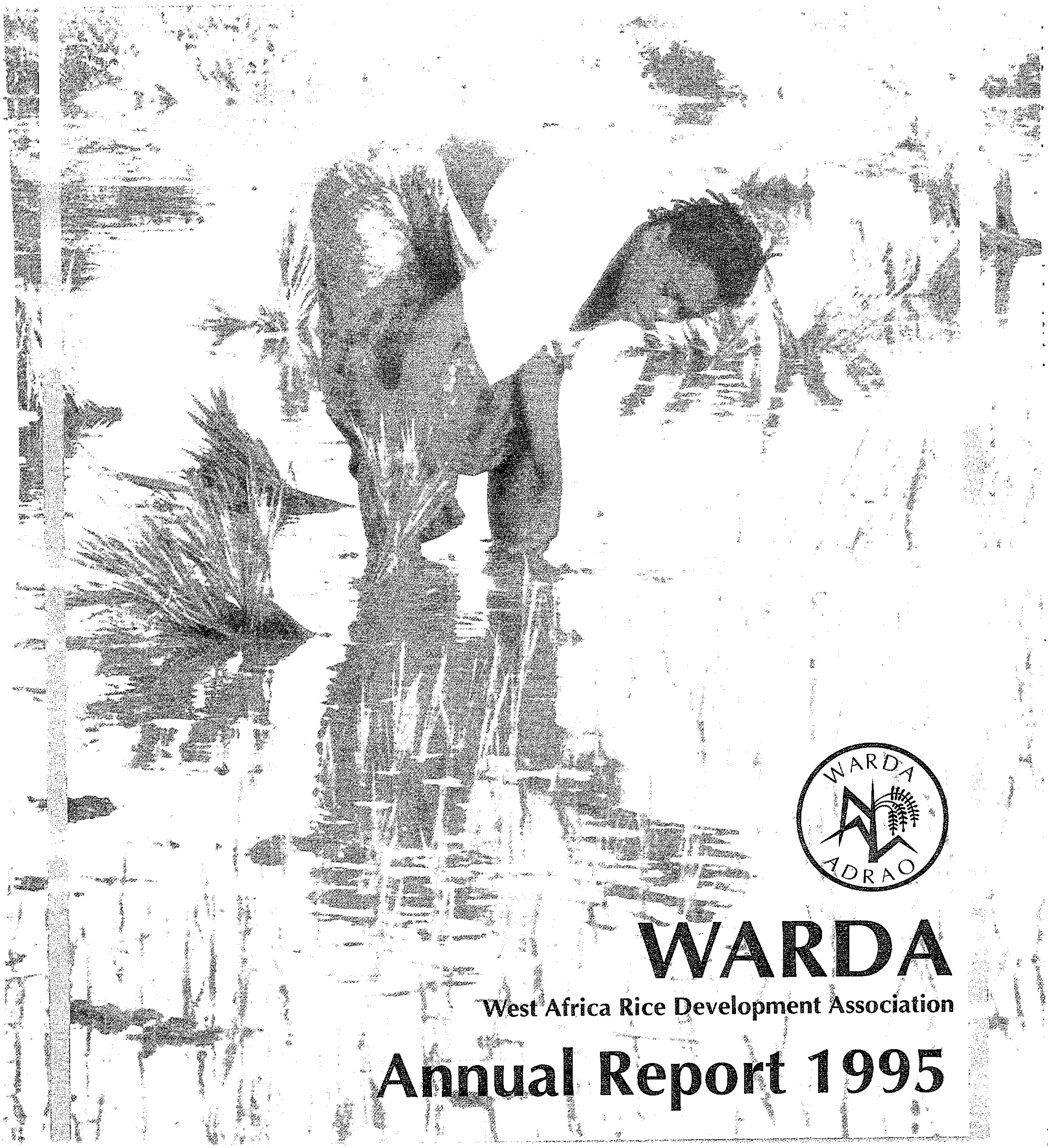


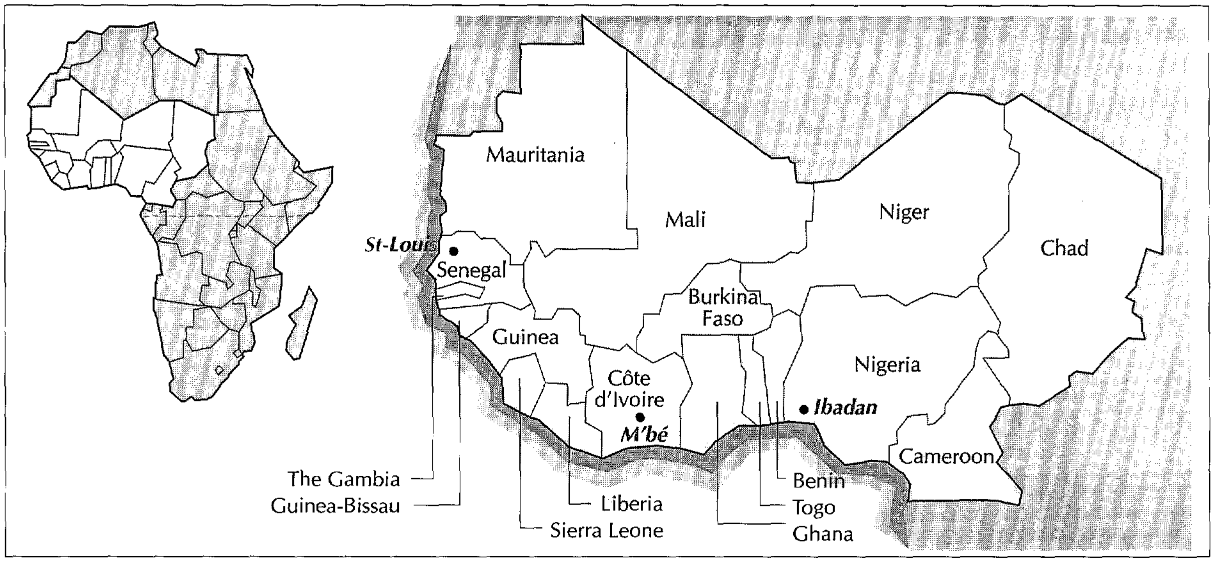
WARDA ADRAO

WARDA

West Africa Rice Development Association

Annual Report 1995

West Africa Rice Development Association (WARDA) member states and principal research centers



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WARDA Annual Report

1995

West Africa Rice Development Association

Association pour le développement de la riziculture en Afrique de l'Ouest

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About the West Africa Rice Development Association (WARDA)

The West Africa Rice Development Association is an autonomous intergovernmental research association with a mission to strengthen West Africa's capability in rice production science, technology and socio-economics through research, training and communications activities.

In collaboration with the national agricultural research systems of member states, academic institutions, international donors and other organizations, the work of WARDA ultimately benefits West African farmers — mostly small-scale producers — who cultivate rice, as well as the millions of African families who eat rice as a staple food.

WARDA was established in 1971 by 11 countries with the assistance of the United Nations Development Programme (UNDP), the Food and Agriculture Organization of the United Nations (FAO) and the Economic Commission for Africa (ECA). It now comprises 17 member states: Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, the Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo.

The headquarters and main research facilities of WARDA are located at M'bé, near Bouaké, Côte d'Ivoire. Regional research centers at St-Louis, Senegal and Ibadan, Nigeria focus on research for rice production under irrigation in the Sahel and lowland rice breeding, respectively.

WARDA is a member of the Consultative Group on International Agricultural Research (CGIAR), a network of 16 international research centers supported by more than 45 public and private sector donors.

Unique and innovative partnerships

Unique among CGIAR centers is WARDA's regional West Africa focus and its origins as an intergovernmental association of 17 member states. Each state appoints a representative to the WARDA **Council of Ministers**, usually the government Minister of agriculture, rural development or scientific research. The Council ensures accord between WARDA program objectives and national agricultural policies, and strengthens WARDA's ability to guide the development of a coordinated regional rice research program. The Council of Ministers thus examines WARDA's medium- and long-term plans to identify convergences and synergies with national agricultural development policies and plans, as well as approves the regular and special financial contributions of member states. The Council, along with its allied National Experts Committee, normally meets in regular session once every two years.

The Twentieth Ordinary Session meeting of the Council of Ministers, opened by the Prime Minister of the Republic of Niger, was held in Niamey, Niger, in September 1995.

WARDA also works closely on an operational level with the national agricultural research systems (NARS) of member states through nine **Task Forces**: an innovative mechanism that fully involves national scientists in the planning, execution and review of collaborative research activities. The Task Forces are:

- Mangrove swamp rice improvement
- Sahel irrigated rice
- Upland rice breeding
- Lowland rice breeding
- Integrated pest management
- Cropping systems
- Problem soils
- Rice economics
- Irrigated rice breeding

Task Force membership includes countries where the target ecosystem is important for rice production and where at least one national scientist is actively engaged in research on the focal theme. As well, Task Force membership includes other regional collaborators such as CORAF (Conférence des responsables de la recherche agronomique africaine) and INGER-Africa (International Network for Genetic Evaluation of Rice-Africa Branch). Each Task Force is self-managing and operates as a mini-network for exchanging information and seeking strengths and comparative advantage among its members for leading advanced research and generating new technologies for the benefit of the entire region.

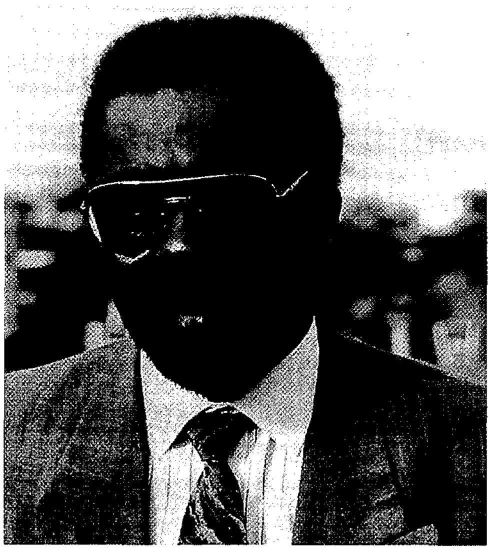
WARDA has also pioneered the **Open Center** approach to maximizing the collaboration of national, regional, international institutions, universities, non-governmental organizations and other CGIAR centers in regional rice research. WARDA, as an open center, encourages researchers from other organizations to visit, participate in exchanges or be posted on-site. This approach aims to make efficient use of available resources, to avoid overlap and duplication in research activities, and to develop research leadership through identification of institutional comparative advantage. One major benefit of the open center approach is having a larger and more dynamic group of scientists working together to provide creative and interdisciplinary solutions to rice science challenges.

