The bulk of WARDA's recent selections probably differ from varieties adopted by Sahelian farmers because they were selected for specific seasons, whereas farmers prefer to use one variety for both seasons. Bi-varietal rice cropping systems have evolved only where the climate left no alternative, such as in the Senegal river delta. Economic

FIGURE 8: Principal component analysis for the photothermal constants T_{base} (base temperature for development), T_{opt} (optimum temperature), T_{sum} (heat units required for flowering), CPP (photoperiodic slope costant) and BVP (basic vegetative phase) for 48 genotypes



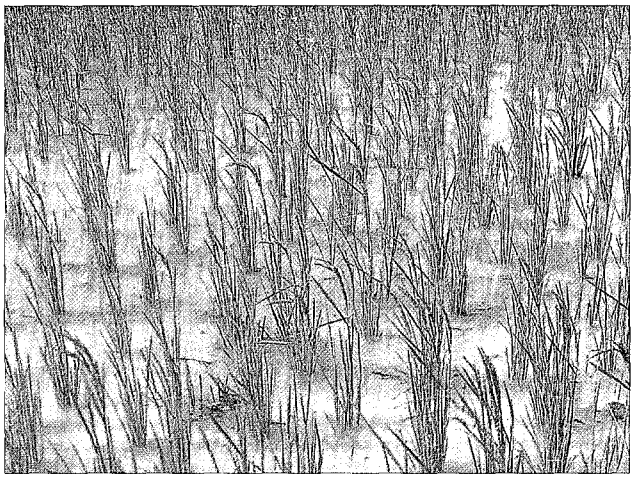
The numbers used for the genotypes are the same as those in Table 5. Genotypes adopted by Sahelian farmers are in italic. The components of the axes are given in Table 5.

pressures and the technical evolution of production systems, however, might in the future favor the more productive bi-varietal system elsewhere. Meanwhile, the development of more type III genotypes which potentially perform well in both seasons remains a high priority. Genotypic photothermal constants and models that predict crop duration will help to identify genotypes suited to specific cropping calendars, sites and production systems.

VARIETAL ADAPTATION TO PROBLEM SOILS

Soil degradation and declining yields under rice-rice double cropping systems have been identified as priority research problems by the Task Force. A leadership role in regional research on soil evolution and regeneration was given to Mali. WARDA was assigned the task of developing varietal tolerance to salinity and sodicity.

Marine-derived soil salinity is an inherent problem in the Senegal river delta, where irrigated rice is grown on about 40 000 ha, and sodicity is increasing in irrigated floodplains in inland areas. Evaporation, rising groundwater tables and poor drainage are the main causes of these problems. Salinity and sodicity have similar effects on the plant, although the latter is more complex and is compounded by nutritional imbalances. Tolerant germplasm is needed to help regenerate degraded soils and sustain rice cultivation where soil or floodwater salinity can be



The variety BG90-2 in an irrigation scheme in Mali, exhibiting poor performance under the combined stresses of soil alkalinity, salinity and nematode infestation

stabilized economically only at elevated levels. Preliminary studies showed that under arid conditions even moderate salinity seriously affects rice yields.

In 1991, WARDA scientists initiated research to characterize a broad range of genotypes for salt tolerance and to determine the compatibility of tolerance to moderate salinity with high yield potential in the Sahelian climate. To meet these objectives, a continuous field-based trial with controlled flood water salinity was established at WARDA's naturally saline farm at N'Diaye. Between 28 and 35 genotypes are exposed every season to saline (3.5 mS cm^{-1} electric conductivity) and freshwater irrigation treatments. Genetic materials are characterized for reductions in yield, dry matter, spikelet fertility and grain weight and for the uptake and distribution of K^+ and Na^+. Genotypes remain in the trial for four seasons and are compared with IKP, IR4630-22-2 and Pokkali (tolerant checks) and IR28 and IR31785-58-1-2-3-3 (susceptible checks). Details of the experiment were reported in the *WARDA Annual Report 1992* and we can now present findings for a broader range of genotypes.

New entries for the salinity trial are taken from advanced yield trials (characterization of agronomically promising selections) or an initial evaluation trial for salinity, based on other sources such as callus regenerates (in collaboration with the University of Louvain-La-Neuve, Belgium) and IRRI's salt tolerance nurseries (*see* Figure 6).

Mean yield reduction attributable to salinity in 34 genotypes and over two to four seasons was 49% (from 7.3 to 3.7 t ha^{-1}) (*see* Table 6). The highest yields under saline conditions were achieved with the local tolerant check, IKP (5.0 t ha^{-1}). WARDA's susceptible check, IR31783, one of the best ultra-short duration selections for the arid climate, yielded only 1.1 t ha^{-1} (83% less than under freshwater irrigation). Pokkali, a traditional variety which is salt-tolerant in monsoonal Asia, was found to be salt-susceptible under arid conditions, suffering a 60% yield reduction.

The only short-duration genotypes planted by farmers in the saline Senegal delta, IKP and Aiwu,

Irrigating a varietal salt-tolerance trial from a water reservoir under controlled salinity conditions, at WARDA's research farm at N'Diaye, Senegal

were among the highest yielding varieties under saline conditions. These varieties, however, have *japonica*-type grains which are not popular among consumers. Jaya, the most important *indica* type in the delta, was salt susceptible. Four semi-dwarf varieties bred at IRRI for salt tolerance (CSR10, CSR11, IR46330-PMI-2-2-1-3 and IR4630-22-2) were also salt tolerant in the Sahel. Among WARDA's high-yielding selections for the Sahel, three medium-duration types (IR64 from IRRI, ITA222 from IITA and BW293-2 from Sri Lanka) also yielded well under saline conditions. However, many other selections for the Sahelian environment, including IR31785-58-1-2-3-3, IR3941-86-2-2-1, IR29725-76-3-3-2 and IR22107-14-2-1 (short duration) and IR4422-98-3-6-1, KH998 and S449-B28 (medium duration), were highly salt susceptible.

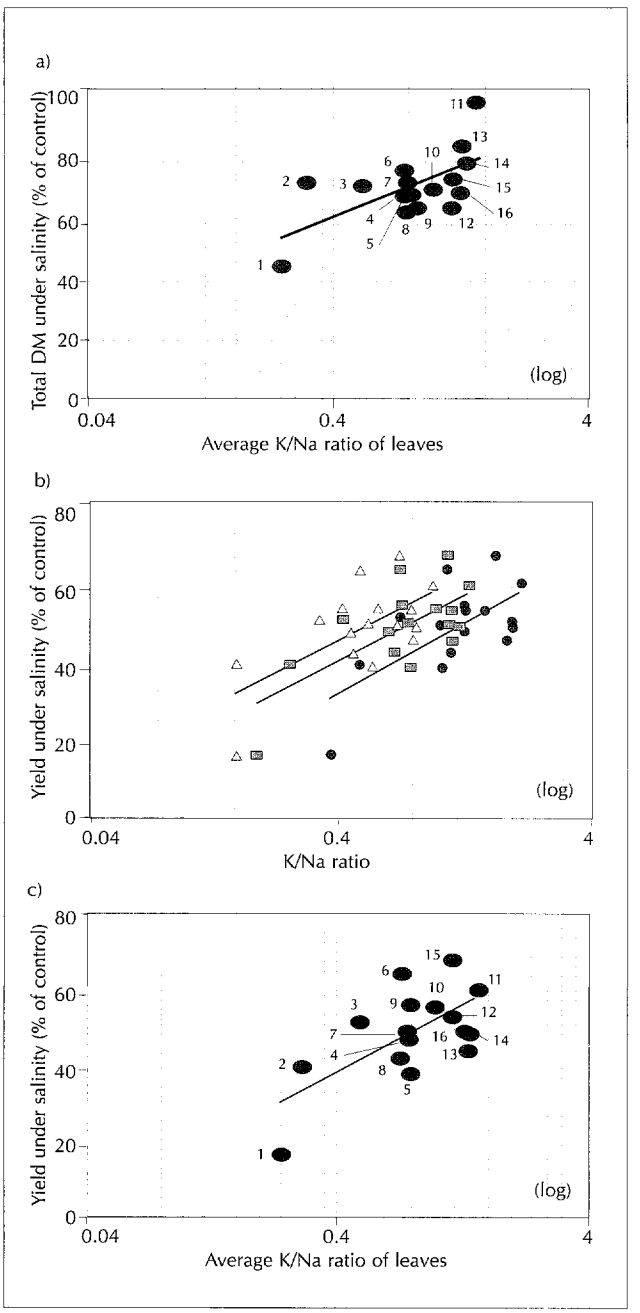
Plant tissue analyses showed that the K/Na ratio, a commonly used index for salt stress intensity, was 2.0-2.8 times higher in young leaves (L1) than in older leaves (L3) (*see* Table 6), with two notable exceptions: Pokkali had much greater differences among leaf positions and a pronounced senescence gradient, and ITA306 had a weaker gradient.

TABLE 6: Grain yield at maturity and leaf K/Na ratio at about panicle initiation stage for 34 genotypes under controlled salinity conditions in the field, based on at least two experiments with three replications for each entry, N'Diaye, Senegal, 1991-93

	Grain yield (t ha^{-1})				K/Na ratio (SAL; Mol mol^{-1})[f]				
Genotype[a]	SAL[b]	SE±[c]	CTR[d]	% reduct.[e]	L1	L2	L3	Mean	L1/L3
I Kong Pao	5.0	0.1	7.8	35	*1.10*	*0.72*	*0.50*	*0.77*	*2.20*
IR64	4.8	0.3	7.2	32	1.70	1.11	0.72	1.18	2.36
ITA222	4.7	0.1	8.6	35					
CSR10	4.6	0.2	7.0	32					
IR46330	4.5	0.7	6.3	32					
Aiwu	4.5	0.9	8.5	47					
CSR11	4.4	0.8	6.8	36					
IR4630-22-2	4.3	0.5	7.5	39	*2.15*	*1.35*	*0.96*	*1.48*	*2.24*
BW293-2	4.3	0.6	8.5	50	1.88	1.37	0.87	1.38	2.16
IR52718-2B-6-2B-1	4.2	0.6	6.9	39					
IR32429	4.1	0.5	6.5	36					
TOS103	4.1	0.3	6.6	37					
SIPI6920	4.1	0.5	7.5	46	1.54	1.15	0.77	1.16	2.00
IR29725-40-3-2-3	4.1	0.3	7.9	48	1.09	0.61	0.51	0.77	2.14
32XUAN-5C	3.9	0.1	7.3	45	1.26	1.03	0.59	0.96	2.14
BG400-1	3.8	0.1	7.9	52					
IR9884-54-3-IE-PI	3.7	0.5	8.2	54	1.53	0.97	0.71	1.07	2.15
IR29692	3.6	0.6	7.0	49					
IR50	3.6	0.3	7.1	50	1.99	1.12	0.71	1.27	2.80
IR31851-96	3.6	0.1	7.3	51					
ITA230	3.6	0.5	8.2	56					
ITA306	3.6	0.6	9.5	61	1.07	0.86	0.67	0.87	1.60
IR13240-108-2-2-3	3.5	0.5	7.1	51	1.25	0.66	0.46	0.79	2.72
B5322-PN-LM-5-1	3.5	0.2	7.1	49					
Jaya	3.5	0.1	8.6	57					
S449-B28	3.4	0.8	9.0	60					
IR22107-14-2-1	3.3	0.5	6.1	45					
KH998	3.3	0.3	6.6	51					
IR4422-98-3-6-1	3.3	0.6	9.0	60					
IR29725-76	3.1	0.4	6.1	49					
IR28	3.0	0.4	6.1	49	*1.07*	*0.76*	*0.53*	*0.79*	*2.02*
IR3941-86-2-2-1	2.7	0.8	6.4	58					
Pokkali	1.4	0.5	3.5	60	*2.98*	*1.44*	*0.79*	*1.73*	*3.77*
IR31785-58-1-2-3-3	1.1	0.1	6.4	83	*0.38*	*0.19*	*0.16*	*0.24*	*2.38*
Mean	3.7		7.3	49	1.50	0.95	0.64	1.03	2.33

Note:
- a Entries are arranged according to grain yield under saline conditions; check varieties are in italics
- b Salt treatment, based on constant 3.5 mS cm^{-1} electric conductivity in the floodwater
- c Standard error across experiments
- d Controls, irrigated with freshwater
- e Percentage yield reduction
- f L1, L2 and L3 = leaf yield under saline conditions

FIGURE 9: Relationships between dry matter (DM) and grain yield under salinity (vertical axes) and the molar K/Na cation ratios of the top three leaf positions at panicle initiation stage (horizontal axes) for 16 rice cultivars grown in the field under controlled salinity, N'Diaye, Senegal, 1991-93



These observations may indicate significant physiological differences among the genotypes but they were not associated with salt tolerance in this study. Grain yield and dry matter, expressed as a fraction of control values, were positively correlated with K/Na ratios across 16 genotypes (*see* Figure 9). Dry-matter production was generally less affected than grain yield by salinity, indicating that reproductive processes are particularly susceptible.

These results enable us to make a preliminary classification of genotypic response patterns to salinity. IR4630-22-2 had no reduction in dry matter but a strong reduction in yield, indicating that it might be a potential donor of salt-tolerance traits for vegetative growth. In contrast, IKP, IR64 and IR9884-54-3-IE-PI had low yield reduction but a marked reduction in dry matter, and could be potential donors for salt tolerance traits in reproductive processes. IKP is a particularly interesting case because it achieved high yields with low leaf K/Na ratios (*see* Table 6), which is indirect evidence of high tissue-level tolerance to salinity. This finding was confirmed by collaborative *in vitro* callus studies at the University of Louvain-la-Neuve. Once a broader pool of potential donors for such component traits has been identified, WARDA will initiate a hybridization program for salt-tolerant materials.

The present study will be complemented in 1994 by collaborative trials with the national program in Mali on sodic-alkaline soils. A selection of the most salt-tolerant genotypes will be tested to identify those to be used for the regeneration of degraded soils. As a parallel activity, screening tools for salt and sodicity

1	IR31785	9	IR22107
2	IR4422-98	10	32Xuan
3	IR29725-40	11	IR4630-22
4	IR13240	12	SIPI6920
5	ITA306	13	IR9884
6	I Kong Pao	14	BW293
7	IR28	15	IR64
8	Jaya	16	IR50

● Leaf 1
▩ Leaf 2
△ Leaf 3

tolerance will be developed in collaboration with IRRI and the University of Hamburg, Germany. This will accelerate varietal selection for high-yielding genotypes adapted to problem soils in the Sahel.

TOWARDS A VARIETAL CATALOGUE FOR THE SAHEL

Three examples (advanced yield trials and varietal studies on climatic and edaphic stresses) have shown how WARDA selects and characterizes genotypes for the Sahelian environment. In addition, we conduct complementary experiments on grain quality and varietal adaptation to crop establishment practices. Apart from helping in varietal selection, this work aims to establish a varietal catalogue for irrigated rice in the Sahel from which local production systems, research on resource and crop management, and systems analysis can readily draw information. The catalogue will comprise full sets of the following information:

- general descriptors of origin and morphology
- yield and yield stability at benchmark sites in the Sahel
- performance on farmers' fields
- grain type and quality
- photothermal constants (T_{base}, T_{opt}, T_{sum}, BVP and CPP), enabling simulation of crop duration for any site x date scenario
- physiological constants for temperature tolerance at seedling and reproductive stages to simulate seedling growth rates and spikelet sterility for any site x date scenario
- salinity and sodicity tolerance
- suitability for transplanted and direct-seeded cultural practices
- complementary information from third sources

Only genotypes with proven adaptation to one or more environments in the Sahel will be included in the catalogue. The catalogue will be updated continuously to include results from WARDA and Task Force research, and will be made available to WARDA's partners within and outside the Sahel.

A NEW ROLE FOR SYSTEMS RESEARCH IN VARIETAL IMPROVEMENT

Systems research tools have become an indispensible component of WARDA's rice breeding activities for the Sahel. The genotypic photothermal constants governing crop duration, spikelet sterility and temperature-limited seedling growth were obtained by calibrating models. These models are now being used for agro-climatic zonation of the Sahel, using simulated crop parameters. As a direct feedback to breeding, through simulation we can identify target zones and production systems for improved varieties and define zone-specific criteria for varietal selection. At a much finer level of detail, we are using physiological models to identify component traits for salt and temperature tolerance that help us develop screening tools. Lastly, potential-yield models are currently being adapted to quantify yield gaps in the region and estimate the potential impact of improved production technologies.

WARDA's systems approach will help aggregate technology components to form site-specific technology packages. For example, the varietal catalogue will enable a potential user to select a genotype for a specific environment and test, by way of simulation, its compatibility with any existing or alternative cropping calendars. Models derived from our phenological model (RIDEV) will also enable estimations to be made of water consumption and climatic risks to production for any such scenario, based on soil and climatic characteristics. Information on varietal salt and sodicity tolerance will help in devising technology packages for the regeneration of degraded soils.

Technology packages generated with the help of the varietal catalogue and models will have to be

validated *in situ* before they are introduced into the production sector. Compared with conventional methods, however, our approach has two crucial advantages:

- economy — the user can efficiently eliminate technology options which need not be tested *in situ*
- flexibility — WARDA's approach avoids prescribing 'ready-made' solutions to problems; instead, a variety of component options are offered and the user, through simulation, can test and select combined scenarios

FUTURE PROSPECTS

WARDA'S integrated program for breeding, agro-ecological characterization and technology packaging has been found to be operationally efficient. Feedback from WARDA's national partners and clients has been extremely positive. However, WARDA's concept, as shown in Figure 6, is an innovative experiment and must ultimately be evaluated according its regional impact, based on rates of varietal adoption, use of the varietal catalogue and associated models as tools in national research and development, and a general improvement in the flow of research information across national boundaries. The impact will be measurable within 3-4 years, when all the research components summarized in Figure 6 are fully implemented.

The Sahel Irrigated Rice Improvement Task Force is already playing a major role in the regional coordination of rice research. It provides invaluable institutional links between national programs and WARDA for the implementation of our interdisciplinary approach to technology generation. Success also depends upon sustaining and strengthening collaboration with WARDA's external partners, including IRRI and the Universities of Hamburg, Leuven and Louvain-La-Neuve.

SUMMARIES OF RESEARCH ACTIVITIES

UPLAND/INLAND SWAMP CONTINUUM PROGRAM

The continuum is the largest rice growing environment in West Africa, covering approximately 82% of the total rice area and accounting for 75% of regional production. It consists of several contiguous ecosystems in which rice can be grown within the warm subhumid and humid tropics of West Africa. Distinguished primarily by hydrology, these ecosystems include:

- the upland rainfed ecosystem (57% of the area), where the rice crop depends entirely upon *in situ* rainfall for soil moisture
- the hydromorphic ecosystem (18%), where the water table is within the rooting zone of the rice crop during key periods of crop growth
- the lowland rainfed ecosystem or inland valleys (20%), where the rice crop is periodically flooded
- the irrigated lowland ecosystem (5%), where the rice crop benefits from a high level of water control

The main constraints in the upland/hydromorphic ecosystem are drought stress, low soil fertility, acidity and erosion. In the lowland/hydromorphic ecosystem, a complex of poorly understood soil conditions, including iron, aluminum and manganese toxicity, are often critical. Major biotic stresses common to both ecosystems are weeds, rice blast, leaf scald, brown spot and insect pests, mainly the African rice gall midge (*Orseolia oryzivora*), stem borers and the stalk-eyed fly (*Diopsis* spp.). The rice yellow mottle virus (RYMV), unique to Africa, is a potential major threat to increased rice production in the lowland/hydromorphic ecosystem. Although local rice varieties are generally well adapted to low-input systems, most of them have modest yield potential and poor response to improved inputs such as fertilizers and insecticides.

Infestation of a rice field by *Striga* spp., a parasitic weed

The goal of the Continuum Program is to develop a range of technology options that are appropriate for resource-poor farmers in the transition from extensive to intensive cropping systems. Appropriate technologies should be socially profitable, maximize the use of farm resources and minimize the use of purchased inputs, be technically sustainable, minimize environmental degradation, be subject to incremental adoption of new components, and minimize the need for major changes in social behavior and institutions.

WARDA's strategy is to assist West African farmers to intensify, profitably, the cropping systems within which rice is a major component. During 1993, WARDA continued to emphasize technology development for land types best suited to sustainable intensification. Technology options were designed to enable farmers to reduce pressure on marginal and fragile uplands by shifting towards intensive cultivation of more robust and higher potential land types across the continuum. Particular stress was placed on developing more productive and sustainable cropping systems for inland valley ecosystems where rice has a strong comparative advantage. WARDA's research activities in 1993 are outlined here under five main projects.

PROJECT 1: CHARACTERIZATION OF RICE GROWING ECOSYSTEMS

The rice growing ecosystems of the upland/inland swamp continuum are highly diverse. Their production potential is determined by the interplay of many factors, including geology, climate, soil types, hydrology, vegetation and socio-economic factors. Within these ecosystems, farmers have developed rice cropping practices that vary across and within ecosystems. The development of

appropriate technologies for this environment requires a thorough understanding of the socio-economic and bio-physical conditions under which rice is grown in each ecosystem and how farmers use their resources to minimize risks and optimize production. Because rice ecosystems are an integral part of broader farming systems, the development of new rice technologies needs to be based on a detailed micro-level characterization of the technical fit and relative profitability of rice systems within existing farming systems. The characterization project aims to identify and assess quantitatively the major factors affecting rice production possibilities in the continuum in different agro-ecological zones.

Given the scope of the research problems involved, this project requires close collaboration between institutional partners. This collaboration is coordinated under a major new eco-regional initiative focused on the sustainable intensification of inland valleys in sub-Saharan Africa. The initiative is being implemented by the Inland Valley Consortium (IVC), formed in 1993 and including seven national institutes from West African countries (Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, Nigeria and Sierra Leone) and five international institutes (CIRAD, IITA, WARDA, Agricultural University of Wageningen and Winand Staring Center). The IVC is taking a two-stage approach to characterizing the continuum: first, a macro-level characterization of the major agro-ecologies; and second, a micro-level characterization in which representative key sites are selected for intensive diagnostic research on the soils, hydrology, cropping systems and socio-economics determining overall system productivity.

WARDA is now in its second year of detailed village-level studies. These studies focus on micro-level socio-economic characterization at three key sites in the humid forest, forest-savanna and savanna zones of Côte d'Ivoire and cover 120 rice farming households. This work aims to:

- provide detailed household-level data on the on-farm and off-farm activities of rice farming households
- determine the socio-economic factors and resource constraints affecting sustainable productivity increases in existing rice production systems
- determine the effects of farm policies on the patterns of the farm-level profitability of rice and competing crops
- determine the relative productivity and profitability of rice systems within the general farming systems.

Farm-level profitability of crops in the rice-based systems of the humid forest zone of Côte d'Ivoire
A.A. Adesina

In the development of new rice production technologies, it is important to understand the farm-level costs and profitability of activities within current farming systems. In 1993 we developed detailed budgets for all the major crops grown in the humid forest zone of Côte d'Ivoire. These budgets were based on detailed cost-route

TABLE 7: Financial profitability of crops in rice-based cropping systems in the humid forest zone of Côte d'Ivoire, 1993

	Net returns per ha ('000 FCFA)	Total costs per ha ('000 FCFA)
Rice production systems		
Upland/traditional	49	39
Upland/modern	89	36
Unimproved lowlands	102	54
No external inputs	101	51
Herbicide alone	108	60
Fertlizers/herbicides/insecticides	108	76
Semi-improved lowlands	136	54
No external inputs	117	38
Herbicides/insecticides	158	52
Fertilizers/herbicides/insecticides	163	60
Improved lowlands	129	81
No external inputs	132	59
Fertilizer alone	157	67
Herbicides alone	121	71
Herbicides/insecticides	123	77
Fertilizers/herbicides/insecticides	183	88
Other crops		
Yams	673	189
Maize	174	26
Cocoa	116	15
Coffee	21	38

surveys (covering the 1992-93 crop season) of a representative sample of 60 farm households in the Gagnoa area in the south-west of the country. The zone has a bimodal rainfall pattern (1500 mm average) and a population density of 26-35 persons per km^2. The major food crop is rice; yams and maize are of moderate importance. Major cash crops are coffee and cocoa. Agro-ecological studies (using satellite images) have shown that the survey area is very representative of larger areas of the equatorial forest zone of West Africa.

Our crop budgets distinguished 13 rice production system combinations (*see* Table 7). The first-level classification criterion was the ecosystem, separating upland and lowland plots. For the uplands, two production subsystems were identified, based on the type of variety used: traditional and modern. For the lowlands (where modern varieties tend to predominate), three subsystems were identified, based on the level of water control: unimproved lowlands, semi-improved lowlands and improved lowlands.

All the lowland areas receive water from stream diversions via gravitation and there is no use of pumps. The unimproved lowlands lack dykes or water control structures. In the semi-improved lowlands, farmers construct dykes and rudimentary water canals to achieve a minimum level of water control. These are often non-permanent structures which have to be reconstructed or repaired each season. The improved lowlands, with semi-permanent bunding and water drainage canals, provide the highest level of water control. All three subsystems were further subdivided according to the use of external inputs, as shown in Table 7.

Our analysis showed that modern upland systems are more profitable than traditional upland systems. At 1993 prices, the net returns per ha were FCFA 88 896 and FCFA 49 251 for modern and traditional upland systems, respectively (FCFA = CFA Franc; FCFA 280 = US$ 1 in 1993). Our data also showed that all lowland systems are generally more profitable than both upland systems, the most profitable being the semi-improved lowlands. At 1993 prices, net returns per ha averaged FCFA 136 060. For improved lowlands, the net returns per ha averaged FCFA 128 928, and for unimproved lowlands they averaged FCFA 101 609. When farmers used external inputs, their profits increased with each level of water control. For the unimproved lowlands, the two subsystems using external purchased inputs were the most profitable (FCFA 107 000 ha^{-1}). For the semi-improved lowlands, the subsystem which used the full package of fertilizers, herbicides and insecticides was the most profitable (FCFA 163 293 ha^{-1}), followed by the use of both herbicides and insecticides (FCFA 158 148 ha^{-1}). Similarly, for the improved lowlands the most profitable subsystem was that in which the full package of fertilizers, herbicides and insecticides was used (FCFA 182 999 ha^{-1}), followed by the subsystem using fertilizers alone (FCFA 157 330 ha^{-1}).

We also compared the profitability of rice systems with those of the other major crops in the agro-ecological zone. We found that yams were the most profitable, followed by maize

TABLE 8: Net returns to labor for different crops in the humid forest zone of Côte d'Ivoire, 1993

	Net returns to family labor (FCFA/person-day)
Rice systems	
Upland/traditional	191
Upland/modern	404
Unimproved lowlands	420
No external inputs	418
Herbicide alone	446
Fertilizers/herbicides/insecticides	444
Semi-improved lowlands	351
No external inputs	303
Herbicides/insecticides	408
Fertilizers/herbicides/insecticides	421
Improved lowlands	621
No external inputs	642
Fertilizer alone	766
Herbicides alone	586
Herbicides/insecticides	594
Fertilizers/herbicides/insecticides	882
Other crops	
Cocoa	3867
Maize	1657
Yams	1445
Coffee	187

and then rice systems (*see* Table 7). All the rice systems were more profitable than coffee, for which world prices are at almost all-time lows. We observed that coffee yields were very low as farmers no longer use external inputs. Our data also indicated that all the semi-improved and improved lowland rice systems were more profitable than cocoa. Indeed, field surveys have found that traditional coffee and cocoa farmers in the study zone are abandoning the upkeep of their fields and are shifting to lowland rice cultivation.

Labor is the most limiting factor for farmers in the Gagnoa area. Analysis of labor productivity for rice indicates that net returns per person-day in the farm household is highest on average for the improved lowland rice systems (*see* Table 8). Across the other rice systems the returns to labor are slightly lower than the on-going rural wage rate of FCFA 500 per day. As with returns to land, returns per person-day in each rice system increase with greater use of external inputs.

Members of a farmers' cooperative using a jointly owned machine to process their rice

Relative economic efficiency of rice farms in Côte d'Ivoire

A.A. Adesina, K.K. Djato (Research Scholar) and J.H. Pegatienan (University of Abidjan)

Policy makers in Côte d'Ivoire are currently debating a number of institutional changes, including land reform, which are needed to increase rice production. Although about 80% of the rice farms are small (average size 0.5-2.0 ha), the government has traditionally encouraged large farms through the importation and preferential distribution of highly subsidized seed, mechanized equipment and chemical inputs. Justification for promoting large farms may arise if these farms show relatively higher economic efficiency. Some policy makers favor increasing domestic production through encouragement of rice production on large farms. They argue that extension, input distribution and marketing costs are lower if there are fewer producers.

We examined economic efficiency differences between small and large rice farms in northern Côte d'Ivoire using dual profit functions. Data analysis was based on pooled data, collected in 1992-93 from 410 rice farms in three zones. In northern Côte d'Ivoire, large farms (over 3 ha) were concentrated in one of the study zones, whereas small farms (under 3 ha) were concentrated in the other two zones. These locational factors were accounted for in the empiral models. The analysis suggested that large farms are more economically efficient than small farms. This result was found to be stable under alternative specifications of the models.

We also examined a number of factors that may explain the greater efficiency of large farms. Our data show that there are significant differences in educational background, access to and use of modern rice varieties, and contact with extension or rice development agencies between the operators of large and small rice farms. Whereas 100% of large farms use modern rice varieties, the figure for small farms is only 50%; 37% of large farm owners have been to school compared with 9% of small farm owners; and 96% of large farm owners have contacts with extension and rice development agencies compared with only 26% of small farm owners. We also found that 100% of large farm owners had access to credit for fertilizer, improved seeds, herbicides and insecticides, whereas the figure for small farm owners was only 35%. These patterns suggest that efficiency differences are not necessarily attributable to size alone but could also have arisen from previous public policy decisions that gave large farms preferential access to inputs, credit and new technologies.

It appears that large and small farms face different pricing and technical opportunities. To assist in drawing up

policy recommendations, studies are needed to elucidate the causes of the differences in economic efficiency. We will be pursuing this issue further by using stochastic production function and/or profit function frontiers to derive indices of efficiency for each rice farm. These indices will be regressed on certain socio-economic factors and other non-physical inputs in order to isolate clearly the factors explaining the observed economic efficiency differences between large and small farms.

PROJECT 2: CROPPING SYSTEMS

Demographic growth and land shortage problems are forcing many West African farmers to intensify their rice production systems. Inefficient use of soil resources and external inputs, destruction of the natural environment, and declining crop yields are often associated with intensified land use under traditional low-input cropping practices. Concern about the negative environmental effects of current farming practices call for the development of rice production technologies that contribute to more sustainable land use.

Reducing the length of fallow periods in uplands generally leads to a decline in soil fertility (soil organic matter, N supplying capacity, and erosion) and rapid infestation with problem weeds. New cropping system options are needed to control weeds and to stabilize these fragile uplands. Research is focusing on improved fallow management through screening, evaluation and the integration of weed-suppressing, N-fixing leguminous shrubs and cover crops.

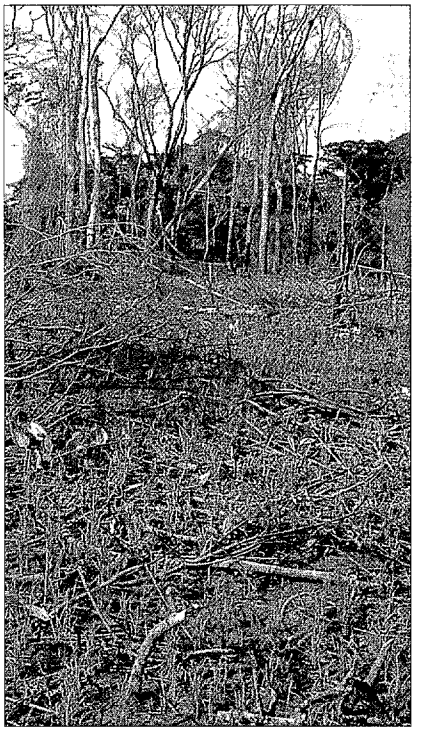
Lowland environments are generally more robust and therefore better suited to intensified use, and rice is the crop best adapted to cultivation in moist and flooded conditions. However, soil resources, added plant nutrients and water are usually inefficiently exploited in West African rice lowlands. Nutrient outputs are rarely balanced and the use of external and purchased inputs is generally low. This, combined with the lack of appropriate water management and land conservation practices, results in a decline in the quality of the resource base which can lead to reduced production potential. New cropping systems options must therefore aim at improving resource-use efficiency. WARDA's research is increasingly focusing on resources that are internal to the cropping system itself. Such resources include the use of biological N fixation in leguminous green manure crops, the management of native soil N, and the improved use of soil residual moisture for cropping intensification and diversification.

The main thrusts of the cropping systems project are, therefore, the stabilization of upland rice-based cropping systems and the sustainable intensification of lowland rice-based cropping systems. Emphasis is given to low-cost production technologies that control weeds and improve resource-use efficiency.

Weeds of rice on the continuum

D.E. Johnson (NRI) and R. Diallo

To establish weed management research priorities, studies have been conducted on the importance and distribution of the major weed species in the various rice production ecosystems. These activities complement past research on the weed flora in rice fields and aim at providing a better understanding of weed problems by identifying weed distribution and importance according to position on the toposequence and the growth stage of the rice crop. The activities in 1993 included a study of weed growth in an on-station experiment planted along the toposequence at M'bé, Côte d'Ivoire, and a survey of farmers' fields.



Early weed growth in a rice field after a long fallow period

In the on-station experiment, initiated in 1992, weed species were sampled at three periods of rice crop growth: tillering, flowering and harvest. Samples were taken at five positions along the toposequence, from upland to flooded lowland (*see* Figure 10 *overleaf*). Some of the more important species sampled at 28 days after rice emergence are shown in Table 9 (*overleaf*). After the 1992 rice crop, the site had been left fallow for about 6 months until cultivated in preparation for the 1993 crop. We observed a shift in the weed flora between the 1992 and 1993 seasons, with certain species becoming more important

FIGURE 10: Weeds in rice along the toposequence at 28 days after emergence, 1993

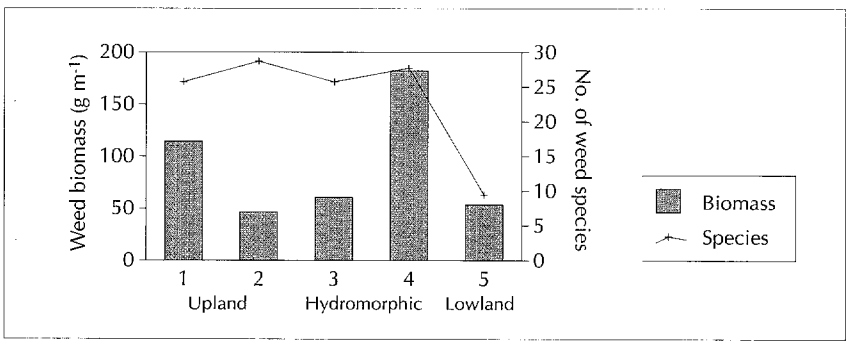


TABLE 9: Weeds in rice along the toposequence, Mbé, Côte d'Ivoire, 1993

	◄ Upland		Hydromorphic		Lowland ►
	weed weight (g m^{-2})				
Weed species	**1**	**2**	**3**	**4**	**5**
Aspilia bussei	6	9	4	0	0
Eleusine indica	3	4	2	1	0
Digitaria horizontalis	74	15	18	0	0
Ageratum conyzoides	0	3	17	13	0
Eclipta prostrata	0	1	4	4	0
Leersia hexandra	0	0	0	14	0
Fimbristylis littoralis	0	0	0	50	3
Cyperus difformis	0	0	0	92	28
Sphenoclea zeylanica	0	0	0	7	3
Heteranthera callifolia	0	0	0	0	8

over time, while others became less so. *Digitaria horizontalis*, which has rapid early growth, dominated the upland areas in the second season, whereas it had been only a minor weed in the first season. *Aspilia bussei* was less important in the second season than in the first season. In the lowland parts of the toposequence, *Cyperus difformis* and *Fimbristylis littoralis* were the dominant weed species, with little change between the years.

The weed flora in upland rice on farmers' fields near Touba in the forest-savanna transition zone of Côte d'Ivoire was dominated by the grass species *Hackelochloa granularis*, *Imperata cylindrica*, *Paspalum scrobiculatum*, *Pennisetum* spp. and *Rottboellia cochinchinensis*, which were widespread. The dominant annual broadleaved species was *Ageratum conyzoides*.

Studies on the changes in weed species and distribution along the toposequence will continue at the same site in 1994. Weed problems of farmers' fields will also be studied in 1994, with fields selected on the basis of length of the preceding fallow period and position on the toposequence. The studies will include sites in the forest, forest-savanna transition and savanna zones in Côte d'Ivoire. We will record the weed species present and their importance, and estimate rice yield losses attributable to weed competition.

Competitiveness of rice with weeds
D.E. Johnson (NRI), M.P. Jones and T. Koupeur (University of Abidjan)

Weeds are a serious constraint to yields in most upland rice fields in West Africa. Farmers rely mainly on manual methods of weed control but, because of competing labor demands, weed populations are only partially reduced and so weeds continue to cause significant yield losses. Research at WARDA to identify rice varieties which can compete successfully with weeds began in 1992 with the screening of a range of varieties grown under low-input conditions. The varieties exhibited differences in weed competitiveness.

In 1993, 20 rice cultivars and advanced lines, including *Oryza glaberrima* and traditional and improved *O. sativa*, were screened under low-input conditions. Low levels of fertilizer were applied (40 kg ha^{-1} urea) and the plots were hand-weeded twice, allowing weed growth for much of the growing period. In a second experiment, the response of three rice varieties to differing levels of weed competition was measured. The test varieties used were Iguape Cateto (intermediate plant type, tall stature and broad droopy leaves), WAB96-1-1 (intermediate plant type, tall stature and semi-erect leaves) and ITA257 (compact plant type, semi-dwarf stature and erect leaves). The treatments were hand-weeded at 21, 42, 21 and 42 DAS. The site for the second experiment had been cultivated in the two preceding years and fertilizer was applied at a rate of 200 kg NPK ha^{-1} to the seedbed and 100 kg urea ha^{-1}

divided between the tillering and panicle initiation stages.