Perhaps no partnership is as critical to WARDA's success as that with our **donors**, whose contributions have made it possible for WARDA to become a center of scientific excellence. The benefits of the support received during WARDA's restructuring and rebuilding can be seen in our research results. In 1995, WARDA welcomed Spain as a new donor. Many member countries also made or renewed their commitment to donate funds, often in spite of severe financial constraints.

The 1995 WARDA donors were:

- African Development Bank
- Canada (CIDA)
- Denmark
- European Union
- France
- Germany (BMZ/GMZ)
- International Development Research Centre (Canada)
- Japan
- Korea
- the Netherlands
- Norway
- Rockefeller Foundation
- Spain
- Sweden
- United Kingdom (ODA)
- United Nations Development Programme
- United States of America (USAID)
- WARDA member states
- World Bank.

Message from the Director General



Dr. Eugene R. Terry
Director General WARDA

1995 marked a year of organizational consolidation for the West Africa Rice Development Association (WARDA), yet one where exciting progress continued to be made on several scientific projects.

Nearly half of WARDA's complement of research scientists was recruited in 1994, thus 1995 marked their first full year of work here. As the research features and summaries later in this Annual Report demonstrate, we are already reaping the benefits from the major effort devoted to our core research agenda.

> "A major breakthrough was the development of new, genetically stable and fully fertile hybrids between *Oryza glaberrima* and *O. sativa* rices."

Our rice breeding program is the cornerstone of our research agenda. A major breakthrough was the development of new, genetically stable and fully fertile hybrids between *Oryza glaberrima* (African species) and *O. sativa* (Asian species) rices. The physiological and agronomic characterization of the hybrids constitute an important step towards creating a new highly weed-competitive rice plant type suited for low-input management.

The West Africa rice sector study was completed in 1995, and this Annual Report discusses the comparative advantage of rice production in two of the countries studied: Sierra Leone and Niger. Earlier results suggest that most African rice farmers are indeed highly competitive, especially those producing rice for towns distant from seaports and for primarily local consumption. Policy reforms during the last decade have also contributed to significant gains in efficiency and economic competitiveness, especially in the post-harvest sector.

An interesting finding in our Sahel irrigated rice program research was that double-cropped fields with good drainage had less salt accumulation than single-cropped fields either with or without drainage. More research will be concentrated in this area in the future, to ascertain whether in fact this system might result in reduced salinity.

In September 1995, WARDA hosted the first international symposium on rice yellow mottle virus (RYMV), an epidemic which has spread widely across West Africa, threatening lowland rice production. The symposium encouraged further cooperation among WARDA and other institutions to develop resistant cultivars and other solutions to the RYMV problem.

As will be evident from a comparison of WARDA's financial statements for 1994 and 1995 (*see* pages 113-115), there were significant increases in donor support in unrestricted fund allocations, and for restricted and complementary activities. On behalf of WARDA's Board of Trustees, management and staff, I wish to tender our sincere appreciation for this endorsement of our progress to date, and manifestation of confidence in the future prospects for impact. We fully expect to continue to justify this support and confidence as WARDA matures as an organization.

> "Whether scientist, secretary, technician or field hand, WARDA employees demonstrate that by working together, the organization can produce good science."

One key reason for our success is the dedication of staff. In 1995, WARDA's staff represented some 20 different nationalities, including those of most West African and many donor countries. WARDA has developed a bilingual, multicultural, interdisciplinary environment — and has become the more dynamic for it. Whether scientist, secretary, technician or field hand, WARDA employees demonstrate that by working together, the organization can produce good science.

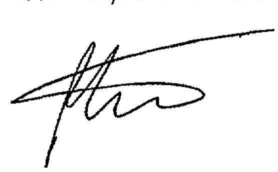
The excellence of WARDA staff is recognized by our peers and our partners. For example in 1995, Dr. Kouamé Miezan, the WARDA Sahel Program Leader, was awarded the "Grand prix du mérite de l'Association Ivoirienne des Sciences Agronomiques" in recognition of his contributions to rice science research.

An important part of WARDA's mandate is building rice science capacity in West Africa through training, internships and WARDA visits. We are very proud of the calibre of our African Development Bank Research Fellows, as are their home countries. Kofi J.V. Afun, a Ghanaian ADB Fellow completing his field studies for his Doctorate (Wye College, University of London, UK) at WARDA throughout 1995, was named "Best Agricultural Researcher for 1995" by the Government of Ghana. Afun studied the role of weeds in the natural control of upland rice insect pests in Côte d'Ivoire. His supervising scientists at WARDA were Dr. David Johnson (weed science) and Dr. Elvis Heinrichs (entomology).

> "The UNDP gave high commendation to WARDA for its training programs."

Rice science capacity is also being developed through training and communications. An end-of-project evaluation for the United Nations Development Programme (UNDP)-supported training that commenced in 1990, gave high commendation to WARDA for effectiveness and impact, especially for its training programs that targeted women rice farmers.

I like to think that effectiveness and impact were integral to all WARDA activities in 1995. As you review this Annual Report, I hope you will agree.



Eugene R. Terry

Rice science research

Research in 1995: a year of consolidation and solid progress

P.J. Matlon

Following two years of rapid expansion in staff and research activities, 1995 was a period of consolidation during which solid progress was achieved in several important areas.

Among the highlights was the completion of a major multi-year study of the West African rice sector. The research closely examined rice production and marketing systems in 11 countries to evaluate their economic competitiveness. The results suggest that most African farmers are indeed highly competitive and shed new light on the factors affecting regional comparative advantage during a period of uncertainty marked by rapid policy reforms.

Significant advances were also achieved by WARDA breeders with the development of the first fixed progeny resulting from our interspecific rice breeding program. In a broadly interdisciplinary effort, the new materials were tested in a range of trials with extremely encouraging results. Our on-farm impact was also documented in adoption and impact studies conducted by collaborators in national research programs, with WARDA rice varieties showing significant uptake by farmers in several countries.

At the same time several new collaborative initiatives were launched in response to threats to both plant and human health. The spread of rice yellow mottle virus (RYMV) inspired WARDA to intensify its cooperation with several institutions both within and outside of Africa with the goal of quickly identifying resistant cultivars to replace the highly susceptible varieties which are planted on essentially all irrigated areas of West Africa. And, after five years of planning, an exciting cross-sectorial program of research on the human health consequences of lowland rice cultivation was finally launched as field work began in villages in Côte d'Ivoire and Mali.

Continuum Program research highlights

Out of approximately 4.1 million hectares cultivated with rice in West Africa, 84% are rainfed, and 93% are located in the moist savanna and humid forest zones. In these environments, rice is mostly cultivated with low management inputs on hydrologically variable toposequences within small watersheds. The major landscape units within this complex "continuum" environment are free-draining uplands (1.8 million ha), hydromorphic valley fringes and rainfed lowlands (0.7 million ha), and irrigated lowlands (0.2 million ha). WARDA's Continuum Program addresses these systems through a fully interdisciplinary team approach that considers both the diversity and scale specificity of biophysical phenomena, and the range of farmers' objectives and resources.

Our research in the continuum is driven by two strategic goals: first, the ecological and economic stabilization of upland rice-based systems, which are increasingly threatened by shortened fallows and declining resource base productivity; and secondly, the sustainable and intensified cultivation of the more resilient and productive lowlands, less than 10% of which are currently used for rice production.

Major components of WARDA's strategy for the uplands are the management of soil fertility and post-rice weed successions through improved fallow practices incorporating, for example, multi-purpose legumes; the management of internal and external phosphorus resources, particularly in acid soils; and the development of highly weed-competitive and drought-resistant rices, based on *Oryza sativa* x *O. glaberrima* crosses.

Our major research foci for the intensification of lowland systems are improved pre-rice land management reducing losses of native nitrogen; post-rice crop options exploiting residual soil-moisture; control of iron toxicity; low-cost improved water management practices; development of high-yielding rice germplasm resistant to rice yellow mottle virus; and, the integrated control of rice pests and aquatic vector-borne human diseases.

During 1995, WARDA Continuum Program scientists conducted research addressing these issues within six team projects.

Refining the research agenda through agro-ecosystem characterization Given the extreme spatial and temporal diversity of continuum environments in Africa, a systematic characterization of socio-economic and biophysical environments is essential to set research priorities and to estimate probable research impacts. During 1995, a micro-level socio-economic characterization of three benchmark sites in Côte d'Ivoire located in distinct agro-ecological zones was completed with analyses of costs of production, gender roles in rice production, and farmers' perception of biotic and soil constraints. Parallel studies were nearing completion at the agronomic level focusing on farmer-level yield gap analyses. The agronomic analyses were combined with on-farm studies on natural biological control mechanisms for rice pests, complemented with on-station trials.

> "Our work also showed that natural control of insect pests through parasitoids and a range of predators is strong in many rice environments."

Results of these studies confirmed that upland/hydromorphic rice yields are falling as fallow periods become shorter. This is primarily due to increasing weed pressure and secondly due to reduced nitrogen-supplying capacity of the soil. Our work also showed that natural control of insect pests through parasitoids and a range of predators is strong in many rice environments. The socio-economic results are now being compiled in a broadly accessible database which, in combination with the yield gap studies, will support future *ex ante* impact analyses of new technologies.

WARDA scientists also initiated new characterization research in collaboration with the Inland Valley Consortium (IVC), aimed at developing hydrology-based extrapolation tools for land-use planning within small watersheds. Biophysical models are being formulated based on the results of detailed studies in a small watershed on WARDA's main research farm at M'bé, and validated at our well-characterized benchmark on-farm sites in Côte d'Ivoire. These models will be used to extrapolate technologies and land use concepts regionally. Results obtained during 1995 provided first insights on water and nutrient dynamics along toposequences and in small watersheds at different scales.

Plant nutrition management for resource-poor farmers More than 100 leguminous species of diverse agro-ecological adaptation and potential uses (grain, fodder, medicinal, weed suppression, soil-improvement) underwent their first tests in a number of on-farm locations in our key sites in Côte d'Ivoire as well as at WARDA's main research center. Our goal is to identify legume species that are economically attractive to resource-poor farmers as components of improved upland fallow systems.

Also in 1995, on-station studies of nitrogen dynamics measured nitrogen losses due to denitrification of up to 30 kg N ha^{-1} from upland soils, 70 kg N ha^{-1} on hydromorphic soils and 40 kg N ha^{-1} from lowland rice fields with the onset of rains before rice is planted. These results are now being confirmed through quantitative nitrogen balances, and validated for key cropping systems. During 1995, first concepts for toposequence-based models on nitrogen transformations and fluxes were developed. These will be used to analyze and predict resource dynamics after more quantitative information has been generated. The objective of this work is to develop low-cost cropping systems approaches that capture a significant proportion of the lost nitrogen, thereby making it available for the rice crop.

Multi-season field experiments to determine the availability and utilization of residual phosphorus by upland rice showed strong varietal differences in nutrient response. Two distinct types of response were identified which require different phosphorus management approaches. The most commonly used local improved japonica cultivar tested showed low response to fresh phosphorus, but strong response to residual P during subsequent seasons. In contrast, several WARDA-developed elite upland rice varieties showed a strong initial response to applied phosphorus followed, however, by a rapid decrease of residual effects. While these latter types have a superior ability to extract phosphorus, it appears that they accelerate the depletion of the natural pool. Depending on the probability of losses of applied phosphorus through permanent fixation or topsoil erosion, and depending on the level of initial phosphorus inputs, one or the other type would provide higher cumulative returns to applied phosphorus across years. Following complementary economic analyses, these results will help WARDA soil scientists to develop phosphorus recommendations specific to different varietal types.

Research during 1995 on iron toxicity indicated that, in many situations, yield losses can be reduced through correction of secondary nutrient imbalances caused by excess ferrous iron. In combination with recently selected iron-toxicity tolerant

Harvesting test plots at WARDA's main research centre, M'bé varieties, scientists are now formulating a package of nutrient management packages to economically reduce yield losses at iron-toxic sites.

Integrated pest management Integrated pest management (IPM) research in 1995 focused on five major problems: rice yellow mottle virus (RYMV), rice blast disease, African rice gall midge (ARGM), weeds, and parasitic nematodes. A number of insect pests feeding on rice were also studied, with particular emphasis on conserving natural biological control mechanisms.

Within the last 15 years, an RYMV epidemic has spread across Africa, threatening lowland rice production. All commonly grown lowland rice cultivars are highly susceptible to the virus, with farmers' yield losses as high as 60 to 100% reported from Côte d'Ivoire, Niger, and Mali during 1993 and 1994. RYMV can survive in a number of hosts and is transmitted by several mechanisms. Further complicating the search for a solution is the fact that there are no known sources of stable resistance within the indica rice group. In view of the rapidly expanding threat, and the immediate potential for disaster in large irrigated rice schemes, WARDA, the national agricultural research systems (NARS) of West Africa and several advanced research institutes in the north have combined their efforts to find a solution in the shortest time possible.

Several pioneering efforts were initiated to create or identify new genetic sources of resistance to RYMV. Cooperation with the Sainsbury Laboratories in the United Kingdom and with the International Laboratory for Tropical Agricultural Biotechnology in the United States was initiated in 1995 to transfer into high yielding rice varieties new transgenes for RYMV resistance. Collaborative projects with CIRAD and ORSTOM in France address the genetic diversity of the pathogen. In-house studies on the virus's epidemiology, as well as the genetics of natural resistance to RYMV in *O. sativa* and *O. glaberrima*, were also launched during 1995. As a short-term complement to these projects seeking long-term solutions, the search for readily utilizable rice varieties with partial or location-specific resistance was intensified in close collaboration with several NARS within West Africa.

Research on rice/weed competition identified several highly weed-competitive *O. glaberrima* upland rices. Their mechanisms for competition for resources differed markedly from those commonly observed in *O. sativa* tropical japonica types. Most importantly, early analyses suggest that the mechanisms may be physiologically compatible with traits for high yield potential, which is commonly lacking in tall-traditional upland japonicas. These results helped guide ongoing breeding activities in WARDA that are targeting the development of weed-competitive interspecific *O. sativa* x *O. glaberrima* rices. *O. glaberrima* was also found to be a promising, and in some cases the only available, stable source of resistance to the parasitic weed *Striga* spp., blast disease, ARGM, RYMV, root nematodes, and drought.

Developing new rice types A major breakthrough in 1995 was the development and physiological and agronomic characterization of genetically stable, and fully fertile hybrids between *O. glaberrima* and *O. sativa* rices. This is an important step towards creating a highly weed-competitive upland rice type well adapted to the production systems of resource poor farmers, but with high yield potential as well. Through studies conducted in 1995, the underlying traits and physiological mechanisms for weed competitiveness and their compatibility with high yield potential are now much better understood. These results are helping us formulate a more efficient breeding strategy and refined selection methods. Important progress was also achieved in the development of more effective anther culture methods for the rapid genetic fixation of wide crosses by doubled haploidization.

Intraspecific breeding for locally adapted upland rices continued, and a number of such lines have been adopted by farmers in Côte d'Ivoire, Nigeria, the Gambia, Guinea-Bissau and Cameroon. These include lines with high levels of physiological and agronomic P-use efficiency and adaptation to acid soils. For lowland rice, very substantial progress was also recorded selecting high-yielding lines tolerant to iron toxicity, and lines that are partially resistant to RYMV. These were requested by NARS Task Force members for multi-location and on-farm testing in Côte d'Ivoire, Nigeria, and the Gambia.

Improving rice sector policies One often hears the remark that African farmers are at a competitive disadvantage when pitted against the much more experienced and productive rice farmers of Thailand, Vietnam and other Asian countries, as well as with the much larger commercial farmers in developed countries such as the United States. Beginning in 1992, WARDA initiated a multi-year research program to test this conventional wisdom with a series of comparative advantage analyses on rice systems in four Sahelian countries. In 1994, our policy work was expanded to seven additional countries through a special project contracted to Development Alternatives, Inc. of the USA. Scheduled to be completed in 1996, the goal of the study has been to examine the comparative advantage of current rice production systems through an economic analysis of domestic production.

"good news is emerging that African rice farmers are becoming increasingly competitive with their Asian and northern counterparts"

During 1995 preliminary analyses of comparative advantage for domestic rice production were prepared, and reports completed for Niger and Sierra Leone. Results from these two countries document the dramatic changes that have occurred in the West African rice sector as structural adjustment reforms over the past fifteen years have progressively reduced government intervention in the rice sector and liberalized paddy and rice markets. The economic analysis is revealing that West African rice production systems distant from coastal port cities or destined for consumption near the zone of production display a strong comparative advantage. We also found that significant gains in efficiency and economic competitiveness have occurred in many rice systems during the last decade with the introduction of policy reforms, with some of the most important gains due to fundamental restructuring in the post-harvest sector. In short, good news is emerging that African rice farmers are becoming increasingly competitive with their Asian and northern counterparts.

Sahel irrigated rice program research highlights

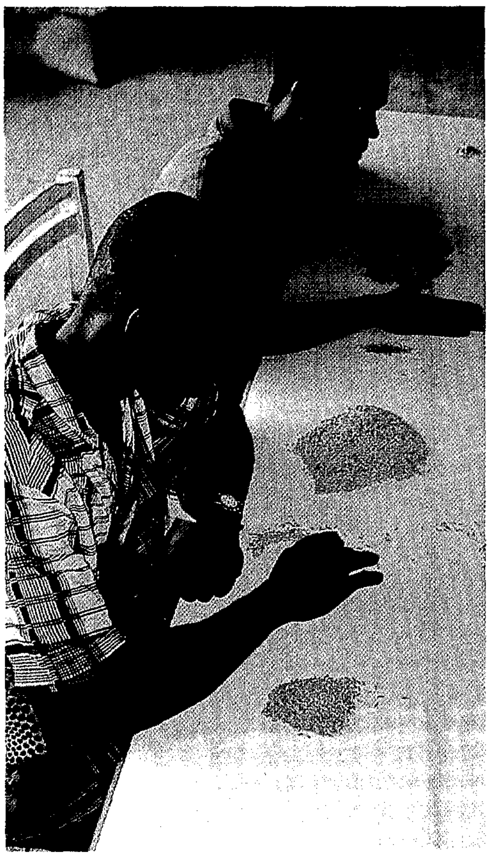
Governments in all Sahelian countries have identified rice as a crop of strategic importance and accorded rice production priority status in agricultural development plans to the end of this century. Major new investments to expand the irrigated area were completed within the last decade, and structural adjustment reforms have liberalized production with an enormous increase in small farmer-scale irrigation. At the same time, in a growing number of irrigated schemes, evidence of degradation due to salinization and alkalinization is increasing, closely associated with declining yield potential.

Past rice production strategies in all Sahelian countries have been based on concepts drawn primarily from Asian experience where rice is grown under humid and semi-humid environments. Production and post-harvest systems tailored to the unique climate, soils, and socio-institutional structures of the Sahel have been lacking. As a result, performance has been generally disappointing, reflected in inefficient input use and productivity well below economic potentials. WARDA's strategy for research on irrigated rice in the Sahel is to provide information and technologies that specifically target Sahelian conditions, and which lay the basis for sustainably improving rice productivity within increasingly competitive local, regional and global markets.

In 1995, our Sahel team worked toward these goals through diagnostic studies identifying inefficiencies and quantifying yield loss factors on farmers' fields, through the selection of high yielding varieties adapted to extreme temperatures and salinity, and through the development of improved cropping practices to improve resource-use efficiency and to arrest and reverse resource base degradation.

"We found that salinity is indeed strongly related to double-cropping but, contrary to conventional wisdom, that in the short-term double-cropping with good drainage actually reduces salt build-up by flushing salts out of the rooting zone of the rice plant."

Understanding farmers' constraints A multi-annual yield gap trial was initiated in 1995 conducted with the close participation of farmers in the Senegal River Delta. Farmers' fields were selected to represent typical single- and double-cropping production systems. Holding input levels constant, we measured a yield gap varying between 3 to 5 t ha^{-1}. The major share of this enormous gap was attributed mainly to poor soil fertility management and, in some extreme cases, to weed pressure. Farmers' practices resulted in particularly low nitrogen use efficiency. We are encouraged by these results as they suggest that very significant improvements in productivity may be possible with little or no increase in use of purchased inputs. Work is on-going to determine how yield gaps may vary with cropping intensity, and the socio-economic bases for inefficient cultural practices.