In the first experiment, significant differences in weed biomass growing among the entries were apparent. Weed growth was lowest among the two *O. glaberrima* lines, which also produced a high number of tillers and achieved a high leaf area index (LAI) at 50 days. LAI and tiller number were negatively correlated with weed weight ($r = -0.292^{**}$, $r = -0.290^{**}$, $n = 80$); there was no significant correlation between rice plant height and weed weight.

In the second experiment, weed growth was severe and consisted mainly of the annual grass *Digitaria horizontalis*. Grain yield was markedly affected by weed control treatments, with the most severe weed competition reducing yield to about 40% of those areas weeded at 21-day intervals. There were no significant interaction effects between weeding treatments and varieties, with the different levels of weed infestation having a similar effect on the grain yield of the different varieties but no effect on their ranking. Weed growth at 42 days did not significantly differ between the varieties, although at harvest it was higher in ITA257 plots. Weed growth was negatively correlated with rice tiller number at 35 days and flowering ($r = -0.289^{*}$, -0.665^{***}, $n = 48$) and plant height ($r = -0.314^{*}$), suggesting that these characteristics are related to competitive ability. The main effects of varieties on some parameters are shown in Table 10.

The 1993 results confirm earlier studies indicating that differences in the competitiveness of varieties exist within current WARDA selections and that early vegetative growth is an important factor in weed suppression. In addition, the results of the second experiment suggest that among the varieties tested, comparison at one level of weed infestation would have been sufficient to determine ranking, for grain yield, as this appeared to be unaffected by differing weeding regimes; this has implications for future screening. Varieties showing characteristics that may be important for determining competitiveness with weeds have been selected and multiplied for experimental work in 1994.

PROJECT 3: SOIL FERTILITY MANAGEMENT

Nitrogen and phosphorus deficiency constitutes the most important nutrient constraint to rice production in all ecosystems in West Africa's humid and sub-humid zones. P deficiency is more serious in the forest zone and in acidic uplands. Iron toxicity is a major nutrient disorder in lowland and irrigated ecologies; this complex nutrient disorder may involve deficiencies in other nutrients, such as P, K, Ca, Mg and Zn. The development of improved varietal tolerance to nutrient disorders such as iron toxicity is considered the most practical solution. WARDA's research on soil fertility management is focusing on the diagnosis and management of these and other soil disorders. Studies also continued in 1993 on identifying nutrient disorders as they develop within cropping systems in the upland and lowland rice ecologies.

TABLE 10: Tiller number, plant height and weed weight at harvest of three rice varieties grown at M'bé, Côte d'Ivoire

Variety	Tiller no. at 35 days (m^{-2})	% of tillers producing panicles	Plant height (cm)	Weed weight at harvest ($g\ m^{-2}$)
Iguape Cateto	83.4	56	84.3	85.0
WAB96-1-1	94.7	72	91.4	94.6
ITA257	71.4	85	75.2	118.2
SE±	3.91	6.9	1.75	6.53
CV (%)	18	19	8	26

The role of other nutrients in iron toxicity management
K.L. Sahrawat and S. Diatta

In rice cultivation, iron toxicity is caused by excess amounts of ferrous iron in soil solution mobilized by soil reduction under flooded conditions. It is a complex nutrient disorder and at times iron toxicity-like symptoms may be expressed in the rice plant because of a deficiency in nutrients such as P, K, Ca, Mg or Zn. To test the role of other nutrients in iron toxicity, a field experiment was conducted at an iron-toxic site at Korhogo, Côte d'Ivoire.

The varieties tested were Suakoko 8 (tolerant) and Bouaké 189 (susceptible). The effects of nine nutrient treatments (*see* Table 11 *overleaf*) were tested in a randomized complete block design, with four replications. The plot size was 24 m^2. Nitrogen was applied as urea at a rate of 100 kg ha^{-1} in three splits; P as triple superphosphate at a rate of 50 kg ha^{-1}; K as KCl at a rate of 80 kg ha^{-1}; and Zn as ZnO at a rate of 10 kg ha^{-1}. All nutrients except N were added as basal applications.

TABLE 11: Effects of application of nutrients on the yield of two varieties in an iron-toxic soil at Korhogo, Côte d'Ivoire, 1993

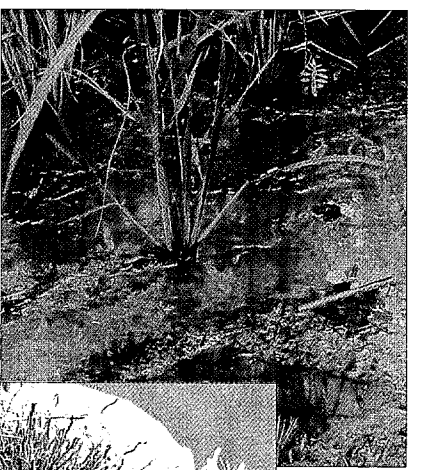
Treatment	Grain yield (t ha^{-1}) Suakoko 8	Grain yield (t ha^{-1}) Bouaké 189	Iron toxicity score Suakoko 8	Iron toxicity score Bouaké 189
Check (no fertilizer)	5.79	4.47	3	5
N	5.43	4.59	3	4
N+P	6.02[a]	6.70	3	4
N+K	6.77	6.24	3	4
N+Zn	6.12	5.75	3	4
N+P+Zn	6.09[a]	5.58	3	5
N+K+Zn	5.37[a]	5.36	3	5
N+P+K	6.85	5.70	3	4
N+P+K+Zn	6.05	6.19	3	4
SE±	0.239	0.413		
CV (%)	8	15		

Note: a Bird damage

In the check treatment (no fertilizer), Suakoko 8 outyielded Bouaké 189 (*see* Table 11). The effects of different nutrient combination treatments for Suakoko 8 were not clear, however, because of severe lodging, especially when N was applied. Nutrient application also did not affect the iron toxicity score for Suakoko 8. However, the applications of N+P+K and N+P+K+Zn significantly increased the yield of Bouaké 189. While the application of N alone did not affect the yield or iron toxicity score of either variety, the application of P or K in combination with N and Zn significantly increased the yield of Bouaké 189.

These results suggest that the role of other nutrients such as P and K could be important in increasing the yield of susceptible rice varieties grown in iron-toxic soils. They confirm our earlier observations in greenhouse pot experiments where the application of P alone or in combination with other nutrients delayed the appearance of iron toxicity symptoms but did not alleviate them. However, it is not clear whether the deficiency of the other nutrients is the cause or result of iron toxicity. The lack of a clear relationship between iron toxicity symptoms and yield was again apparent. It would seem that the appearance of iron toxicity-like symptoms can be corrected by the application of other nutrients in some situations but not in others. Further research will attempt to distinghuish between induced and natural iron toxicity.

Rice plants at M'bé (right), growing at a site where iron has accumulated from the upper slopes, and (below) the effect of iron toxicity on rice root morphology and colour; severely affected roots (extreme left of picture) are dark red and stunted



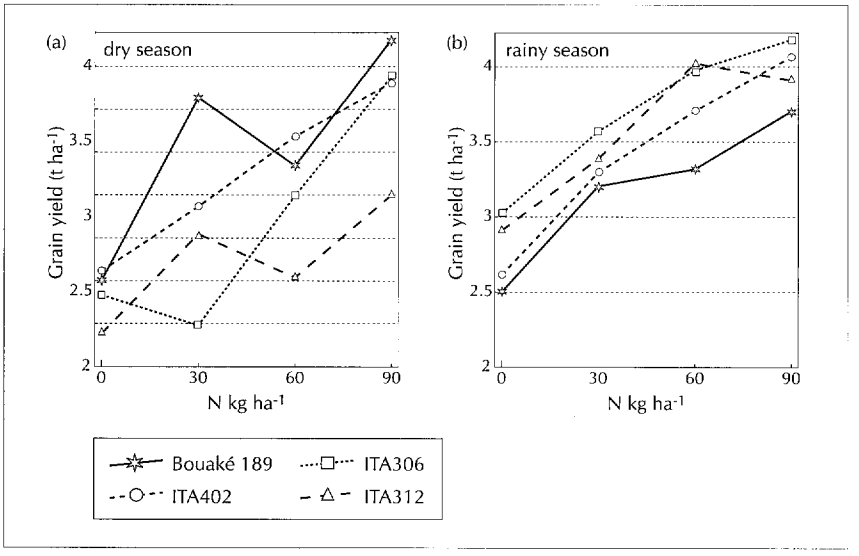
Nitrogen responsiveness of irrigated lowland varieties

K.L. Sahrawat and S. Diatta

With assured soil moisture, lowlands provide a more conducive environment for high and stable rice yields than uplands. Lowland rice varieties are also more responsive to fertilizer inputs, especially N. An experiment was conducted at M'bé in the dry (February to June) and rainy (August to December) seasons in 1993 to study the N response of four promising lowland varieties (Bouaké 189, ITA402, ITA306 and ITA212) under irrigated conditions. Four levels of N applied as urea (0, 30, 60 and 90 kg ha^{-1}) were tested. The varieties were transplanted in 15 m^2 plots and did not receive any other nutrients because our preliminary trials at this site had indicated no response to P or K. A randomized complete block design was used, with four replications.

The rice grain yields were generally higher in the dry season than in the

FIGURE 11: Response of four lowland varieties to N fertilizer under irrigated conditions in the (a) dry and (b) rainy seasons, M'bé, Côte d'Ivoire, 1993



rainy season (*see* Figure 11, a and b). When no N was applied, the top yielders were ITA402 (dry season) and ITA306 (rainy season). When N was applied, the top yielders were Bouaké 189 (dry season) and ITA402 (rainy season). In general, there was no significant response to N applications above 60 kg ha^{-1} in either the dry or rainy seasons. For all four varieties, the N response as reflected in grain yields was higher in the rainy season than in the dry season.

This study will continue in 1994 with basal applications of P and K. The N-use efficiency of the varieties will also be determined following the analysis of the plant samples that is currently being undertaken.

Zinc deficiency in upland rice
K.L. Sahrawat, S. Diatta and M.P. Jones

In 1993 we continued with the multi-year experiments initiated to determine the status of mineral reserves in upland and lowland soils. The experiments are located in lowland, rainfed upland and irrigated upland rice ecologies. The varieties being used are IDSA6 (in rainfed and irrigated upland ecologies) and Bouaké 189 (in the lowland ecology). A new experiment involving controlled irrigation was established in an upland soil at M'bé during the year to study the rate of nutrient depletion. The experimental design includes a complete fertilizer (CF) treatment (100 kg N ha^{-1} as urea, 100 kg P_2O_5 ha^{-1}, 100 kg K_2O ha^{-1} as KCl, 50 kg CaO ha^{-1} as hydrated lime, 50 kg MgO ha^{-1} as $MgCO_3$ and 10 kg ZnO ha^{-1} as $ZnSO_4$) and treatments in which N, P, K, Ca, Mg and Zn are individually omitted.

In the lowland experiment, which is now in its second year of cropping, the yield produced by Bouaké 189 increased only with the application of N. The rainfed upland experiment, now in its fifth year, was severely affected by drought and the applied nutrients had no significant effect on the grain yields. Thus, it was not possible to confirm the results of earlier years which indicated that N deficiency is the most important nutrient deficiency in the humid forest-savanna transition zone under rainfed cropping.

In the irrigated upland experiment, the yield produced by IDSA6 in the treatment CF-N was significantly lower than the yield in the CF treatment (*see* Table 12 *overleaf*). The treatment CF-Zn also gave lower grain yield than the CF treatment. From the results shown in the table, it is clear that N and Zn were the nutrients which were deficient at this site.

The Zn deficiency recorded in the irrigated upland experiment is important as it is the first time we have observed this in upland conditions. The deficiency was expressed as brown blotches and streaks on the lower leaves of the plant and severely retarded plant growth and tillering. The soil at this site is sandy and low in organic matter, and the surface soil is slightly eroded. Because Zn in soils is usually present in the surface layer, erosion of the surface soil may have resulted in Zn deficiency in the treatment where Zn was not added. An analysis of plant tops at tillering showed that the Zn content of the tissue ranged between 4 and 7 mg kg^{-1} of the dry weight in the plants at the tillering stage of rice plant growth. If Zn content is lower than 10 mg kg^{-1}, plants are considered to be Zn deficient.

Severe Zn deficiency was also observed during a survey of breeders' upland material at tillering stage near Foro in the Sudan savanna zone of Cote d'Ivoire. Typical Zn deficiency symptoms were observed on the leaves of the plants. Plant top samples were collected from 18 cultivars showing Zn deficiency symptoms.

TABLE 12: Yield and yield components of IDSA6 under different fertilizer treatments in the first year of a continuous cropping experiment under upland irrigated conditions, M'bé, Côte d'Ivoire, 1993

Treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Tillers (no. m^{-2})	Panicles (no. m^{-2})
Check (no fertilizer)	0.52	1.09	222	125
CF[a]	1.49	2.43	312	163
CF-N	0.78	1.30	248	123
CF-P	1.12	2.55	323	181
CF-K	1.52	2.37	262	178
CF-Ca	1.36	2.45	344	164
CF-Mg	1.10	2.26	325	159
CF-Zn	0.97	2.06	312	148
SE±	0.202	0.264	26	12
CV (%)	32	22	16	14

Note: a CF = complete fertilizer treatment

The samples were analysed for elemental composition of macro-nutrient (N, P, K, Ca, Mg and Na) and micro-nutrient (Fe, Mn and Zn) elements. Comparing samples with and without deficiency symptoms, there were no or only small differences in the elemental composition of the plants with regard to nutrients other than Zn. Plants which showed symptoms of deficiency, however, contained lower amounts of Zn (4-7 mg kg^{-1} dry weight, with an average of 6 mg Zn kg^{-1}) than those showing no or only mild symptoms (7-11 mg Zn kg^{-1} dry weight, with an average of 9 mg Zn kg^{-1}). We will continue this survey in order to select cultivars that can tolerate low Zn levels.

Zinc deficiency is generally considered to be a nutrient disorder of lowland rice but our results suggest that it may also become a problem in uplands, especially in light-textured soils and where surface soil has been eroded. Studies in 1994 will determine the extent of the Zn deficiency problem in upland rice.

PROJECT 4: DEVELOPMENT OF INTEGRATED PEST MANAGEMENT PRACTICES

The rapidly increasing demand for rice in West Africa is causing farmers to intensify rice production systems. However, there is evidence that certain agricultural practices used to increase yields contribute to increased pest populations. Integrated pest management (IPM), a major component of sustainable agriculture, uses natural resources, minimizes environmental pollution and contributes to high yields of good-quality grain.

In 1993 the level of activity in WARDA's IPM project increased. Experiments were designed to obtain information on weed/insect/disease interactions and the data needed to develop technologies for the integrated control of weeds, insect pests and diseases. Characterization of the continuum provided information on the pest species affecting production, at the different toposequence sites from upland to lowland, and the interactions among these pests.

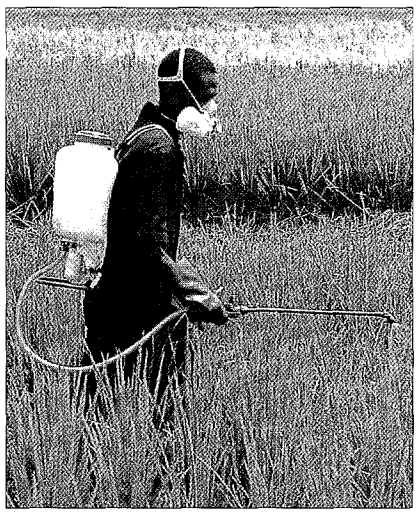
Significant progress was made in developing an inventory of insect pests and their natural enemies and in improving our understanding of the diversity of disease pathogens. Cultural control technologies suitable for use by resource-poor farmers were also tested. During the year WARDA and CAB International initiated a joint research project to develop a technology for controlling the African rice gall midge (*Orseolia oryzivora*), now a severe pest in several West African countries. In 1994 we plan to initiate two additional collaborative projects on: rice nematodes, with CAB International and the International Institute of Parasitology; and weed/insect interactions, with the NRI.

Determinants of insecticide and herbicide adoption in rice-based cropping systems

A.A. Adesina, D.E. Johnson (NRI) and E.A. Heinrichs

To develop sustainable pest control technologies for rice in West Africa, information is urgently needed on current use patterns of pesticides by farmers, how use varies across ecosystems, and factors affecting the adoption of pesticides. To fill this gap in Côte d'Ivoire, we surveyed 178 farmers in three agro-ecological zones: humid forest zone, forest-savanna transition zone and savanna zone. Information was collected on farmers' cropping systems, socio-economic characteristics, perceptions of pests, and the use of herbicides and insecticides for weed and insect pest control.

The results showed that the use of chemicals for weed and insect pest control tends to vary systematically across zones. Adoption of insecticides was highest among farmers in the forest-savanna and savanna zones; insecticide adoption was highest among farmers in the forest-savanna zone. We used logit and probit models



Applying a pesticide in an upland rice field

to examine factors influencing insecticide and herbicide adoption. A broadly defined agro-ecological variable for the savanna zone (value of 1 if the farmer is in the savanna or forest-savanna zone; value of 0 otherwise) was used as a control for locational effects. The results showed that the probability of farmers using insecticides on rice is explained, in decreasing order of importance, by:

1 size of cultivated area in lowlands

2 use of herbicide on rice

3 farmers' perception of losses from insect pests

4 membership of farmers' associations

5 value of non-farm income

The agro-ecological variable was not statistically significant. Three variables explained the probability of herbicide adoption: area cultivated in lowlands; use of insecticides on rice; and the agro-ecological variable. The significantly positive relationship between adoption of insecticides and herbicides in both models may indicate technical complementarities, jointly determined demand, or supply factors. The significance of the agro-ecological variable in the herbicide model reflects the very active promotion of herbicides by CIDT, a para-statal cotton agency in charge of rice production in the savanna zones of Côte d'Ivoire.

Our results have important implications for the planning and targeting of IPM extension programs for rice farmers. First, they suggest that the probability of adoption of both herbicides and insecticides is much higher for farmers cultivating lowland than upland rice (*see* Tables 13 and 14). For lowland rice farmers, the probability

TABLE 13: Predicted conditional probabilities of adoption of insecticides by rice farmers in different agro-ecological zones of Côte d'Ivoire, 1993

	Cultivated area (ha)				
Ecosystem	**0.2**	**0.5**	**1.0**	**1.5**	**3.0**
Lowland rice agro-ecosystem					
Membership of farmers' associations					
Forest	0.14	0.40	0.87	0.98	0.99
Savanna and forest-savanna	0.20	0.51	0.92	0.99	0.99
Non-membership of farmers' associations					
Forest	0.03	0.12	0.59	0.94	0.99
Savanna and forest-savanna	0.05	0.18	0.70	0.96	0.99
Upland rice agro-ecosystem[a]					
Forest	0.06	0.07	0.09	0.11	0.20
Savanna and forest-savanna	0.09	0.11	0.13	0.17	0.28

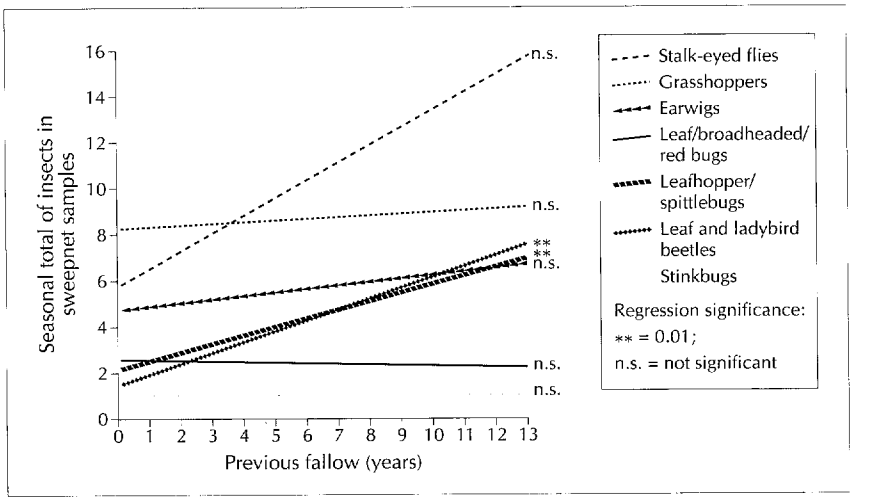
Note: a These estimates are for farmers who cultivate upland rice, belong to farmers' associations and have other income-generating activities in addition to farming

TABLE 14: Predicted conditional probabilities of adoption of herbicides by rice farmers belonging to farmers' associations and operating in different agro-ecological zones of Côte d'Ivoire, 1993

	Cultivated area (ha)					
Ecosystem	**0.2**	**0.5**	**1.0**	**1.5**	**3.0**	**4.0**
Lowland rice ecosystem						
Forest	0.06	0.09	0.16	0.28	0.77	0.93
Savanna and forest-savanna	0.16	0.23	0.38	0.55	0.91	0.98
Upland rice agro-ecosystem						
Forest	0.05	0.06	0.06	0.07	0.11	0.14
Savanna and forest-savanna	0.14	0.17	0.17	0.19	0.26	0.33

of adoption rises significantly as cultivated areas exceed 1.0-1.5 ha. This suggests that IPM strategies to reduce pesticide use need to focus more on lowland rice farmers, especially those with larger farms. Second, the predicted probabilities of pesticide use are much higher for farmers belonging to farmers' associations. In the forest-savanna and savanna zones, the CIDT has vigorously distributed highly subsidized pesticides through farmers' associations. These associations could be used to inform farmers about alternative non-chemical pest control strategies.

FIGURE 12: Effect of length of fallow period on insect pests



Rice weed and insect pest populations on the continuum as affected by length of fallow period in the humid forest zone

E.A. Heinrichs, D.E. Johnson (NRI) and D. Robison (State University of New York)

Traditional shifting cultivation systems appear to be sustainable if fallow periods are long enough to restore soil fertility, maintain soil structure and suppress weeds. These systems are threatened in West Africa by increasing land pressure, resulting in shorter fallow periods.

Studies were conducted in farmers' fields in the humid forest zone near Gagnoa, Côte d'Ivoire (bimodal rainfall 1500 mm annually, with peaks in March and July) to determine how fallow length affects populations of insect pests and their natural enemies, weed growth and yield losses due to weeds. Fields in both upland and hydromorphic ecosystems were selected; they included fields cleared from short forest fallows (0-3 years) and longer forest fallows (5-13 years). Farmers planted traditional rice varieties, from March to April, intercropped with maize. No pesticides were applied.

Insect samples were taken from 22 farmers' fields. Weed weights, weed species and grain yields were recorded for 31 fields. Sweepnet sampling for insect pests and natural enemies was done at approximately 28, 56, 84 and 112 DAS. Deadheart counts were made at 28 DAS, termite and defoliation damage at 56 DAS and stem dissections for stem borers at 84 DAS. To study weed growth and the resulting yield losses, five paired plots (each 25 m^2) were located on a transect across each farmer's field. The plots were sown by the farmers, but one of each pair was hand-weeded at 28, 56 and 84 DAS under researcher management, with weed species and biomass recorded. Rice yields were taken from both the researcher-managed and farmer-managed plots.

Length of fallow influenced the abundance of certain arthropod species. As shown in Figure 12, populations of stalk-eyed flies (*Diopsis* spp.), leaf-feeding beetles and leafhoppers/spittle bugs were significantly higher in the long fallow fields

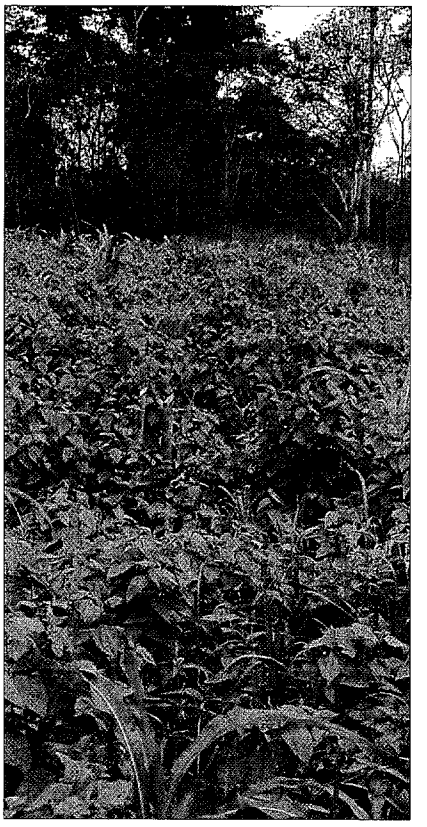
Sweepnet sampling of insects at the research farm at M'bé, Côte d'Ivoire

than in the short fallow fields. The natural enemy complex consisting of spiders, predaceous ladybird beetles and dragonflies/damselflies also increased with fallow length; however, fallow length had no effect on the number of assassin bugs.

Insect pests and natural enemies generally increased with plant age. Topographic position had a variable influence on populations of insect pests and predators. Canopy spiders, dragonflies/damselflies and stalk-eyed flies were more abundant in wetter (hydromorphic) areas than in the drier upland areas. Deadhearts, probably caused by stalk-eyed fly larvae, were also more abundant in the wetter areas of the toposequence. These findings confirm the results obtained at M'bé in 1992.

Weed growth at 28 and 56 DAS was greater in upland areas than in hydromorphic areas. At 28 DAS it was greater in fields cleared after a short fallow period than in those cleared after a long fallow period. Grain yields on the weeded plots were greater in hydromorphic fields than in upland fields, but fallow length had no significant effect on grain yield. Overall, yields from farmer-weeded plots were significantly less (41%) than researcher-weeded plots. *Chromolaena odorata* was a principal component of the fallow vegetation in many of the fields, and because of its growth from cut stems and seeds it was the most common weed in the rice crops after both short and long fallow periods. Other common weeds were *Panicum laxum, Momordica charantia, Triumfetta* spp., *Mariscus alternifolius, Croton hirtus, Phyllanthus amarus, Spigelia anthelmia, Centrosema pubescens* and *Scleria verrucosa.*

The influence of fallow length on rice arthropods and weeds requires further study. Our results suggest that longer fallow periods do not necessarily reduce insect pest pressure, as conventional wisdom suggests, but reduces weed pressure during the early stages of rice crop growth. In 1994, fallow periods longer than the 13 years in the current study will be included to determine whether the longer fallow periods may in fact suppress pests as forest conditions return.



Chromolaena odorata regrowth in a rice crop after fallow vegetation has been cut and burnt

Ecology and management of the African rice gall midge
C. Williams (CAB International), E.A. Heinrichs and K. Harris (IIE)

The African rice gall midge (*Orseolia oryzivora*) is the most serious rice insect pest in Burkina Faso and Nigeria, and instances of high infestation have been reported recently from other African countries. It is mainly a pest of lowland rice but damage in upland rice systems appears to be increasing. In 1993 a 3-year project to develop IPM systems for the gall midge was initiated in collaboration with CAB International. The project is based at WARDA's lowland breeding unit at IITA, Ibadan, Nigeria.

Project activities include surveys of gall midge distribution and pest status, experiments on the relationship between gall midge infestation level and yield loss, ecological studies with the emphasis on alternative host plants and dry-season survival, studies on the impact of natural enemies, screening of rice germplasm to identify varieties for use as parents in WARDA's lowland breeding program, and trials on IPM practices. Activities in 1993 concentrated on preliminary surveys of the gall midge and its parasitoids, and the establishment of a gall midge rearing program.

Visits to rice growing areas in Burkina Faso, Côte d'Ivoire, Mali and Nigeria provided information on the pest status of the gall midge and the ecological conditions in infested areas. In Burkina Faso, two irrigation projects were compared. Gall midge damage appeared to be related to the level of crop management. No damage was observed at Vallée du Kou where farmers planted synchronously, water management was good and weed populations were low. Damage was observed at Karfiguela where crop management was poor.

Dry-season sampling at Ibadan and in farmers' fields in south-east Nigeria began in November. Galls collected from late-planted rice crops and ratoons showed an average parasitism by *Platygaster diplosisae* and *Aprostocetus pachydiposisae* of 41% and 44%, respectively. Both species appear

to be important in reducing midge populations in the dry season. In monthly plantings of irrigated rice at IITA, active (non-diapausing) populations of the midge and its parasites survived, at low levels, to the year-end.

In 1994, studies will include surveys in selected countries to determine the distribution and infestation level of the gall midge, monitoring of farmers' fields for the gall midge and its natural enemies, experiments on yield loss and biotic and abiotic factors affecting egg survival, screening of rice lines for midge resistance, and screening of wild grass species to identify alternate hosts of the gall midge.

Activity of predaceous spiders on the continuum toposequence
E.A. Heinrichs, D.E. Johnson (NRI) and A. Russell-Smith (NRI)

Spider species are diverse and populations high in West African rice ecosystems. Spiders are predaceous and are considered to be a major factor in the natural biological control of rice insect pests. In previous studies we determined the abundance of spiders in the rice canopy. In 1993 we expanded the study on spider populations to include the ground-dwelling species.

In a multi-year study to characterize the continuum toposequence at M'bé, we installed pitfall traps to investigate the activity of ground-dwelling arthropods, especially predaceous spiders. The treatments consisted of two rice varieties, Bouaké 189 (lowland) and IDSA6 (upland); three toposequence sites (upland 1, upland 2 and hydromorphic 1); and weeded and unweeded areas. Traps which consisted of plastic containers with an opening of 8.5 cm in diameter were placed in the soil, with the top of the container flush with the soil surface. Two traps were placed in each plot. A solution consisting of water with a preservative was placed in each trap on Mondays, the contents removed on Wednesdays, and the traps again filled with the solution on Wednesdays and emptied on Fridays. Sampling began at sowing and continued beyond harvest.

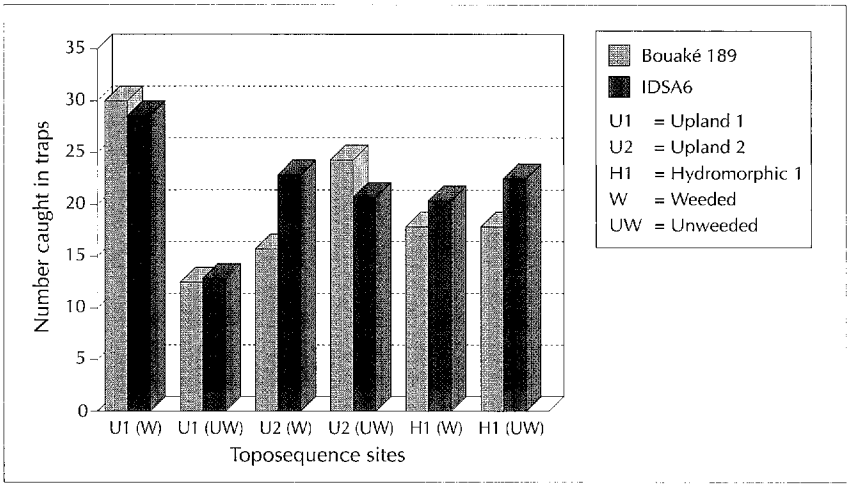
Spiders and ground-dwelling insects were collected. The most abundant spiders collected belonged to the genera *Pardosa, Wadicosa, Tetragnatha, Langbiana* and *Trochosa*. The insects collected belonged to the families Acrididae (grasshoppers), Carabidae (predaceous ground beetles), Chrysomelidae (leaf beetles), Gryllidae (crickets) and Formicidae (ants). The activity of *P. injucunda*, the most abundant spider species, was similar in both rice varieties but differed according to toposequence site and weeding regime (*see* Figure 13), being highest in the upland 1 weeded plots and lowest in the upland 1 unweeded plots. Other treatments did not produce significant differences. The high activity in the upland 1 weeded plots may have been due to their location at the upper portion of the toposequence, near a fallow bush/grass area which served as a spider refuge. The activity of ground-dwelling insects was similar in all treatments.

In 1994, further evaluation of weed/spider interactions will be conducted at M'bé and in slash-and-burn fields at Gagnoa, Cote d'Ivoire. These studies will include observations on the effect of field border fallow areas on spider activity within rice fields and the effect of leaving weed residue in fields after weeding to serve as spider refuges. The results will be used to develop cultural practices that enhance spider activity.

Strepsipteran parasitism of white leafhoppers
E.A. Heinrichs

White leafhoppers (*Cofana* spp.) are abundant throughout the continuum, from the upland to the lowland areas. Strepsipterans of the genus *Halictophagus* are internal parasites

FIGURE 13: Number of *Pardosa injucunda* collected over a 20-week period in two pitfall traps in weeded and unweeded plots of Bouaké 189 and IDSA6 at toposequence sites, M'bé, Côte d'Ivoire, 1993



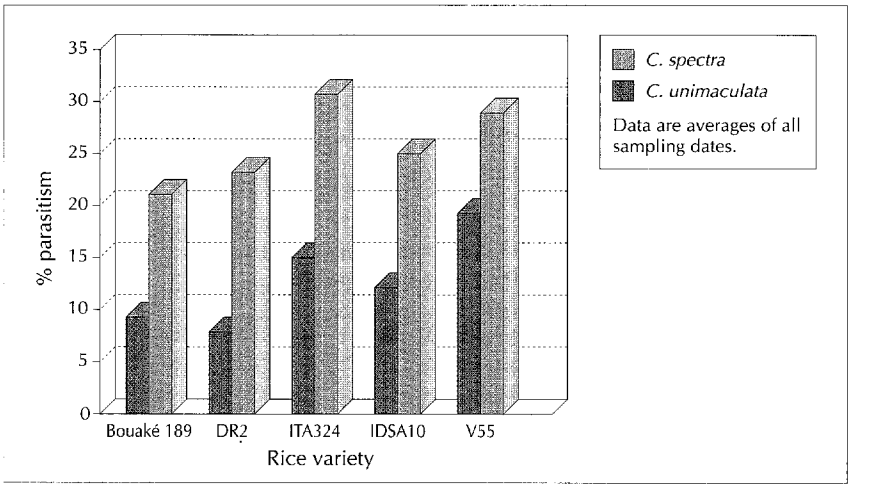
which feed in the abdomen of white leafhoppers and are easily observed because the head of the sedentary, wingless female protrudes from between the abdominal segments of the leafhopper host. One female can produce up to 2000 larvae, which leave the parasitized host and move on to a rice leaf in search of a new host. In routine surveys of rice insects in Côte d'Ivoire in 1992 and 1993, white leafhoppers were observed to have a high rate of strepsipteran parasitism.

Studies were conducted to determine the importance of strepsipteran parasitism in regulating the population of the white leafhopper species, *C. spectra* and *C. unimaculata*. Sweep-net collections of *Cofana* species were made every 2 weeks throughout the vegetative stage of five rice varieties (Bouaké 189, DR2, ITA324, IDSA10 and V55) growing in irrigated lowland fields at the M'bé research farm. The leafhoppers were examined in the laboratory to determine the percentage parasitism and the various parasite stages present in the leafhopper hosts.

The species *H. spectrus* (Strepsiptera: Halictophagidae) was most abundant on hosts of *C. spectra*, with an average percentage parasitism for all sampling dates of 21-31% in *C. spectra* and 8-19% in *C. unimaculata* on the five varieties (*see* Figure 14). Percentage parasitism was generally similar throughout the sampling period. On V55, parasitism of both leafhopper species reached 57% at 68 DAT. The maximum number of adult parasites observed per leafhopper was six. In both *C. spectra* and *C. unimaculata* about 60% of the parasite pupae and adults were males and 40% females.

In 1994, a survey will be conducted at key locations in Côte d'Ivoire to determine the percentage of white leafhopper parasitism by strepsipterans, the species of *Halictophagus* parasitizing white leafhoppers, and the relationship between length of the fallow period in traditional slash-and-burn cultivation and percentage strepsipteran parasitism.

FIGURE 14: Percentage parasitism of *Cofana spectra* and *C. unimaculata* by *Halictophagus spectrus* on five rice varieties grown under lowland irrigated conditions, M'bé, Côte d'Ivoire, 1993



Seedling age and plant spacing effects on insect pests in lowland irrigated rice

E.A. Heinrichs, D.E. Johnson (NRI) and A.A. Sy

Crop husbandry practices can have the dual purpose of increasing crop production and suppressing insect pest populations. In 1993, experiments were conducted at the M'bé research farm to determine the effect of seedling age and plant spacing on insect pests, disease incidence and subsequent rice plant damage.

The seedling age experiment consisted of four treatments: seedlings transplanted at 20, 30, 40 and 50 days after the nursery was sown. Seedlings in the plant spacing experiments were transplanted at five spacings (*see* Table 15 *overleaf*). There were two plant spacing experiments; they were identical except that the first one was transplanted on 17 March and the second on September 13. Weed weights, by species, were recorded and the plots were then weeded at 21, 42 and 63 DAT. In all experiments, insect populations were assessed by making sweepnet counts. Rice yellow mottle virus (RYMV) incidence, leaf damage caused by insects and stem borer damage were visually assessed and the percentage of tillers infested by stem borers was determined by dissecting rice stems. Rice leaf area

A stem borer, one of the major insect pests of rice in West Africa

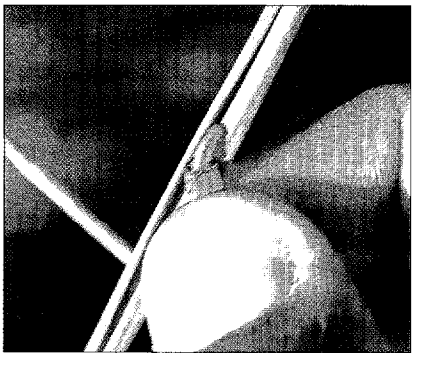


TABLE 15: Effect of plant spacing on caseworm (*Nymphula depunctalis*) defoliation, stem borer infestation, leaf area index, weed weight and grain yield at indicated days after transplanting irrigated lowland rice, M'bé, Côte d'Ivoire, 1993

Plant spacing (cm)	Caseworm defoliation (%)	Whiteheads (%)	Leaf area index 43 DAT[a]	Leaf area index 67 DAT	Weed weight (g m^{-2}) 21 DAT	Weed weight (g m^{-2}) 42 DAT	Yield (t ha^{-1})
10 x 10	68	16.3	4.3	6.5	29.0	18.0	4.75
14 x 14	68	8.3	2.8	3.7	40.6	11.7	4.26
20 x 20	20	3.7	1.5	1.4	69.5	18.3	5.01
30 x 30	20	2.0	0.6	0.8	82.3	19.4	4.37
40 x 40	16	3.7	0.3	0.4	106.5	29.8	3.39
SE±	4.90	0.46	0.24	0.54	13.39	2.82	0.305
CV (%)	22	74	21	37	35	25	12

Note: a DAT = days after transplanting

index (LAI) readings were taken with a LiCor leaf area meter.

Seedling age had little effect on insect populations. RYMV was extremely high in all treatments, but lowest in the 20-day-old seedling treatment. High RYMV incidence resulted in low grain yields in all treatments.

In the first plant spacing experiment, sweepnet counts indicated that the highest populations of *Diopsis macrophthalma, D. apicalis* and *Trichispa sericea* occurred in plots with close plant spacings. RYMV was high in all treatments but lowest in the 10 x 10 cm spacing treatment. The LAI was lowest in the wider spaced treatments. LAI, even in the wide spaced treatments, increased little over time because the plants were severely damaged by RYMV and *T. sericea*. Yields were highest in the 10 x 10 cm spacing treatment.

In the second plant spacing experiment, insect pest counts were similar in all treatments but percentage defoliation due to whiteheads and feeding by caseworms (*Nymphula depunctalis*) were highest in the most closely spaced treatments (*see* Table 15). The LAI was 14 times greater in the 10 x 10 cm treatment than in the 40 x 40 cm treatment at 43 DAT. This dense rice growth suppressed weed growth, which was four times greater in the 40 x 40 cm treatment than in the 10 x 10 cm treatment at 21 DAT. Dominant weed species were *Marsilea minuta, Cyperus difformis, Heteranthera callifolia* and *Sphenoclea zeylanica*. Composition of the weed growth was not affected by spacing treatments. Grain yield was highest at the closer spacings.

These initial studies indicate that plant spacing affects the abundance of certain insect species, the extent of insect-caused plant damage and possibly the incidence of RYMV. This cultural practice also has distinct effects on weed growth. Studies in 1994 will continue to evaluate the various interactions in order to select the most suitable combinations of practices for farmers.

Selection of RYMV-resistant cultivars and estimation of RYMV-induced yield loss under natural and artificial pressure
A.A. Sy, K. Alluri (INGER-Africa) and K. Akator

In the past decade rice yellow mottle virus (RYMV) has spread rapidly in the lowland ecosystems of Africa. Although information on its geographic distribution is available and methods have been developed for artificial inoculation and serological diagnosis, little or no data exist on yield losses caused by RYMV, on pathogen biotypes or on the genetic profiles of susceptible and resistant rice germplasm. In 1991, a major regional project was initiated to fill this information gap. In 1993, two experiments were conducted to identify the resistance profiles of a range of materials and estimate yield losses caused by RYMV under artificial and natural selection pressure.

In the first experiment, at Gagnoa, we screened 138 entries (100 of which came from the INGER-Africa RYMV nursery). Two 3 m-long lines of each entry were transplanted at a spacing of 20 x 20 cm in a non-replicated trial. One line of each entry was subjected to natural infestation; the other was manually inoculated with naturally infected extract from the highly susceptible variety, Bouaké 189, grown in adjacent plots. Levels of resistance were estimated using the IRRI Standard Evaluation System for Rice and included five factors: chloroses severity; reduction in the number of tillers; reduction in panicle exsertion;

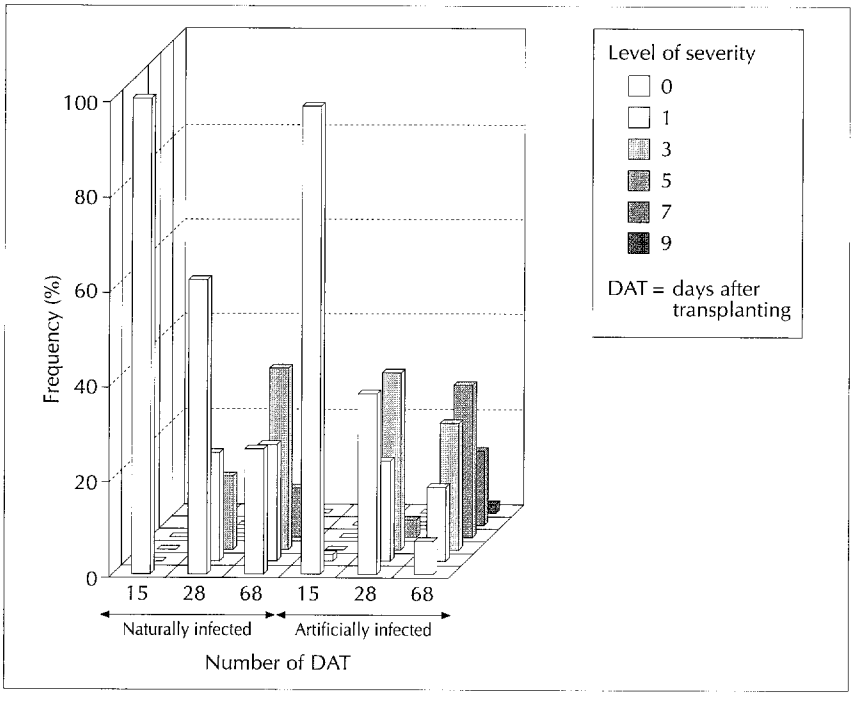
reduction in panicle filling; and reaction to sero-diagnostics. Observations were made at 15, 28 and 68 DAT.

Figure 15 shows the resistance profile of the 138 test entries. In entries that were naturally infected, 36 (26%) were categorized as superior (rating of 0) at 68 DAT, compared with 10 (7%) for the artificially inoculated set. The varieties showing the highest resistance were TOG5672, TOG5681, CNA762324, FAROX300, FARO39, FAROX43, IRAT161, ITA257, TOX6873 and ITA305. These materials will be subjected to additional multilocational screening in 1994 to confirm their RYMV resistance.

The second experiment consisted of a mini-trial of two susceptible varieties (Bouaké 189 and BG90-2) and one highly resistant variety (Moroberekan). The test materials were exposed to two RYMV treatments: artificial inoculation and natural disease pressure. The entries were grown in plots of six lines, each 3 m long, with each treatment combination replicated four times. The experiment was planted at M'bé in a screenhouse protected against external vectors.

A comparison of the yields from inoculated and naturally infested materials showed a yield reduction rate of 84% for Bouaké 189, 67% for BG90-2 and 4% for Moroberekan. The spectacular yield losses for the two susceptible varieties could be explained by pronounced morpho-physiological changes induced by the virus at the vegetative and reproduction stages. These changes included a large reduction in chlorophyll activity following severe chlorosis, and substantial reductions in height, tillering index, panicle exsertion, ratio of full panicles and 1000-grain-weight. These findings indicate that farmers' fields with a severe RYMV epidemic can suffer a high level of crop loss.

FIGURE 15: Distribution of entries according to resistance/susceptibility to rice yellow mottle virus, Gagnoa, Côte d'Ivoire, 1993



Sources of rice blast resistance and identification of sites for the selection of blast-resistant cultivars

A.A. Sy, Y. Séré (INERA), K. Alluri (INGER-Africa), E.D. Imolehin (NCRI), S. Sreenivasaprasad (Queens University, Belfast)

Rice blast, caused by the fungus *Pyricularia oryzae*, is the most important pathogenic constraint to rice production in West Africa. Although much is known about this disease, the extreme variability of the *P. oryzae* pathogen constantly challenges research findings and poses a major obstacle to developing durable resistance in improved cultivars. The WARDA pathologist, in collaboration with WARDA breeders and IRRI, CIAT and national program scientists, has developed an integrated approach for the selection and development of varieties with enhanced levels of resistance to blast. Three sets of activities were conducted in 1993:

- an accelerated pre-selection screening of materials resistant to leaf blast
- multilocational screening; and the identification of representative sites for more efficient blast screening in the field under natural pressure
- IPM Task Force work to determine the resistance/susceptibility profiles and genetic make up of materials from various origins; measure the representativeness of screening sites in West Africa from the perspective of quantitative pressure (environmental index, I_j) and qualitative pressure (molecular phenotypes); and implement coordinated regional screening activities with national scientists

The accelerated screening trial included 590 entries from WARDA's Continuum and Sahel Programs (291 entries) and from CIAT (299 entries). The entries were planted in an upland field at M'bé. The conventional IRRI blast nursery design was used, with each entry repeated four times. The susceptible checks were C039, Maratelli, OB677, OS6 and WAB96-1-1 and the resistant checks were CG20, TOX8903, IR36 and TOG5810. The infected rows were planted with a mixture of IR5 and Usen in equal proportions. In the first set of 291 entries, 170 showed a high level of resistance (in the 0-1 class, *see* Figure 16), of which 18 were completely immune (*see* Table 16). In the second set of 299 entries, 11 showed a high level of resistance (*see* Table 16).

The objective of the multilocational screening trial was to measure the spatial and temporal resistance of promising blast-resistant varieties. The trial included 188 entries, one resistant local check (Moroberekan), one multilocational resistant check (IDSA6) and one multilocational susceptible check (KTH17). The trial was laid out according to the standard INGER-Africa blast nursery design. Both ends of the plot and the interspersed sections were infested with a mixture of IR5 and Usen in equal proportions. The IRRI Standard Evaluation System for Rice was used to evaluate materials at 21, 27, 34, and 41 DAS. Thirty-seven entries (out of 188) showed a total absence of perceptible leaf symptoms at 41 DAS (*see* Table 17).

A trial to identify representative sites for future regional blast screening was conducted as a collaborative activity within the Integrated Pest Management Task Force. Twenty-four entries selected from the 50 varieties tested in 1992 were screened. The test materials were from Burkina Faso, Ghana, Nigeria and WARDA. A randomized complete block design was used, with four replications and elementary plots of 3 m^2. The data for 1993 have been analyzed for the following sites: Farako-Bâ (Burkina Faso), Man and

FIGURE 16: Distribution of entries according to resistance/susceptibility to rice blast, M'bé, Côte d'Ivoire, 1993

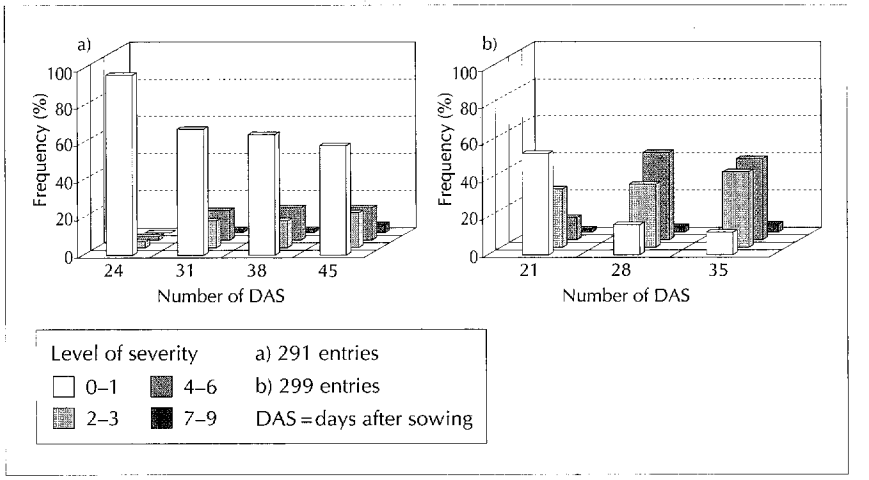


TABLE 16: Selection for resistance to leaf blast, showing the best profiles for series A (18 immune entries at 45 DAS[a]) and series B (maximum severity score of 1 for 11 entries at 35 DAS), M'bé, Côte d'Ivoire, wet season, 1993

Series A (immune entries)	Series B (entries at severity = 1)
CT6570-7-12-9-M	TOX3112-41-1-3-6-3
TOX3440-16-1-2-1-1	TOX3872-19-3-3-2
TOS8903	IR36
TOX3440-47-5-3-2-1	TOG5810
TOX3440-127-1-2-3-2-2	TOX3118-47-1-1
TOX3441-96-1-1-2-1-1	TOX3739-30-3-1-3-3
WAB510-25	TOX3562-61-1-3-2-1-1
WAB510-26	TOX4008-34-1-1-2
WAB510-27	TOX3562-61-1-1-1-3-3
WAB510-32	TOX3870-38-3-1-1
WAB514-8	IR52280-117-1-1-3
P4711 F2-78-4-1X	
WAB514-11	
WAB514-12	
WAB514-15	
TOX3219-5-1-1-1	
TOX3553-34-3-2-3-2-2	
TOX3558-73-2-1-1-1-3	

Note: a DAS = days after sowing

TABLE 17: Selection for resistance to leaf blast, showing the best profiles (37 immune entries at 41 DAS[a]), M'bé, Côte d'Ivoire, 1993

Varieties		
Akiyudaka	IR28222-9-2-2-2	TOX3069-66-2-1
BG367-4	IR31899-30-1-1-3	TOX3084-143-1-4-3
B5592F-5-ST-31-11	IR36	TOX3093-10-2-3-2-3
B8906F-13-13-ST-37	IR37704-131-2-1-3-2	TOX3107-56-1-2-2
Carreon	IR4422-98-3-6-1	TOX3107-56-1-2-2-5
IR5931-113-1	IR46	TOX3114-10-1-2-3-3
WABIS675	IR54	TOX3118-12-1-3-1
FAROX	IR70	TOX3118-6-E2-3
FAROX317-8-2	ITA234	TOX3133-59-1-2-4
FAROX37 (ITA 306)	ITA252	TOX3183-59-1-2-4-1
IRI346	ITA312	TOX902-5-103-3-101-2
IR21141-24-2	MK14-87	
IR28118-138-2-3	TOX2078-1-2-3	

Note: a DAS = days after sowing

M'bé (Côte d'Ivoire), and Ibadan and Onne (Nigeria). A two-way analysis of variance confirmed highly significant differences in the five test environments in intrinsic host potential, and significant interactions between host and environment.

A comparison of mean performance at each site and overall performance across sites (Dunnett test) enabled us to rank the test materials according to low occurrence and severity (*see* Table 18 *overleaf*). Our ranking gives priority to the severity criterion. The absolute superiority of FARO37 was observed at Farako-Bâ (zero incidence and severity). At Man, the best varieties were FARO37, FARO29, TR2, ITA257, WAB56-39, WAB56-50, WAB56-104 and WAB56-125. At Ibadan, where there was 100% incidence, the best entries were WAB56-39, WAB56-50, WAB56-104 and WAB56-125. The highest blast pressure was observed at Onne, where there was 100% incidence on all entries. The least susceptible entry under this extreme pressure was WAB56-104 (severity score of 45.3). The M'bé site had low discriminatory ability. It was characterized by low selection pressure, with 11 out of 24 entries showing immunity. Our analysis of varietal reactions across all sites indicated that WAB56-125 was the least susceptible entry, confirming its excellent performance in the blast screening trials conducted in 1992.

The selection pressure observed at each site can be quantitatively represented by an environmental index, I_j, where I_j is the mean performance of host plant populations across all environments subtracted from the mean performance of the host plant population in environment $_j$, thus:

$$I_j = \Sigma_i Y_{ij}/V - \Sigma_i\Sigma_j Y_{ij}/Vn$$

where:

- i = blast score (1 = no lesions; 7 = > 50% leaf surface covered with lesions)
- j = site
- Y_{ij} = number of plants with score I at site j
- N = number of plants observed
- V = number of test varieties
- n = total number of sites

The results show a considerable shift in site indexes between 1992 and 1993. In 1992, Farako-Bâ showed the greatest pressure (I_j = 8.57), followed by Onne (-0.98), Man (-1.38), Ibadan (-1.96) and M'bé (-4.24). In 1993 the figures were: Onne (30.79), Ibadan (13.85), Farako-Bâ (-0.71), Man (-15.16) and M'bé (-27.80). These rankings suggest that in future we need to give close attention to the Farako-Bâ, Ibadan and Onne sites. We also need to confirm these empirical field reactions by integrating the results of analyses of *P. oryzae* molecular data from samples taken at each site.

In qualitative terms, the molecular analysis of 12 *P. oryzae* samples from Farako-Bâ, Man, Ibadan and an additional site, Ikenne, suggested the existence of five different pathogen lines. We also found that isolates from differentiated hosts (Usen and FKR33) at the same site (Ikenne) exhibited a single molecular phenotype (100% similarity). In contrast, isolates from the same variety (IR5) at different sites (Farako-Bâ, Man and Ibadan) were substantially different (76-78% similarity). While these preliminary data are interesting, further research is needed to compare the virulence spectrum of these isolates in terms of varietal differential series. This work will continue in 1994, as will the trials at Onne, Farako-Bâ, Ikenne, Man and M'bé.

PROJECT 5: VARIETAL IMPROVEMENT

More than 75% of the 1.8 million ha of upland rice in West Africa is cultivated under extensive crop management systems, including slash-and-burn rotation, low use of external inputs and little or no weeding. With intensification, the soils in these areas are becoming physically and chemically degraded. Periodic drought further reduces production

TABLE 18: Graded profiles of the best genetic materials across environments (49 DAS[a])

Varieties	Farako-Bâ (I)[b]	Farako-Bâ (S)[b]	Ibadan (I)	Ibadan (S)	Man (I)	Man (S)	M'bé (I)	M'bé (S)	Onne (I)	Onne (S)
TR1/Moro	—	—	—	—	—	—	1	1	—	—
	—	—	—	—	—	—	0.0	0.0	—	—
TR2[c]	2	2	—	—	1	1	1	1	—	—
	3.9	1.6	—	—	0.0	0.0	0.0	0.0	—	—
ITA257	—	—	—	—	1	1	1	1	—	—
	—	—	—	—	0.0	0.0	0.0	0.0	—	—
WAB56-104	—	—	1	1	1	1	1	1	1	1
	—	—	90.0	24.1	0.0	0.0	0.0	0.0	90.0	45.3
WAB56-125	5	6	1	1	8	8	1	1	1	2
	19.7	7.8	90.0	24.1	3.9	2.2	0.0	0.0	90.0	47.8
WAB56-50	4	5	1	1	1	1	1	1	1	6
	14.6	5.8	90.0	24.1	0.0	0.0	0.0	0.0	90.0	53.0
FARO29	3	4	—	—	1	1	—	—	—	—
	10.8	4.3	—	—	0.0	0.0	—	—	—	—
FARO33	13	3	—	—	—	—	—	—	—	—
	81.9	3.1	—	—	—	—	—	—	—	—
FARO37	1	1	—	—	1	1	1	1	—	—
	0.0	0.0	—	—	0.0	0.0	0.0	0.0	—	—
WAB181-11	—	—	—	—	—	—	1	1	—	—
	—	—	—	—	—	—	0.0	0.0	—	—
WAB56-39	—	—	1	1	1	1	1	1	1	5
	—	—	90.0	24.1	0.0	0.0	0.0	0.0	90.0	52.7
WAB56-57	—	—	1	5	—	—	1	1	—	—
	—	—	90.0	26.9	—	—	0.0	0.0	—	—
FKR27	—	—	—	—	—	—	1	1	1	3
	—	—	—	—	—	—	0.0	0.0	90.0	49.9
FKR33	—	—	—	—	—	—	—	—	1	4
	—	—	—	—	—	—	—	—	90.0	50.2
$\bar{Y}_j$[d]	64.2	30.9	90.0	45.5	29.1	16.4	8.6	3.8	90.0	62.4

Note: a DAS = days after sowing
b Transformed incidence and severity (arc sin √%)
c TR2: FARO29 (Farako-Bâ), IDSA13 (Ibadan), WAB99-14 (Onne), WAB56-50 (Man, M'bé)
d $\bar{Y}$ .. (I) = 56.2; $\bar{Y}$ .. (S) = 31.6

potential for upland rice in all but the highest rainfall areas.

Most inland valley rice farmers use no or only marginally effective water control methods. This contributes to weed problems, low fertilizer efficiency, dry areas on valley fringes and waterlogging and submergence in valley bottoms. Iron toxicity can be severe where poor drainage and inflow of seepage water result in high concentrations of ferrous iron.

Traditional varieties have a degree of resistance/tolerance to these stresses and give low but relatively stable yields under low-input management. Because of their poor responsiveness to inputs, however, their cultivation does not ensure adequate economic returns to the improved management required to achieve sustainable intensification. In contrast, modern varieties that are high yielding under favorable conditions generally lack sufficient stress resistance and the other traits necessary for widespread adoption under the low and moderate management regimes characteristic of the early stages of intensification. Although the introduction and development of varieties for irrigated conditions has had some impact, varietal improvement research for the uplands and rainfed lowlands has not yet led to significant changes in technology or yield.

The main objectives of this project are to develop improved germplasm with high yield potential, superior grain quality, resistance to major stresses, appropriate plant type for weed tolerance or suppression, and a growth duration of 90-140 days, and to share this germplasm with national programs. The overall goal is to develop varieties to suit low- and high-input production systems in the upland/hydromorphic and lowland/hydromorphic ecosystems of West Africa.

A high-yielding upland rice variety

In 1993, upland yield and stress trials were conducted in Côte d'Ivoire at WARDA's research farm at M'bé (forest-savanna transition zone; bimodal rainfall; 1993 total rainfall 1001 mm), Man and Gagnoa (humid forest zone; monomodal; 1639 mm and 1500 mm, respectively) and Korhogo (savanna zone; monomodal; 1204 mm).

Over 400 elite and advanced breeding lines were evaluated for yield potential and resistance/tolerance to major stresses. Eighty-seven new crosses were made, with seven involving *Oryza sativa* and *O. glaberrima* parents. F_2 populations were grown from 57 crosses. Some 6482 pedigree nursery rows were evaluated for yield potential under low and/or high input levels of management, for ability to tolerate or suppress weeds, for resistance/tolerance to major stresses and for good grain quality. A total of 690 advanced generation lines were bulk harvested for observational and replicated yield trials scheduled to be conducted in 1994. Anther culture was used to obtain rapid homozygous lines and to overcome grain sterility problems encountered in early segregating progenies from *O. sativa* and *O. glaberrima* crosses. Over 2000 fixed and segregating populations were composed in 40 yield and stress nurseries screened in 13 Task Force member countries in West Africa.

WARDA's varietal improvement research for rainfed and irrigated lowland ecosystems is based at IITA, Ibadan, Nigeria. Trials are being conducted at several Nigerian sites (iron toxicity tolerance trials at Edozhigi; drought tolerance screening at Kano; and African rice gall midge, blast and leaf scald screening at Itoikin, Ikenne and Onne, respectively).

In its second year of activities, the Lowland Rice Breeding Task Force coordinated the distribution of 136 sets of seed materials to rice breeders in 16 West African countries. Some 282 improved lines were evaluated in 14 yield trials. In addition, segregating populations from crosses for iron toxicity, African rice gall midge, leaf scald and lowland drought were supplied to various national programs. Lines

selected from on-station trials in 1992 were further tested in multilocational on-farm and on-station elite varietal trials in Benin, Cameroon, Côte d'Ivoire, Gambia and Guinea-Bissau, with many performing better than local checks (*see* Table 19).

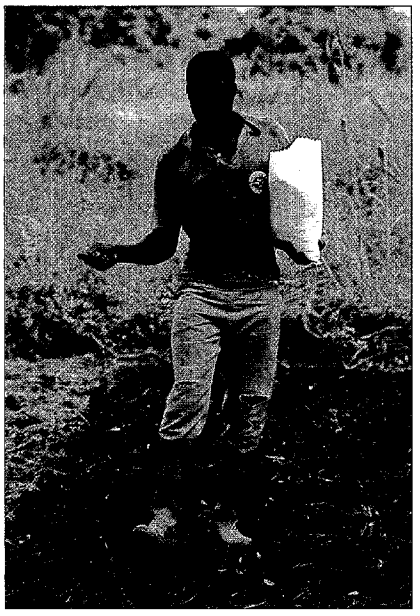
A new prefix, WITA, was adopted for elite lines identified by WARDA for on-farm trials of materials developed by the earlier IITA rice program. TOX3118-6-E2-3 was designated WITA 1 for farmers' field testing in Nigeria through the NAFPP. The lines TOX3093-35-2-3-3 and TOX3100-32-2-1-3-5 were selected by the national program in Côte d'Ivoire and subsequently designated as WITA 2 and WITA 3 for on-farm testing in that country.

A total of 259 new crosses (from WAT511 to WAT769) were made for various breeding objectives, including resistance/tolerance to African rice gall midge, iron toxicity, medium-deep water conditions, rice yellow mottle virus (RYMV), drought and rice blast. Crosses were also made to incorporate drought tolerance from *O. glaberrima* into improved *O. sativa* lines. In addition, 46 F_2 populations, 82 F_3 bulks and 16 660 pedigree lines were sown and selections made, 560 improved lines were evaluated in six on-station trials and 953 were evaluated in observational nurseries. The selection of rice

TABLE 19: Top-ranking entries in an elite varietal trial, at different locations in various countries during the 1993 wet season

Location	Ecology	Designation and yield (t ha^{-1})
M'bé, Côte d'Ivoire	Irrigated lowland	TOX3100-32-2-1-3-5 (3.10); Cisadane (2.66); TOX3876-56-1-4 (2.59); TOX3093-35-2-3-3 (2.53); Bouaké 189[a] (1.18)
Korhogo, Côte 'Ivoire	Iron-toxic irrigated lowland	TOX3073-17-1-3-3-3 (6.70); ITA312 (6.10); TOX3084-136-1-3-1-2 (6.10); TOX3233-46-3-3-4-2-2 (6.10); Bouaké 189[a] (4.60)
Bouaké, Côte d'Ivoire	Favorable rainfed lowland	TOX3052-56-3-1-3-2 (6.40); TOX3050-6-E2-3-4 (6.00); TOX3118-47-1-1 (5.90); ITA230 (5.80); Bouaké 189[a] (4.70)
Gagnoa, Côte d'Ivoire	Irrigated lowland	TOX3050-6-E2-3-4 (9.70); TOX3052-41-E1-2-1-2 (7.70); ITA230 (7.10); Bouaké 189[a] (4.70)
Lagdo, Cameroon	Irrigated lowland	TOX3100-32-2-1-3-5 (11.30); TR46 (8.90); ITA230 (8.80); TOX3050-6-E2-3-4 (8.80); ITA306[a] (7.70)
Gambia	Drought-prone rainfed lowland	DJ11-509[a] (2.17); TOX3233-46-3-3-4-2 (1.95); TOX3217-69-3-1 (1.88); TOX3553-65-3-3-2 (1.73); TOX3399-84-2-1-3 (1.70)
Agbagoule, Benin	Drought-prone rainfed lowland	IRA306[a] (6.40); TOX3050-6-E2-3-4 (6.30); TOX3154-17-1-3-2-2 (6.30); TOX3133-75-1-2 (6.20); TOX3052-39-1-2-1 (0.70).
Tre, Benin	Iron-toxic rainfed lowland	ITA342 (2.79); Cisadane (2.58); TOX3133-75-1-2 (2.15); TOX3154-17-1-3-2-2 (2.15); ITA306[a] (0.99)
Lema Dassa, Benin	Favorable rainfed lowland	TOX3050-6-E2-3-4 (7.21); ITA230 (6.42); TOX3440-151-1-3-2 (5.95); ITA306[a] (5.88); TOX3052-39-1-2-1 (5.16)
Carantaba, Guinea-Bissau	Irrigated lowland	TOX3100-32-2-1-3-5 (5.73); TOX3050-6-E2-3-4 (5.64); TOX3118-2-E2-2-1-1 (5.43); TOX3100-44-1-2-3-3 (5.43); ITA212[a] (4.90)

Note: a Check



Applying fertilizer in a lowland rice yield trial

genotypes which perform well under low-input management was also initiated.

Initial screening of new lines for adaptation to upland/hydromorphic conditions
M.P. Jones and S. Mandé

Since 1985, about 6000 varieties/lines have been introduced and evaluated by WARDA for their adaptation to a range of upland and hydromorphic rice growing conditions in Côte d'Ivoire. In 1993, 200 introductions from CIAT and 300 newly fixed lines were evaluated in observational nurseries at M'bé, Man and Korhogo in Côte d'Ivoire. The entries were grown in single plots (4 rows, 5 m long); the check varieties, WABC165 (short duration) and IDSA6 (medium duration) were repeated after every 20 test entries. Seeds were drill-planted in rows spaced 25 cm apart. Fertilizer was applied at a rate of 60-40-40 (N-P_2O_5-K_2O) kg ha^{-1}, with N applied in three equal doses and P_2O_5 and K_2O applied basally. The herbicide Ronstar was applied 1 DAS at a rate of 4 liters ha^{-1}.

Promising lines were identified among the materials received from CIAT, as well as among WARDA crosses:

- at all locations, entries with consistently good performance and high phenotypic acceptability scores: CT11216-6-3-M-M, CT11218-3-5-M-M, CT11231-1-3-M-M, CT11231-35-4-M-E, WAB384-B-3-H2, WAB384-B-4-H1, WAB307-B-B-6-H9, WAB326-B-B-4-H1, WAB245-B-B-9-H1-1, WAB384-B-3-H2 and WAB384-B-4-H1

- at Man, entries showing tolerance to acidity and low P (pH < 4.00): CT11626-2-5-M-M, CT1126-6-3-M-M, WAB377-B-20-H5 and WAB365-B-6-H2-HB

- at Korhogo and M'bé, entries with good drought resistance: CT6196-33-11-1-34, CT6947-7-1-4-2-1-M, WAB337-B-B-8-H5, WAB337-B-B-6-H4 and WAB331-B-B-B1-H2-1

A total of 208 entries with acceptable grain properties, better phenotypic acceptability scores than the check varieties and resistance/tolerance to major stresses such as blast, sheath rot, glume discoloration, drought and acidity were selected for evaluation in observational yield trials in 1994.

Screening promising upland rice selections under high-input management
M.P. Jones and S. Mandé

To identify varieties with high and stable yields under high-input management in upland and hydromorphic ecosystems, WARDA is collaborating with breeders in national programs to conduct observational and replicated yield trials of promising varieties and advanced lines. In 1993, trials were conducted at 17 sites in 13 West Africa countries, including Côte d'Ivoire.

Observational yield trials (short and medium duration) were conducted at M'bé, Man and Korhogo in Côte d'Ivoire to evaluate 260 entries under various environmental conditions. An early-duration trial was also conducted at M'bé on a hydromorphic soil. Entries were grown in single plots (2 x 5m), with the check varieties WABC165 (short duration) and IDSA6 (medium duration) replicated after every 20 entries. Twenty-seven varieties and advanced lines that had outyielded the best check plots by 12-48% were selected. An additional 42 entries were selected for good seedling vigor, earliness, plant type, grain quality and resistance/tolerance to blast, sheath rot, glume discoloration and drought. The results were as follows:

- the highest yielding entries (2.85-4.36 t ha^{-1}): WAB368-B-1-H2-HB, WAB56-125, WAB368-B-8-H1-HB, WAB181-18, WAB365-B-B-H2-HB, WAB337-B-B-11-H5, WAB337-B-B-12-H4, WAB337-B-B-11-H1 and WAB337-B-B-7-H1

- under hydromorphic conditions, 22 varieties and advanced lines outyielded the best checks by up to 42%; the top five varieties (yields exceeding 3.5 t ha^{-1}): TOX1010-14-4-7-5, WAB126-B-B-15-HB, TOX1010-6-3-5-1, WAB126-B-B-8-HB and WAB126-B-B-13-HB

A total of 159 entries were also screened in three preliminary yield trials, two advanced yield trials and two elite variety trials at M'bé, Man and Korhogo in Côte d'Ivoire. A randomized complete block design was used, with 3 x 5 m plot sizes and four replications. Grain yields were

TABLE 20: Performance of the three highest yielding short-duration varieties and the check variety in preliminary yield trials in upland conditions at M'bé, Man and Korhogo, Côte d'Ivoire, 1993

Entry	Grain yield (t ha^{-1})	Plant height (cm)	Days to maturity	Stress resistance rating[a] Leaf blast	Neck blast	Glume discol.	Drought stress	Acidity tolerance
M'bé (transition zone, bimodal rainfall)								
WAB99-126	4.07	112	96	1	1	3	1	—
WAB96-21	3.74	111	96	1	1	1	1	—
WAB181-18	3.31	105	96	1	3	3	1	—
WABC165 (check)	2.31	119	103	1	3	3	1	—
Mean of 24 entries	2.78							
SE±	0.31							
CV (%)	15.69							
Man (forest zone, monomodal rainfall)								
WAB99-84	1.62	104	98	3	3	3	3	3
WAB181-37	1.53	95	102	5	1	3	1	3
IAC233/79	1.49	85	115	1	1	3	1	3
WABC165 (check)	1.21	95	115	3	3	3	1	3
Mean of 24 entries	0.98							
SE±	0.31							
CV (%)	22.38							
Korhogo (savanna zone, monomodal rainfall)								
WAB95-B-B-HB	3.79	103	103	1	1	1	3	—
WAB96-3	3.76	108	105	1	1	1	3	—
WAB176-B-B-25-HB	3.71	96	100	1	3	1	3	—
WABC165 (check)	2.87	114	107	1	3	3	3	—
Mean of 24 entries	3.15							
SE±	0.31							
CV (%)	13.97							

Note: a Scored according to the IRRI Standard Evaluation System (0 = no damage, 9 = dead plant)

generally higher at M'bé than at Man and Korhogo (*see* Table 20). Soil acidity, low P, leaf and neck blast, sheath rot and glume discoloration were recorded at Man. Drought stress, leaf and neck blast and termite damage were severe at Korhogo.

The highest yielding entries in the preliminary, advanced and elite variety trials were:

- at M'bé: IRAT144, WAB99-14, WAB56-57, WAB99-5, WAB181-11, WAB56-125, WAB99-126, WAB181-18, WAB99-H-16-HB, WAB99-H-14-HB and TOX3445-14-2-3-2
- at Man: WAB56-125, WAB56-57, CNA6656, ITA132, WAB99-5, WAB99-84, WAB181-37, IAC233/79, WAB181-18 and WAB176-42-3
- at Korhogo: WAB32-80, WAB32-25, WAB33-17, IDSA46, WAB99-14, WAB56-125, WAB99-10 and WAB95-B-B-7-HB

The entries that showed moderate tolerance (score of 1-3) to acidity and low P at Man were WAB181-32, WAB181-18, WAB99-84, WAB99-47, WAB181-37, WAB95-B-B-14-HB and WAB181-30. The entries that showed

moderate resistance (score of 3-5) to drought and blast at both M'bé and Korhogo were WAB176-B-B-25-HB, WAB96-21, WAB181-68, CNA6712, WAB99-100, WAB181-30 and IAC233/79.

Members of the Upland Rice Breeding Task Force conducted 10 short-duration and seven medium-duration replicated yield trials, using the region's highest yielding upland materials, in Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Nigeria, Senegal, Sierra Leone and Togo. The entries that yielded as much or more than local checks at more than one site were ITA257, WAB181-18, WAB99-1-1, WAB56-104, WAB56-125, WAB56-50, WAB96-1-1, TOX1889-7-103-2-1, WAB33-25, IDSA46, WAB99-14 and WAB96-36. National breeders selected 35 entries for further evaluation during 1994.

Breeding for plant type, grain yield and yield stability under low-input management

M.P. Jones, D.E. Johnson (NRI) and S. Mandé

Over 80% of the 1.8 million ha under upland and hydromorphic rice varieties in West Africa is cultivated according to local practices, with little or no use of external inputs. Traditional upland rice varieties grown by farmers show good yield stability but low yield potential under such conditions. An upland rice breeding thrust was initiated in 1991 to develop improved high- and stable-yielding rice varieties for low-input management conditions.

In 1993, WARDA continued to evaluate fixed and segregating populations under low-input management at M'bé. Fixed lines were evaluated in observational and replicated yield trials.

For low-input field screening, minimum land disturbance was achieved by limiting soil tillage to a shallow (5 cm deep) hand hoe scarification. Urea was applied at 40 kg N ha^{-1} in equal doses, 15 and 45 DAS. Plots were hand-weeded once, at 25-28 DAS.