Selecting rice seed, M'bé

Developing better adapted varieties WARDA scientists greatly expanded the evaluation of introduced germplasm in 1995, characterizing a wide diversity of genetic materials in terms of duration, panicle type, grain characteristics, and phenotypic acceptability under the extreme climatic conditions of the Sahel. In a significant development, we were able to identify new germplasm among our advanced lines which are shorter duration and higher yielding than the best varieties selected by WARDA in 1994, that were recently released in Senegal, Mauritania and Burkina Faso. Our hybridization work also expanded in 1995, as new crosses were made for tolerance to salinity, macro-nutrient use efficiency and for genetic studies of photothermal constants.

Developing more efficient and sustainable cropping systems On-farm experiments in 1995 within the Senegal River Delta aimed at finding out whether double-cropping of rice contributed to increasing soil salinity. We found that salinity is indeed strongly related to double-cropping but, contrary to conventional wisdom, that in the short-term double-cropping with good drainage actually reduces salt build-up by flushing salts out of the rooting zone of the rice plant. We observed the highest salinity levels on single-cropped fields without drainage, and on abandoned fields. These results suggest that double-cropping of rice can not only contribute to increasing the return to investments in infrastructure, but can also reduce plot level salinity. Our results also underlined the importance of upward salt transport due to capillary rise from the shallow saline groundwater table. This result focuses our attention on the urgent need to determine the maximum surface that can be irrigated in the Delta without risking contact between topsoil and the highly saline groundwater, a theme on which we will direct substantial research effort in the future.

Finally, we field-tested soil puddling equipment as a means of reducing salt levels. Repetitive puddling, using an International Rice Research Institute (IRRI) hydro-tiller, combined with surface water drainage were very effective in removing salt from the soil profile. However, due to the destruction of soil structure, we found that plant roots may still be exposed to high salinity levels after puddling. This suggests that rice cropping should be reintroduced on fields abandoned due to salinity only after soil structure has been reestablished through drying.

Perspectives

As we look to our future research agenda, we can take satisfaction that scientific momentum was maintained and increased with solid progress and several significant achievements in 1995. Our scientific staff — both WARDA core scientists and researchers from collaborating institutions, and many of whom are recent arrivals — coalesced into effective and mutually supportive interdisciplinary teams.

The participation of national scientists in our research activities also grew in 1995, and contributed very substantially to our gains. Through nine Task Forces, our national colleagues continued to help refine our research objectives to ensure that we are responding to the priority needs in our members states. An increasing number of visiting scientists from national programs were hosted by WARDA where they were able to update their skills learning the most modern research methods, carry out research that required the equipment and infrastructure available at the WARDA main research center, and develop plans for new collaborative research initiatives with their WARDA colleagues. The number and quality of Task Force projects continued to increase in 1995, greatly improving the efficiency of research within both national programs and WARDA.

We remain excited by the continued acceleration of WARDA activities and research outputs, and by the impact we are already witnessing on farmers' fields. As you read through the more detailed reports that follow, I know that you will share our sense of accomplishment. Most importantly, I hope that you will continue to share our confidence in the exciting contributions WARDA and its many partners will soon make working in close collaboration.

The comparative advantage of rice production in Sierra Leone and Niger

T.F. Randolph

With limited human and financial resources, WARDA and the national rice research programs in its member countries are faced with the challenge of improving productivity for rice grown in West Africa. Research managers must therefore carefully allocate their scarce research resources among different rice production systems and ecosystems in such a way as to optimize the eventual impact of their research programs. This article explores one criterion for guiding such decisions based on economic efficiency.

"Rice is a strategic crop in West Africa. It is the staple food for rural populations across a large zone stretching from the Gambia to Côte d'Ivoire, as well as among the rapidly growing urban populations throughout the region."

Rice is a strategic crop in West Africa. It is the staple food for rural populations across a large zone stretching from the Gambia to Côte d'Ivoire, as well as among the rapidly growing urban populations throughout the region. Demand for rice has expanded at the average rate of 4.9% a year since 1983, due partly to population growth (2.9% per year) and partly to a larger share of rice in diets (accounting for 2.0% growth per year). The region currently produces only 64% of its rice requirements and so imports large quantities of rice, mostly from Asia. Nearly 3 million tons were imported annually in the early 1990s, representing a total yearly cost of $800 million in scarce foreign exchange.

The strategic nature of rice has long drawn the attention of policymakers who view promoting domestic rice production as the means to reducing the dependency on imports, lowering the burden on foreign currency reserves, ensuring stable and low-priced sources of food for their population, and generating income for rice growers. Using an array of price, institutional, and technology policies, governments have invested heavily in expanding production capacity and in providing incentives for operators within the rice sector to increase production. These policies have undoubtedly contributed to the impressive growth in regional production since 1983 — 8.3% per year — but most of this growth has come from area increases rather than improved yields. To sustain growth, productivity must increase and agricultural research will play a key role.

Due to its wide adaptability, rice is produced in a number of different agro-ecologies ranging from submerged conditions in the coastal mangrove swamps and inland valley swamps to seasonal floodplains, irrigated systems and rainfed upland systems in the humid zone. In traditional production zones where rice is an important staple, especially in the "rice belt" stretching along the Atlantic Coast from the Gambia to Côte d'Ivoire, rice is grown primarily for subsistence needs. In areas and irrigated systems where rice culture is more recent, the crop is typically grown for the market. This diverse set of situations is further associated with an array of different production techniques ranging from small-scale traditional low-input, manual systems to large-scale high-input, mechanized (tractor-plowing, combine harvesting) systems. Depending on the location and individual country policies, rice producers also face varying degrees of competition from imported supplies.

To ensure that scarce research and development resources are allocated for maximum impact, it is important to evaluate the competitiveness of rice production under these different production systems. Competitiveness provides an indicator of a system's viability, and suggests the likelihood that in the future the system will expand, contract, or remain unchanged. Research should target those systems likely to grow in importance.

Our knowledge regarding the economic viability of rice production systems in West Africa has come primarily from the seminal study by a team of researchers from Stanford University in collaboration with WARDA in the late 1970s (Pearson et al. (1981)). The authors evaluated production systems in five countries: Senegal, Mali, Côte d'Ivoire, Liberia, and Sierra Leone. The study suggested a pattern of comparative advantage whereby rice production is only economically viable in those zones in West Africa that benefit from being located far from the coastal ports where imported rice supplies enter the region, or by poor infrastructure which also increases the cost of delivering rice imports inland. Otherwise, rice production generally did not enjoy a comparative advantage beyond satisfying on-farm subsistence needs, and therefore offered little promise for expansion and supplying rice demand in cities and non-rice producing areas. Among production systems, those with some degree of water control and an intermediate level of mechanization (i.e. animal traction) were found to be more efficient than traditional manual systems or those with motorized operations.

Many changes have occurred within the West African rice sector since the late 1970s, many of which are related to the reduction of public intervention in the rice sector accompanying structural adjustment programs. To what degree have these changes affected the composition of the rice sector and the associated patterns of comparative advantage? To answer this question, in 1994 WARDA expanded its review of the West African rice sector, funded by a special grant from the African Development Bank and carried out by Development Alternatives, Inc., a consulting firm in the United States. In addition to reviewing trends in rice production, consumption, and trade at the regional level, the study is conducting an in-depth economic analysis of rice production systems in seven countries (Senegal, Mali, Niger, Nigeria, Côte d'Ivoire, Sierra Leone and Guinea).

This article reports preliminary findings based on the first two country case studies completed: Sierra Leone and Niger. Comparing and contrasting systems in these two countries is particularly useful since in many ways they represent two extremes: a land-locked Sahelian country where rice plays a minor role in the food economy versus a coastal country where rice is the principal crop and food staple. Many of the principal production techniques are also found in the two countries: from intensive irrigated production in Niger to various upland-lowland systems in Sierra Leone. However, in terms of rice policy, the two countries share much in common.

The Policy Analysis Matrix approach

We used the Policy Analysis Matrix (PAM) approach to conduct the comparative economic analyses of the rice production systems in each country. The methodology is simple and transparent and readily applicable by regional economists. Although solidly founded in economic trade theory, the approach is based on a simple, straightforward, accounting balance sheet. For each major domestic rice commodity system, representative enterprise budgets are developed for each stage in the production, beginning with paddy production on the farm, to assembly and processing, and finally to distribution and marketing. Production costs are first valued in terms of financial prices ("private" prices in PAM terminology) and are then revalued in terms of economic ("social") prices which reflect the opportunity cost to society of individual inputs, factors, and products. Differences between private and social prices may arise from policy interventions, such as taxes and subsidies, or from market failures. The PAM summarizes each set of budgets as total costs, broken down into tradable inputs and domestic factors (labor, capital), total revenues, and net profits. The standard measures of financial competitiveness and economic comparative advantage can be derived directly from the PAM.

Data used to construct representative enterprise budgets and to value social prices were collected primarily from secondary sources, and supplemented by key informant interviews when possible. Civil unrest in Sierra Leone severely limited data collection efforts in that country.

The rice economy of Sierra Leone

Rice is the staple food of Sierra Leone, which is located in the middle of the rice belt along the humid southwest coast of West Africa. The average Sierra Leonean consumes 103 kg of rice per year, representing 45% of total caloric intake (Table 1 *overleaf*). Per capita consumption has declined in recent years, but this has been due to reduced overall food consumption rather than substitution by other foods. Total demand for rice continues to rise, however, in line with population growth. Rice is the principal crop cultivated by the largely subsistence-oriented farm sector and, until the late 1970s, domestic production was generally sufficient to satisfy the country's rice requirements. Since achieving a high of 620 000 t produced in 1978, annual paddy production has stagnated at between 450 000-500 000 t, and has even fallen recently due to civil disruption. By the early 1990s, Sierra Leone was importing one-third of its rice consumption needs each year.

Inappropriate rice policies have contributed to the poor performance in domestic rice production. Over the past 25 years, the government has pursued two principal — and largely contradictory — rice policies: investment in the development of lowland rice production, and regulation of imported rice markets to maintain low consumer prices. Government-supported Integrated Agricultural Development Projects gave high priority to improving water control in inland valley swamps and establishing large-scale mechanized rice production in the boliland (wide plain or prairie with a swampy bottom) and riverine grassland ecologies. Large-scale industrial rice mills were also built to handle the surplus production to be generated by the projects. Most technologies introduced by the projects proved to be unsustainable, however, and so were largely abandoned. Many of the projects were fully dependent on government provision of inputs and mechanized services, ignoring the need to develop private sector capacity to supply services. As government participation in such projects declined, farmers quickly abandoned the projects. In the bolilands, it soon became apparent that the ecology was extremely fragile and could not sustain production.