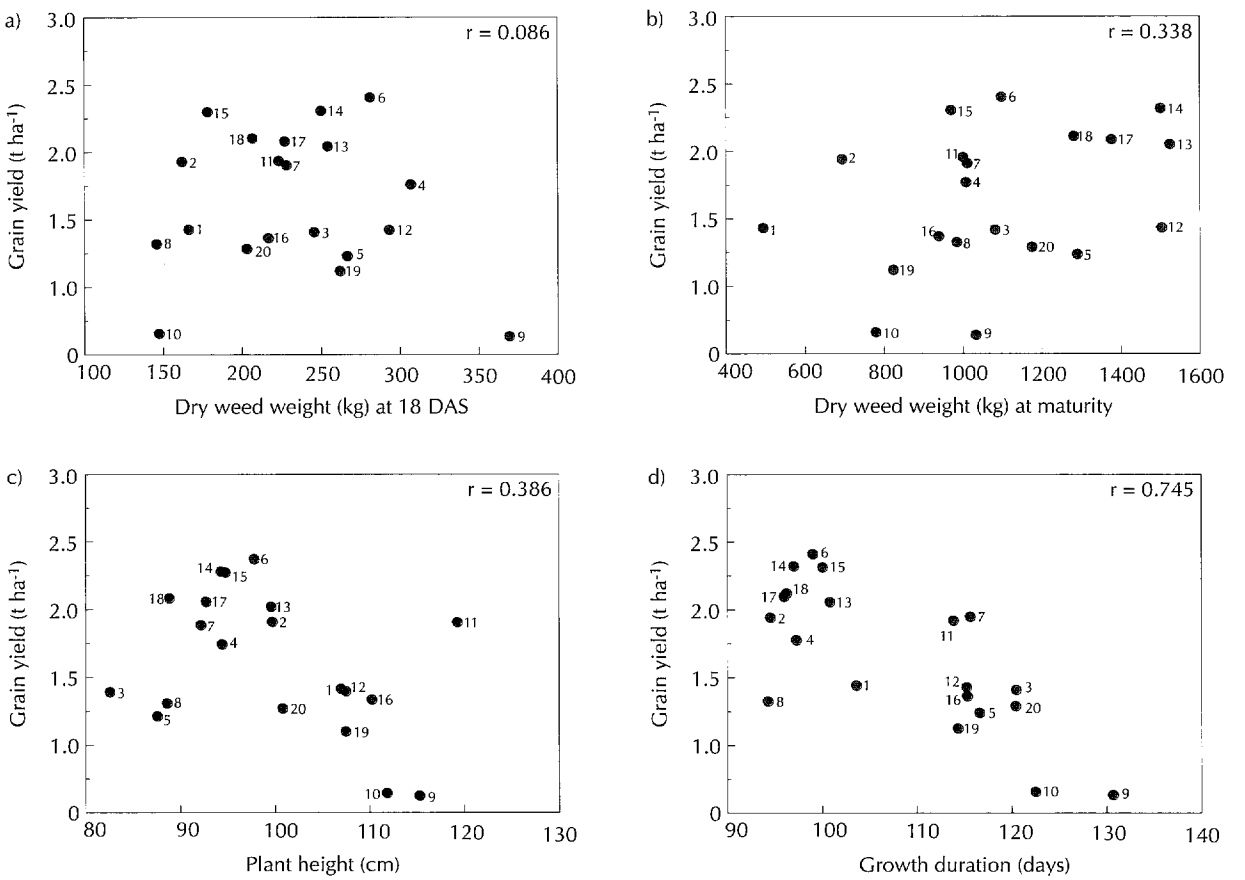
In the observational yield trial, 92 traditional and improved varieties were tested against WABC165 (single plots, four rows, each 5 m long). Grain yields ranged from 0.42 to 4.16 t ha^{-1}; the check yielded 1.13-2.14 t ha^{-1}. On the basis of high grain yield, seedling vigor, good phenotypic acceptability and weed tolerance or suppression, 44 varieties were selected for further testing. The varieties that yielded over 3.0 t ha^{-1} and exceeded the best check plot by 30-98% were M2, WAB99-1-1-K1, WAB376-B-B1-L1-LB, WAB377-B-5-L1-LB, WAB377-B-17-L1-LB, WAB56-104, WAB377-B-8-L2-LB, WAB376-B-14-LB, Vemo, WAB377-B-14-L2-LB, CG17, WAB377-B-14-L3-LB and WAB375-B-7-L1-LB.

Twenty entries were also evaluated in a replicated yield trial (12 rows, 5 m long and four replications). The entries included two *Oryza glaberrima*, four traditional *O. sativa* and 14 improved *O. sativa* cultivars. They were evaluated for yield potential, seedling vigor, plant height, growth duration and weed tolerance or suppression. Grain yields ranged from 0.62 to 2.48 t ha^{-1}.

The highest yielding entries were IRAT144, WAB56-104, WAB56-125, WAB181-18 and WAB99-1-1. These varieties showed superior ability to tolerate weeds as grain yields were satisfactory despite high weed infestation 18 DAS. They were intermediate to tall statured (*see* Figure 17 *overleaf)* and had high tillering ability. Other varieties, including two

Screening rice varieties for low-input management and poor soil fertility conditions

FIGURE 17: Distribution of weed weight (a) at 18 days after sowing, (b) at maturity, (c) according to plant height and (d) according to growth duration, vs. grain yield of rice varieties screened under low-input conditions at M'bé, Côte d'Ivoire, 1993

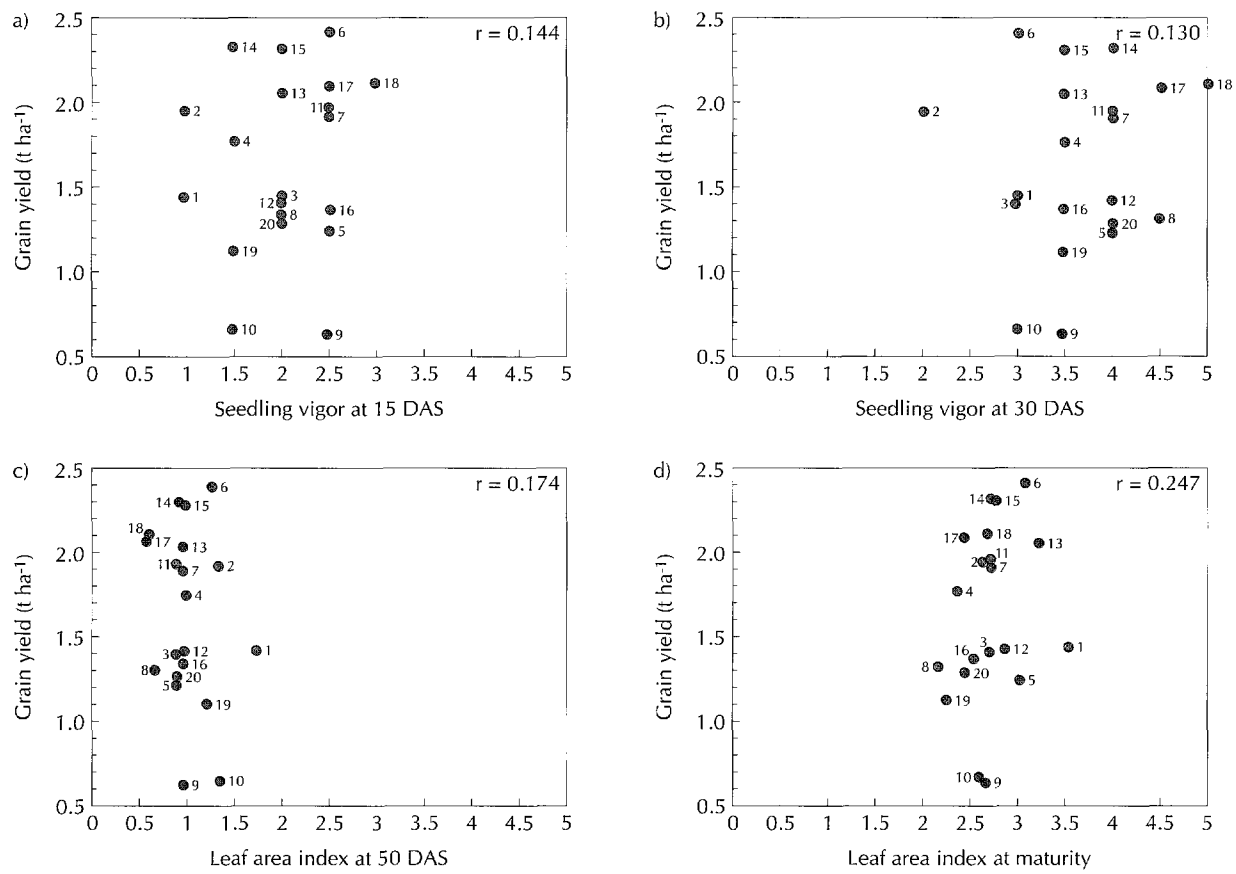


1	CG14	8	ITA257	15	WAB56–125		DAS = days after sowing
2	CG20	9	LAC23	16	WAB96–1–1		
3	IDSA6	10	M22	17	WAB99–1–1		
4	IDSA10	11	SP4	18	WAB181–18		
5	IDSA76	12	WAB32–80	19	YG236		
6	IRAT144	13	WAB56–50	20	Iguape Cateto		
7	ITA301	14	WAB56–104				

O. glaberrima varieties (CG20 and CG14), two improved *O. sativa* varieties (WAB56-125 and WAB96-1-1) and three traditional *O. sativa* varieties (M22, YS236 and SP4), had low weed biomass from their plots at 18 DAS and/or at maturity, with rapid vegetative growth (seedling vigor) and fairly high leaf area index (LAI). These entries were able to suppress weeds and all of them gave fairly high grain yields (1.0-2.5 t ha^{-1}) (*see* Figures 18 and 19).

Some 386 segregating F_3-F_5 populations were evaluated under low-input management conditions in 0.5 x 5 m plots (two rows, each 5 m long, no replication). The check varieties, WABC165 (short duration) and IDSA6 (medium duration), were replicated

FIGURE 18: Distribution of seedling vigor and leaf area index, vs. grain yield of rice varieties screened under low-input conditions at M'bé, Côte d'Ivoire, 1993

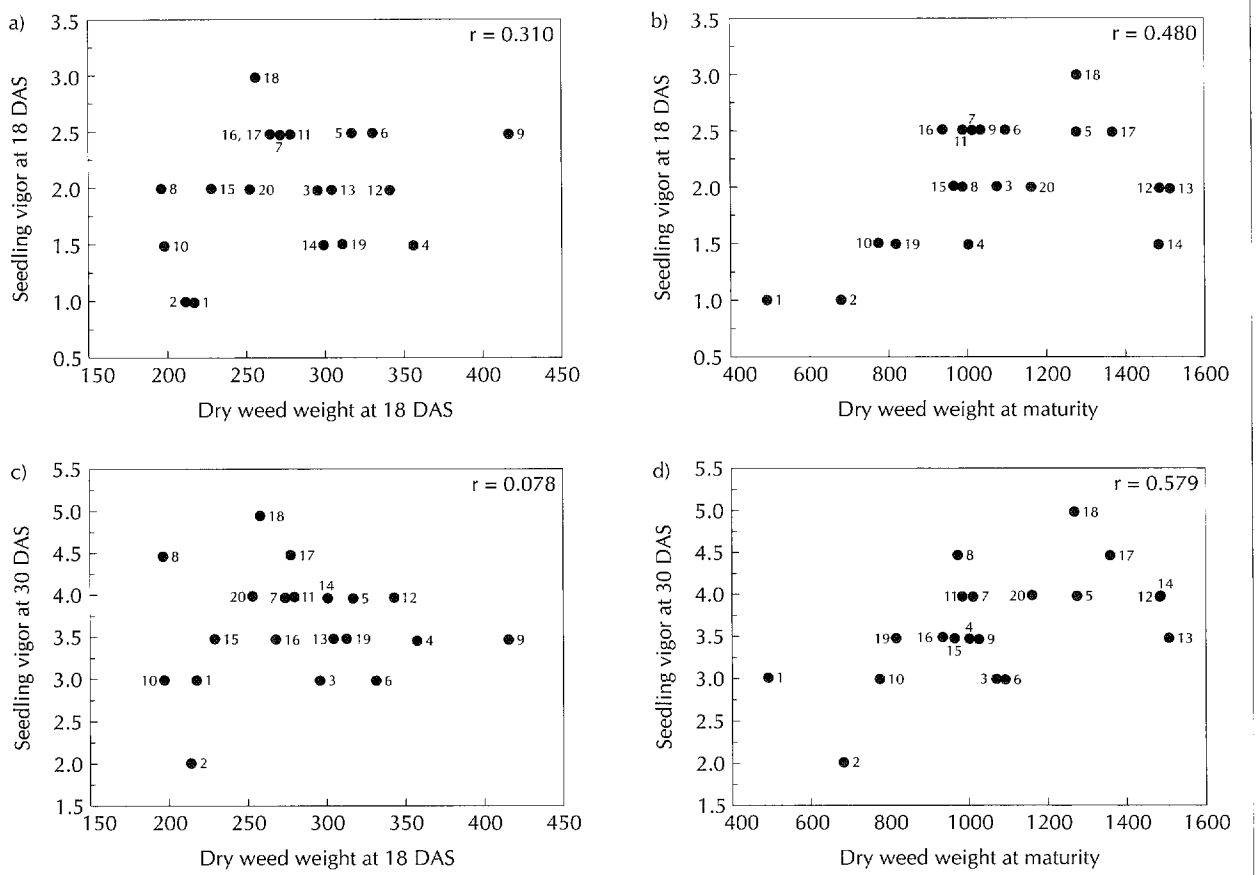


1	CG14	8	ITA257	15	WAB56–125	DAS = days after sowing
2	CG20	9	LAC23	16	WAB96–1–1	
3	IDSA6	10	M22	17	WAB99–1–1	
4	IDSA10	11	SP4	18	WAB181–18	
5	IDSA76	12	WAB32–80	19	YG236	
6	IRAT144	13	WAB56–50	20	Iguape Cateto	
7	ITA301	14	WAB56–104			

after every 20 test entries. The seeds were dibbled at a spacing of 25 x 25 cm, with one seed per hill. A total of 531 individual plants were selected on the basis of the following characteristics: seedling vigor, plant type, tiller number, weed tolerance or suppression, good phenotypic acceptability, grain characteristics, and disease and insect pest resistance/tolerance. A further 104 populations that were fixed for various characteristics were bulk harvested for screening in observational yield trials scheduled to be conducted in 1994.

During 1994, further studies will be conducted to identify the factors that determine inter-varietal differences in yield performance under low-input management. Promising varieties and lines will be further evaluated in observational and replicated yield trials.

FIGURE 19: Distribution of dry weed weight at 18 days after sowing (DAS) and maturity, vs. seedling vigor at 18 DAS and 30 DAS under low-input conditions at M'bé, Côte d'Ivoire, 1993



1	CG14	8	ITA257	15	WAB56–125	DAS = days after sowing
2	CG20	9	LAC23	16	WAB96–1–1	
3	IDSA6	10	M22	17	WAB99–1–1	
4	IDSA10	11	SP4	18	WAB181–18	
5	IDSA76	12	WAB32–80	19	YG236	
6	IRAT144	13	WAB56–50	20	Iguape Cateto	
7	ITA301	14	WAB56–104			

Breeding drought-resistant upland rice varieties

M.P. Jones and S. Mandé

Drought is one of the most important constraints to increased rice production in the uplands. It reduces and destabilizes rice yields under current practices and will become increasingly serious as production intensifies. WARDA continues to search for resistance sources and to develop improved drought-resistant upland and hydromorphic rice varieties.

In the 1993 wet season, 200 varieties and advanced lines selected for promising drought resistance during 1992 were evaluated in the screenhouse. Seeds of each entry were drilled in a 1 m row, with resistant (OS6) and susceptible (IR20) checks repeated after every 20 entries. Plots were sprinkler-irrigated for the first 15 DAS and from 50 DAS until maturity. An application of 200 kg NPK ha^{-1} was made at planting and

80 kg N ha^{-1} was applied as urea in equal doses, 15 and 50 DAS. The IRRI Standard Evaluation System for Rice was adopted in scoring for drought resistance and recovery (drought: 0 = no visible symptoms of stress, 9 = all plants apparently dead; recovery: 1 ≥ 90% of plants fully recovered, 9 ≤ 20% of plants fully recovered).

Forty-eight entries scored higher than the resistant check after 35 days of exposure to moisture stress during the vegetative stage. The results were as follows:

- entries rated as drought resistant (score = 1): WAB95-B-B-14-H2, RP2469-4216-64-50-35-09-, D10CT 156-1-2-2-0-1 and IR477310-94-4-3-1
- entries rated as moderately drought resistant (score = 3): WAB96-13-1, IDSA10, TOX1870-47-103-2-1-1, WAB326-B-B-10-H3, WAB56-30 and OS6
- entries that recovered completely (score = 1) after 35 days of drought stress: WAB93-B-B-B-1-H1, RP2469-4216-64-50-65-09, DWCT152-1-2-0-1, ITA212 and IR47310-94-4-3-1
- entries with 75% recovery (score = 3) after 35 days of drought stress: 63-83, WAB99-21, WAB95-5, WAB326-B-B-H2, WAB326-B-B-11-H2, WAB362-B-B-2-H1, WAB326-B-B-11-H2, WAB362-B-B-22-H1, IR52211-B-B-2 and IDSA6.

Several breeding lines from the crosses WAB326 and WAB95 have shown good drought resistance over the past 3 years.

In the 1993 wet season, 79 entries selected from the field screening in 1992 were evaluated in non-replicated observational yield trials at M'bé and Korhogo for yield potential and reaction to drought. Fertilizer was applied basally at 200 kg ha^{-1} (10-18-18 NPK), with a top dressing of 40 kg N ha^{-1} at 45 DAS. Drought was mild during the vegetative and reproductive stages at M'bé and Korhogo. The top six yielders (> 2.5 t ha^{-1}) were ITA301, IDSA46, WAB56-77, WAB326-B-B-15-H1, IDSA10 and WAB272-B-B-2-H2. Replicated yield trials of 25 entries selected from 1992 observational yield trials were also grown at M'bé and Korhogo. We used a randomized complete block design in plots of 3 x 5 m, with four replications. At planting, 200 kg NPK ha^{-1} was applied, and at maximum tillering or flowering 80 kg N ha^{-1} was applied as urea in equal doses. Sixteen entries yielded 1.5-2.3 t ha^{-1}, compared with 1.2 t ha^{-1} for the check, Moroberekan. The top five yielders were WAB56-50, WAB97-B-B-B-B-24-H1, WAB272-B-B-5-H2, WAB100-B-B-B-11-H1 and WAB95-B-B-B-7-H1.

Members of the Upland Rice Breeding Task Force tested 568 entries for resistance to drought in drought-prone locations in Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Guinea-Bissau and Nigeria. The following entries performed well at more than one location and were among the 108 entries selected for further regional screening in 1994: WAB303-B-B-B-12-H3, WAB330-B-B-5-H2, WAB303-B-B-B-12-H3, WAB375-B-12-H3, WAB326-B-B-18-H3, WAB272-B-B-5-H4, WAB272-B-B-11-H1, WAB375-B-7-H1, WAB326-B-B-16-H1, WAB326-B-B-6-H6 and WAB340-B-B-9-H2. Benin, Burkina Faso, Côte d'Ivoire and WARDA will continue to play leading roles for germplasm evaluation, the development of appropriate drought screening methodology, and hybridization. Selected promising cultivars/lines will be further evaluated at 'hot spot' locations and/or in observational and replicated yield trials in the region during 1994. Donors identified for resistance to drought will be used in the crossing program.

Response of upland rice varieties to phosphorus deficiency in a forest zone Ultisol

K.L. Sahrawat, M.P. Jones and S. Diatta

Phosphorus deficiency is one of the most important nutrient disorders in the acidic soils of West Africa's humid forest zone. Availability of P in these soils is reduced by reaction of soluble P with iron and aluminum oxides. An effective root system in upland rice varieties is a highly desirable trait for efficient utilization of nutrients and water. To determine varietal efficiency for P utilization, we evaluated the rooting response of five promising upland varieties (WAB56-125, WAB56-104, WAB56-50, IDSA6 and ITA257) to P application at Man, Côte d'Ivoire.

To determine rooting response to P, the root distributions of the five varieties were studied at flowering stage in two out of four replications, using a 60 x 30 cm grid with 72 squares, each measuring 5 x 5 cm. The soil is an Ultisol (pH 4.8; organic C 1.5%) which is low in available P (2.9 ppm Bray-1 extractable P). A randomized complete block design was used, with four P treatments

Measuring rice roots in a phosphorus deficiency experiment at Man, Côte d'Ivoire

(0, 30, 60 and 90 kg P ha^{-1} applied as triple superphosphate) and four replications. Root development was evaluated by measuring root depth and density.

The distribution of roots of the five varieties at the four rates of P application is shown in Figure 20. For most varieties, rooting depth and density increased with the application of P, with the greatest response obtained at the lowest rate (30 kg P ha^{-1}). Without applied P, most roots were confined to the top 30 cm of the soil; WAB56-104 and WAB56-50 had the deepest rooting, followed by IDSA6. With the application of P, rooting depth increased from about 30 cm to about 60 cm in all cultivars, with IDSA6 showing the deepest root development.

In another experiment in 1993, the grain yield response of four upland varieties to five rates of P (0, 45, 90, 135 and 180 kg P ha^{-1} applied as triple superphosphate) was studied at Man in Cote d'Ivoire in an Ultisol (pH 4.9; organic C 1.35%) low in extractable P (2.7 ppm Bray-1 extractable P). This was a repeat of a 1992 experiment but with the P rates covering a higher range. A randomized complete block design was used, with four replications. In 1992 there had been a response to P applications up to 60 kg P ha^{-1}. In the 1993 experiment, without applied P the variety WAB56-50 gave the highest grain yield, followed by IDSA6 and WAB56-104 (*see* Figure 21). The highest response to applied P was achieved at 45 kg P ha^{-1}; there was no significant response to applied P beyond 90 kg P ha^{-1}.

FIGURE 20: Root response of five rice varieties to applied P in an Ultisol in the forest zone, Côte d'Ivoire, 1993

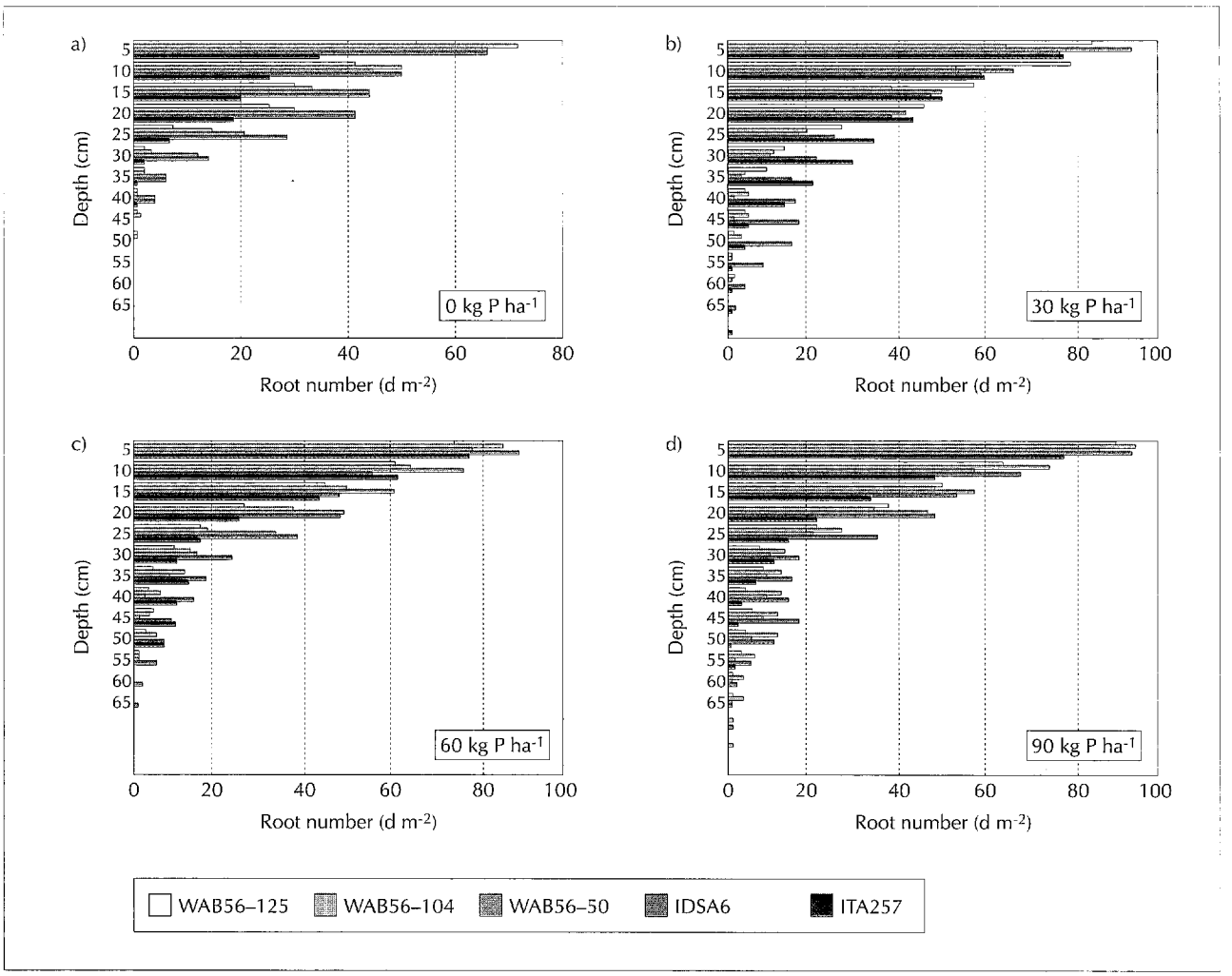
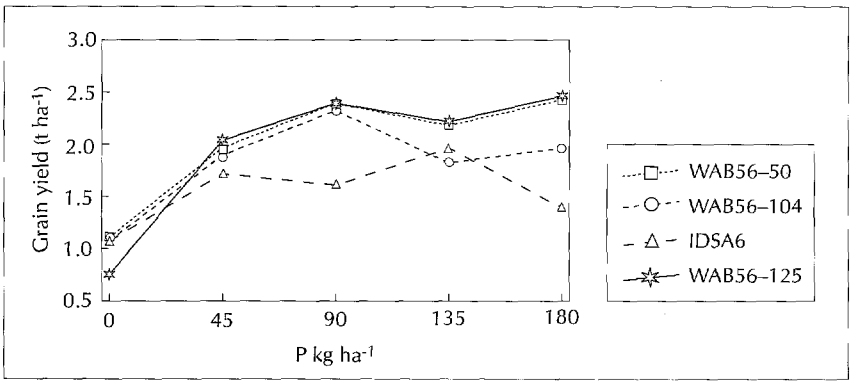


FIGURE 21: Response of four upland varieties to applied P in an Ultisol in the forest zone, Côte d'Ivoire, 1993



Data from this 2-year study indicate that marginal technical response (kg grain per kg of applied P) to applied P is maximized at about 60 kg P ha^{-1} and that there is little response at higher rates. Our results also suggest that acidity in Ultisols limits the range of yields to 2.5-3.0 t ha^{-1}. In future studies we will explore the use of natural phosphate rock in various forms as a substitute for imported soluble P sources; this substitute may be more cost effective in ameliorating the effects of soil acidity.

Breeding for resistance to soil mineral stress
M.P. Jones and K.L. Sahrawat

Over 70% of the upland rice ecosystems in West Africa are characterized by acidic soils, especially in the more humid areas because of the leaching of bases. Soil problems associated with acidic conditions include phosphorus deficiency and aluminum and manganese toxicities. Most traditional upland cultivars have been selected by farmers on acidic soils, and thus show good yield stability. An upland breeding program initiated in 1992 aimed to produce materials with improved yields under low to moderate input and to increase resistance/tolerance to acidity. Field screening at a 'hot spot' location at Man, Côte d'Ivoire was conducted in 1993.

Two hundred elite varieties and advanced lines were evaluated in soils with a pH of less than 4.3 and low P availability (2.8 ppm Bray-1 extractable P). The entries were sown in single plots (4 rows, 5 m long), with the check varieties IAC23 (tolerant) and ITA301 (susceptible) repeated after every 20 entries. Forty-eight entries were selected for further studies on the basis of their seedling vigor, phenotype acceptability and tolerance to acidity and low P. These included entries that had also shown tolerance to acidity and associated soil problems in 1992: WAB181-18, WABC165, WAB181-44, CT6258-5-2-3-3P, IREM192, WAB32-80, WAB32-59, WAB33-A, WAB56-50 and CT6240-12-2-2-3-6P. Advanced breeding lines with acidity tolerance and good phenotypic acceptability were: WAB326-B-B-12-H1, WAB331-B-B-B-H1, WAB331-B-B-H8-H4, WAB242-B-B-2-H2, WAB365-B-2-H1-HB, WAB368-B-7-H3-HB and WAB376-B-14-H1-HB.

In regional Task Force trials, national scientists made the following selections of materials that performed well in low pH conditions, with the top yielders being selected for further trials in 1994:

Côte d'Ivoire: Out of 17 entries screened at Man, 16 gave grain yields equal to or higher than the check varieties. The top yielders were IRAT168, ITA335, ITA321, IDSA75, WAB217-B-B-HE and WAB32-60.

Gambia: Under extremely acidic conditions, 50 out of 81 entries produced grain yields ranging from 0.4 to 1.5 t ha^{-1}. The top yielders were WAB36-34-FX, CT6946-9-1-3-M3, IRAT146, IRAT287 and WAB36-34-FX.

Guinea-Bissau: The top yielders included WAB56-50, WAB56-104 and WAB32-80.

Sierra Leone: Under mildly acidic conditions at Rokupr and Rotifunk, 12 entries gave yields in excess of 2.0 t ha^{-1}. The top yielders were ITA150, WAB181-11, WAB99-25, WAB99-21, WAB99-1-1, WAB96-13 and WAB96-10.

Breeding for blast resistance
M.P. Jones, A.A. Sy and S. Mandé

Rice blast is one of the most important biotic constraints to rice production in the uplands of West Africa. The traditional varieties Moroberekan, OS6, 63-83 and LAC23 have shown durable resistance to blast but have low yield potential. Efforts to transfer durable resistance into high-yielding varieties have met with little success because resistance to blast tends to break down after a few years. One of WARDA's upland breeding activities, therefore, is aimed at developing improved high-yielding rice varieties with durable blast resistance.

In 1993, 25 new crosses were made to incorporate genes for blast resistance

into improved varieties. From the F_2 populations, 280 new selections were made. Several individuals with field resistance to blast were selected from the following crosses: WAB510, WAB508, WAB499 and WAB470. The latter two are *Oryza sativa* and *O. glaberrima* crosses for which anther culture is being used to obtain rapid homozygous lines and fertile plants from selected F_2 plants.

In observational yield trials of promising blast-resistant varieties and advanced lines, conducted at M'bé, Man and Korhogo in Côte d'Ivoire, the average grain yield ranged from 0.24 to 3.38 t ha^{-1}. Some 102 varieties outyielded the check variety, Moroberekan, by up to 181%. The top five yielders (> 3.0 t ha^{-1}) were IR47701-6-3-1, CT6775-5-17-4-2-11P, WAB181-43, CNQ6787 and WAB181-44. Seventeen entries were selected for replicated yield trials in 1994 and a further 40 entries were selected for evaluation by members of the Upland Rice Breeding Task Force.

A replicated yield trial of 22 entries was also conducted at M'bé, Man and Korhogo. Grain yields ranged from 1.4 to 2.4 t ha^{-1}, with 19 entries outyielding Moroberekan. The following entries significantly outyielded Moroberekan: WAB181-18, WAB96-35, WAB181-36, IDSA6, WAB181-46, CT6196-33-11-2-2-1P, ITA301, WAB99-2-1, ITA135 and WAB99-4. All entries are early to medium duration (140-125 days) and suitable for cultivation in the savanna and forest-savanna transition zones.

The Upland Breeding and IPM Task Forces coordinated the screening of 380 entries for resistance to blast at 14 sites in the region. In 1993 blast was severe in western and north-western Cameroon, northern Guinea and north-western Sierra Leone but mild in Benin, Burkina Faso, Côte d'Ivoire, Guinea-Bissau, Nigeria and Senegal. The entries showing good resistance at more than two locations were: WAB281-B-B-B-2, WAB331-B-B-9LI, WAB310-B-B-IL3, WAB310-B-B-2L2, IRAT216, WAB56-50, WAB56-104, WAB181-44, WAB181-18 and ITA301. These and 48 other entries were selected for 'hot spot' location screening during 1994.

Characterization of farmers' traditional lowland cultivars
B.N. Singh

To guide the development and selection of new lowland cultivars, WARDA scientists characterize the varieties currently grown by farmers and identify those traits that farmers consider most important. With this objective, farmer surveys were initiated in 1991 in seven villages (Gara, Gadza, Mambe, Gbadafu, Patita, Edozhigi and Bida) in Nigeria. Grain samples of rice varieties grown by farmers were collected for laboratory analyses and screening.

Farmers in these villages grow 31 rice varieties with a range of traits. The majority of farmers grow tall varieties (125-162 cm) which tend to lodge in fertile soils. Most of the varieties preferred by farmers have medium to long grains, with high chalkiness, high amylose content (27-30%), hard gel consistency and intermediate gelatinization temperature. A variety strongly preferred because of its long slender grains, good aroma, taste and soft gel consistency is Eguazanpa. This variety has been selected for use in our hybridization program to incorporate preferred grain quality traits into semi-dwarf plant types.

In 1992 and 1993, the cultivars collected were screened for disease resistance, photoperiod sensitivity, drought tolerance and agronomic traits. The variety Jindaji was highly resistant to blast but none of the varieties collected was resistant to rice yellow mottle virus (RYMV). Puruga appeared to be highly resistant to drought at the vegetative stage, while 11 other lines showed moderate resistance. Preliminary studies showed that most varieties were photoperiod sensitive.

Yield trials to identify superior varieties for lowland ecosystems

The farmers' rice varieties will be further characterized in 1994 for resistance to iron toxicity, African rice gall midge, white fly and stalk-eyed fly. SE^1 and SE^2 gene markers will be used to characterize degrees of photoperiod sensitivity.

Breeding for irrigated and favorable rainfed lowlands
B.N. Singh and O. Oladimeji

WARDA's breeding activities for irrigated and favorable lowland ecosystems aim to develop rice varieties with high yield potential and resistance to blast, rice yellow mottle virus (RYMV), African rice gall midge, Bakanae and iron toxicity.

Selected materials were tested in three sets of yield trials conducted in 1993: on-station observational yield trials, on-station replicated yield trials, and regional yield trials coordinated by the Lowland Rice Breeding Task Force. To identify superior varieties for the favorable rainfed lowlands, two replicated yield trials and one Task Force regional trial were conducted. For irrigated lowlands, one on-station observational yield trial, one replicated yield trial and two regional trials (early and medium duration) were conducted. The fertilizer dose in irrigated trials was 80-40-40 (N-P_2O_5-K_2O) kg ha^{-1}. For favorable rainfed lowlands the dose was 60-30-30 (N-P_2O_5-K_2O) kg ha^{-1}. Half the N was applied basally and the remaining N in two top dressings, 3 and 6 weeks after transplanting.

The observational yield trial conducted at Ibadan, Nigeria included 350 irrigated lowland lines selected from the pedigree nursery in 1992. An augmented design was used, with IR46, ITA306, IR36 and ITA222 as checks. Although high gall midge infestation was observed, 26 lines were not attacked by this pest. These lines will be evaluated in a separate regional gall midge observational yield trial in 1994. Another 84 selected lines will be tested in various regional observational yield trials.

In a replicated yield trial using a randomized complete block design, with three replications, 48 irrigated lowland entries selected from observational trials conducted in 1992 were tested. The trial was conducted at Ibadan where high sheath blight infestation had been observed. Only three lines, TOX85C-C5-88-1, TOX85C-C5-B1-1 and TOX3440-47-6-2-3-1, showed moderate resistance. The highest yielding entries were TOX3440-16-2-1-2-1 (5.4 t ha^{-1}) and TOX3440-16-3-3-2-2 (5.3 t ha^{-1}). Thirty-six lines were selected for the regional Task Force observational yield trial scheduled to be conducted in 1994.

In other on-station trials for favorable rainfed lowlands, 36 short-duration entries and 48 medium-duration entries, selected from 1992 trials, were tested in replicated yield trials using a randomized complete block design, with three replications. In the short-duration trial, TOX4007-72-1-3 gave a maximum yield of 4.6 t ha^{-1}, followed by TOX3378-14-2-2-1 (4.5 t ha^{-1}). Twenty lines were selected for the 1994 regional rainfed lowland observational trial. In the medium-duration trial, TOX3716-22-1-3-1 gave a maximum yield of 5.5 t ha^{-1}, significantly higher than the yield produced by IR46, the check. Twenty-eight lines were selected for regional observational trials to be conducted in 1994.

Members of the Lowland Rice Breeding Task Force conducted a regional replicated yield trial of the most promising irrigated lines identified during 1992. Twelve short-duration and 12 medium-duration lines were grown at 10 sites in nine and seven countries, respectively, with IR72 as the regional check. The highest yielding line at three locations in the short-duration trial was TOX3090-135-1-3-2-2 (9.8 t ha^{-1} at Midekhine, Chad) (*see* Table 21). Other high-yielding lines were FAROX303-6-3-2, TOX3049-13-1-2-3-1, ITA416 and TOX3559-6-2-1. In the medium-duration trial, TOX3107-39-1-2-1-1 gave a maximum yield of 9.2 t ha^{-1} at Lagdo, Cameroon (*see* Table 22 *overleaf*). This variety has consistently outyielded the checks over the past 2 years. Other promising entries were TOX3233-46-3-3-4-2-2 and ITA230. In yield trials for

TABLE 21: Top-ranking entries in a regional irrigated lowland yield trial, early duration, 1993

Location	Entry and yield (t ha^{-1})
M'bé, Côte d'Ivoire	TOX3090-135-1-3-2-2 (3.33); TOX3049-13-1-2-3-1 (3.00); FAROX303-6-3-2 (2.95); IR72 (2.90); Bouaké 189 (2.13)
IITA, Ibadan, Nigeria	FAROX303-6-3-1 (5.36); TOX3049-13-1-2-3-1 (5.18); FAROX308-1-2 (4.68); TOX 3559-6-2-1-1 (4.63); IR 72 (4.04)
Rokupr, Sierra Leone	TOX3049-13-1-2-3-1 (5.00); ITA416 (4.30); FAROX303-6-3-2 (4.30); FAROX308-1-2 (4.10); IR72[a] (3.00)
Lagdo, Cameroon	TOX3090-135-1-3-2-2 (7.30); TOX3049-13-1-2-3-1 (7.10); TOX3559-6-2-1-1 (6.90); TOX3217-69-3-1 (6.70); IR72 (6.20)
Midekhine, Chad	ITA416 (9.90); TOX3090-135-1-3-2-2 (9.80); TOX3058-18-1-1 (9.60); FAROX303-6-3-2 (9.40); IR72 (9.20)

Note: a Regional check

TABLE 22: Top-ranking entries in a regional irrigated lowland yield trial, medium duration, 1993

Location	Entry and yield (t ha^{-1})
M'bé, Côte d'Ivoire	TOX3233-46-3-3-4-2-2 (3.39); ITA306[a] (3.38); ITA230 (2.88); TOX3093-35-2-3-3 (2.71); TOX3052-46-3-3-1 (2.52) SE± 0.38; CV (%) 25.4
IITA, Ibadan, Nigeria	TOX3093-35-2-3-3 (5.10); TOX3255-82-1-3-2 (4.56); ITA222 (4.52); TOX3107-39-1-2-1-1 (4.30); ITA306[a] (4.15) SE± 0.31; CV (%) 12.8
Lagdo, Cameroon	TOX3107-39-1-2-1-1 (9.20); ITA230 (8.70); TOX3233-46-3-3-4-2-2 (8.60); ITA300 (8.60); ITA306[a] (8.30) SE± 0.42; CV (%) 8.7

Note: a Check

TABLE 23: Top-ranking entries in a regional favorable rainfed lowland yield trial, 1993

Location	Entry and yield (t ha^{-1})
M'bé, Côte d'Ivoire	ITA306[a] (2.67); Cisadane (2.26); TOX3069-66-2-1-6 (2.16); TOX3095-52-3-2-3 (1.71); Bouaké 189[b] (1.52) SE± 0.46; CV (%) 58.1
IITA, Ibadan, Nigeria	TOX3100-44-1-2-3-3 (3.86); TOX3963-8-1-3 (3.84); ITA328 (3.69); TOX3967-17-1-1 (3.45); ITA306[a] (3.19) SE± 0.42; CV (%) 22.7
NCRI, Badeggi, Nigeria	BG90-2[b] (4.40); TOX3095-52-3-2-3 (3.27); TOX3440-132-3-3-1 (3.27); TOX3967-17-1-1 (3.27); ITA306[a] (2.84) SE± 0.34; CV (%) 20.2
Gambia	ITA324 (1.89); TOX3068-66-2-1-6 (1.61); ITA306[a] (1.42); ITA368 (1.21); ITA3967-17-1-1 (1.16) SE± 0.14; CV (%) 19.3

Note: a Regional check
b Local check

favorable rainfed lowlands, TOX3100-41-1-2-3-3, ITA 324 and TOX3095-52-3-2-3 were the highest yielding entries (*see* Table 23).