While trying to promote rice production at the farm level, the government also attempted to protect producers' and consumers' interests by directly managing rice markets. The government assigned monopoly control over the wholesale rice trade, including fixing prices, to parastatal agencies which preferred to concentrate on the lucrative imported rice market, ignoring markets for domestic production. Through this mechanism, the government started a "chit" system

Table 1: Summary statistics for the national rice economy: Sierra Leone and Niger.

	Sierra Leone		Niger	
	Average 1991-94	Growth rate[d] 1985-94	Average 1991-94	Growth rate[d] 1985-94
Population[a] (millions)	4.2	2.3%	8.4	3.3%
GDP per capita[b] (US dollars)	147	-0.1%	284	-2.4%
Agricultural production per capita index[a] (1979-81 = 100)	90	-2.3%	83	2.0%
Area cultivated in rice[a] (ha)	370 000	0.9%	27 000	3.0%
Paddy rice production[a] (t)	480 000	0.0%	71 000	3.4%
Paddy rice yield[c] (t ha^{-1})	1.3	na	2.7	na
Rice consumption per capita[a] (kg year^{-1})	103	-1.5%	13	-1.0%
Rice imports[a] (t)	161 000	16.9%	41 000	5.3%
Self-reliance ratio[c] (percent)	69	-4.7%	69	-2.9%

Source: [a] FAOSTAT-PC (95); [b] World Bank data base; [c] Computed from FAO data. Self-reliance ratio is computed as paddy production in rice equivalent (tons) divided by total rice disappearance. [d] Average annual growth rates estimated by Ordinary Least-Squares regression method.

providing substantially subsidized imported rice quotas to government workers and politicians. This kept open market rice prices low. Currency overvaluation during the 1980s and early 1990s encouraged such a strategy by making imported rice supplies artificially cheap. Many of these policies have now been dismantled under structural adjustment, and currency distortion has been largely eliminated. As of 1995, the main policies affecting the rice sector are continued distribution of subsidized imported rice to government workers to promote political stability and a 15% *ad valorem* tariff on commercial rice imports.

A key feature of the rice sector in Sierra Leone today is the widely dispersed smallholder production base. Rice is grown on small farms using traditional, manual, low-input production techniques in five main agro-ecosystems: rain-fed upland (accounting for an estimated 49% of paddy produced in the period 1990-94) and inland valley swamps throughout the country (37%), mangrove swamps along the coast and rivers (9%), riverine grasslands along the southern coast (2%), and the bolilands in the north central area (2%). The main inputs are land and labor; input markets to support rice production are poorly developed or non-existent. Farmers have little, if any, access to formal credit or to supplies of quality seed, fertilizers, pesticides, and agricultural machinery.

Farm families keep the greater part of production for on-farm consumption or seed. The remainder may be marketed locally, and some supplies, particularly from production zones in the northern mangrove and southern riverine grassland areas, flow seasonally through small-scale private trade into the regional centers and the capital, Freetown. Most paddy is converted to rice by hand-pounding using a large wooden mortar and pestle; the remainder, estimated to be less than 10% of production, is milled using small-scale Engelberg-type rice mills. Parboiling is common. Supplies of 25-35% broken rice ("brokens") imported from Asia by larger scale traders represent the bulk of the rice trade in Sierra Leone, and flow from the port in Freetown to the secondary towns and rural areas.

To evaluate the economic efficiency of current rice production systems, we identified seven main rice commodity systems to incorporate into the PAM (Table 2). Each system is defined by two major components: the paddy production technique, which is largely a function of the agro-ecology in which the rice is grown; and post-harvest operations, as determined by milling technique (hand-pounding versus small-scale dehuller) and final destination (on-farm consumption or marketed). The representative systems account for an estimated 95% of national production.

For upland and inland valley lowland systems, a farm located 250 km inland from Freetown was taken as the representative point of production. Production zones for the remaining systems are well defined geographically, and representative farms for these systems were assumed to be located 50 km from the regional center associated with the production zone (Table 2). Technical coefficients were drawn mainly from synthetic budgets reported in the 1993 Agricultural Sector Master Plan (Minster (1993)). All farm-level production systems are manual with essentially no input use beyond seed from the farmer's own stocks. In upland systems, rice is typically the primary crop intercropped with cassava, sorghum, millet, or maize, but in lowland systems rice is most often sole-cropped. Varieties are mostly traditional, except

Table 2: Representative rice commodity systems in Sierra Leone: financial and economic indicators for 1994.

Commodity system	Share of national output (%)	Paddy yield (t ha^{-1})	Private Cost ($ t^{-1})	Private Profit ($ t^{-1})	Social Cost ($ t^{-1})	Social Profit ($ t^{-1})	DRC[a]
1 Traditional manual upland, hand-pounded, consumed on farm (250 km from Freetown)	47	1.0	250	157	252	202	0.53
2 Traditional manual inland valley swamp, hand-pounded, consumed on farm (250 km from Freetown)	27	1.8	240	165	243	210	0.52
3 Traditional manual inland valley swamp, small-scale dehuller, marketed in regional urban center (250 km from Freetown, transported to 50 km to regional center)	9	1.8	332	75	328	33	0.89
4 Manual inland valley swamp with improved water control, hand-pounded, consumed on farm (250 km from Freetown)	1	2.3	317	88	320	132	0.69
5 Traditional manual mangrove swamp, hand-pounded, consumed on farm (near Port Loko)	8	2.2	120	285	122	303	0.27
6 Traditional manual boliland, hand-pounded, consumed on farm (near Makeni)	2	1.3	255	150	258	182	0.57
7 Traditional manual riverain grassland, hand-pounded, consumed on farm (near Torma Bum)	2	1.4	182	223	185	268	0.38
Representative systems combined	96		239	162	242	196	0.53

Table 3: Representative rice commodity systems in Niger: financial and economic indicators for 1994.

1 Traditional flooded, hand-pounded, consumed on farm	4	1.0	247	121	239	260	0.44
2 Traditional flooded, small-scale dehuller, marketed	3	1.0	216	192	202	151	0.50
3 Private pump-irrigated, animal traction, transplanted, high-input, small-scale dehuller, consumed on farm	3	5.3	349	23	345	179	0.51
4 Private pump-irrigated, animal traction, transplanted, high-input, small-scale dehuller, marketed	5	5.3	362	45	334	17	0.91
5 Public pump-irrigated, animal traction, transplanted, high-input, small-scale dehuller, consumed on farm	24	4.7	235	134	245	255	0.38
6 Public pump-irrigated, animal traction, transplanted, high-input, small-scale dehuller, marketed	34	4.7	233	174	242	111	0.57
7 Public pump-irrigated, animal traction, transplanted, high-input, industrial rice mill, marketed	22	4.7	321	117	314	70	0.73
Representative systems combined	96		263	137	246	142	0.52

Representative milling rates used in the analysis are for Sierra Leone: 0.67 kg rice kg^{-1} paddy for hand-pounding and 0.65 for the small-scale dehuller; and for Niger: 0.70 for hand-pounding; 0.60 for small-scale dehullers; and 0.647 for industrial rice milling.
[a] Domestic resource cost.

in the mangrove and riverine grassland ecologies where improved varieties have been adopted to some degree. Low input use across systems is reflected in low yields, averaging 1.0 t ha^{-1} for upland systems to 2.3 t ha^{-1} for improved inland valley lowlands. Production from most systems is assumed to be oriented to subsistence needs; the inland valley swamps systems are presumed to be the only ones to be occasionally market-oriented, although data are lacking to confirm this supposition.

We used representative factor and output prices for 1994 to value costs and returns, and computed the social value for rice based on the 1994 freight on board (FOB) price for Thai 35% broken rice (\$245 t^{-1}) with an exchange rate of 600 Leones to the US dollar, plus shipping and handling charges to the final destination of each domestic rice commodity system (e.g. at the representative farm 250 km inland from Freetown).

Table 4 presents the aggregate PAM for rice production in Sierra Leone. When valued in private prices (the nominal prices actually faced by farmers and agents, shown in the first row), domestic rice production consumed a total of \$87.5 million in production costs in 1994, generated \$129.9 million in revenues, and thus yielded \$52.4 million in profits. When revalued in terms of opportunity cost (the underlying economic value of the factors and output, shown in the second row), revenues and profits increase while costs remain essentially unchanged. The third row of the table ("divergences") is the difference between the first two rows, and can be attributed either to the impact of policies or market failure. Looking at the revenue column, the rice sector as a whole receives \$11.9 million less in revenue than the parity value of the rice it produces. Producers receive less than the parity value because local rice markets in rural areas are largely insulated from the imported rice market due to high transportation costs, with prices being determined by local supply and demand conditions. The differential is in effect a neutral welfare transfer since it represents a transfer from farmers (foregone profits) to themselves as consumers (rice expenditure savings).

Table 4: National aggregate PAM (in US\$ millions) Sierra Leone.

		Costs		
	Revenues	**Tradable inputs**	**Domestic factors**	**Profits**
Valued in private prices	A 129.9	B 7.9	C 69.6	D 52.4
Valued in social prices	E 141.7	F 7.8	G 70.4	H 63.5
Divergences (transfers)	I (11.9)	J 0.1	K (0.8)	L (11.1)

Table 5: National aggregate PAM (in US\$ millions) Niger.

Valued in private prices	A 17.0	B 3.8	C 7.4	D 5.8
Valued in social prices	E 16.5	F 3.9	G 6.5	H 6.0
Divergences (transfers)	I 0.6	J (0.1)	K 0.9	L (0.2)

Numbers in parentheses indicate negative values.