The first regional Task Force rice yield trial for irrigated lowland ecologies was conducted in Gambia and at Ibadan, Nigeria. The objective of the trial was to select five grain varieties with good cooking and eating quality and good aroma. At Ibadan, the local check ITA222, gave the highest yield (4.7 t ha^{-1}), followed by Niaris 85-12n (4.4 t ha^{-1}) and DR2 (3.9 t ha^{-1}). The entries will be re-tested in 1994.

Some 10 900 pedigree irrigated lines were evaluated in a blast nursery. Of these, 78% were found to be resistant to leaf blast. These lines were transplanted to the field for further evaluation and selection.

Selecting rainfed lowland rice for low-input conditions

B.N. Singh and O. Fashola

Over 630 000 ha of rice in West Africa are cultivated under low to moderate levels of management in valley-bottom ecosystems where farmers weed only once, hand puddle and apply little or no fertilizer. Semi-dwarf rice varieties with a high yield potential generally perform poorly under these conditions.

A new activity was initiated in 1993 to develop lines well adapted to these harsh agro-ecosystems. The major breeding objectives were good weed competitiveness, stable yield production under moderate fertility, and resistance to iron toxicity, blast and the African rice gall midge. In collaboration with Task Force members, 50 lines with intermediate plant height, good seedling vigor and ability to compete with weeds were evaluated in a regional observational yield trial at three locations (*see* Table 24). At

Smallholder farmers preparing the land for growing rice under low-input conditions

NCRI in Nigeria, the trial was direct-seeded and 20 kg N ha^{-1} was applied as topdressing a month after weeding. Brown spot was one of the major diseases at this location. TOX3399-84-2-1-3 gave a maximum yield of 5.5 t ha^{-1}. At Ibadan in Nigeria and Rokupr in Sierra Leone, the trials were transplanted. TOX3050-46-E2-3-3-3 gave the highest yield (4.3 t ha^{-1}). At Ibadan, weed counts and species were also recorded before weeding at 35 DAT. Of the 13 weed species recorded, the dominant ones were *Cyperus iria, Ageratum conyzoides* and *Fimbristylis littoralis.*

In 1994, 12 selected entries from observational trials will be further tested in a regional Task Force low-input replicated yield trial. In addition, 10 entries from observational trials and another 40 entries with intermediate plant height selected from the 1993 on-station rainfed lowland replicated yield trial will be evaluated in a regional Task Force observational yield trial.

TABLE 24: Top-ranking entries in a regional low-input observational yield trial, 1993

Location	Entry and yield (t ha^{-1})
NCRI, Badeggi, Nigeria	TOX3399-84-2-1-3 (5.50); TOX3552-109-2-1-3-2 (4.30); TOX3100-44-1-2-3-3 (4.00); TOX3561-56-2-3-2 (4.00); Mahsuri[a] (3.9)
IITA, Ibadan, Nigeria	TOX3050-46-E2-3-3-3 (4.28); TOX3052-41-E1-2-1-2 (3.80); TOX3154-17-1-3-2-2 (3.78); TOX3118-2-E2-1-2-3 (3.73); Mahsuri[a] (2.61)
Rokupr, Sierra Leone	Chupi (3.45); Chibica (Chokwe) (3.30); Chines (Naputo) (3.08); De Primuri (Naputo) (2.97); Mahsuri[a] (2.99)

Note: a Check

Breeding for drought-prone rainfed lowlands

B.N. Singh

Periodic drought at vegetative or reproductive stages can severely reduce grain yields in rainfed lowland ecosystems. Although the problem is greatest in valley fringes, drought stress can also occur in valley bottoms when water control is lacking. Two drought-stress screening nurseries were established in 1993, one under controlled conditions to test for tolerance to drought stress at the vegetative stage, and the other to test for tolerance under natural rainfall conditions. Drought-tolerant materials selected in previous years were also tested in regional observational and replicated drought yield trials coordinated by the Lowland Rice Breeding Task Force.

In the first drought screening nursery, 350 lowland lines from the observational yield trial in 1993 were tested under controlled screenhouse conditions in the dry season. Seedlings were grown under irrigated conditions for 30 days before drought was imposed. After 35 days of drought, the susceptible check, IR20, was permanently wilted. Test entries were compared with the resistant check, OS6. Forty-seven lines were tolerant, and in the 1994 wet season will be further evaluated in hydromorphic valley fringes for yield potential.

In the second drought nursery, at Kano in Nigeria, 146 lines were direct seeded in an augmented design to evaluate drought tolerance under natural rainfall conditions (642 mm). Drought scores for test lines were

recorded and compared to the scores for the susceptible check, IR20. Two lines, CNA4136 and TOX1870-47-103-2-1-1, were highly tolerant, while 16 were moderately tolerant. These lines will be further evaluated at Ibadan, Nigeria in 1994.

In the Task Force regional observational drought yield trial, 69 entries were tested in rainfed lowland hydromorphic ecosystems at Ibadan, Nigeria and in Chad, Ghana, Guinea-Bissau and Togo. Promising lines included 20 at Ibadan and in Chad, 19 in Ghana and 30 in Togo. At Ibadan, the groundwater table was below 50 cm during the period from 60 DAT till harvest, and thus drought was observed at the reproductive stage. The best performing lines across the locations were TOX3369-47-1-1-2, TOX3441-12-3-3-2-1-2 and TOX3441-103-1-1-3-2-3. These lines will be tested in a regional Task Force drought replicated yield trial to be conducted in 1994.

In the Task Force replicated drought yield trial, 12 entries were tested at five sites, with IR54 as the drought-tolerant check. At Ibadan, the trial was transplanted in a hydromorphic area. The groundwater table was below 50 cm during the period from 65 DAT till harvest, and thus drought was observed at the reproductive stage. The results of this Task Force trial are given in Table 25.

In our program of hybridization for drought tolerance, 82 F_3 bulk crosses were screened for drought tolerance in the post-rainy season and tolerant plants were transplanted. Bulk harvests were made to advance the material for further evaluation in 1994. Another 4129 pedigree lines were evaluated under rainfed lowland conditions and 1313 lines were selected for further evaluation in 1994. Some 1200 *Oryza glaberrima* accessions from the IITA Genetic Resource Unit were screened, and 18 lines were found to possess better drought tolerance and recovery ability than Salumpikit, the resistant check. These lines will be evaluated for yield potential in 1994 wet season.

TABLE 25: Top-ranking entries in a regional rainfed lowland drought tolerance yield trial, 1993

Location	Entry and yield (t ha^{-1})
M'bé, Côte d'Ivoire	Bouaké 189 (3.75); TOX3100-44-1-2-3-3 (3.03); ITA212 (3.02); TOX3237-10-4-2-3-2 (2.81); TOX3580-47-1-1-2 (2.58)
IITA, Ibadan, Nigeria	TOX3552-39-1-2 (2.47); TOX3100-44-1-2-3-3 (2.17); TOX3580-71-3-2-2 (2.05); TOX3084-136-1-3-1-2 (2.03); ITA212 (1.63)
Mala, Chad	IR54 (4.35); ITA212[a] (3.87); IR46 (3.80); TOX3084-136-1-3-1-2 (3.66); TOX3237-10-4-2-3-2 (3.62)
Adeta, Togo	TOX3100-44-1-2-3-3 (4.29); TOX3580-71-3-2-2 (2.48); ITA212 (2.40); TOX3237-10-4-2-3-2 (2.26); TGR1[a] (1.88)
Gambia	TOX3084-136-1-3-1-2 (1.33); TOX3562-15-3-2-1 (1.31); TOX3580-47-1-1-2 (1.15); TOX3237-10-4-2-3-2 (1.10); ITA212[a] (1.09

Note: a Local check

Breeding rice varieties for medium-deep water ecosystems
B.N. Singh

Flooding depths of up to 50 cm in flood plains and valley bottoms can result in poor plant survival, low tillering and lodging, which in turn lead to reduced grain yields and poor grain quality. Faced with these constraints, farmers often transplant tall and aged seedlings or sow the crop on ridges. In 1991, work was initiated to develop varieties of a non-lodging type that would tolerate medium-deep waterlogging conditions. During 1993, materials that had shown promise in previous years were tested in an on-station replicated yield trial at Ibadan, Nigeria and in a Task Force replicated trial in Nigeria, Gambia and Côte d'Ivoire.

In the Ibadan trial, 48 entries were tested using a randomized complete block design, with three replications. Eleven entries were high yielding and well adapted to medium-deep water conditions. The two best lines, TOX3093-4-5-1-1 and TOX3100-12-1-2-2, will be advanced to regional trials scheduled to be conducted in 1994.

In the Task Force trial, 12 entries were evaluated at four sites, with FARO15 as the regional check (*see* Table 26). Based on grain yields, TOX3440-164-3-3-2 performed well at all sites. The

TABLE 26: Top-ranking entries in a regional medium-deep water yield trial, 1993

Location	Entry and yield (t ha^{-1})
M'bé, Côte d'Ivoire	TOX3553-65-3-3-2 (2.90); TOX3118-47-1-1-2-3-2 (2.75); TOX3440-164-3-3-2 (2.29); ITA328 (2.86); FARO15[a] (1.86) SE± 0.39; CV (%) 32.4
IITA, Nigeria	TOX3399-64-2-2-1 (3.28); TOX3118-47-1-1-2-3-2 (3.24); TOX3052-41-E1-2-1-2 (2.96); TOX3440-164-3-3-2 (2.69); FARO15[a] (2.48) SE± 0.28; CV (%) 19.1
Birnin Kebbi, Nigeria	TOX3965-7-1-2 (4.12); TOX3440-164-3-3-2 (3.98); FARO15[a] (3.69); TOX3399-64-2-2-1 (3.69); TOX3052-41-E1-2-1-2 (3.69) SE± 0.30; CV (%) 15.7
Gambia	TOX3440-164-3-3-2 (2.85); TOX3399-64-2-2-1 (2.69); TOX3965-7-1-2 (2.59); TOX3552-109-2-1-3-2 (2.55); FARO15[a] (1.55) SE± 0.36; CV (%) 31.8

Note: a Local check

Screening rice varieties for lowland medium-deep water ecosystems

other high-yielding lines were TOX3965-7-1-2, TOX3399-64-2-2-1, TOX3118-47-1-1-2-3-2 and TOX3552-109-2-1-3-2. These five lines have been selected by Gambian breeders to be advanced for testing in researcher- and farmer-managed on-farm trials in 1994. TOX3965-7-1-2 and TOX3440-164-3-3-2, along with FARO15, will be tested Nigerian national scientists in on-farm trials at Birnin Kebbi.

In 1993, 1631 pedigree lines from crosses made for tolerance to medium-deep water conditions were screened, and 425 of these lines were selected for further evaluation.

Breeding lowland rice for disease resistance

B.N. Singh

Leaf and panicle blast, rice yellow mottle virus (RYMV), sheath blight, sheath rot, Bakanae, leaf scald and glume discoloration are the major rice diseases in lowland ecosystems. The WARDA lowland breeder and pathologist collaborate to screen and develop improved varieties with multiple disease tolerance. Specific breeding activities for resistance to blast, RYMV and leaf scald are also undertaken, and observations on the incidence of other diseases under natural infestation are recorded.

In a regional Task Force leaf and panicle blast nursery, 120 lines were evaluated in 1993 at Ibadan, Ikenne and Onne in Nigeria, at M'bé in Côte d'Ivoire and at Mbo Plains in Cameroon. Leaf blast was recorded only at Ibadan, Ikenne, Onne and M'bé, while both leaf and panicle blast were observed at Mbo Plains. At Onne and Mbo Plains, 17 and 31 lines, respectively, were selected. At M'bé, all the lines in the screening nursery were blast resistant and, based on grain yield, 39 were selected for observational yield trials in 1994. In

genetic male-sterile facilitated recurrent selection, 746 lines were evaluated for leaf blast resistance; about 95% showed a high degree of resistance. Using the pedigree method, further selections were made for trials in 1994 to select uniform lines.

In a regional Task Force RYMV observational yield trial, 50 entries were evaluated at Ibadan in Nigeria, at Rokupr in Sierra Leone and at Gagnoa in Côte d'Ivoire. Based on grain yield, RYMV infection, plant height and non-lodging, 25 entries were selected at Rokupr, 19 at Ibadan and 11 at Gagnoa. High-yielding lines from this trial will be advanced to a regional Task Force replicated yield trial in 1994. Task Force members also tested 12 RYMV-resistant lines in a replicated yield trial at six sites in the region (*see* Table 27). The entries TOX3052-45-E2-2-2-4-3, TOX3217-69-3-1, TOX3211-14-1-2-1-2, TOX3553-36-2-2-3 and TOX3440-171-1-2-1 outyielded the checks. In addition, 642 lines were screened for RYMV resistance under inoculated conditions in the screenhouse. Resistant plants were harvested and will be re-tested in 1994. In the search for new donors, lines from eastern India and Sierra Leone were also screened at Ibadan under artificial inoculation. Highly resistant fixed lines will be multiplied for yield testing in 1994.

For leaf scald, 120 lines were screened at Ikenne in Nigeria; 45 were found to be resistant or moderately resistant. Some 15 F_2 crosses were sent to Nyankpala, Ghana and to Mbo Plains, Cameroon for *in situ* screening. Resistant plants were selected and F_3 populations will be grown in 1994.

TABLE 27: Top-ranking entries in a regional trial for rice yellow mottle virus, 1993

Location	Entry and yield (t ha^{-1})
Ibadan, Nigeria	TOX3271-69-3-1 (5.19); TOX3211-14-1-2-1-2 (5.15); TOX3553-36-2-2-3 (5.03); TOX3049-13-1-2-3-1 (5.00); ITA306[a] (4.60)
Karfiguela, Burkina Faso	TOX3052-45-E2-2-2-4-3 (1.75); ITA306[a] (1.61); TOX3440-176-1-2-1 (1.46); TOX3440-171-1-1-1-1 (1.43); TOX3556-2-2-2 (1.33)
Gagnoa, Côte d'Ivoire	Bouaké 189[a] (6.00); TOX3553-36-2-2-3 (5.60); TOX3211-14-2-1-2 (5.60); TOX3217-69-3-1 (4.90); TOX3052-45-E2-2-2-4-3 (4.90)
IDESSA, Bouaké, Côte d'Ivoire	TOX3440-171-1-2-1 (4.00); TOX3558-14-1-2-1-2 (4.00); TOX3440-176-1-2-1 (3.90); TOX3233-31-6-2-1-2 (3.90); Bouaké 189[a] (2.80)
Rokupr, Sierra Leone	TOX3052-45-E2-2-2-4-3 (4.90); TOX3217-69-3-1 (4.60); ITA306[a] (4.50); TOX3233-31-6-2-1-2 (4.30); TOX3058-28-1-1 (4.20)
M'bé, Bouaké	TOX3058-28-1-1 (8.75); TOX3440-171-1-1-1-1 (8.68); TOX3553-36-2-2-2 (8.11); TOX3052-45-E2-2-2-4-3 (7.81); ITA306[a] (6.98)

Note: a Check

Breeding for resistance to insect pests
B.N. Singh and S. Okihidieviebe

Satisfactory progress was made in 1993 in identifying lines with resistance to the major insect pests of rice in lowland ecosystems: African rice gall midge, stalk-eyed fly, white fly and white stem borer. In replicated yield trials, high-yielding varieties that had shown some resistance to gall midge in earlier trials were tested.

Collaboration was initiated with several Indian research institutes in 1993 with the goal of identifying new sources of gall midge resistance. Seventy lines from the Directorate of Rice Research in Hyderabad, 41 from the Agricultural University in Raipur and 12 from the Central Rice Research Institute in Cuttuck were screened at Itoikin in Nigeria. All these materials had previously been identified as resistant to the Asian rice gall midge. Of these lines, three (WGL3825, WGL3943 and WGL47978) showed good resistance, while seven (PTB10, WGL2424, WGL2436, WGL3929, WGL3962, WGL4797 and Heera) were moderately resistant. The lines carrying the *GM1* and *GM2* resistance genes for Asian gall midge biotypes were observed to be susceptible. Ten *Oryza glaberrima* lines were highly resistant. In 1994, the resistant lines will be screened in Nigeria at NCRI, Badeggi and at Itoikin.

The regional Task Force replicated yield trial for African rice gall midge was conducted at five sites in 1993 (*see* Table 28). Twelve lines were selected from the best-performing entries in the 1992 regional observational yield trial. Gall midge incidence was mild at M'bé, Karfiguela, Mala, Ekoimbat and Ibadan. Lines that outyielded the local checks and the regional check, Cisadane, were identified at several locations. At Ibadan, TOX3233-46-3-3-4-2-2 yielded significantly better than

Cisadane. At Karfiguela, BW348-1 yielded significantly better than the local check, ITA123. In an on-farm trial at Gadza, Nigeria. Cisadane gave a maximum yield of 3.9 t ha^{-1}, compared with 3.2 t ha^{-1} from ITA306. In a regional Task Force observational yield trial, 50 entries were tested at Ibadan and in Guinea-Bissau. At Ibadan, seven entries performed better than the check, Cisadane. Among the promising lines were TOX3809-38-1, TOX3876-58-1-1 and TOX4093-12-3. These entries will be re-tested in regional trials in 1994.

For resistance to stalk-eyed fly, 350 lines were evaluated in an observational nursery under artificial pressure in a screenhouse at Ibadan. The flies were collected regularly for a month and concentrated in the screenhouse. Based on average infestation levels at 25 and 50 DAT, 44 lines showed moderate resistance. Individual undamaged plants were tagged and harvested separately for second-cycle screening. An additional 40 lines that had been selected in 1992 were screened in the 1993 wet season for the second time, using a randomized complete block design; lines were replicated four times and infestation was recorded at 20, 40 and 60 DAT. The average infestation varied from 17 to 30% deadhearts. Eight lines had moderate resistance (a score of 3, on a 1-9 scale). TOX3817-32-3-3-3-2, TOX3440-16-2-1-2-3 and TOX3553-7-3-3-2-2 had the lowest infestation (17%). A total of 358 individual plants with no stalk-eyed fly infestation were harvested for third-cycle screening in the 1994 wet season. Twenty lines selected in 1992 for stalk-eyed fly resistance were evaluated for the third time in a screenhouse during the 1993 wet season. The experimental design resembled that used in the second-cycle screening. Infestation was very high. Nine lines were moderately resistant. Plants with no infestation were tagged and will be tested further during 1994. The 20 lines will also be tested for yield potential under natural infestation in 1994.

TABLE 28: Top-ranking entries in a regional trial for African rice gall midge resistance, 1993

Location	Entry and yield (t ha^{-1})
Ibadan, Nigeria	TOX3233-46-3-3-4-2-2 (4.66); TOX3118-47-1-1 (4.33); TOX3255-82-1-3-2 (4.24); ITA312 (4.16); Cisadane[a] (3.95)
Ekoimbat, Nigeria	ITA312 (2.32); BW348-1 (2.17); TOX3876-58-1-2 (1.99); TOX3093-35-2-3-3 (1.99); Cisadane[a] (1.85)
Mala, Chad	TOX3255-82-1-3-2 (5.92); TOX3876-56-1-4 (5.66); TOX3233-46-3-3-4-2-2 (5.48); TOX3876-58-1-2 (4.46); Cisadane[a] (4.18)
Karfiguela, Burkina Faso	BW348-1 (1.95); TOX3093-35-2-3-3 (1.78); BG400-1 (1.77); TOX3876-56-1-2 (1.72); ITA306 (1.32)
M'bé, Côte d'Ivoire	TOX3876-58-1-2 (3.60); TOX3876-56-1-4 (3.20); Cisadane[a] (3.10); TOX3233-46-3-3-4-2-2 (3.10); TOX3255-82-1-3-2 (3.00)

Note: a Regional check

We have observed consistently high white fly damage under natural infestation in screenhouse conditions at Ibadan during the dry season. Forty-nine lines assessed as promising in 1992 were further evaluated in the screenhouse in 1993. Tiller infestation, recorded at 25 and 50 DAT, varied from 13.6 to 38%. The 19 lines found to be moderately resistant will be further evaluated in the 1994 dry season in a replicated screening trial.

Twenty lines selected in 1992 for resistance to white stem borer were further evaluated. Based on stem dissections made at maturity, infestation varied from 62 to 79%. Only ITA348 and ITA376 had significantly lower infestation than OS6, the susceptible check, and were similar to IR43, the resistant check. These lines will be further evaluated in replicated yields trials in rainfed upland and irrigated lowland ecosystems in the 1994 wet season.

Evaluating promising rice cultivars for iron toxicity in lowland soils

K.L. Sahrawat, B.N. Singh and S. Diatta

Varietal tolerance is potentially the most practical and cost-effective means of increasing rice production in iron-toxic soils. From our evaluation in 1992 of the yield performance of 20 rice cultivars at M'bé and Korhogo in Côte d'Ivoire, 12 were further tested at these sites in 1993. A randomized complete block design was used, with four replications. All plots (12 m^2 at M'bé; 24 m^2 at Korhogo) received a basal application of 200 kg ha^{-1} of 10-18-18 NPK. Table 29 (*overleaf*) summarizes the yield data. As in 1992, these two sites represented markedly different iron toxicity pressures. The iron toxicity rating for the standard

TABLE 29: Performance of 12 rice cultivars at sites with high iron toxicity (Korhogo) and low iron toxicity (M'bé), Côte d'Ivoire, 1993

Cultivar	Grain yield (t ha^{-1}) Korhogo	M'bé	Iron toxicity score at Korhogo
CK4	5.87	8.17	2
CK73	5.62	2.28[c]	3
TOX3118-6-E2-3	5.53	3.45[c]	6
TOX3027-43-1-E3	5.36	7.38	4
TOX3050-46-E3-3	5.36	5.87	5
TOX3081-36-2-3	5.22	7.43	5
TOX3100-32-2-1	5.17	3.42[c]	6
ITA326	5.13	4.45	6
Suakoko 8[a]	5.07	5.28	5
ITA408	5.06	5.52	6
ITA247[a]	4.22	3.15	7
Bouaké 189[b]	4.08	5.30	8
SE±	0.251	0.699	
CV (%)	9	24	

Note: a Check
b Local check
c Severe bird damage

tolerant check, Suakoko 8, was high (5) at Korhogo and low (1) at M'bé. The cultivar CK4 was the top yielder at both sites. With no iron toxicity pressure at M'be, CK4 gave a yield of 8.17 t ha^{-1}. As in 1992, TOX lines performed well, with yields in excess of 5 t ha^{-1}. Suakoko 8 gave similar yields at both M'bé and Korhogo but lodged badly at the M'bé site.

The results of this 2-year study demonstrate a range in iron toxicity tolerance in rice cultivars. Rice grain yields in excess of 5 t ha^{-1} were obtained under high toxicity stress. However, we face several methodological problems with our field screening. First, results are highly variable from one season to another, even at the same site. In 1994 we will use a measure of relative yield response based on the performance of standard tolerant and susceptible cultivars. A second problem is the lack of a close relationship between iron toxicity scores and yield response. Several factors could affect the score, including the timing of scoring, genetic differences in the visible expression of toxicity symptoms, differences in tolerance across growth stages, and growth duration of the cultivars. Our results suggest that scoring several times during the growing season may help to determine the most appropriate timing for scoring. The use of relative iron toxicity tolerance should also be tested as an alternative criterion for scoring. More frequent use of tolerant and susceptible varieties in the experimental design, especially when a site has high inter-plot variability, should also help overcome the observed variability in iron toxicity tolerance scores for individual cultivars.

Breeding for iron toxicity tolerance
B.N. Singh and O. Fashola

High concentrations of iron in the ferrous state can be toxic to rice plants, severely reducing vegetative growth and grain production. WARDA's lowland breeder and soil chemist are working to identify genetic materials with tolerance to iron toxicity. In 1993, one off-site observational nursery and two regional Task Force observational and replicated yield trials were planted at Edozighi, Nigeria.

In the observational nursery, 807 fixed line entries were tested in an augmented design, using Suakoko 8 as the tolerant check. The 229 lines observed to be promising will be tested in an observational yield trial in 1994.

In the regional Task Force observational yield trial, 50 lines were tested in an augmented design. Of these, 28 lines were found to be tolerant at Korhogo, Côte d'Ivoire and 27 at Edozhigi. Selected lines will be evaluated in a replicated observational yield trial in the 1994 wet season.

Twelve lines selected from 1992 trials were tested in a replicated Task Force yield trial at nine sites, with Suakoko 8 as the tolerant check. High iron toxicity damage was observed at Korhogo in Côte d'Ivoire, at Ikot Obong in Nigeria and at Kabala in Sierra Leone. It was particularly significant that two nominations from Guinea, CK4 and CK73, performed better than Suakoko 8 at some sites (*see* Table 30). Suakoko 8 was the highest yielding entry at Lagdo in Cameroon and at Ikot Okong in Nigeria. Other promising entries were TOX3100-32-2-1-3-5, TOX3118-6-E2-3-2, TOX3027-43-1-E3-1-1-1 and TOX3081-36-2-3-1. The national program in Côte d'Ivoire selected two iron toxicity-tolerant lines, TOX3093-35-2-3-3 as WITA 2 and TOX3100-32-2-1-3-5 as WITA 3, for on-farm testing in 1994.

Selections were made from 25 F_2 crosses grown at Edozhigi and

TABLE 30: Top-ranking entries in a regional iron toxicity tolerance yield trial, 1993

Location	Entry and yield (t ha^{-1})
Korhogo, Côte d'Ivoire	CK4 (5.87); CK73 (5.62); TOX3118-6-E2-3 (5.53); TOX3027-43-1-E3 (5.36); Suakoko 8[a] (5.07)
Edozhigi, Nigeria	TOX3050-46-E3-3-3-3 (2.98); TOX3027-43-1-E3-1-1-1 (2.84); CK73 (2.69); CK4 (2.58); Suakoko 8[a] (2.56);
Ikot Okong, NCRI, Nigeria	Suakoko 8[a] (1.63); TOX3118-6-E2-3-2 (1.34); FARO15 (1.12); TOX3027-43-1-E3-1-1-1 (1.09); TOX3050-46-E3-3-3-3 (0.95)
Kabala, Rokupr, Sierra Leone	CK73 (5.70); CK4 (5.00); ITA326 (4.90); TOX3027-43-1-E3-1-1-1 (4.50); Suakoko 8[a] (2.80)
Lagdo, Cameroon	Suakoko 8[a] (8.00); TOX3118-6-E2-3-2 (4.00); TOX3100-32-2-1-3-5 (3.30); CK73 (3.10); TOX3050-46-E3-3-3 (3.00)
Mala, Chad	TOX3118-6-E2-3-2 (4.95); CK4 (4.92); ITA408 (4.26); TOX3100-32-2-1-3-5 (4.25); Suakoko 8[a] (3.44)
Camp Penal,Côte d'Ivoire	CK4 (7.10); TOX3081-36-2-3-1 (5.70); CK73 (5.40); ITA326 (5.40); Suakoko 8[a] (5.20)
Kwadaso, CRI, Ghana	TOX3081-36-2-3-1 (7.20); TOX3027-43-1-E3-1-1-1 (7.00); TOX3050-46-E3-3-3-3 (6.80); CK73 (6.70); Suakoko 8[a] (5.10)
WARDA (off-site)	ITA368 (4.81); Mambeshi (3.91); TOX3027-43-1-E3-1-1 (3.39); Cisadane (3.02); Suakoko 8[a] (0.99)

Note: a Check

Rokupr, Sierra Leone. The blast-resistant, genetic male-sterile population, WAT MSP1, was grown at Edozhigi to select male-sterile and male-fertile plants. About 150 male-sterile individual plants were harvested, and crosses will be made by open pollination with 10 iron toxicity-tolerant lines in the 1994 dry season. Fifteen male-fertile plants were harvested from the male-sterile interbreeding population and will be evaluated for iron toxicity tolerance in 1994.

SAHEL IRRIGATED RICE PROGRAM

The irrigated area of the Sahel is the second largest rice growing environment in West Africa (over 150 000 ha). Compared with other rice-based ecosystems in West Africa, irrigated rice in the Sahel involves intensive and technologically advanced production methods. Investments in irrigation infrastructure and its maintenance costs are generally high and must be justified by high crop yields. The natural resource base must also be maintained.

The rice sector in the Sahel is undergoing rapid changes as a result of the shift of decision-making responsibility from government development agencies to small private producers. More efficient use of resources and greater yield stability, associated with steady incomes for these producers, are therefore priority goals of WARDA's research for the Sahel region. Among the environmental factors limiting rice yields in this region are lowtemperatures during the seedling and reproductive stages, soil salinization or alkalinization, weed infestation and bird damage. These stress factors are unevenly distributed across seasons and sites. Cropping intensity and cultural practices such as planting method modulate the effects of environmental stresses.

Research in WARDA's Sahel Program focuses on stress resistance and temporal escape, including genetic and crop management. An agro-ecological characterization study indicated that the most promising mechanism for sustaining high yields is to develop appropriate, site-specific combinations of cultural practices, cropping calendars and genetic materials. During 1993, the emphasis was placed on two projects: Sahel characterization and germplasm

Women threshing rice in Mali

improvement. The main activities were:

- identification of high-yielding varieties for wet and dry seasons
- zonation of the Sahel environment using rice crop simulation tools
- development of RIDEV.REC, a simulation tool to assess climatic risks and improve rice crop management calendars
- assessment of the evolution of soil characteristics under continuous cultivation at N'Diaye (delta) and Fanaye (middle valley) in Senegal
- characterization of varieties for photothermal response to climate and tolerance to cold at the seedling stage

The assessment of varietal reaction to soil salinity led to a better understanding of the physiological factors influencing salt tolerance in arid environments. Collaborative networks were established with national programs through the Sahel Task Force, and experiments at benchmark sites now permit a regional evaluation of germplasm and micro-meteorological studies.

PROJECT 1: CHARACTERIZATION OF RICE GROWING ECOSYSTEMS

A project was initiated in 1991 to characterize the Sahel irrigated rice ecosystems agro-ecologically and economically. Most of the information accumulated by researchers and development workers in recent decades has been highly site-specific, disciplinarily fragmented and poorly documented. We therefore sought to integrate the existing information to describe the spatial diversity of the ecosystem, its dynamics and the relationships between the prevailing constraints to crop yield. This required collaborative field experiments and surveys at benchmark sites, conducted by WARDA and national program scientists within the framework of the Sahel Task Force.

In 1993, monthly planting schemes for key rice varieties at benchmark sites, equipped with monitoring units for micro-meteorological conditions, helped us to formulate and validate crop models for the region. Using climate-driven simulation, we subdivided the Sahel into zones characterized by specific varietal requirements, potential calendars for rice-rice double cropping and climatic constraints to yield. Because of the specific thermal requirements of rice, this zonation differed markedly from previous rainfall-based zonations. Environments were also characterized according existing cropping systems and the economic and policy parameters governing rice production.

The evolution under rice-rice double cropping of key parameters for soil fertility was studied on WARDA's farms at N'Diaye and Fanaye in Senegal. Related experiments on poorly understood constraints, such as soil infestation with parasitic nematodes, are being conducted by the Task Force at other benchmark sites in the Sahel.

Through an innovative systems approach and experimental components, the characterization project generated not only valuable information but also risk-assessment, decision-making and training tools of immediate relevance to technology generation and transfer. Research in 1994 will continue to emphasize the direct spill-over from characterization activities to applied research.

Economics of irrigated rice production in the Sahel
T. Randolph

Prevous analyses have often questioned the economic viability of irrigated rice production in the Sahel. The rice sector in this region, however, has changed considerably over the past decade. Reforms have liberalized many agricultural markets and privatized state services, while investments in irrigation have expanded the area under rice.

As part of its characterization project, WARDA's Sahel Program is examining how the competitiveness of irrigated rice production systems has evolved in Mali, Mauritania, Niger and Senegal. The research seeks to identify the principal production systems and analyze their relative profitability for producers and for society, using the policy analysis matrix (PAM) framework. By

One of WARDA's characterization trials for yield potential under direct-seeded and transplanted conditions, N'Diaye, Senegal

comparing costs and returns valued at nominal prices with those valued at their shadow prices, this approach permits the evaluation and quantification of efficiency distortions introduced by government policies and market imperfections. This approach also helps us to devise various comparative advantage measures, indicating where and under what conditions rice production can compete economically with imports.

Analyses have been completed for Mauritania and are nearing completion for the other three countries. The results for Mauritania indicate that structural adjustment is improving the overall competititve position of irrigated rice production systems by encouraging the expansion of production by private commercial farmers under low-cost irrigation systems and by favoring a shift from industrial to small-scale milling. Public policy continues to influence producer profitability through public irrigation subsidies and a substantial tariff on rice imports.

The study ends in 1994 and the results will be published as WARDA research reports. Colleagues in national programs will be given a copy of the computer model and will be trained in its use as a tool to evaluate the economic impact of policies and research on the irrigated rice sector in their respective countries.

The Sahelian rice economy under structural adjustment
T. Randolph

In the 1980s and early 1990s, governments of Sahelian countries initiated macro-economic stabilization and structural adjustment programs to reinvigorate their stagnant economies. In most cases, these programs involved major reforms in the rice economy, redefining its structure and policy environment. While studies have been conducted on the overall performance of the programs, their evolution within the rice sector has not been investigated.

To understand the effect of structural adjustment programs on the economic viability of irrigated rice production systems, WARDA evaluated the impact of the programs in Cameroon, Mali, Mauritania, Niger, Nigeria and Senegal. In addition to making an inventory of the reform measures in each country, the research included a scoring scheme to depict the timing and intensity of reforms. This enabled us to determine when reforms were effectively initiated in each country, facilitating before-and-after comparisons of selected indicators.

Our review confirmed that reforms in the Sahelian rice economy have been extensive. They have reduced the role of state agencies in producing and purchasing paddy, marketing rice and determining prices, and have

FIGURE 22: Evolution of liberalization in the rice sector of six countries in West Africa

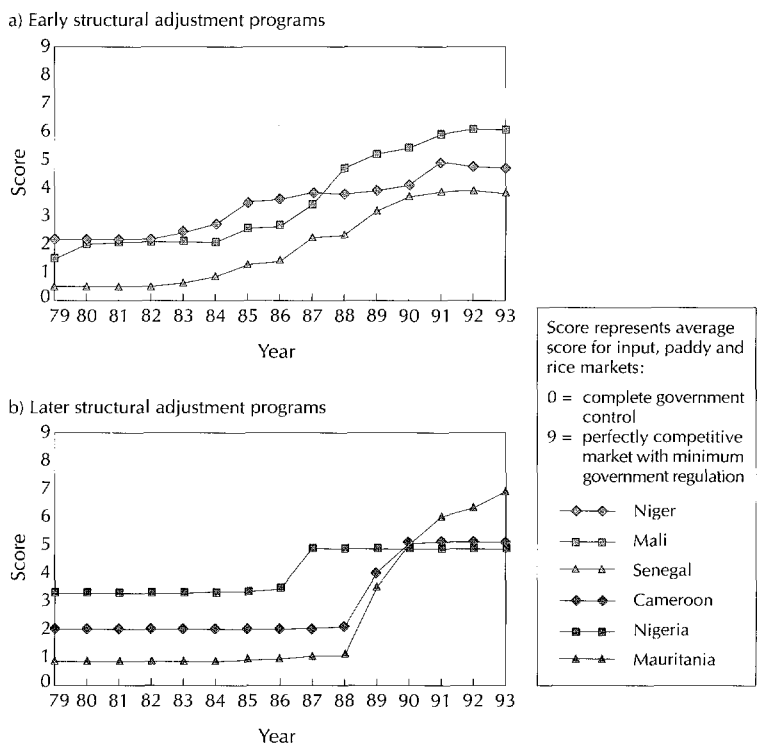


TABLE 31: Changes in selected indicators after initiation of reforms in the rice sector[a]

	Senegal	Mali	Niger	Mauritania	Nigeria	Cameroon
First structural adjustment program initiated	1980	1982	1983	1985	1986	1988
Reforms in the rice sector initiated (RSAP)	1985	1985	194	1989	1987	1989
Total change in liberalization score 1979-93	3.4	4.6	2.5	6.2	1.3	3.0
Annual growth in domestic rice production[b]						
Pre-RSAP	10%	-24%	21%	18%	7%	9%
Post-RSAP	5%	19%	5%	-2%	15%	-4%
Real producer paddy price (LCU kg^{-1})[c]						
Pre-RSAP	72	52	69	19	1.5	93
Post-RSAP	83	67	76	16	1.5	46
Real fertilizer price (LCU kg^{-1} urea)[c]	56	109	45	20	0.4	50
Pre-RSAP	90	131	54	21	0.5	69
Ratio of paddy price : fertilizer price						
Pre-RSAP	1.5	0.5	1.6	1.0	7.5	1.8
Post-RSAP	1.0	0.5	1.4	0.7	3.2	1.0
Real consumer rice (LCU kg^{-1})[c]						
Pre-RSAP	150	172	139	26	1.7	212
Post-RSAP	142	181	155	28	2.2	133
Annual growth in per capita rice consumption[b]						
Pre-RSAP	1%	13%	11%	9%	-2%	7%
Post-RSAP	0%	0%	2%	-4%	-6%	9%
Annual growth in rice imports[b]						
Pre-RSAP	2%	31%	-8%	7%	-10%	17%
Post-RSAP	2%	-10%	6%	2%	5%	6%
Self-sufficiency ratio for rice (domestic production divided by consumption)						
Pre-RSAP	18%	63%	46%	21%	67%	45%
Post-RSAP	23%	76%	50%	32%	94%	58%
Government budget (+ = reduced burden)	+	+	+	+	-	+

Note: a RSAP = year in which reforms began to be implemented in the rice sector. For each comparison, the pre-RSAP period covers from 1979 to the year preceding RSAP, and post-RSAP covers from RSAP to the most recent year for which data are available (usually 1991-93). Statistics are averages for the relevant period.

b Annual growth rate estimated using semi-log regression analysis with FAO data (production, imports) and USDA-ARS data (per capita consumption).

c Real prices are nominal prices deflated by the CPI or, if not available, the GNP deflator (World Bank sources). Prices are given in local currency units (LCU).

increased private sector participation at each level of the domestic rice marketing chain. Change has been less dramatic in markets for inputs and imported rice. Early programs were implemented gradually, while later reforms were introduced abruptly (*see* Figure 22). An analysis of key indicators before and after the reforms suggests that structural adjustment in the rice sector has generally reduced producer incentives, left consumer incomes unchanged and benefited government budgets (*see* Table 31). Production growth rates have declined in four of the six countries, but this probably reflects declining investment in new irrigation infrastructure, a trend which had begun before structural adjustment policies were introduced, rather than a supply response to reform. Import growth rates have also declined, with the net result of enhanced self-sufficiency.