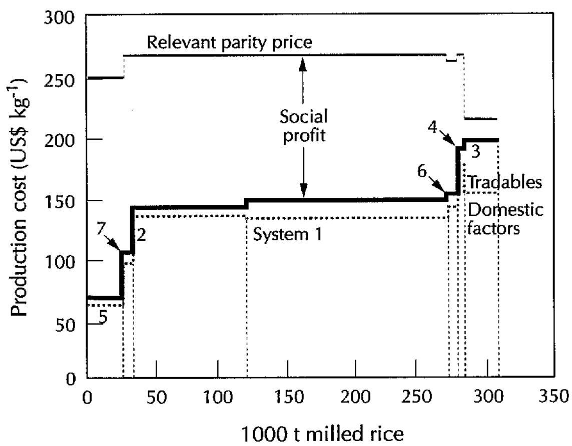
Several indicators can be derived from Table 4. Positive private profits mean that financial incentives exist and that rice production is a viable activity for operators in the sector, at least in the short run. More importantly, positive social profits indicate that the activity has a comparative advantage and contributes to raising national income, and so is most likely economically viable in the longer term. The national average Domestic Resource Cost (DRC), computed as cells G/(E-F), is 0.53. That it is well below one, means that the opportunity cost of domestic factors consumed in producing rice is significantly less than the net foreign exchange saved by avoiding having to import a marginal unit of rice.

Another policy indicator is the Nominal Protection Coefficient (NPC), which is computed as cells A/E and tells us to what degree a differential exists between domestic and parity (world) prices. If there is no distortion, then the NPC equals one. For Sierra Leone, the NPC is 0.92, again showing, that local rice prices are somewhat lower than parity prices, representing an implicit subsidy to consumers and an implicit tax on producers.

The same type of results is generated for each individual commodity system, permitting their comparison. All commodity systems generate a net private profit for operators within the sector as well as a net social profit for the nation (Table 2, page 15). Among the systems, both financial incentives (private profits) as well as indicators of longer term economic viability (social profits) are highest in the mangrove and riverain grassland systems, and lowest in the improved inland valley swamp and market-oriented systems.

These results are presented visually as a step supply curve (the solid black line) in Figure 1. Each step represents total social costs for an individual commodity system, starting with the lowest cost to the left. The length of the step corresponds to that system's current contribution to national production of rice. Production costs are divided into tradables (above

Figure 1: Supply curve for Sierra Leone rice production valued in social prices.



Note: Refer to Table 2, page 15 for commodity system descriptions.

the dotted grey line) and domestic factors (below the dotted grey line). As evident in Figure 1, tradables — mostly seed — account for only a very small portion of total costs. The green line indicates the parity price at which the rice produced by each system is valued, and so the area between the parity price and the supply curve represents the net social profit.

DRC coefficients confirm that the same pattern exists in terms of comparative advantage. That all DRCs are less than one (or equivalently, that social profits are greater than zero) indicates that all seven existing systems enjoy a comparative advantage. This means that rice production in all seven systems is efficient and contributes positively to national income.

The poor results for improved inland valley swamp systems reflect the lack of significant sustained yield improvements achieved in these projects despite often large investments in land development to improve water control. Farmers in such projects often find that the higher labor requirements associated with maintaining improved systems does not fit well into their farming systems, and so they adopt a more extensive — and lower yielding — production strategy.

The rice economy of Niger

In the interior Sahelian country of Niger, rice plays a less important role in a food economy otherwise dominated by millet and sorghum. Traditionally, rice was only consumed within a small production zone along the Niger River in the southwestern corner of the country. Following independence in 1960, rice consumption grew rapidly at an average 10% a year through to the mid-1980s as rice became increasingly popular among the growing urban population. Its growth has since slowed and now roughly keeps pace with increasing population. Rice currently accounts for an average 5% of caloric consumption nationally, with the average Nigerien consuming 13 kg of rice annually.

"Like Sierra Leone, Niger is dependent on imports for one-third of its rice consumption requirements."

Traditionally, domestic rice production was limited to flooded systems along the Niger River until irrigated rice production was introduced with the development of pump-irrigation schemes beginning in the mid-1960s. Continued irrigation development in the 1980s has permitted rice area and production to expand at par with population growth in recent years (*see* Table 1, page 14). Like Sierra Leone, Niger is dependent on imports for one-third of its rice consumption requirements.

Since independence, the central tenet of Niger's rice policy has been the development of irrigated rice production, both to meet increasing demand for rice and to provide the nation with a source of food production less vulnerable to climatic risks. The government adopted what might be termed an "industrial" approach to achieving these objectives, directing a large share of public agricultural investment into the construction of sophisticated medium- and large-scale pump-irrigation schemes along the Niger River and three industrial rice mills. During much of the 1970s and 1980s, the government directly managed nearly every aspect of the rice sector, creating parastatal agencies to run the schemes; manage the farmers; supply inputs and custom-hire services; run the mills; and, handle the rice trade, including imported supplies. As the state gradually reduced its involvement in selected aspects of the rice sector under structural adjustment reforms beginning in 1984, rice policy concentrated on protecting the state's "industrial" investments. This took the form of continued support to the public irrigation schemes and an escalating protectionist trade policy to ensure the survival of the national rice milling company, Riz du Niger (RINI). RINI faced increasing competition from imported supplies made artificially cheap by the overvalued CFA franc. Political instability stalled the reforms in the early 1990s, but the devaluation of the CFA franc in early 1994 improved the competitiveness of domestic production and permitted a final set of reforms to be implemented. As of late 1994, policies having a direct impact on the rice sector include continued public subsidies to maintenance of the major irrigation works, a 10% tariff on rice imports, import taxes on inputs and equipment, and various domestic taxes (e.g. market and business taxes).

At present, the domestic component of Niger's rice sector is concentrated in the Niger River Valley production zone. An estimated 80-90% of national production comes from intensive, high-input irrigated systems in the public schemes located along the river. Rice growers farm small plot (0.25-0.5 ha), using animal traction for land preparation, applying large amounts of fertilizer, and manually transplanting and harvesting high-yielding semi-dwarf varieties, mainly IR 1529 and BG 90-2, with two harvests per year. Paddy yields average 4.7 t ha^{-1}. The remaining national production is grown in traditional, low-input flooded systems (average yield 0.7 t ha^{-1}) or in private small-scale pump-irrigated systems (5.0 t ha^{-1}) that have begun to appear. Most paddy (50-70%) is milled by small-scale operators using Engelberg-type rice mills, whether destined for consumption on-farm or for sale. RINI, now largely privatized, handles another 20-25% of national production in its three industrial rice mills. The remainder is hand-pounded.

Most domestically produced rice is consumed and traded locally in the Niger River Valley area, which encompasses the capital, Niamey, although a small volume of RINI supplies may be distributed to other towns to the east. Imported rice supplies are mostly 25-35% broken rice coming from Asia, usually via the ports of Lomé or Cotonou. Trade of both locally produced and imported rice is handled by the private sector.

We again constructed a Policy Analysis Matrix (PAM) to evaluate the economic efficiency of domestic rice commodity systems in Niger as they existed in 1994. The model includes seven commodity systems, accounting for an estimated 96% of national rice production. Paddy is assumed grown in three systems — traditional flooded, public pump-irrigated, and private pump-irrigated — by a representative producer located 25 km from the town of Tillabéri in the main production zone. Based on information from key informant interviews, production from these three systems was allotted to on-farm consumption or marketed toward the main urban center, Niamey, with the bulk of production being milled by small-scale rice mills. Traditional hand-pounding of paddy is considered the main milling technique for production from traditional flooded systems that is kept for consumption on-farm, whereas the principal source for RINI paddy is the public irrigated sector.

The same world price used in the Sierra Leone study was also used here to value the opportunity cost of the higher quality local rice, whereas the 1994-95 world price of $220 t^{-1} was applied to lower quality rice (100% brokens). The post-devaluation exchange rate of 530 CFA francs to the US dollar was used, and assumed to correctly reflect the underlying equilibrium exchange rate. The rural labor market was presumed to function competitively, and a representative daily wage of 750 FCFA was used. Only the opportunity cost of capital to society (5% per annum) is considered different from the real interest rate (10%) faced by agents in the sector.

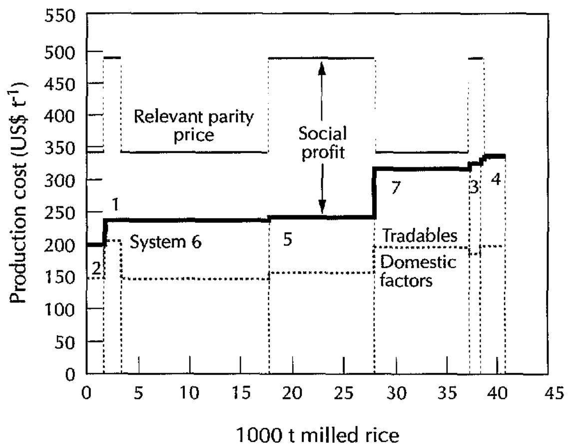
Table 5 (page 16) summarizes results of our analysis at the national level. The first row indicates that in financial terms, domestic production provided a total $17.0 million in revenues on $11.2 million in tradable and factor inputs, thereby generating $5.8 million in profits. The second row revalues costs and returns in terms of their opportunity cost to society, and confirms that rice production in Niger is highly profitable in social terms. A comparison of revenues in the two rows suggests that prices received for domestically produced rice are higher than their parity equivalents, mostly attributable to the protectionist tariff on rice imports. The differential of $0.6 million represents a welfare transfer from consumers toward farmers, millers, and traders in the rice sector. Continued subsidized provision of management and maintenance services for public irrigation schemes, only partly offset by import taxes on certain inputs, explains why operators in the sector pay less than value for tradable inputs. Similar subsidies in terms of factor costs (labor, capital) are more than offset, however, by the impact of higher private than social interest rates. Overall, there is a small net transfer, or implicit tax, of $0.2 million from the domestic rice sector towards the rest of the economy.

Positive private and social profits again indicate that rice production offers sufficient financial incentive to ensure its short-run viability and sufficient comparative advantage to ensure its longer-run sustainability. The overall DRC is 0.52. The NPC is very close to one at 1.03, suggesting that the import tariff and other rice policies introduce minimal distortion between the world rice prices and domestic prices.

"despite high yields, private irrigation offers the lowest financial profits per unit of output, and also exhibits borderline comparative advantage when market-oriented"

Comparing commodity systems (Table 3, page 15; Figure 2), we can see that the most efficient and probably most viable systems in the longer term are the traditional flooded and public irrigated production. Private pump-irrigation appears the least promising; labor and irrigation water pumping costs are substantially higher in the small-scale private irrigation schemes than in the larger-scale public schemes. Thus, despite high yields, private irrigation offers the lowest financial profits per unit of output, and also exhibits borderline comparative advantage when market-oriented. The results also confirm that for paddy produced in the public

Figure 2: Supply curve for Niger rice production valued in social prices.



Note: Refer to Table 3, page 15 for commodity system descriptions.

irrigation schemes, the small-scale milling sector offers significantly higher incentives, both financial and economic, for rice destined for the market than does the industrial milling sector.

Comparing Sierra Leone and Niger

Despite the very different environments and the role rice plays in the food economies of Sierra Leone and Niger, the evolution of their respective rice policies is strikingly similar. In the face of increasing dependency on imported supplies in the 1970s and early 1980s, both governments chose to invest in capital-intensive rice production and milling technologies and establish parastatals to develop production capacity and manage rice markets. In both cases, however, currency distortions and the tendency to manipulate trade policies worked against efforts to promote domestic production. Structural adjustment reforms in the 1980s and early 1990s reversed a number of these trends by reducing government intervention in the rice sector and realigning exchange rates.

The two countries also differ, however, in significant ways. Niger has pursued policies more oriented to protecting its investments for domestic production, whereas Sierra Leone has given more attention to protecting a politically important subset of consumers. Niger has successfully introduced capital-intensive irrigation development, whereas Sierra Leone's attempts to develop lowland rice production using capital-intensive technologies have largely failed.

What does the PAM tell us about the outcome of these processes? First, as of 1994, the same general patterns of comparative advantage exist for rice as those described by the earlier study in the 1970s. Domestic rice production generally enjoys a clear comparative advantage in both Sierra Leone and Niger, mainly because most production is destined for consumption inland from coastal port cities, where imported supplies offer the most competition.

Second, the comparative advantage of domestic production has been enhanced by the changing composition of the rice sector which has shifted away from unsustainable large capital-intensive technologies to more appropriate, smaller-scale technologies. The most significant trends in this sense include the reduced importance of motorized mechanization, the marginalization of industrial milling and rapid growth of the small-scale milling sector, and the replacement of bureaucratic marketing parastatals by private trade.

Third, the PAM offers two major unexpected findings:

- the clear comparative advantage exhibited by the capital-intensive high-input public irrigated systems in Niger; and,
- the relative disadvantage for the improved inland valley swamp systems in Sierra Leone.

For irrigated production in Niger, success has been linked to combining capital-intensive land development with an appropriately intensive rice production technology based on rice-rice double-cropping, animal traction land preparation, and transplanting that yields among the best agronomic performances for rice in West Africa. In Sierra Leone, the attempt to introduce an improved technology package based on better water control, tractor mechanization, and high input use in lowland ecologies proved to be inappropriately designed and unsustainable. As a result, existing improved inland valley swamps are generally exploited at lower than intended intensity, leading to the disappointing results.

Fourth, policy is seen to have relatively modest impact currently on domestic rice production in both countries. After structural adjustment reforms, policy interventions are generally limited to relatively modest *ad valorem* taxes on imported rice supplies and inputs, and in Niger, some continued subsidization of irrigation services. The welfare transfers associated with these policies are rather small.

Finally, comparison of the results of the economic analysis with current rice research priorities in each country indicate general congruence concerning the production systems and agro-ecologies identified as offering the highest potential for optimizing returns to successful research. In Niger, research is focused almost entirely on intensive irrigated systems. In Sierra Leone, research has concentrated mostly on lowland systems, particularly in the mangrove swamp and inland valley swamp ecologies. The results from the PAM would argue for more attention on upland systems. Based on past experience, it is also advised to shift emphasis from developing high-input technology packages to giving priority to more gradual introduction of appropriate low-input technologies.

Future collaborative research

Country studies of comparative advantage based on the PAM approach, such as those described in this article, will serve as the basis for WARDA's recently established policy economics project. The PAM provides WARDA and national researchers with a powerful tool for characterizing domestic rice production and the relative importance of different production systems. It also reveals criticial areas where we know too little, particularly with respect to traditional rice farming systems, rice milling, and marketing, that merit special research efforts. Most important, the PAM is a policy analysis tool that with minimal training is easily accessible to national policy analysts and policy makers. WARDA is already involved in transferring this valuable tool to national analysts through a series of workshops in collaboration with the World Bank's Economic Development Institute and USAID's Agricultural Policy Analysis Project. WARDA will continue extending the comparative analysis studies to other countries in the region, and in this manner will develop a network of country PAMs sharing a common methodological approach that will provide the basis for integrated regional analysis in the near future.

Soil degradation in the Sahel: myths and reality

M.C.S. Wopereis, J. Ceuppens (SAED), P. Boivin (ORSTOM) and K. Miezan

For non-insiders, the concept of growing rice in the Sahel is hard to grasp. "The Sahel" brings back images from the 1970s of dry, barren and cracked land, crop failures, dramatic grain shortages, and famine. It is an environment where one would not expect rice, which is usually associated with abundance of water.

"the main crop grown under irrigation by Sahelian farmers is rice"

While millet and sorghum are still the main rainfed cereals grown in West Africa, some 200 000 ha in the West African Sahel (which includes parts of Senegal, Mali, Mauritania, Niger, Burkina Faso, Chad, Cameroon and Nigeria) are now under full irrigation control. Irrigation water from Sahelian rivers is brought to farmers' fields through pumping, dam irrigation, and diversion of waterways. Part of the irrigation infrastructure in place was constructed by the international donor community as a direct response to the droughts of the 1970s. The main crop grown under irrigation by Sahelian farmers is rice.

The use of irrigation in the Sahel has become controversial because results have not met expectations. It was anticipated that full control of irrigation would enable farmers to grow two rice crops per year. In reality, only 10% of rice fields in the Sahel is double-cropped. Actual yield levels per growing season are about 4 to 5 t ha^{-1}, which is well below the potential of 8.5 t ha^{-1}. A range of agronomic and socio-economic constraints is responsible for this yield gap. WARDA and the national agricultural research systems (NARS) of the region are trying to bridge this gap by supplying farmers with technologies tailored to local agronomic and socio-economic settings (e.g. varieties adapted to specific growing seasons in combination with advice on the best crop-soil-water management practices).

The ecological impact of irrigation in the (semi-)arid Sahelian climate and the sustainability of current and future irrigation systems has been gaining more and more attention over the last few years. The processes involved are complex and have led to controversy and misunderstanding. The purpose of this article is to shed light on these issues and to report on research progress in 1995.

The impact of irrigation

Irrigating a field implies not only adding water but also salts. In (semi-)arid climates like that of the Sahel, the concentration of salts in the soil solution may increase rapidly due to the high evaporative demand of the air. Moreover, if the drainage capacity of the soil is poor, irrigation water will stagnate in the topsoil. Salts that are brought in with the irrigation water are not flushed downwards and the result is *salinization.* Salinization refers to an increase in the total amount of soluble salts in the floodwater or soil solution and may cause osmotic stress in the rice plant. It can be expressed in concentrations of salts (milligrams per liter), or in electrical conductivity (EC in mS cm^{-1}; 1 mS cm^{-1} is equivalent to about 640 mg of NaCl per liter). Soluble salts move with water flow and soil salinity is, therefore, highly dynamic in space and time.

"The irrigation water of the major Sahelian rivers has a low salt content and is often considered to be of high quality. However, upon concentration it becomes highly dangerous."

The irrigation water of the major Sahelian rivers has a low salt content and is often considered to be of high quality. However, upon concentration it becomes highly dangerous. All major Sahelian rivers have a positive residual alkalinity, i.e. they contain a relatively large amount of carbonate ions relative to calcium and magnesium ions. Concentration of irrigation water containing positive residual alkalinity will lead to precipitation of calcite ($CaCO_3$). Soils that are relatively rich in calcium at the onset of irrigation have a certain buffer capacity against alkalinization. However, if soil leaching by the irrigation water is insufficient, and no preventive measures are taken, this buffer capacity will sooner or later run out. Due to the excess of carbonate ions as opposed to calcium in the irrigation water, precipitation of calcite will then occur at increasingly smaller concentrations of calcium, and increasingly higher concentrations of carbonate. Calcite will start to accumulate in the soil, and, due to the high carbonate concentrations in the soil solution, the pH will rise (*alkalinization*).

Eventually, the soil solution will consist of mainly carbonate and sodium ions, leading to an increase in the Exchangeable Sodium Percentage (ESP), i.e. the amount of sodium adsorbed at the negatively charged clay mineral surfaces (*sodification*). This secondary process changes the behaviour of the clay minerals and therefore of the soil, which may ultimately turn into a sterile, impermeable mass without a clear structure. The high soil solution pH may also separate organic matter in the soil from the soil matrix. Soils affected by sodicity and alkalinity are extremely difficult to rehabilitate as the processes involved are almost irreversible.

Salinization: the example of the Senegal River Delta

The salinity survey in the irrigation scheme of Thiagar (16°25'N, 15°70'W), northern Senegal (900 ha, constructed in the 1970s) was conducted because of large scale abandonment of double-cropping by farmers at the onset of the dry season in 1995. The main reasons mentioned by a group of 22 farmers of two different farmers' cooperatives were: problems in obtaining credit, a tight cropping calendar, a decline in soil fertility, and increasing levels of soil salinization. It was this last cause that prompted the survey reported here.