Annual patterns of crop performance in rice garden trials
M. Dingkuhn, A. Samb and A. Sow

To understand the differences between potential and actual rice grain yields, climatic effects on the crop must be known. Climatic stresses in the Sahel vary with year, season, site and genotype. The rice garden system, originally developed for rice production, is being used to characterize crop x climate interactions at WARDA's farms at N'Diaye and Fanaye in Senegal. The aim is to determine the performance of key rice genotypes under optimal management in various climatic situations.

Since early 1991, seven rice genotypes have been transplanted monthly in replicated rice garden trials at the two sites. A local check, Jaya, and an international check, IR64, are planted at all dates and sites. New selections and regional checks are planted on 18 dates, then rotated with other entries; 150 kg N ha^{-1} is applied as urea in a triple split, and yield is determined from sample areas (each 6 m^2). We also measure phenological and vegetative growth parameters and yield components at maturity. The soil is a slightly acid Vertisol clay at both sites.

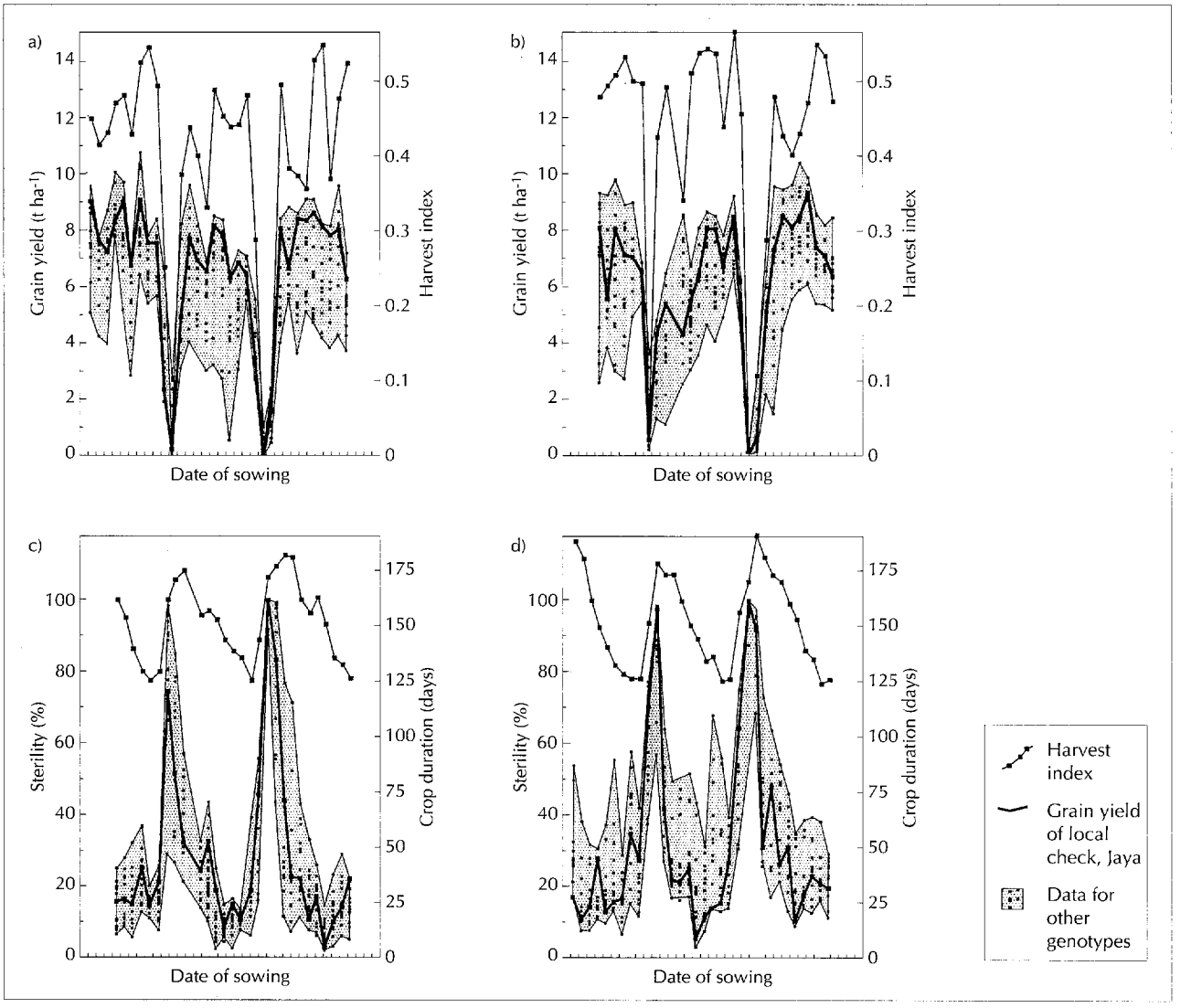
Our results on grain yield and sterility for the tested genotypes over the 1991-93 period are presented in Figure 23 *(overleaf)*. The grain yield of Jaya was 7-9 t ha^{-1} at both sites if sown between December and July. Sowing between August and November, however, was associated with strong yield reductions caused by cold-induced sterility. The relatively stable yields observed in the absence of this stress is in marked contrast to the variability of crop duration, which ranged from 125 days (sowing in July) to 180 days (sowing in December). Thus, the longer duration in the cool season did not benefit yield. The harvest index varied between 0.40 and 0.55 and showed no seasonal trend.

Up to 10 t ha^{-1} were occasionally produced at both sites but mean yields were mostly below those of Jaya. If cross-varietal ranges of observed yields are any indication of the harshness of the climate, conditions were most favorable for the crop sown in July at the onset of the wet season. This is the locally recommended planting date for the wet season. Extreme ranges of yield were observed in the dry season (November to June). High levels of sterility occurred throughout the year at Fanaye, a site with high diurnal temperature fluctuations. At N'Diaye, where the climate is buffered by the site's proximity to the sea, sterility was a major constraint only during the cool period. Jaya outyielded the other genotypes at Fanaye but gave average yields at N'Diaye.

The rice garden trials have helped us understand climate x crop interactions and enabled us to develop screening tools and extrapolative models for the region. To validate these tools and characterize benchmark research sites in the Sahel, rice garden trials have been initiated with national programs in Burkina Faso and Mali. Each trial is equipped with a micro-meteorological station. Using available data, we are now adapting the rice yield model ORYZA1 for regional analyses of yield gaps.

Jaya, a sturdy medium-duration variety favored by farmers in Senegal and Mauritania, partly because its long, wide flag leaves hide the panicles from the view of birds, even at advanced stages of maturity

FIGURE 23: Yield and some yield components in monthly rice garden planting schemes at N'Diaye and Fanaye, Senegal, 1991-93



Zonation of the Sahel using rice crop simulation tools

M. Dingkuhn

To be relevant to local agriculture, the agro-ecological zonation of a region must be based on the environmental parameters that determine the performance of production systems. The Sahel is commonly described according to rainfall quantity and distribution, parameters that are of little relevance to irrigated rice.

Using a weather-driven model that simulates the key parameters of rice performance (crop duration and temperature-induced spikelet sterility), we attempted a zonation of the Sahel for irrigated rice. Simulations were performed for 39 sites, 10 years (1970-79) and six sowing dates. Direct-seeded Jaya was used as the reference crop. The sowing dates were 15 December (cold-dry season), 15 February (hot-dry season) and four dates for the wet season (15 July, 1 and 15 August, and 1 September). These are key dates for rice-rice double cropping in the Sahel: a cold-dry season crop is succeeded by early sowing in the wet season (for example, in Niger) or a hot-dry season

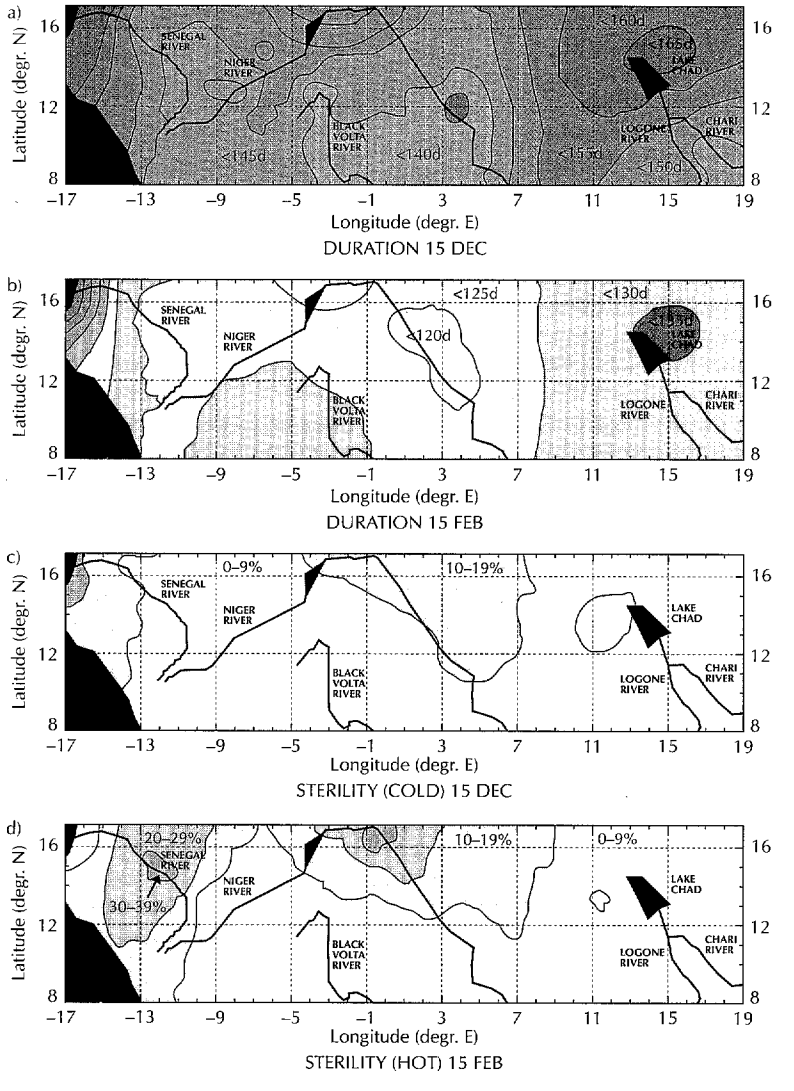
crop by late sowing (for example, in Senegal).

The simulation results for the dry season are shown in Figure 24. As the maps are based on interpolations mainly between sites where rice is grown, data for sites not located on rivers should be interpreted with caution. In the cold-dry season, crop duration was up to 180 days due to low temperatures, particularly in northern and coastal areas (*see* Figure 24, a and b). In the hot-dry season, crop duration was 120-135 days (only 5-20 days above the physiological minimum for Jaya) in most parts of the Sahel but reached 155 days in the Senegal delta and middle valley. Spikelet sterility was caused by cold in the cold-dry season and heat in the hot-dry season (*see* Figure 24, c and d). About 20-29% mean sterility was simulated for the Senegal river delta in the cold-dry season, thus rendering rice cultivation risky. By contrast, sterility was low for the cold-dry season in much of the hinterland due to a shorter cool period. In the hot-dry season, sterility was high in the Senegal upper valley and in the area flanking the bend of the Niger river, both known to be the hottest rice environments in the Sahel.

The combined results indicate that the hot-dry season is better suited to rice culture than the cold-dry season in the Senegal delta and middle valley. In the northern part of the Niger river bend area, the cold-dry season is associated with excessively long crop duration and the hot-dry season with high heat-induced sterility, causing problematic dry-season cropping. In the remaining parts of the Sahel, hot-dry and cold-dry season cultivation appears to be feasible but crop duration and hence water consumption are expected to be lower in the former.

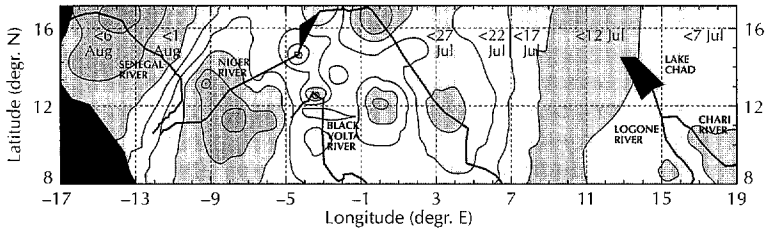
For the wet season, previous studies have shown that the climate is generally favorable for rice if planting is performed early enough to escape cold injury during the reproductive stage. We determined the latest possible sowing dates that would permit mean cold-induced sterility rates of less than 10% (*see* Figure 25 *overleaf*). In two subregions, rice can be sown safely as late as early August: in the Senegal delta and valley and at

FIGURE 24: Spatial representation for the Sahel of simulated crop duration for direct-seeded Jaya rice sown on (a) 15 December (cold-dry season) and (b) 15 February (hot-dry season), and (c and d) temperature-induced sterility for the same seasons



Duration in days and sterility as % of spikelets and the corresponding shades of colour are indicated. Simulated means for 1970–79 weather date.

FIGURE 25: Latest possible sowing dates for direct-seeded Jaya rice for the wet season in the Sahel, based on simulated crop duration and cold-induced spike sterility for 1970-79



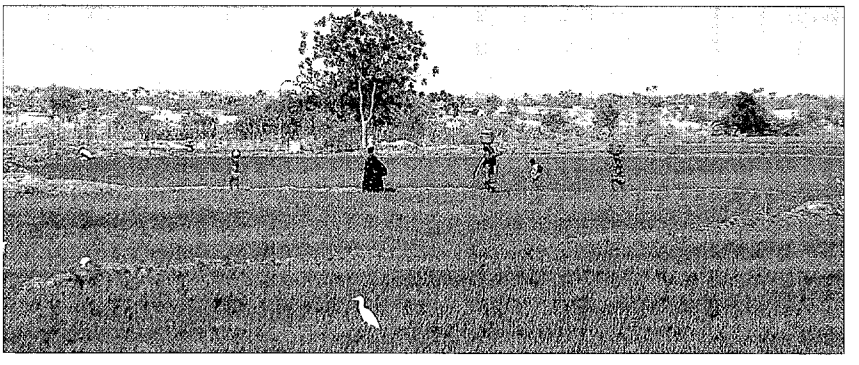
A maximal mean sterility of 10% was set as the limit for the acceptibility of sowing dates.

Gao at the eastern part of the Niger river bend area. In the Chad basin and the western (upper) branch of the Niger valley, however, rice must be sown before mid-July to avoid sterility.

We conclude that the probability of successful rice-rice double cropping is high in the Senegal delta and middle valley if the crop is sown in the hot-dry season and relatively late in the wet season to leave sufficient time for operations between the seasons. In the Senegal upper valley, cropping calendars as determined by climate are more flexible for both wet and dry seasons. In much of the remaining Sahel, however, sowing in the wet season must be performed early to avoid cold-induced sterility. Time constraints then eliminate the option of planting in the hot-dry season. In such situations, the only remaining option is the cold-dry season (for example, the Niger valley except in the extreme north). The simulations were in complete agreement with the cropping calendars actually practised in the Sahel.

Simulation studies, in combination with regional surveys and benchmark experiments, provide a spatial dimension to our rice-based characterization of the Sahel and help target breeding efforts. In 1994, additional parameters describing water requirements and potential yield will be studied to refine the zonation.

A dry-season rice crop in Niger, where rice culture is based on small irrigation schemes, generally with two transplanted rice crops per year



Changes in soil pH and salinity at N'Diaye, Senegal during the initial two years of irrigation
M.Dingkuhn

Soil degradation under irrigation in the Sahel is frequently associated with an increase in soil pH and salinity. These factors were monitored at WARDA's research farm at N'Diaye in Senegal to study the effects of rice-rice double cropping on the soil.

The farm was irrigated in early 1991. Onions and rice had previously been grown at low intensity but farmers had abandoned much of the land because of salinity. The topsoil is a shrinking Vertisol clay with variable pH but homogenous texture (40-55% clay, 35-45% silt). Beneath the 0.8-1.0 m clay layer is a saline and acid waterlogged horizon composed of gypsum crystals originating from fossil mangrove roots. The quality of irrigation water was good and the import of salt minimal in 1991-93. These farm characterisics are representative of production systems in the Senegal delta.

At the start of the experiment in early 1991, an annual mapping program was initiated to monitor soil pH and electric conductivity (EC) as a measure of salinity, using core samples from depths of 0-15, 15-30 and 30-45 cm. The samples were taken every January at fixed sites separated by mean distances of 12 m.

The mean pH across the farm in 1991 was slightly acid and decreased with soil depth (*see* Table 32). Mean values changed little between 1991 and 1993. Spatial variation in pH, however, decreased: plots that had been alkaline or acid in 1991 had become more neutral by 1993. Across the farm, topsoil pH shifted towards a convergence point of 5.8 (*see* Figure 26). Soil pH varied in part with topography (alkaline in the higher portions at the

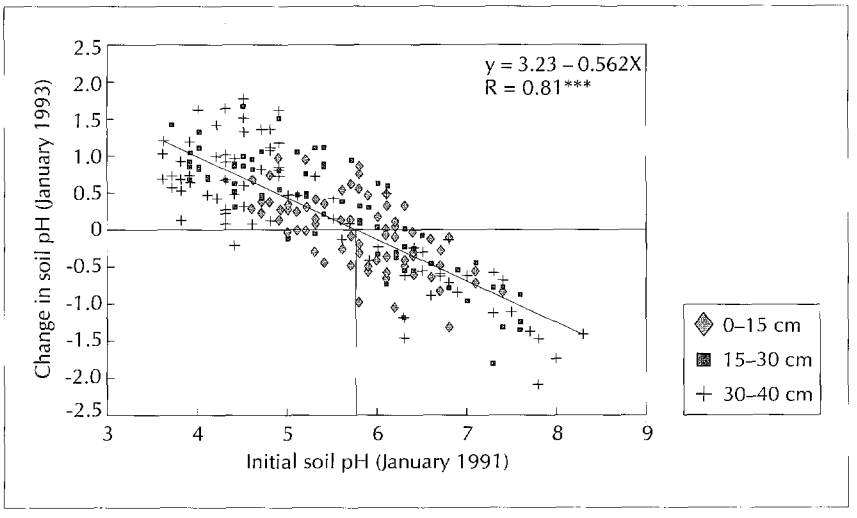
northern edge of the farm and acid in a depression in the central-west portion) (*see* Figure 27, a and b *overleaf*). Mean EC of the topsoil was 0.88 mS cm^{-1} in 1991, and increased with depth (*see* Table 32). Values above 1.0 mS cm^{-1} were associated with low yield. The data indicated extreme micro-variability and apparent mobility of salts (*see* Figure 27 c and d). Although desalinization through flushing and drainage conducted in 1991-93 was successful in plots where this was systematically done, the EC nevertheless increased in the acid depression that was difficult to drain and at a spot with artesian up-welling of salty water.

Our results indicate that 2 years of intensive irrigation have partly homogenized topsoil pH but only slightly reduced salinity. Wherever the EC decreased due to improved water management, the salts were also removed from the farm. Patches with rising salinity occurred because of a capillary or artesian rise of saline water from the rising groundwater table. This pattern is becoming typical of irrigation schemes in the Senegal river delta and in Mali. WARDA is intensifying its research on the hydrology, fertility and salinization/desalinization of irrigated soils. In 1993 WARDA initiated collaborative research projects on these problems with researchers in Mali and at the University of Leuven, Belgium.

TABLE 32: Mean topsoil pH (1 : 2.5 extract) and electric conductivity (EC, mS cm-1; 1 : 5 extract) for WARDA's farm at N'Diaye, Senegal, 1991 and 1993

	Jan 1991	Range	Jan 1993	Range	Change
pH 0-15 cm	5.78	4.6-7.4	5.75	4.8-6.7	-0.04
pH 15-30 cm	5.50	3.7-7.6	5.71	4.6-6.7	+0.22
pH 30-45 cm	5.31	3.6-8.3	5.50	3.9-6.9	+0.19
Mean 0-45 cm	5.53		5.65		
EC 0-15 cm	0.46	0.1-1.4	0.56	0.4-2.4	+0.11
EC 15-30 cm	0.85	0.2-2.6	0.76	0.1-2.2	-0.09
EC 30-45 cm	1.34	0.1-3.3	1.13	0.2-3.5	-0.21
Mean 0-45 cm	0.88		0.82		

FIGURE 26: Change in topsoil pH under intensive irrigated rice cultivation, as a function of initial pH, N'Diaye, Senegal, 1991-93



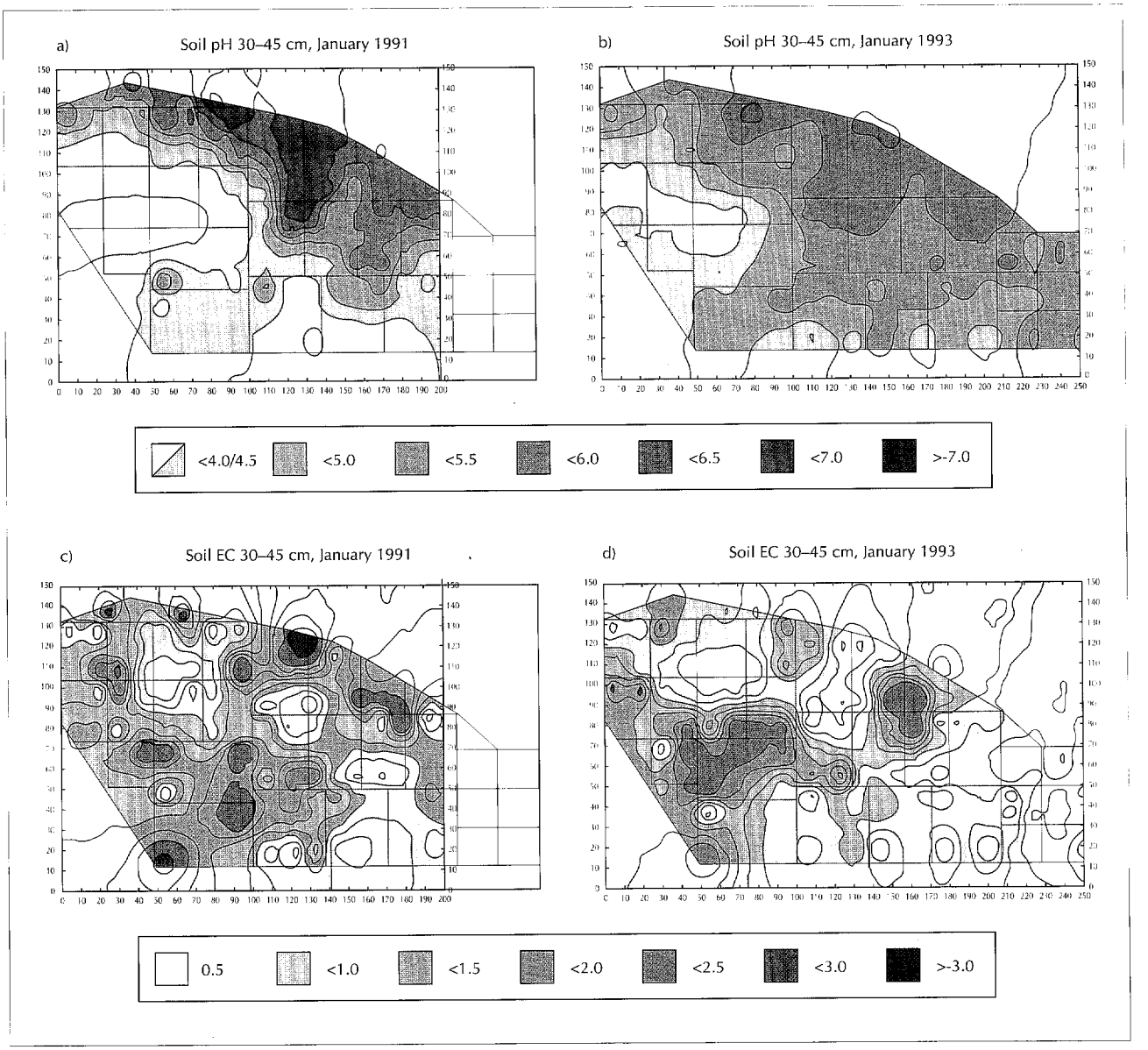
Rice root nematodes at WARDA's N'Diaye farm in Senegal

M. Dingkuhn

An initial survey of rice root nematodes conducted in 1991 with the NRI indicated substantial *Hirschmaniella oryzae* infestation of rice roots and topsoil. This nematode species is widespread in Sahel irrigated rice environments but no yield loss data are yet available.

Two experiments on root nematodes were conducted at N'Diaye in 1992-93. The first addressed seasonal patterns of nematode populations in the soil and roots of rice plants. Observations were made in replicated microplots sown monthly. Root and soil samples were taken 2 months after sowing, followed by ploughing and sowing of the next crop. In the second experiment we studied the spatial relationship between root nematode infestation at heading stage and plant dry matter, yield at maturity and soil pH and EC. A 14 x 26 m plot was homogenized with rice in the dry season of 1992 and planted to I Kong Pao (IKP) in the wet season. Shoots, roots and topsoil were sampled on a 4 x 4 m grid, in October 1992. The soil was a previously saline Vertisol clay (mean pH 6.5; EC 0.2 mS cm^{-1}). The mean grain yield was 4.5 t ha^{-1}. The nematodes were extracted from the root and soil samples using a previously validated method in which

FIGURE 27: Topsoil pH (a and b) and electric conductivity (EC) (c and d) at WARDA's research farm at N'Diaye, Senegal



nematodes quantitatively migrate during 48 hours through a gauze layer into water.

The same two parasitic nematode species occurred in both experiments: *H. oryzae*, which was predominant, and a larger species, probably in the genus *Tylenchorhynchus*. The *H. oryzae* populations were low in the dry season (December to June) and increased in the wet season (August to October) (*see* Figure 28). High nematode populations in rice roots in October/November 1992 were followed by a transitory peak in organic debris in the soil. Since each sequential sample came from a new plant population, it appears that the high nematode populations which built up in the roots in the wet season could not enter the roots in subsequent cold months, and therefore remained in the soil. Populations

decreased sharply in the hot-dry season, probably because the reproduction of *H. oryzae*, which takes place in live roots, had been interrupted by the cold period.

The spatial analysis of data from the second experiment showed the patchy distribution typical of nematode infestation. Nematodes were concentrated in the area where irrigation water entered the field. This was reflected in the yellowing of the rice foliage. Multiple linear regressions across the grid data showed no significant correlation between nematode population and soil pH, soil EC, plant dry matter or yields. The observed range of infestation (5-107 nematodes g^{-1} root) was probably below the economic threshold. These results indicate that although rice root nematodes exist on the N'Diaye farm, their current population levels do not constrain crop yields.

Studies coordinated by the Sahel Task Force are currently being conducted in Burkina Faso and Mali to assess nematode problems in irrigation schemes bordering the Niger and Black Volta rivers. Preliminary data show that *H. oryzae* might be an important constraint in poor soils, particularly under rice-maize rotation in Mali. The results of the Task Force studies will guide future research on nematodes in the Sahel.

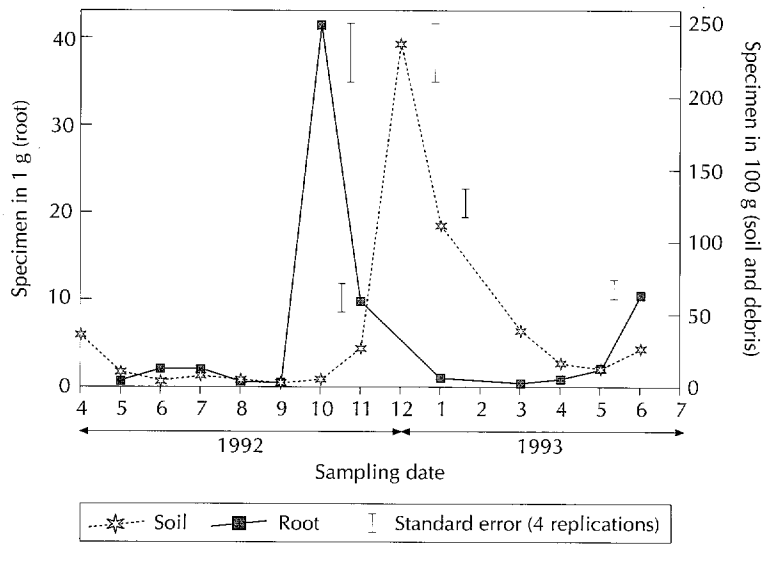
PROJECT 2: VARIETAL IMPROVEMENT

Most varietal improvement programs for irrigated rice in the Sahel aim at developing high-yielding varieties which perform equally well in the various production environments and in the main wet and dry seasons. Available data, however, indicate that irrigated rice environments are diverse and require zone-specific production systems and cropping calendars. WARDA's varietal improvement program in the Sahel attempts to identify germplasm with a broad genetic base from which rice farmers can choose the most appropriate varieties for their production systems. These varieties should be high yielding, resistant to major Sahelian biotic and abiotic stresses, and have a crop duration suited to local cropping calendars.

Analysis of the performance of varieties evaluated at different sites during the wet and dry seasons has revealed highly significant variety x season interactions, and varieties that perform best in the wet season differ from those that perform best in the dry season. The strategy of the Sahel breeding program is therefore to establish specific nurseries for different seasons. As a continuation of the 1992 activities, the following trials were conducted in 1993 during the hot-dry (February to June) and wet (July to November) seasons: an initial evaluation nursery (wet season), composed of entries from IRRI and INGER-Africa); and observational, preliminary and advanced yield nurseries (wet and hot-dry seasons). Only the results from observational preliminary and advanced yield nurseries are reported in the following summaries.

The entries were evaluated on the basis of general adaptability, yields and yield components of vegetative, panicle and grain characteristics, and response to biotic and abiotic stresses. All trials were conducted at Fanaye and N'Diaye in Senegal. The Fanaye site is inland and has typical semi-arid, continental weather. Average minimum diurnal temperatures may exceed 20°C in April and May, the hottest period of the year, while air humidity is generally very low. The lowest and highest temperatures (about 10°C and 45°C) are usually only 2 months apart and are both experienced by the hot-dry season crop planted in February. The wet season (July to October) is

FIGURE 28: Population dynamics of rice root nematodes at N'Diaye, Senegal, 1992-93



A continuous fertility trial in the wet season at Fanaye, Senegal, with Jaya as the test variety

characterized by significantly higher minimum temperatures and air humidity, and the diurnal temperature ranges are usually only 10-15°C. The N'Diaye site is nearer the sea and has more moderate temperature extremes, higher air humidity throughout the year and strong winds. Photoperiod at both sites is 11 hours in December and 13 hours in June/July. The soil is a heavy clay at both sites, with moderate sodic salinity at N'Diaye.

Entries for all trials were transplanted from a seedbed 25 DAS at a spacing of 20 x 20 mm. Each plot received 120 kg N ha^{-1} applied as urea in a triple split, 60 kg P ha^{-1} as single superphosphate and 60 kg KCl ha^{-1}. Weeds were chemically controlled by the application of Propanil (10 liters ha^{-1}), followed by hand-weeding later, as necessary. Insect pests and/or diseases were not controlled. The trials at N'Diaye were covered with fishing nets to protect them from bird damage.

Preliminary nurseries for the wet season
K. Miézan

Varieties selected in observational nurseries for yield potential, crop duration, plant type, grain characteristics and response to major stresses were advanced to preliminary yield nurseries. In 1993, five preliminary nurseries (two short duration, 24 entries each; three medium duration, 24, 21 and 19 entries, respectively) were evaluated for the first, second or third year, depending upon whether they had been composed in 1991, 1992 or 1993. I Kong Pao (IKP) was the short-duration check and Jaya the medium-duration check. All nurseries were planted at both N'Diaye and Fanaye in a randomized complete block design, with three replications.

Third-year short-duration entries which showed good average performance at the two sites compared with IKP (6.7t ha^{-1}) will be selected for advanced yield nurseries. These entries include: IR31851-96-2-3-1 (7.7 t ha^{-1}), C1322-28(7.1 t ha^{-1}), IR32307-107-3-2-2 (7.9 t ha^{-1}), IET9702 (7.8 t ha^{-1}) and B5322-PN-LMS-1-KP-1 (7.7 t ha^{-1}). First-year short-duration entries tested under the same conditions as IKP (5.7 t ha^{-1}) and showing good yield potential were: IR41985-111-3-2-2 (6.3 t ha^{-1}), IR50363-61-1-2-2 (6.7 t ha^{-1}), IR55598-179-2-6-2 (6.3 t ha^{-1}), IR57301-195-3-3 (6.7 t ha^{-1}) and IR57301-73-2-2 (6.4 t ha^{-1}). Subsequent trials will be conducted to confirm these results. Several of the high-yielding short-duration entries also matured up to 7 days earlier than IKP, a trait preferred by farmers.

In the medium-duration groups, IR28118-138-2-3 (7.4 t ha^{-1}), IR28128-45-3-2 (7.5 t ha^{-1}), ITA252 (7.7 t ha^{-1}), ITA212 (7.3 t ha^{-1}), BG380-2 (7.7 t ha^{-1}) and UPR254-85-1-TCA3 (7.7 t ha^{-1}) were among the entries which confirmed the good performance observed in previous years. They will be selected for advanced yield trials. In 1993 other entries, including ECIA156-S4-1 (6.2t ha^{-1}), TOX3081-36-2-3-1 (7.1 t ha^{-1}), B4140C-PN-186-28-KP-2 (6.9 t ha^{-1}), IR32307-107-3-2-2 (6.8 t ha^{-1}) and B5322B-PN-19-MS-27-KP-N (6.7 t ha^{-1}) also outyielded Jaya (5.7 t ha^{-1}) for the second year of evaluation. Spikelet sterility remained high for all nurseries but was lower than in 1992, particularly at Fanaye (7-30%).

While most of the preliminary nurseries will be repeated in 1994, entries which have performed consistently well over the 3 years will be used to compose advanced yield nurseries for the 1994 wet season.

Advanced yield nurseries for the wet season
K. Miézan

Entries identified previously as consistently high yielding in

preliminary nurseries were evaluated in advanced yield nurseries. In addition to the usual observations on yield, we also collected data on yield components, plant morphology, reaction to major stresses, panicle structure and grain quality.

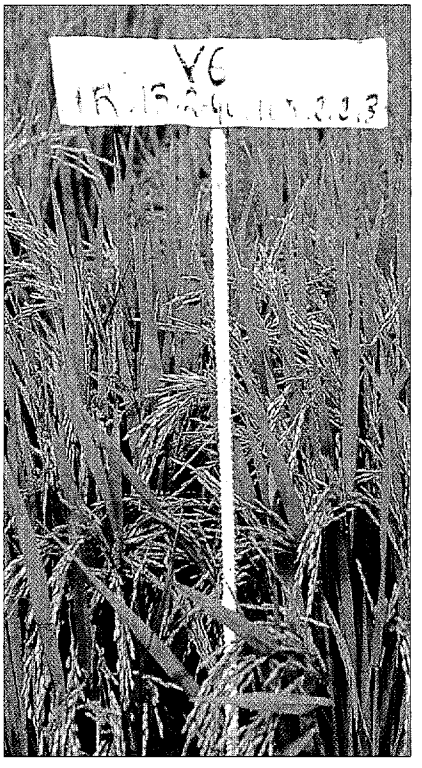
Two advanced yield nurseries (one short duration with eight entries and one medium duration with seven entries) were evaluated in 1993 for the third year at N'Diaye and Fanaye. I Kong Pao (IKP) and Jaya were used as the short- and medium-duration checks, respectively. We used a complete randomized block design, with three replications. Tests in farmers' fields were conducted on unreplicated 2000 m^2 plots at Podor and Matam in the middle and upper areas of the Senegal river valley.

In general, the 1993 results confirmed observations made in previous years. In the short-duration group, IR13240-108-2-2-3 (7.8 t ha^{-1}), 32XUAN5C (7.4 t ha^{-1}), TNAU7893 (7.2 t ha^{-1}), TOS103 (7.1 t ha^{-1}) and IR31785-58-1-2-3-3 (7.0 t ha^{-1}) outyielded IKP (6.6 t ha^{-1}). IR31785-58-1-2-3-3 matured about 10 days earlier than IKP; TNAU7893, 32XUAN5C and TOS103 matured about 5 days later than IKP, and IR13240-108-2-2-3 had the same duration as IKP. TOS103 and 32XUAN5C had higher 1000-grain-weight (about 26 g) than IR13240-108-2-2-3 and IKP (about 24 g). The varieties IR13240-108-2-2-3 and IR31785-58-1-2-3-3 which were tested in farmers' fields outyielded IKP at both sites (5.4 t ha^{-1} and 5.8 t ha^{-1} at Podor, and 8.0 t ha^{-1} and 6.2 t ha^{-1} at Matam for the two varieties, respectively, compared with 5.3 t ha^{-1} and 4.9 t ha^{-1} for IKP). Both varieties are also preferred by farmers for their grain type and cooking qualities.

No superior materials were identified among the medium-duration entries. ITA306 and BW293-2 continued to perform as well as Jaya. BG400-1 also showed high yield potential but was less consistent than Jaya. ITA306 and BW293-2 were also evaluated in farmers' fields at Podor and Matam, but only ITA306 performed as well as Jaya at both sites (average 6.5 t ha^{-1}). We will continue with our efforts to identify a variety with a genetic background which differs from that of Jaya, but which can perform at least as well, in order to broaden the genetic base of irrigated rice varieties cultivated in the Senegal river valley.

The best entries identified in the advanced nurseries will be tested in multilocational trials in the region in 1994, along with other varieties nominated by national programs, based on the network of key sites managed by the Sahel Task Force.

One of WARDA's best-performing selections for the Sahel, IR13240-108-2-2-3, which is suited to both the wet and hot-dry seasons



Preliminary yield nurseries for the hot-dry season
K. Miézan

A first-year preliminary yield nursery for the hot-dry season was planted in 1993 at N'Diaye and Fanaye. It included 23 entries selected from the 1992 hot-dry season observational nurseries. I Kong Pao (IKP) and IR3941-86-2-2-1 were used as checks. We used a complete randomized block design at both sites, with three replications.

The yields were generally much lower at Fanaye (2.7-4.8 t ha^{-1}) than at N'Diaye (4.0-9.0 t ha^{-1}). At Fanaye, there was a lower number of panicles per m^2 (250-470) and spikelets per panicle (54-115) than at N'Diaye (350-600; 64-138). The poor performance of entries at Fanaye may be related to soil Zn deficiency, but this is being verified. At N'Diaye, ECIA24-107-1-1-1-2 and B5322B-PN2-MS-3-NG2 gave the highest yields (9.0 and 8.5 t ha^{-1}, respectively). At Fanaye, the highest yields were produced by IR57298-101-1-3 and IET9702 (4.8 and 4.6 t ha^{-1}, respectively). It should be noted that B5322B-PN2-MS-3-NG2 was also the third best yielder at Fanaye (4.4 t ha^{-1}). Crop duration for the entries varied from 123 to 143 days at Fanaye. This was generally longer than at N'Diaye, probably because of the more extreme temperature conditions at Fanaye. However, a few entries, such as IR3941-86-2-2-1, IET9702 and B5322B-PN2-MS-3-NG2, had consistent duration at both sites. Although the highest-yielding entries appeared to have a slightly longer duration (136 days) than most of the other entries, there was no significant relationship between crop duration and yields.

This nursery will be evaluated for at least 2 more years before selections are made for more advanced evaluation.

Advanced yield nurseries for the hot-dry season
K. Miézan

An advanced yield nursery for the hot-dry season which was composed and tested for the first time in 1992 was repeated in 1993. It was conducted at Fanaye and N'Diaye and consisted of eight entries, with I Kong Pao (IKP) as the check. A complete randomized block design, with three replications, was used. Four of the entries were also evaluated on 2000 m^2 plots in farmers' fields, and three entries (IR50, IR13240-108-2-2-3 and IR31785-58-1-2-2-3) were selected for a short-duration advanced nursery for the wet season.

The average yields were lower at Fanaye than at N'Diaye, probably due to Zn deficiency at Fanaye. At N'Diaye, IR29725-40-3-2-3, IR22107-14-2-1 and IR50 gave the highest yields (8.1, 7.9 and 7.6 t ha^{-1}, respectively). At Fanaye, the highest yields were produced by IR22107-14-2-1, IR50 and IR13240-108-2-2-3 (5.8, 5.5 and 5.4 t ha^{-1}, respectively). These results confirm those obtained in 1992, when IR29725-40-3-2-3, IR22107-14-2-1 and IR50 were among the best entries. It should be noted that IR13240-108-2-2-3 was the best short-duration entry for the wet season after 3 years of testing in advanced yield trials and in on-farm tests in 1992. In farmers' fields, the best test entries were IR31785-58-1-2-2-3, IR13240-108-2-2-3, IR29725-40-3-2-3 and IR50 (3.8, 3.9, 4.2 and 3.6 t ha^{-1}, respectively, at Podor; 4.1, 6.2, 4.7 and 4.8 t ha^{-1}, respectively, at Matam). The yields produced by IKP at these locations were 3.3. t ha^{-1} at Podor and 3.9 t ha^{-1} at Matam. IR29725-40-3-2-3 and IR13240-108-2-2-3 were greatly preferred by farmers because of their shorter duration in the hot-dry season compared with IKP, their grain type which was much better than that of IKP and Aiwu (a *japonica* variety often used by farmers as an alternative to IKP for the hot-dry season crop), and yield potential which was at least as good as IKP.

Although some of the entries are already being tested in farmers' fields, evaluation of the entire nursery will continue for 1 more year, during which grain characteristics and reactions to major diseases, especially blast and salinity, will also be assessed. However, the preliminary results in farmers' fields which confirmed the on-station results suggest that excellent progress is being made in the identification of high-yielding varieties which may be suitable for rice-rice double cropping wherever climatic conditions and water availability permit.

Varietal differences in rice cold tolerance at the seedling stage
M. Dingkuhn

Low temperatures in the Sahel from November to February (inland) or April (coastal) impede rice germination and seedling growth. The lack of hills and the slow initial growth render the crop canopy heterogenous and encourage weed growth.

In continuous rice garden experiments at N'Diaye and Fanaye based on 12 planting dates per year, seedling height was measured 20 days after sowing pre-germinated seed. IR64, an international check, and Jaya, a local check, were planted in 1991, 1992 and 1993. Eleven other genotypes (*see* Table 33) were planted on fewer dates

TABLE 33: Relationship between rice seedling growth rate and atmospheric minimum temperature, based on results of rice garden trials at N'Diaye and Fanaye, Senegal, 1991-93[a]

	SGR = A + B * T_{min}[b]					
Genotype	A	B	R	N	T°	SGR max[c]
IR3941	-0.15	0.42	0.72***	26	0.4	10.4
I Kong Pao	-0.99	0.40	0.71***	26	2.4	9.1
IR13240	-1.03	0.42	0.82**	12	2.4	9.5
32XUAN5C	-1.10	0.45	0.79**	9	2.5	10.1
IR1529	-1.18	0.42	0.83**	11	2.8	9.3
IET109	-1.35	0.47	0.87**	8	2.9	10.5
BG90-2	-1.41	0.44	0.80**	13	3.2	9.6
IR64	-1.83	0.45	0.76***	38	4.0	9.5
Jaya	-2.02	0.47	0.81***	38	4.3	9.8
ITA306	-2.41	0.50	0.81**	12	4.8	10.1
ECIA	-2.33	0.43	0.91***	13	5.4	8.5
SIPI6920	-3.52	0.53	0.87***	14	6.7	9.7
KH998	-1.94	0.55	0.87***	26	7.2	9.7
Mean	-1.79	0.46	—	—	3.8	9.7
SE± (n)	1.02	0.04	—	—	1.8	0.5
	57%	9%	—	—	—	5%

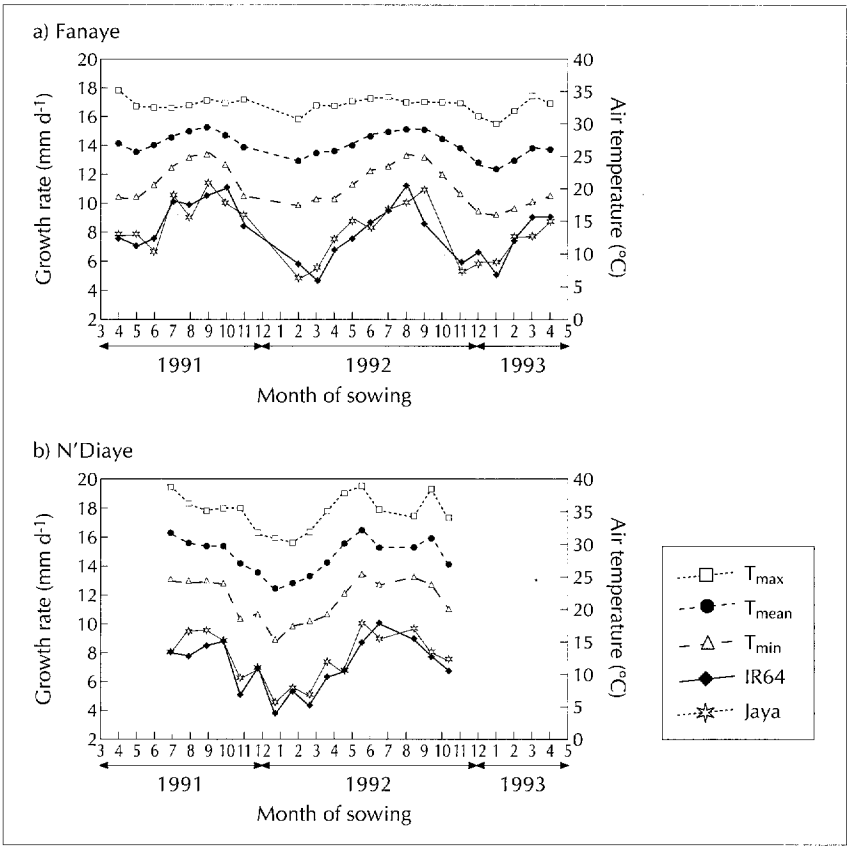
Note: a SGR = rice seedling growth rate (mm d^{-1}); T_{min} = atmospheric temperature (mean for the initial 20 days in the nursery)
b A = intercept; B = slope; R = regression coefficient; * = < 0.05, ** = < 0.01, *** = < 0.001; N = number of environments; T° = extrapolated T_{min} for zero growth
c SGR max = SGR at T_{min} = 25°C

due to a rotation enabling the characterization of new materials. Seedling growth rate was calculated from plant height.

The seedling growth rate depended largely upon the average minimum temperature (T_{min}) during the initial 20 days (IR64: r = 0.76***; Jaya: r = 0.81***; *see* Table 33). It had lower correlation with mean temperature (IR64: r = 0.64***; Jaya: r = 0.71***) and none with maximum temperature. The seasonal variation of seedling growth closely followed the course of minimum temperatures (*see* Figure 29). It was highest (10-11 mm day^{-1}) between July and September (wet season) when T_{min} was about 25°C, and fell to 4-5 mm day^{-1} in January (onset of the hot-dry season) when T_{min} was about 15°C. Thus, seedling growth rate was 2.0-2.5 times higher in the wet season than in the dry season. Whole-season time courses for individual crops showed that the linear relationship between seedling growth rate and T_{min} also governed plant height through to flowering.

The maximum seedling growth rate at 25°C varied little among the 13 genotypes being tested because they had been selected for short stature (*see* Table 33). Slope B of the regression growth rate vs. T_{min} was also similar among genotypes, the main element of varietal diversity being the intercept A. Thus, varieties differed in T°, the extrapolated T_{min} at which growth is zero. Low T° was observed for IR3941-86-2-2-1, selected for its cold tolerance, and I Kong Pao (IKP), the *japonica* type popular in Senegal and also considered to be cold tolerant. IR13240-108-2-2-3 and 32XUAN-5C have comparatively stable duration across seasons, and IR1529-680-3 is successfully grown in both cold-dry and wet seasons in Niger. Among the five genotypes with the highest T°, four (Jaya, ITA306, ECIA and SIPI6920) were selected for the more balanced thermal conditions of the wet season.

FIGURE 29: Seasonal variation in seedling growth rate for WARDA's international check (Jaya) and local check (IR64) varieties for the Sahel, at Fanaye andN'Diaye, Senegal, 1991-93



These results indicate that seedling growth rate might be an effective screening tool for cold tolerance at the vegetative stage. We are adapting the method, in combination with germination tests at low temperature, for use in WARDA's varietal evaluation program for the Sahel.

Varietal differences in rice cold tolerance at the reproductive stage
M. Dingkuhn

Cold nights at the reproductive stage of rice cause yield variability in the wet season in the Sahel. The meiotic phase which coincides with booting is the most sensitive. This study sought to determine whether spikelet sterility induced by cold could be reduced by breeding for physiological tolerance or escape through timing and duration of the crop.

Spikelet sterility observed in 1991-93 for 40 genotypes in various experiments (multiple planting dates, two experiments, two sites — N'Diaye and Fanaye in Senegal) was compared with the mean minimum air temperature (T_{min}) from 5 to 15 days before flowering. A total of 396 sterility x T_{min} observations were taken (*see* Figure 30 *overleaf*). Sterility increased

FIGURE 30: Relationship between spikelet sterility and minimum temperature at booting stage for 396 genotype x environment combinations and the variety Jaya x 46 environments, at N'Diaye and Fanaye, Senegal, 1991-93

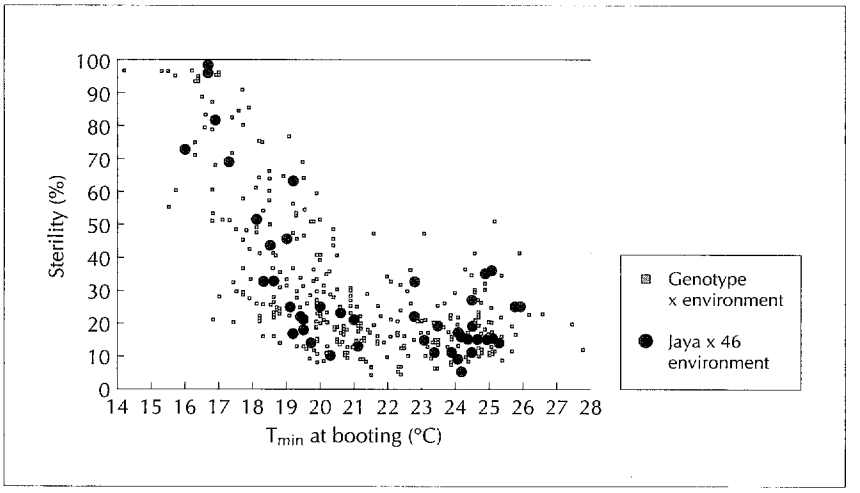


TABLE 34: Response of spikelet sterility to low minimum temperatures (T_{min}) at booting stage (5-15 days before 50% flowering) for 13 genotypes in rice garden trials and pooled for 40 genotypes in unrelated experiments[a]

	CT50[b] (°C)	Observed sterility % min	% max	R[c]	N[d]
BG90-2	17.3	8.2	96.8	0.80**	16
IR64	17.5	6.0	98.1	0.81***	48
I Kong Pao	17.7	5.0	95.7	0.89***	36
IR3941	17.7	9.0	85.9	0.63***	38
ECIA	17.7	8.3	61.4	0.80***	19
KH998	17.8	6.2	86.9	0.75***	34
Jaya	18.1	5.1	99.7	0.88***	46
32XUAN5C	18.1	13.5	98.2	0.95***	11
IET109	18.1	13.4	96.6	0.84*	9
IR13240	18.2	15.0	96.7	0.79**	15
SIPI16920	18.5	6.6	90.2	0.96***	21
ITA306	18.5	20.6	95.0	0.78*	11
IR1529	18.6	12.7	97.8	0.96**	8
Pool (13% CV)	18.0	5.0	99.7	0.83***	312
Pool (40% CV)	18.0	4.0	99.7	0.78***	396

Note: a The range of T_{min} was 14.1 to 27.8°C
b CT50 = critical T_{min} resulting in 50% sterility
c R = regression coefficient for quadratic regressions sterility vs. T_{min} (* = < 0.5, ** = < 0.01, *** = < 0.00)
d N = number of environments (date x site)

as T_{min} dropped below 20°C and was 100% at about 16°C, resulting in total crop failure. The thermal response of the local check, Jaya, followed the general pattern obtained across the pooled genotypes x environments. Separate analyses for the two sites also gave identical patterns.

For 13 genotypes grown in continuous rice garden experiments, sterility vs. T_{min} response curves were established and the constant critical minimum temperature (CT50; the temperature at which 50% of the spikelets turn sterile) calculated (*see* Table 34). The mean CT50 was 18°C across the pooled observations for 40 genotypes in various experiments and for the 13 genotypes studied in detail in rice garden trials. Genotypic values for CT50 fell into a narrow band between 17.3°C (BG90-2, grown in Mali) and 18.6°C (IR1529-680-3, grown in Niger), despite the genetic diversity of the sample (*japonica* and *indica* types, ultra-short-duration to medium-duration types, diverse origin). We observed no correlation between CT50 and T°, a base temperature for seedling growth determined for the same genotypes (*see* previous summary). Other reports also indicated that no link exists between rice cold tolerance at the vegetative and reproductive stages.

The genetic diversity among the test genotypes was too small to justify breeding for lower CT50 to improve cold tolerance at the reproductive stage. Reducing CT50 to 16°C would require a major breeding effort with an uncertain outcome. In the Sahel minimum temperatures drop rapidly to below16°C (often to below 10°C) at the onset of the cool season. Planting 2 weeks earlier or reducing crop duration by 2 weeks theoretically has the same effect and is easier to achieve. Future research on low-temperature stresses at the reproductive stage (wet-season) will emphasize escape

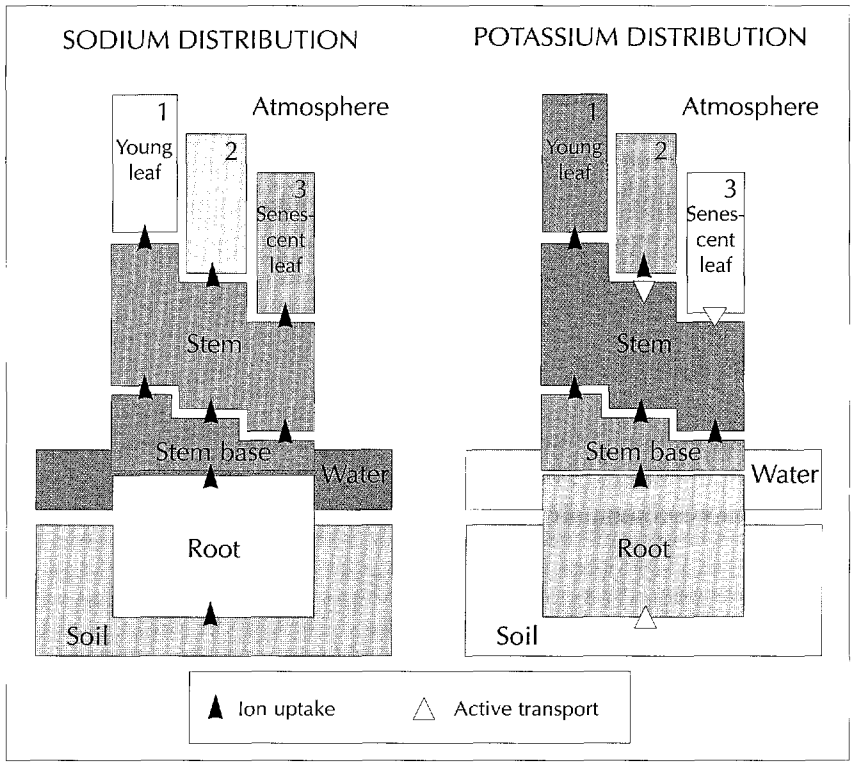
strategies through varietal crop duration and cropping calendars. For the vegetative stage (hot- and cold-dry seasons), breeding will address both crop duration and cold tolerance.

Testing hypotheses on rice salt tolerance by simulation
M. Dingkuhn and F. Asch

Soil salinity is a major constraint to rice production in coastal and some inland irrigation schemes in the Sahel. Salt-tolerant varieties are needed for soil regeneration and production systems where salinity can be only partially controlled.

WARDA's research on rice salt tolerance under arid conditions in 1993 focused on the component traits governing salt uptake and tolerance. Physiological and varietal studies revealed recurrent patterns of inorganic, monovalent cation relationships among plant organs. Young leaves had low Na^+ and high K^+ concentrations, whereas old ones were high in Na^+ and low in K^+. Under saline conditions, the combined concentration of K^+ and Na^+ was similar among leaves, possibly indicating an upper osmotic limit to their accumulation. Leaf sheaths and the stem-base accumulated both cations, whereas the root and the developing panicle had low concentrations. A summary diagram of hypothetical cation fluxes based on observed concentrations in plant organs is presented in Figure 31.

FIGURE 31: Rice ion uptake models, showing hypothetical sodium and potassium cation transport in irrigated rice under saline conditions, developed from field studies at N'Diaye, Senegal



Simulation was used to determine the physiological assumptions required to explain observed concentrations, based on the transpiration-driven transport of Na^+. In a simple hypothetical system in which plant organs behave as open pipes, cation flow is driven by the concentration in the soil solution and the transpiration rate, surface and lifespan of leaves. The resulting accumulation of cations in leaf tissues is proportional to transpiration and reciprocally proportional to growth rate. A basic model operating with daily increments was formulated to simulate leaf succession, leaf transpiration derived from the Penman-Monteith model, and field observations on stomatal conductance and growth of the various organs. Using cation concentrations in the soil solution and weather data as inputs, the model simulated water and cation fluxes and cation accumulation in plant organs.

The basic model simulating only passive fluxes over-estimated leaf Na^+ and under-estimated K^+ concentrations but gave realistic relative gradients for Na^+ across leaf positions. Some physiological hypotheses were tested by incorporating them into the model. The following factors were essential in explaining field observations:

- active uptake of K^+ and a 'filter' in the root to partially exclude Na^+ from being taken up (the 'filter' reduced the Na^+ concentration in the xylem to 2% of that in the soil solution; the filter may either be physical or a result of compensatory Na^+ excretion; exclusion of Na^+ varied greatly among genotypes)
- partial interception and storage of Na^+ in sheath and stem base tissues (all genotypes controlled Na^v accumulation in leaves by removing some Na^+ from the transpiration stream)

- export of K^+ from senescing leaves (particularly if Na^+ and K^v together exceeded a certain, probably genotypic, concentration)

The data did not suggest a downward transport of Na^+ in the phloem. Models assuming passive Na^+ transport and Na^+ 'filtering', interception in sheaths and K^+ export from senescing leaves fitted saline and non-saline conditions. They accurately predicted rice to be more salt susceptible under arid than humid conditions, and more susceptible at seedling stage (when canopies are open) than at mid-season (when leaves shade each other), and suggested that rice salt tolerance under arid conditions depends mainly on root properties. The model did not, however, explain the high sensitivity of reproductive processes to salinity. This is now being studied.

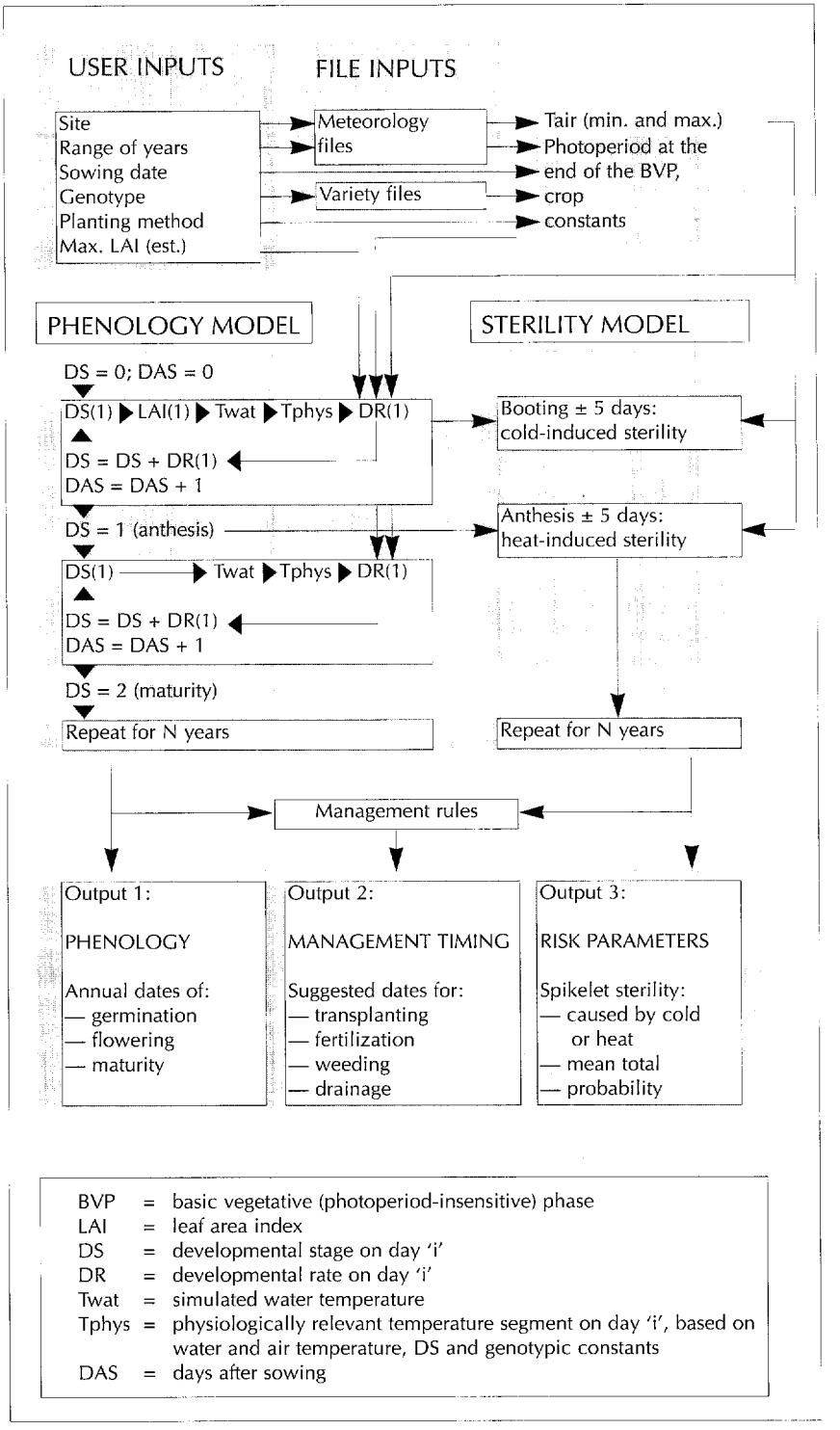
In 1994, the present physiological hypotheses will be validated. The results will help us develop tools to evaluate and select salt-tolerant, high-yielding rices under arid conditions.

RIDEV.REC, a simulation tool to improve the management of rice crop calendars in the Sahel
M. Dingkuhn

Structural adjustment policies have given greater responsibility to the private sector, which in general lacks experience in Sahelian rice production. Rice farmers in Sahelian Senegal are now experimenting with alternative cropping calendars and varieties. Extension workers need tools to evaluate the risks associated with such changes and to make appropriate recommendations. WARDA has developed a model to:

- predict phenology and crop duration for any combination of rice variety, planting date and site

FIGURE 32: Structure of the RIDEV.REC model



- predict the probability of cold- or heat-induced spikelet sterility, a major cause of variable yields
- suggest agronomically appropriate calendars for crop management operations, based on technologies that are already in use.

The emphasis is on calendars for planting and crop management because variability in farmers' fields frequently depends more upon the timing of these operations than upon the choice of technologies. A schematic diagram of the model is shown in Figure 32.

The user chooses the site, genotype, planting method (direct seeding or transplanting), sowing date and a range of weather scenarios (n reference years). Ten reference years or more are needed to estimate the variability of crop duration. A phenology model generates the time frame for simulations of spikelet sterility and the timing of crop management. The sterility model represents a risk-assessment tool. It enables the user to identify and avoid high-risk site x date x genotype options. The timing of crop management operations is simulated for two technology packages associated with transplanting or broadcasting pre-germinated seed. This comprises dates for transplanting, fertilizer application, weeding and drainage. The underlying package for transplanted rice is based on: a 50%-50% split application of N in association with a drainage-irrigation cycle, the first dose broadcast after recovery from transplanting shock and the second at early panicle differentiation stage; hand-weeding prior to the first N application; and drainage of plots at mid-ripening. Drainage-irrigation cycles are emphasized because of the threat of salinization throughout the Sahel. For broadcast seeding, an early application of post-emergence herbicide and hand-weeding at panicle initiation stage, prior to the respective applications of N fertilizer, are suggested. All dates are calculated on the basis of the crop's development stage and prevailing temperatures.

The model does not suggest any specific planting date, method or input dosage because these vary among production systems. The basal broadcast-and-incorporation method of fertilizer application recommended by IRRI and some national programs was not followed because few farmers have the necessary equipment. The model was developed by WARDA for extension and training personnel, rice development projects and producers' cooperatives in the Sahel.

TRAINING AND COMMUNICATIONS

OVERVIEW

Anthony Youdeowei
Director of Training and Communications

WARDA's Training and Communications Division is playing a major role not only in the development of rice science skills and information dissemination in the West African region but also in CGIAR efforts to strengthen collaboration on training and information activities amongst the Africa-based IARCs. The activities carried out by the division continue to be supported with funds from UNDP, CTA and IDRC, and efforts were initiated in 1993 to seek support from other donors.

Training activities intensified during the year. The UNDP-supported group training program continued, and there was a significant increase in the number of research scholars conducting thesis-related research under the supervision of WARDA scientists. The number of people who came to WARDA for short-term non-degree training on the research farm also increased. As part of the trainer-intern program for West African women, one woman from Côte d'Ivoire joined the program in 1993. In addition to these activities, WARDA launched a program to produce training materials to assist national programs in rice-related training activities.

The movement of the Library and Documentation Center from Bouaké to the Main Research Center and Headquarters at M'bé in January 1993 considerably facilitated operations and services during the year. Five librarians and documentalists from national agricultural research programs were trained in various aspects of agricultural information database management. This training was provided in response to requests received from national program libraries and is within the framework of WARDA's efforts to strengthen the capacity of national programs in rice science information management.

In line with the efforts to promote joint activities amongst the CGIAR centers in Africa, the Director of Training and Communications took a leading role in the discussions at a meeting in Kenya of the Africa-based IARC training officers. At that occasion, WARDA was asked to host the next meeting, scheduled to take place in 1995.

During the year, WARDA hosted several visitors from the Ivoirian government and Abidjan-based diplomatic and donor community. The visitors were briefed on various aspects of WARDA's work and were given the opportunity to see at first hand the contribution being made by the Association towards sustainable agricultural development and natural resources management in the West African region. This event contributed to the major public awareness effort now being undertaken by WARDA.

SUMMARIES OF TRAINING ACTIVITIES

A. Youdeowei

GROUP TECHNICAL TRAINING

Only five UNDP-supported group training courses were organized in 1993 (*see* Table 35). This was mainly because of the long duration of the training course on 'Rice production and research', which lasted from June to September. National program rice scientists, as well as WARDA research staff, were fully involved as resource persons in the implementation of all group training activities.

Development of training materials

A detailed curriculum for this course was developed by WARDA with assistance from Dr Bansh Tripathi of ILCA and Dr Rainer Zachmann of IITA. The course was held at WARDA's training center at M'bé from 1 to 28 March. The participants were drawn from Gambia, Ghana, Liberia, Nigeria and Sierra Leone, and included trainers, agricultural extension personnel, and rice scientists with training responsibilities.

The overall objective of the course was to introduce the participants to the planning and production of training materials for rice production. Emphasis was given to hands-on experience in the design and production of a variety of training materials, and the best two projects were awarded the WARDA Director General's prize. In 1994 the course will be conducted in French.

TABLE 35: Number of participants in WARDA's group training courses, 1993

Course	Location	Number of participants Men	Women
Development of training materials (English)	WARDA, Bouaké, Côte d'Ivoire	16	4
Rice research techniques (English)	CRI, Kumasi, Ghana	21	2
Rice production and research (French/English)	WARDA, Bouaké, Côte d'Ivoire	26	2
Rice agronomy (English)	IRA/NCRE, Garoua, Cameroon	14	5
Mangrove rice production (French/English)	RRS, Rokupr, Sierra Leone	20	0
Total		97	13

Rice research techniques

The participants in this group training course, held from 2 to 28 May in Ghana, were research assistants who provide technical support to rice scientists; they came from national programs in Gambia, Ghana, Liberia, Nigeria and Sierra Leone. The course was a collaborative training activity between WARDA and the CRI in Kumasi. Among the resource persons for the course was a former WARDA trainee, who served as an associate technical coordinator.

The course was designed to upgrade the knowledge and strengthen the skills of research assistants in field experimentation and the use of micro-computers and statistical packages in research data management. It consisted of a combination of formal lectures, field practicals, group activities and class discussions. The participants were also trained in word processing skills for the preparation of research reports. A post-course evaluation conducted by WARDA revealed that the participants' competence in rice research techniques increased significantly as a result of the course.

Rice production and research

Drawn from 16 WARDA member countries, the participants in this course were mainly national program personnel directly involved in rice development projects. Among them were two women from the Ghanaian

Participants in the course on training materials, in which classroom-based sessions (left) were complemented by field-based instruction on the stages of rice production (below)

Women in Agricultural Development project who were specifically selected for the course because of their direct involvement in training smallholder women rice farmers in Ghana. The course was held at WARDA's training center at M'bé, from June to September.

The participants in the course were divided into working groups, and each group was assigned upland and lowland field plots which they prepared and planted to rice, managed until the crop reached maturity, and then harvested and processed the grain. This approach exposed the participants to all stages of rice production in both upland and lowland rice production systems.

Rice agronomy

This course was designed for young research scientists and focused on techniques in rice agronomy research, with particular reference to rice variety trials. It was organised in Cameroon in collaboration with IRA and NCRE.

The participants came from Cameroon, Ghana, Gambia, Liberia, Nigeria and Sierra Leone and included five women. One of the participants was a lecturer from the University of Agriculture, Abeokuta, Nigeria, specifically selected as part of the strategy to introduce rice science into the agricultural curricula of higher institutions in West Africa.

Mangrove rice production

The mangrove rice production course was organised in collaboration with the Rice Research Station at Rokupr, Sierra Leone. It benefited from the results of over two decades of collaborative research between WARDA and national program scientists in Sierra Leone, and thus most of the resource persons, as well as the technical coordinator for the course, were drawn from Sierra Leone's national program.

In addition to upgrading participants' knowledge of mangrove rice growing environments, a major objective of this course was to improve the participants' skills in transferring modern and efficient technologies for the sustainable production of rice in West African mangroves. The participants came from the six countries in West Africa which have mangrove swamp rice programs (Gambia, Guinea, Guinea-Bissau, Nigeria, Senegal and Sierra Leone). The course was conducted in French and English, with simultaneous interpretation.

TRAINING MATERIALS FOR NATIONAL PROGRAMS

The collection of information for the *Directory of WARDA's Group Training Participants* was expanded to include 1993 data and was completed by end of the year. A pre-publication print out of the directory was prepared for distribution in early 1994 to directors of national institutions for comment and corrections; this information will be incorporated into the first edition of the directory, which is scheduled for publication in late 1994. The directory will provide decision makers and scientists in national programs with useful information which will help them in planning their human resources development in rice science.

Other materials which are being prepared to assist national programs in their training efforts in rice science include a series of topic-specific

Participants in the course on mangrove rice production, studying plant samples

Training Guides, and the *Directory of Resource Persons* and *Handbook of Course Curricula* for group training in rice science. These materials will be published in 1994.

TRAINEE FOLLOW-UP

A major study was initiated in 1993 to provide information on the current professional status of former WARDA trainees and on the effect that WARDA training has had on their job performance and professional development. A questionnaire was designed and sent to over 300 former WARDA trainees throughout West Africa.

The results of the study will be discussed at a WARDA/NARS Training seminar, scheduled to be held in May 1994.

INDIVIDUAL RESEARCH-RELATED TRAINING

Significant progress was made in recruiting research scholars for training, the number of research scholars increasing from six in 1992 to 18 in 1993 (*see* Table 36). Twelve people from West African countries and collaborating institutions in Europe received short-term training at M'bé and in Senegal (*see* Table 37 *overleaf*).

TABLE 36: Research scholars at WARDA, 1993

Name	Country	Degree and university	Topic	Supervising WARDA scientist and discipline
R.N.A. Ahoyo	Benin	PhD, Univ. Hohenheim., Germany	Cost and profitability of different rice production systems at farmer's level in southern Benin	A. Adesina (agro-economics)
D. Birmingham	USA	PhD, Univ. Wisonsin, USA	Indigenous soil management in three rice producing areas of Côte d'Ivoire	A. Adesina (agro-economics) K. Sahrawat (soil science)
A.O. Daleba	Côte d'Ivoire	Doc 3e cy., Univ. Abidjan, Côte d'Ivoire	Rice resistance to drought	M. Jones (plant breeding)
A. Diallo	Senegal	Doc., Univ. CAD, Dakar, Senegal	Rice production, access to resources and women's strategies for irrigated rice cultivation: A case study in the Goye area, upper Senegal river valley (left bank)	T. Randolph (agro-economics)
S. Diatta	Senegal	Doc., Univ. Nancy, France	Pedological and hydrological organization of footslopes in two toposequences in Côte d'Ivoire	K. Sahrawat (soil science)
K.K. Djato	Côte d'Ivoire	Doc. 3e cy., CIRES, Univ. Abidjan, Côte d'Ivoire	Comparative analysis of small- and large-scale rice production systems in Côte d'Ivoire	A. Adesina (agro-economics)

TABLE 36: (contd)

Name	Country	Degree and university	Topic	Supervising WARDA scientist and discipline
N. Fofana	Côte d'Ivoire	Doc 3e cy., CIRES, Univ. Abidjan, Côte d'Ivoire	Women and large-scale rice production: A study of extensive rice production systems in Gagnoa, central-west Côte d'Ivoire, and intensive producton systems in Korhogo, northern Côte d'Ivoire	A. Adesina (agro-economics)
A.V. Houndékon	Benin	Doc. 3e cy., CIRES, Univ. Abidjan, Côte d'Ivoire	Economic analysis of rice production systems in northern Benin	A. Adesina (agro-economics)
A.O. Joda	Nigeria	PhD, Univ. Ibadan, Nigeria	The bio-ecology and the control of *Aspavia armigera* F. (Hemiptera: Pentatomidae) on rice in Nigeria	B. Singh (plant breeding)
A.T. Maji	Nigeria	MSc, Univ. Ibadan, Nigeria	Evaluation of drought tolerance and other agronomic traits in African rice varieties (*O. glaberrima*)	B. Singh (plant breeding)
S. Nacro	Burkina Faso	PhD, Univ. Rennes, France	Ecology and biology of the rice gall midge (*O. oryzivora* H + G), and its parasitoids in Burkina Faso	E. Heinrichs (entomology)
A. Ouattara	Côte d'Ivoire	Doc. 3e cy., CIRES, Univ. Abidjan, Côte d'Ivoire	Ex-ante analysis of financial profitability and the constraints to adoption of new rice production technologies in the Korhogo region of Côte d'Ivoire	A. Adesina (agro-economics)
N.T. Sow	Senegal	Doc., Univ. Cath. Louvain, Belgium	Improving rice tolerance to salinity through somaclonal variation	K. Miézan (plant breeding) M. Dingkuhn (physiology)
A.A. Touré	Niger	MSc, Purdue Univ., USA	Economic constraints to rice-based rotations in Niger	T. Randolph (agro-economics)
C.O. Traoré	Mali	Doc 3e cy., CIRES, Univ. Abidjan, Côte d'Ivoire	Economic constraints to irrigated rice production in the Salingué rice scheme in south-western Mali	A. Adesina (agro-economics)

TABLE 37: Short-term trainees at WARDA's research stations at M'bé, Côte d'Ivoire and St Louis, Senegal, 1993

Name	Country	Institution	Discipline
Upland/Inland Continuum Program			
O.M. Kuller	Netherlands	Agricultural Univ. of Wageningen	Agronomy
C. Groen	Netherlands	Agricultural Univ. of Wageningen	Agronomy
D. Hartkamp	Netherlands	Agricultural Univ. of Wageningen	Agronomy
B.N. Diané	Mali	Station de Recherche Agronomique de Sikasso	Pathology
Sahel Irrigated Rice Program			
S. Ducheyne	Belgium	Univ. of Leuven	Soil science
A. Leyman	Belgium	Univ. of Leuven	Soil science
M.M. Guèune	Senegal	Univ. CAD	Entomology
Farm Management			
N. Puillet	France	ORSTOM	Agronomy
P.K.J. Gboko	Côte d'Ivoire	ENSTP	Urban planning
V.K. Koffi	Côte d'Ivoire	ENSTP	Draftsmanship
M. Fofana	Côte d'Ivoire	CET	Auto-mechanics
F.I. N'Guessan	Côte d'Ivoire	CET	Mechanical construction

SUMMARIES OF COMMUNICATIONS ACTIVITIES

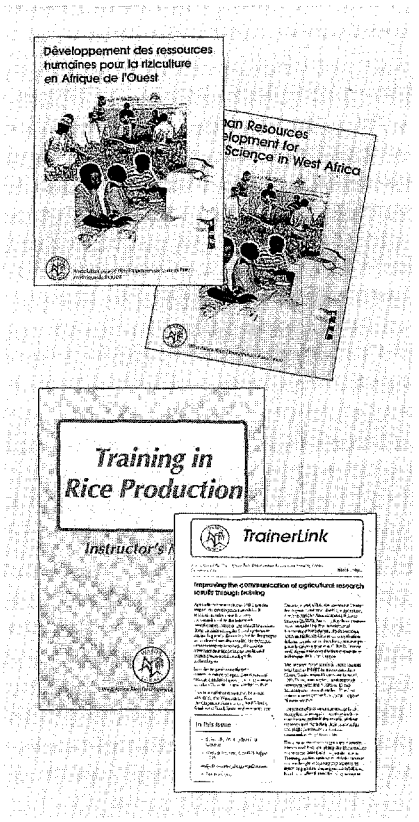
A. Youdeowei, C. Diop and A. Diallo

PUBLICATIONS UNIT

In 1993 WARDA's in-house publishing activities were seriously constrained by a shortage of staff and a lack of the funds required to recruit adequately qualified staff for the unit.

The publications produced during the year included:

- *WARDA Annual Report 1992* (English and French)
- *Rice Trends in Sub-Saharan Africa* (English and French)
- *Inauguration of WARDA's Main Research Center and Headquarters, M'bé, Bouaké, Côte d'Ivoire* (English and French)
- *Human Resources Development for Rice Science in West Africa* (English and French)
- *Training in Rice Production: Instructor's Manual* (English)
- *Maladies du Riz Transmises par les Semences et Tests Phytosanitaires* (co-published with CTA) (French)
- *Collaboration among NARS in a Regional Systems Approach: A Potential Role for International Centers* (English and French)
- *Trainerlink* (December 1993) (English)



TRANSLATION AND INTERPRETATION SERVICES

With the increase in the volume of WARDA's activities, there was a significant increase in the demand for interpretation and translation services. The staffing situation in the Translation Unit was therefore re-organised during the year, with two full-time in-house translators being recruited; one of the translators also works with consultant freelance interpreters at official and technical WARDA meetings, as well as during the group training courses.

The combined volume of simultaneous interpretation by in-house and consultant interpreters in 1993 amounted to 2618 hours. WARDA continued to depend upon outside translators for French-to-English translations. The numbers of documents which were translated during the year are given in Table 38.

TABLE 38: Type and number of documents translated, 1993

Type of document	Number of documents	Total pages
English to French (in-house translations):		
Office of the Director General	70	682
Administration	42	100
Research	40	296
Training and Communications	51	565
Total	203	3286
French to English (contracted translations):		
Office of the Director General	2	163
Administration	1	10
Research	2	40
Training and Communications	1	40
Total	6	253

PUBLIC AWARENESS ACTIVITIES

Considerable effort was made during 1993 to increase public awareness about WARDA and the CGIAR through a series of WARDA Open Days which were organized for various groups resident in Côte d'Ivoire. Among those invited to attend these Open Days were the African ambassadors accredited to Côte d'Ivoire, representatives of the donor and international development community, and senior Ivoirian government officials.

During the Open Days, visitors were briefed about WARDA's research, training and communications activities and taken on a tour of the facilities at the Main Research Center and Headquarters, the research farm and the Library and Documentation Center. The subsequent increase in the number of people asking to visit the headquarters or to be provided with information about WARDA is a clear indication of the success of this public awareness strategy.

LIBRARY AND DOCUMENTATION CENTER

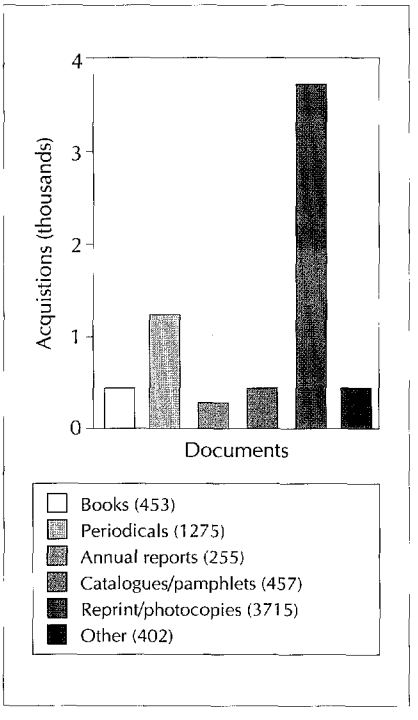
Efforts continued during the year to strengthen and upgrade the library resources and improve information and documentary services to WARDA and national program scientists. The construction of a specially designed building at M'bé to house the Library and Documentation Center temporarily was successfully completed, and the building was occupied in January.

In May 1993, the documentalist visited the headquarters of WARDA's Sahel Program in N'Diaye, Senegal to provide advice on improving the program's library facilities. The progress which had been made to date was evaluated and necessary changes were implemented in the library and database management procedures.

Library collections

The acquisition of library materials on rice research and production and related subjects was intensified during the year. A special effort was made to acquire publications in French and those relevant to environmental and sustainability issues (*see* Figure 33). The library subscribed to 160 journals and received several other journals through exchange arrangements.

FIGURE 33: WARDA library acquisitions, 1993



The acquisition of 'grey literature' from WARDA member countries was also intensified. There is a wealth of agricultural and rice science literature in these countries, but it is seldom indexed according to the conventional bibliographical tools which are used for acquisitions. This type of literature is often ephemeral and tends to go out of print quickly if it is not acquired immediately upon publication. Obtaining such documents can be a complex and time-consuming task.

One of the major challenges facing WARDA's Library and Documentation Center is to add these documents to its collection and database in order to make them available to the rice research community. Members of WARDA's research Task Forces and the Training Working Group have been approached to participate in this activity.

A member of WARDA's Economics Task Force, who is a Senior Research Officer at the NCRI in Badeggi, Nigeria, travelled extensively throughout his country to collect relevant literature. This material consisted mainly of theses submitted to Nigerian universities. As a result of this exercise, 153 publications were added to WARDA's library collection.

Database management

The West Africa Rice Bibliographic Database (WARBI) and the periodicals database (PERIO) now contain 13 700 and 1240 records, respectively. A new database, known as RPRIN, was designed for the management of WARDA's reprint collection.

With financial and technical support from CTA (through its CD-ROM project) and the IDRC, WARDA received regular updates of the

following agricultural databases during the year:

— on CD-ROM:

- AGRICOLA (Agricultural On-Line Access), 1970 to present, updated quarterly
- AGRIS (International Information System for Agricultural Sciences and Technology), 1986 to present, updated quarterly
- *Agronomy Journal* (vols 1-16), 1907-24
- BRIO (Banque de ressources sur les technologies de l'information en langue français/Database of resources on information technology in French), 1980 to present
- CAB ABSTRACTS, 1984 to present, updated annually
- CABPESTCD, 1973-91, updated annually
- CIARL-BRS (Compact International Agricultural Research Library — Basic Retrospective Set), 1962-86; 17 CD-ROM discs covering selected materials from 20 IARCs in 16 countries (WARDA material is on disc T-14)
- CSIS/ICAR (Current Search Information System of USDA and Inventory of Canadian Agri-Food Research, Canadian Agricultural Research Council)
- KIT ABSTRACTS/TROPAG & RURAL (abstracts on agriculture and rural development in the tropics), 1975 to present, updated quarterly
- SESAME (French language literature on tropical agricultural research and rural development from several organizations, including BDPA/SCETAGRI, CIRAD, INRA, ISRA, ORSTOM and the Faculté des Sciences Agronomiques de Gembloux), 1980-91

— on diskette:

- African Development Indicators Data (a World Bank disc containing detailed economic, social and environmental data for 52 African countries), 1980-90
- AGROSTAST.PC (FAO time series statistics), 1960 to present, updated annually
- CURRENT CONTENTS ON DISKETTE (agriculture, biology and environmental sciences), abstracts which give immediate access to the most current bibliographic data from thousands of journals and books; each week, a new diskette is delivered to WARDA, ready to be loaded and read on the computer
- RICE ABSTRACTS (prepared by CAB International), updated quarterly

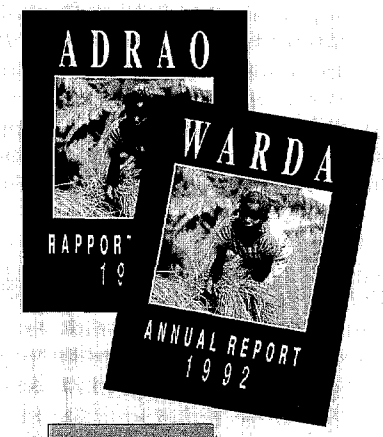
Rice science information services

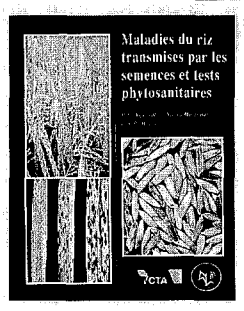
Based on the requests received from WARDA and national scientists during 1993, bibliographic information was retrieved from in-house and external databases and printed or downloaded on to discs. The number of requests for exhaustive searches was higher than in 1992 (over 110 searches were made. The major searches in 1993 are given on pages 99 and 100. A scientist from INERA visited the Library and Documentation Center in 1993 to conduct a survey of the literature for his PhD thesis on water management problems in irrigated and rainfed rice.

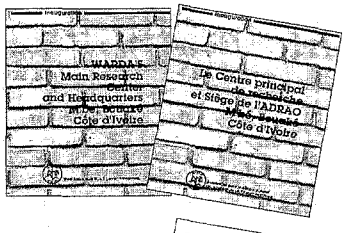
WARDA's SDI service provides bibliographic information on user-specified areas of interest. Information searches are performed on the in-house and external databases, particularly on the Current Contents and Rice Abstracts diskettes. An SDI profile form is used to describe and evaluate individual profiles.

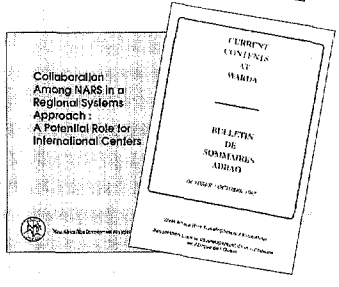
The general SDI profiles are:

Animal traction and mechanization in rice production
Biological control of rice pests
Health and environmental problems in rice production areas
Irrigation and water management in rice
Mangrove swamp rice
Nematodes in rice-based cropping systems
Pyricularia oryzae
Rice diseases and their control
Rice field pests and their control
Rice gall midge
Rice production in inland valleys
Rice soils management and related problems
Rice storage pests
Rice tolerance to low and high temperature and other climate-related stresses
Rice tolerance to salt
Rice yellowmottle virus
Rice-based cropping systems
Socio-economic aspects of rice production
Use of organic and inorganic fertilizers in rice
Weeds and weed control in rice









The monthly publication *Current Contents at WARDA* was produced regularly during 1993 and distributed to all national program rice scientists and institutions in the region. As a result of the interest expressed by rice researchers in WARDA member states, the number of copies distributed increased from 46 in early 1991 to 195 in July 1993.

The production of a *Directory of Rice Scientists in West Africa* is an activity which falls within the UNDP-funded WARIS project. Over 200 scientists responded to the questionnaire which had been sent out in 1992. The database is being completed and will be used to publish a draft edition in 1994.

Other documents prepared for publication in 1993 were the *1991/1993 Catalogue of Rice Literature Searches* (listing the 127 major searches made between 1991 and August 1993, and available upon request to rice researchers) and *Resources and Services of WARDA's Library and Documentation Center.*

In addition to book circulation services, over 450 publications and 49 000 photocopied pages of journal articles and book chapters were sent on request. Over 600 requests for such documents were received in 1993.

Training

In response to requests received from national programs, five people in charge of agricultural information services in the region received training in library and database management during 1993:

- Odile Tahouo (in charge of the library services at IDESSA, Côte d'Ivoire), December 1992 to January 1993 (Mrs Tahouo was trained on Mini-Micro CDS/ISIS software and bibliographic database definition, implementation and management; during her training, WARDA staff helped her design and develop two bibliographic databases to manage the monograph and serial holdings of IDESSA's library network)
- Calixte Houndonougbo (Head of the Documentation Center at the DRA, Benin), September to October 1993
- Ramatou Diomande (in charge of the Documentation Service at CIDT, Côte d'Ivoire), October 1993
- Antoinette Assouan and N'Gole Roger Malan (in charge of the Documentation Service at CIMA, Côte d'Ivoire), October to November 1993

During the training, WARDA Library and Documentation Center staff visited the trainees' institutions and held discussions with institution executives. The Director of CIMA and the Director of Training at CIDT visited WARDA to see their staff at work and to learn about the WARIS service. A follow-up mission to Benin is planned when a micro-computer is allocated to the DRA Documentation Center.

REGIONAL AND INTERNATIONAL COLLABORATION

CTA/ECOWAS project

In 1992 CTA, in collaboration with ECOWAS, commissioned a study of agricultural information needs in West Africa. Entitled 'Increasing access to scientific and technical information in West Africa', this project evaluated the agricultural

information needs of users and institutions in order to establish the basis for a regional STI program. WARDA played a major role in organizing a Regional Workshop and participated in the committee meeting convened to prepare the first meeting of the Evaluating, Planning, and Monitoring Regional Committee in Banjul, The Gambia. At the meeting, WARDA was given the task of coordinating the preparation, editing, translation, production and distribution of the reports from the workshop and the meeting, and will play a leading role in implementing the regional STI program.

REDACI

WARDA Library and Documentation Center staff regularly visited relevant institutions and information services in the Bouaké and Abidjan areas of Côte d'Ivoire in order to establish and strengthen collaborative links. They also participated in the activities and quarterly meetings of REDACI, and helped design a questionnaire that will be used to collect data for a national directory of agricultural information services and documentation centers in Côte d'Ivoire.

CAB International

In collaboration with CAB International, WARDA is developing a project to strengthen the information base for rice research. The aims of the project are to enhance WARDA's capacity to serve as the primary rice-based farming systems information center for Africa and to improve the information services of rice research programs in member countries and their access to international agricultural literature.

Main literature searches conducted by WARDA in 1993

Aleiodes spp. (for H. Abdoulaye, IER, Mali)
Aleiodes spp. (for H. Abdoulaye, IER, Mali)
Assimilate source-sink relationships in rice (M. Dingkuhn, WARDA, Senegal)
Birds and rice (for A.O. Bright, NCRI, Nigeria)
Bracon spp. (for H. Abdoulaye, IER, Mali)
Bracon spp. (for H. Abdoulaye, IER, Mali)
Chaetocnema spp. (for S. Nacro, INERA, Burkina Faso)
Characterization of inland valleys (for V.J. Mama, Director, CENATEL, Benin)
Chilo (zacconius and *diffusilineus*) diapause (for S. Djiba, ISRA, Senegal)
Chnootriba (Epilachna) similis (for S. Nacro, INERA, Burkina Faso)
Cochliobolus miyabeanus (for B.N. Diane, IER, Mali)
Dactylispa spp. (for S. Nacro, INERA, Burkina Faso)
Development of uplands for irrigated rice production (for A.B. Rashid-Noah, Njala University College, Sierra Leone)
Echinochloa colona vs. upland rice (for M. Dingkuhn, WARDA, Senegal)
Economic aspects of rice in the Gambia (for R. Rakey Cole, Cornell University, USA)
Economic entomology and rice cultivation (for M. Aliyageen Alghali , Department of Plant Protection, Njala University College, Sierra Leone)
Epidemiology of rice yellow mottle virus disease: Infestation, geographical distribution and economic importance in Africa (for N. Koffi Placide, IDESSA, Côte d'Ivoire)
Genetic variance components in cereals (for K. Miézan, WARDA, Senegal)
Genetics and varietal improvement of rice (for S. Dogbe, INCV, Togo)
Green manuring with respect to rice cultivation, nitrogen fixation, nutrient content, integrated use of green manure and fertilizers (for E.O. Ajayi, NCRI, Nigeria)
Heredity in rice and other cereals (for S. Dogbe, INCV, Togo)
Heritability of self-pollinated crops (cereals) (for K. Miézan, WARDA, Senegal)
Hydrology of the inland valleys of West Africa (for I. Postna, Agricultural University of Wageningen, Netherlands)
Impact of acidity on rice cultivation in the mangrove ecology (for E. Akpomudjere, NCRI, Nigeria)
Influence of chemical fertilizers (with the emphasis on nitrogen fertilizers) on the development of quantitative characters of rice (for A. Pascal, INRAB, Benin)
Irrigation and water management in Sahelian countries (for A.B. Rashid-Noah, Njala University College, Sierra Leone)
Irrigation systems management (for A.B. Rashid-Noah, Njala University College, Sierra Leone)
Land preparation for upland rice using low input (for O. T. Whyte, NCRI, Nigeria)

Main literature searches (contd)

Leaf scald disease of rice (for S. N. Fomba, Rice Research Station, Sierra Leone)
Malaria and rice cultivation (for O. Anne-Marie, CEMV, Université nationale de Côte d'Ivoire)
Malaria and rice cultivation (for O. Anne-Marie, CEMV, Université nationale de Côte d'Ivoire)
Mangrove soils (for E. Akpomudjere, NCRI, Nigeria)
Measurement of irrigation water (for A.B. Rashid-Noah, Njala University College, Sierra Leone)
Melanthera spp. as a cover plant (for D.E. Johnson, WARDA, M'bé)
Methodologies for estimating yield loss (for M.S. Mbenga, NARI, Gambia)
Molecular analysis techniques and rice yellow mottle virus disease (for N. Koffi Placide, IDESSA, Côte d'Ivoire)
Paederus fuscipes (for H. Abdoulaye, IER, Mali)
Paederus fuscipes (for H. Abdoulaye, IER, Mali)
Phanaretoma saussurei (for H. Abdoulaye, IER, Mali)
Phanaretoma saussurei (for H. Abdoulaye, IER, Mali)
Pyricularia oryzae (for S. Yacouba, INERA, Burkina Faso)
Rice beetle (*Trichispa seicea* Guer.) (for S. Nacro, INERA, Burkina Faso)
Rice economics in West Africa (for WARDA Rice Economics Task Force)
Rice marketing problems in Africa and elsewhere (for L. Samba, INRAN, Niger)
Rice varietal resistance and susceptibility to rice yellow mottle virus disease (for N. Koffi Placide, IDESSA, Côte d'Ivoire)
Rice yellow mottle virus (for M. Jones and A.A. Sy, WARDA, M'bé, and M.E. Abo, NCRI, Nigeria)
Rodents and rice (for A.O. Bright, NCRI, Nigeria)
Rottboellia exalta (for M. Dingkuhn, WARDA, Senegal)
Salt and other chemical stresses affecting rice in the mangrove ecosystems (for E. Akpomudjere, NCRI, Nigeria)
Spider mites in rice (for S. Nacro, INERA, Burkina Faso, and S. Djiba, ISRA, Senegal)
Storage insects of rice (for S. Nacro, INERA, Burkina Faso)
Structural adjustment in WARDA member countries (for T. Randolph, WARDA, Senegal)
Upland rice and dryland rice weeds (for M. Dingkuhn, WARDA, Senegal)
Water control in inland valley swamps (for A.B. Rashid-Noah, Njala University College, Sierra Leone)
Weed control in upland rice, with the emphasis on dicotyledons and Sudan savanna areas (for S. Estanislasse, INERA, Burkina Faso)
Weed control in West Africa (for S. Dialo, ISRA, Senegal)
Weed dynamics in rice fields (for J. K. Kehinde, NCRI, Nigeria)
Weeds and weed control in irrigated rice cultivation (for S. Sougalo, IER, Mali)
White flies (*Aleurocybotus* spp.) (for S. Djiba, ISRA, Senegal)

Financial statements

Principal personnel

Short-term consultants

Publications by WARDA staff in 1993

Acronyms

WEST AFRICA RICE DEVELOPMENT ASSOCIATION

Statement of Financial Position as at 31 December 1993

(expressed in US dollars)

CURRENT ASSETS	1993	1992
Inventory	468 443	195 418
Accounts Receivable — Donors	1 525 151	2 100 687
Accounts Receivable — Other	865 877	713 837
Cash and Bank Balances	286 742	874 742
	3 146 213	3 884 684
CURRENT LIABILITIES		
Bank Overdrafts	276 309	1 623 685
Accounts Payable	2 814 097	2 384 373
Provisions and Accruals	772 818	1 109 091
Contributions in Advance	492 134	1 356 496
Project Fund Balances	241 688	192 733
	4 597 046	6 666 378
Net Current (Liabilities)	(1 450 833)	(2 781 694)
Property, Plant and Equipment	12 081 405	12 455 494
NET ASSETS	10 630 572	9 673 800
Represented by:		
Restricted Funds		
Capital Invested in Fixed Assets	12 081 405	12 455 494
Capital Fund	(2 796 734)	(3 951 380)
Unrestricted Funds		
Operating Fund	1 345 901	1 169 686
Fund Balances	10 630 572	9 673 800

The financial statements were approved by the Board of Trustees on 21 April 1994 and were signed on their behalf by:

Dr Eugene R. Terry, Director General

Kwame Akuffo-Akoto, Acting Director of Administration and Finance

WEST AFRICA RICE DEVELOPMENT ASSOCIATION

Grants and Contributions for the Year ended 31 December 1993

(expressed in US dollars)

	Unrestricted Core	Restricted Core	Complementary Projects	Capital Development	Total 1993	Total 1992
AfDB	—	1 020 732	142 241	—	1 162 973	723 112
Belgium	—	—	—	—	—	59 679
Canada (CIDA)	547 707	—	—	136 850	684 557	796 646
Canada (IDRC)	—	12 470	81 441	—	93 911	84 591
EEC	—	638 815	110 158	—	748 973	324 529
France	141 379	1 463	—	—	142 842	278 521
Germany (BMZ/GTZ)	301 929	228 574	—	188 160	718 663	2 138 995
Italy	—	—	—	—	—	105 263
Japan	1 280 277	—	43 041	739 256	2 057 574	1 560 925
Korea	50 000	—	—	—	50 000	—
Rockefeller Foundation	—	3 000	—	—	3 000	3 000
Sweden	490 732	—	—	—	490 732	633 817
The Netherlands	137 715	—	49 863	208 122	395 700	135 894
UNDP	—	215 770	415 106	—	630 876	543 917
UK (ODA)	165 506	—	—	—	165 506	189 904
USAID	—	—	189 432	—	189 432	512 506
World Bank	1 400 000*	—	—	—	1 400 000	1 500 000
	4 515 245	2 120 824	1 031 282	1 272 388	8 939 739	9 591 299

* Includes $US 300 000 provided for the cost of WARDA's External Review

WEST AFRICA RICE DEVELOPMENT ASSOCIATION

Statement of Activity by Funding Source for the Year ended 31 December 1993

(expressed in US dollars)

	Unrestricted Core	Restricted Core	Complementary Projects	Operating Expenses	Capital Development	Total 1993	Total 1992
Revenue							
Grants and Contributions							
Donors	4 515 245	2 120 824	1 031 282	7 667 351	1 272 388	8 939 739	9 591 299
Member States	74 520	—	—	74 520	—	74 520	230 937
Other Revenue	85 459	—	—	85 459	—	85 459	(4 179)
	4 675 224	2 120 824	1 031 282	7 827 330	1 272 388	9 099 718	9 818 057
Expenditure							
Research Program	1 762 423	1 861 941	605 825	4 230 189	—	4 230 189	4 215 048
Training and Communications	506 923	214 844	415 106	1 136 873	—	1 136 873	1 314 255
General Administration	1 653 588	—	—	1 653 588	—	1 653 588	2 017 114
Capital Development	—	—	—	—	117 865	117 865	734 242
	3 922 934	2 076 785	1 020 931	7 020 650	117 865	7 138 515	8 280 659
Add							
Depreciation of Fixed Assets	467 277	44 039	10 351	521 667	—	521 667	489 977
Total Operating Expenses	4 390 211	2 120 824	1 031 282	7 542 317	117 865	7 660 182	8 770 636
Recovery of Indirect Charges	(139 755)	—	—	(139 755)	—	(139 755)	(117 434)
Net Operating Expenses	4 250 456	2 120 824	1 031 282	7 402 562	117 865	7 520 427	8 653 202
Excess (Deficit) of Revenue over Expenses	424 768	—	—	424 768	1 154 523	1 579 291	1 164 855
Extraordinary Items	(385 233)	—	—	(385 233)	—	(385 233)	(14 573)
Net Excess (Deficit) of Revenue over Expenses	39 535	—	—	39 535	1 154 523	1 194 058	1 150 282
Allocated as Follows							
Operating Fund	39 535	—	—	39 535	—	39 535	(241 806)
Capital Fund	—	—	—	—	1 154 523	1 154 523	1 392 088

Principal personnel

OFFICE OF THE DIRECTOR GENERAL

Eugene R. Terry, PhD	Director General
Augustine Owusu-Sarpong[1]	Executive Secretary

ADMINISTRATION AND FINANCE DIVISION

Kwame Akuffo-Akoto, BSc, FCCA	Financial Controller and Acting Director of Administration and Finance
Honoré Bobo, MS, MBA	Chief Accountant
Bola Andrews, MA	Administrative Officer
Ursule Konan, ML, CFB[1]	Personnel Officer
Simplice Kra , Lic. Es[2]	Personnel Assistant
Boniface Ouedraogo	Administrative Assistant
Zakrizou Bredou, DUT	Accountant
Mark Etsibah, ICSA (pt II)	Accountant
Casimir Grouto, Ing. Bat.	Physical Plant Services Manager
Helen Nevell, BA	International Purchasing Assistant

RESEARCH DIVISION

Research coordination

Peter Matlon, PhD	Director of Research
Edgar W. Richardson, PhD[1]	Biometrician
Chitti Babu Buyyala, BSc	Farm Manager
Volker Hell, MCC[1]	Assistant Farm Manager (Mechanical Maintenance)
Vincent Elegbo, Ing. Genie. MEC	Assistant Farm Manager
Maxwell Adjei-Fah, Dip. GIL	Executive Secretary

Upland/Inland Swamp Continuum Program

M'bé, Côte d'Ivoire

Monty P. Jones, PhD	Upland Breeder (Acting Program Leader from 1 March 1993
Abdoul Aziz Sy, DI., D.E.Es-Sc.	Pathologist (Acting Program Leader until 1 March 1993)
Elviş Heinrichs, PhD	Entomologist
Akinwumi Adesina, PhD	Production Economist
Kanwar Sahrawat, PhD	Soil Scientist
Mathias Becker, PhD[2]	Cropping Systems Agronomist
David Johnson, PhD	Weed Scientist
Michio Takeda, BSc[1]	Grain Quality Analyst
Roger Diallo, IA	Research Associate, On-Farm Research
Sitapha Diatta, DEA	Research Associate, Soils
Amadou Touré, MSc	Research Assistant, Cropping Systems
Koffi Akator, MSc	Research Assistant, Pathology
Moustapha Gaye, MSc	Research Assistant, Economics
Semon Mandé, MSc	Research Assistant, Upland Breeding

Mobio Sika, MSc	Research Assistant, Soils
Isaac Oyediran, MSc	Research Assistant, Entomology
Teslim Ibrahim, NDAM	Research Assistant, Post-Harvest Technology
Bila Belemgoabga, MA	Administrative Assistant

Ibadan, Nigeria

Baij Singh, PhD	Lowland Breeder
Oyin Oladimeji, MSc	Research Assistant, Lowland Breeding
Charles Williams, PhD[2]	Entomologist

Sahel Irrigated Rice Program

St Louis, Senegal

Kouamé Miézan, PhD	Breeder (Program Leader)
Michael Dingkuhn, PhD	Physiologist
Thomas Randolph, PhD	Economist (Post-Doctoral Fellow)
Aïssatou Samb, DUT	Research Assistant, Physiology
Alioune Ndiaye, DSC	Finance and Administrative Officer

Mangrove Swamp Rice Network

Rokupr, Sierra Leone

Martin Agyen-Sampong, PhD[1]	Entomologist (Network Coordinator)
Robert Guei, PhD[1]	Breeder
Robert Chakanda, BSc[1]	Research Assistant, Breeding
Charles Dixon, MSc[1]	Research Assistant, Soils
Sorie Kamara, BA[1]	Administrative Assistant
Lamin Kargbo, CIS[1]	Administrative Assistant

TRAINING AND COMMUNICATIONS DIVISION

Anthony Youdeowei, PhD, FAAS	Director of Training and Communications
Madeleine Yesso, BTS/S	Executive Secretary

Training

Joseph Kwarteng, PhD[2]	Training Materials Specialist (Consultant)
Zainabou Cole, BSc	Trainer
Lola Goly, MSc, DESS[2]	Trainer-intern

Communications

Alassane Diallo, MSc	Documentalist
Messan Dossekou, MSc[1]	Desk-Top Publishing Assistant
Cheikh Diop, MA[2]	Translator/Interpreter
Memouna Sidi-Touré, MA[2]	Translator

Notes:
1 Left in 1993
2 Joined in 1993

Short-term consultants

Research

Ms Genevieve Herbert	Editing of technical papers by WARDA scientists
Dr Robert Guei	Data compilation and statistical analysis for production of catalogues of upland rice germplasm

Training and Communications

Mr Messan Dossekou	Desk-top publishing
Dr Shar Fomba	Technical coordination of group training course on 'Mangrove rice production'
Mr Barry Hall	Professional photography
Mr Baboucar Manneh	Trainer for group training course on 'Development of training materials'
Mr Lawrence Narteh	Coordination of group training course on 'Rice research techniques' (WARDA alumnus)
Dr A. Rashid-Noah	Writing training guides
Mr Seth Ohemeng-Dapaah	Writing Computer Applications Training Manual
Mrs Kay Sayce	Writing, editing and publishing
Dr Edward Spiff	Technical coordination of group training course on 'Rice production and research'
Dr Julius Takow	Technical coordination of group training course on 'Rice agronomy'
Dr Bansh Tripathi	Trainer for group training course on 'Development of training materials'
Dr Valentine Yapi	Preparation of databases on WARDA group training participants and WARDA photo library
Dr Rainer Zächmann	Trainer for group training course on 'Development of training materials'

Publications by WARDA staff in 1993

Upland/Inland Swamp Continuum Program

Adesina, A.A. and Zinnah, M.M. 1993. Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone. *Agricultural Economics* 9(4): 297-311.

Adesina, A.A. and Zinnah, M.M. 1993. Impact of modern mangrove swamp rice varieties in West Africa: Sierra Leone and Guinea. *International Rice Research Notes* 18(4): 36.

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Hakkeling, R.T.A., Diatta, S. and Smaling, E.M.A. 1993. Response of upland rice soil and hydrological conditions on a footslope in central Ivory Coast. *Geoderma* 59: 45-56.

Johnson, D.E. and Adesina, A.A. 1993. Farmers perceptions of rice weeds and control measures in Côte d'Ivoire, West Africa. In: *Proc. Brighton Crop Protection Conference — Weeds, 1993*. London, UK: BCPA

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Acronyms

AfDB	African Development Bank
BCPA	British Crop Protection Association
BDPA/SCETAGRI	Societé d'études et de conseil pour l'aménagement rural, l'inventaire et la gestion des ressources (France)
BMZ	Bunderministerium für Wirtschaftliche Zusammenarbeit (Germany)
BNDA	Banque national de développement agricole (Mali)
CAD	Cheikh Anta Diop (Senegal)
CD-ROM	Compact disc-read only memory
CEMV	Centre universitaire de formation en entomologie, médicale et veterinaire
CENATEL	Centre national de télédétection et de surveillance du couvert forestier (Benin)
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIDA	Canadian International Development Agency
CIDT	Compagnie ivoirienne pour le développement des fibres textiles
CIMA	Centre ivoirien du machisme agricole
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement (France)
CIRES	Centre ivoirien de recherches sociales et economiques
CNRST	Centre national de recherche scientifique et de technologie (Burkina Faso)
CRI	Crops Research Institute (Ghana)
CTA	Technical Centre for Agricultural and Rural Cooperation (The Netherlands)
DG	Director General, WARDA
DGISP	Danish Government Institute of Seed Pathology
DR	Director of Research, WARDA
DRA	Direction de la recherche agronomiqe (Benin)
DTC	Director of Training and Communications, WARDA
ECA	Economic Commission for Africa
ECOWAS	Economic Community of West African States
EEC	European Economic Community
ENSTP	Ecole national supérieur des travaux public
FAO	Food and Agriculture Organization of the United Nations
FCFA	Franc CFA
GRU	Genetic Resources Unit, IITA
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (Germany)
IARC	International agricultural research center
ICRAF	International Centre for Research on Agroforestry
IDESSA	Institut des savanes (Côte d'Ivoire)
IDRC	International Development Research Centre (Canada)
IER	Ecole inter-Etats d'ingenieurs de l'equipement rural (Mali)
IFS	International Foundation for Science (Sweden)
IIE	International Institute of Entomology
IITA	International Institute of Tropical Agriculture
ILCA	International Livestock Centre for Africa
INERA	Institut de recherches et d'études agricoles (Burkina Faso)
INGER-Africa	International Network for Genetic Evaluation of Rice (Africa branch)

INRA	Institut national de la recherche agronomique (France)
INRAB	Institut national des recherches agronomicoles du Bénin
INRAN	Institut national des recherches agronomiques du Niger
IPM	Integrated pest management
IRA	Institut de recherche agronomique (Cameroon)
IRAT	Institut de recherches agronomiques tropicales et des cultures vivrières (France)
IRRI	International Rice Research Institute
ISRA	Institut sénégalais de recherche agronomique
IVC	Inland Valley Consortium
MRC & HQ	Main Research Center and Headquarters, WARDA
MTP	Medium-Term Plan, WARDA
NAFPP	National Accelerated Food Production Programme (Nigeria)
NARI	National Agricultural Research Institute (Gambia)
NARS	National agricultural research systems
NCRE	National Crops Research and Extension Project (Cameroon)
NCRI	National Cereals Research Institute (Nigeria)
NESDA	Network for Environment and Sustainable Development in Africa
NRI	Natural Resources Institute (UK)
ODA	Overseas Development Administration (UK)
ORSTOM	Institut français de recherche scientifique pour de développement en coopération (France)
PERIO	Periodicals database (WARDA)
REDACI	Réseau de documentation agricole de Côte d'Ivoire
RRS	Rokupr Research Station (Sierra Leone)
RYMV	Rice yellow mottle virus
SDI	Selective dissemination of information
SPAAR	Special Program for African Agricultural Research
STI	Science and technology information
TAC	Technical Advisory Committee, CGIAR
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
WARBI	West Africa Rice Bibliographic Database
WARIS	West Africa Rice Information Systems

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