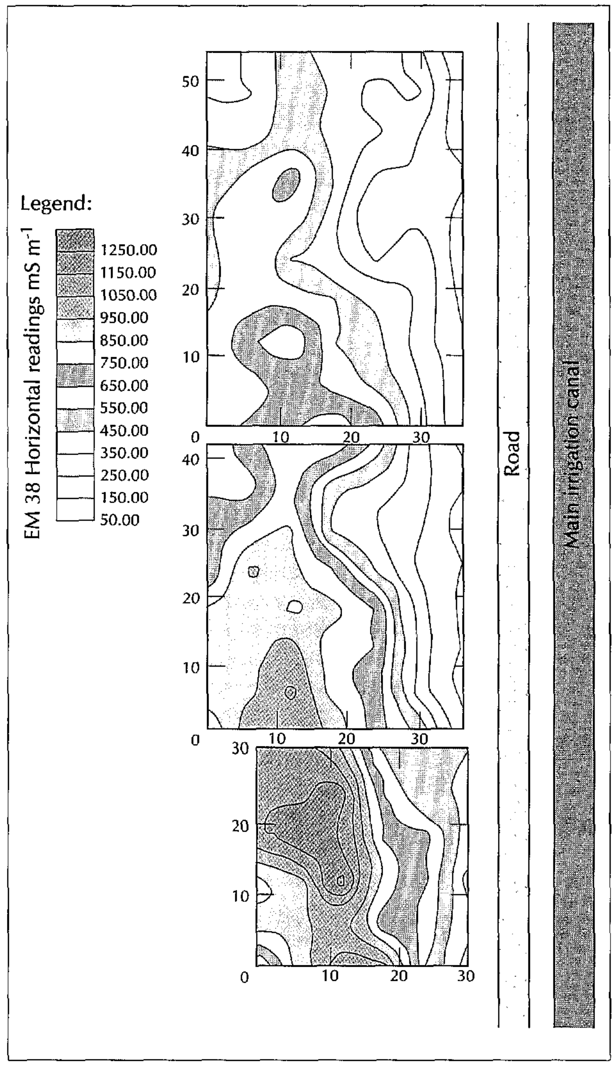
Most fields in Thiagar do not have their own drainage and irrigation facilities: up to four fields can be located between an irrigation and a drainage canal. Field size ranges from 0.5 to 2 ha. The scheme is mainly located on a heavy clay soil (Holladé or Faux Holladé type). Going to the boundary of the scheme soil texture becomes lighter (Fondé type). The percolation rate of Faux Holladé and Holladé clay is between 1 and 2 mm d^{-1}; for Fondé this is about 5 mm d^{-1}. The electrical conductivity (EC) of the groundwater table is generally very high and fluctuates between 20 and 100 mS cm^{-1} (EC of seawater is about 50 mS cm^{-1}). We defined four land use groups for Thiagar:

- double-cropping with drainage, until 1994 (DC-D);
- single-cropping with drainage (SC-D);
- single-cropping without drainage (SC-ND); and,
- abandoned fields, for salinity reasons (A).

Survey 1 In an initial survey (February 1995), the salinity status of four fields per land use group was assessed by horizontal and vertical above-ground measurements of soil electrical conductivity on a regular 6 x 6 m grid, using a Geonics EM38 electromagnetic induction meter (Geonics Limited, Ontario). The EM38 was selected for this survey because it determines soil electrical conductivity of a large volume of soil which reduces its variability. A second important advantage is that measurements can be taken almost as fast as one can walk from one site to another. A total of 3300 horizontal and vertical electromagnetic measurements were conducted in Survey 1.

Salinity contour lines only continued through the bunds (embankments) for group A (Figure 3), indicating that the salinity of abandoned fields was strongly related to soil characteristics (depth of clay layer and water table) and overall topography, regardless of the presence of bunds. Contour lines for the other land use groups were interrupted at the bunds (Figure 4). For these fields, salinity depended

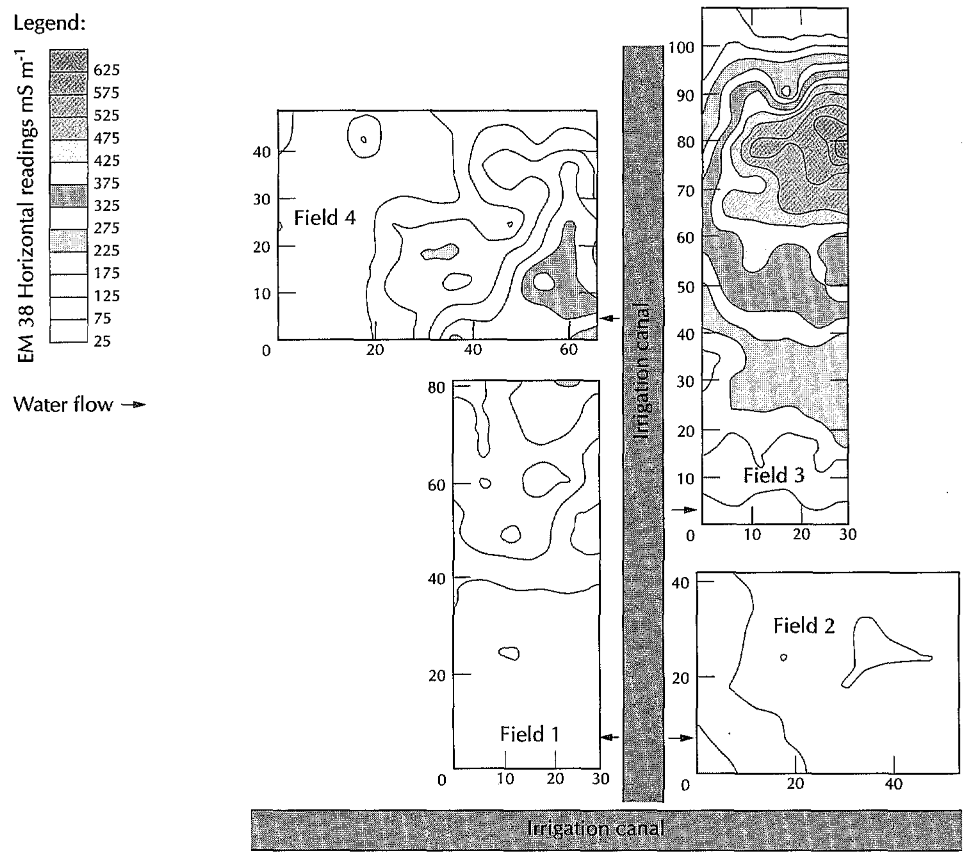
Figure 3: Soil salinity maps of three fields, abandoned for salinity reasons.



more on water management (position in irrigation line and drainage line), farmers' practices and field topography than on soil characteristics. Generally, the last fields in an irrigation line had a higher mean salinity ("dirty" water having been passed on from field to field). The effect of field topography is highlighted by the salinity contour maps of land use group SC-ND (Figure 4). Lower parts of the fields were much more saline than higher parts. This was most probably due to the accumulation and subsequent evaporation of saline water at the end of the growing season.

Survey 2 In order to study the effect of cropping systems, water management and surface drainage, 24 more fields

Figure 4: Soil salinity maps of four single-cropped fields without drainage (SC-ND).



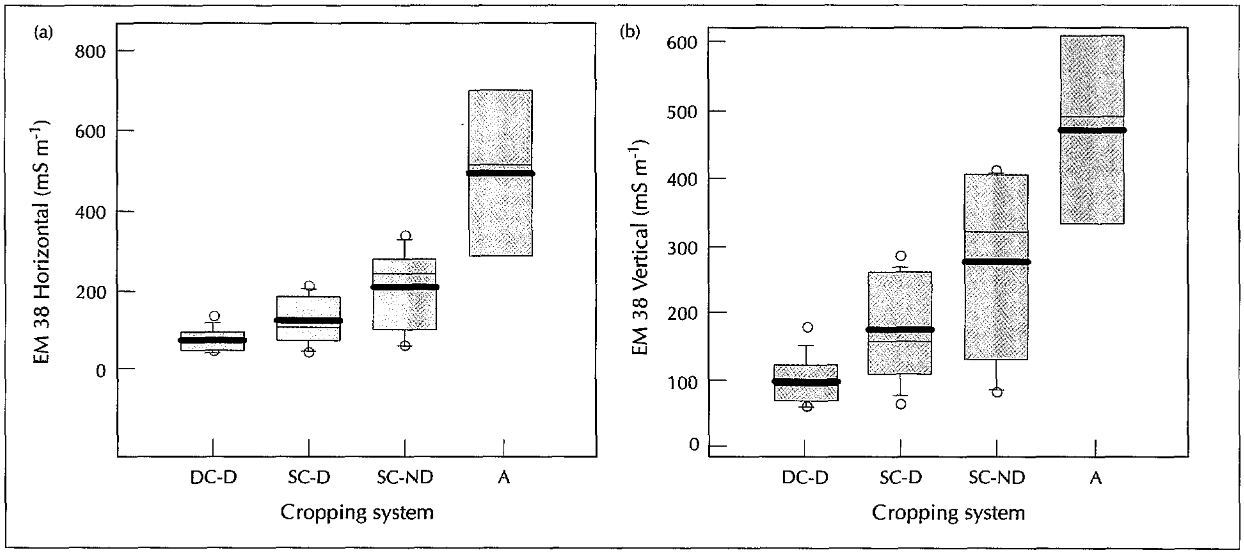
were surveyed in April 1995. Average EM38 readings per field ranged from 40 to 800 mS m^{-1}, very high compared to those reported in literature. Vertical readings in our surveys were generally higher than the horizontal readings, most probably due to the strong influence of the shallow saline groundwater table depth in the Senegal River Delta.

The effect of cropping systems and drainage on soil salinity is shown in Figure 5 *overleaf*. Mean salinity increased in the following order: DC-D<SC-D<SC-ND<A. Fields with drainage under double-cropping were least saline, contrary to farmers' thinking. Two main processes are building up salinity levels in the soil profile:

- capillary rise from the saline ground water table; and,
- salts brought in by the irrigation water.

In the case of double-cropping, the first process can only occur during 3-4 months (in flooded rice fields, capillary rise is blocked by percolation). Double-cropped fields are always drained in Thiagar, so with two to three flushings during the growing season, salts brought in by irrigation water can be evacuated. If the topsoil is flushed before the start of the growing season, salts accumulated by capillary rise are removed. So, with good water management, salt levels in a double-cropped field should go down or remain constant at a low level. For single-cropped fields, capillary rise is present during 9 months. Depending on soil type and depth, and electrical conductivity of the water table, 2-8 t of salt are brought to the topsoil during this period. This amount of salt will require much more flushing at the beginning of the growing season. Thus, for single-cropped fields without drainage, the salinity level will increase almost inevitably in the topsoil. Even with drainage this might still be the case, if the groundwater table remains relatively close to the surface throughout the fallow period. The reasoning above is further confirmed by the low variability of the mean EM38 values obtained for double-cropped fields, as compared to the variability obtained for single-cropped and abandoned fields.

Figure 5: Box plots of horizontal (a) and vertical (b) EM38 readings as a function of land use.



EM38 measurements were calibrated with conventional laboratory EC measurements using two sampling sites close to the EM measurement site (Table 6). The same trend in soil salinity as with the EM38 readings was observed: DC-D<SC-D<SC-ND<A. Rice yields decline sharply if average topsoil salinity (saturated paste extract) is greater than 3-4 mS cm^{-1}.

For single-cropped fields, saturated paste EC values for the topsoil (0-5 cm) range from approximately 5-10 mS cm^{-1}. This indicates that yield reductions due to salinity can be expected for these land use categories. If farmers grow only one crop a year, flushing of surface water at the onset of the wet season and during the growing season is, therefore, essential.

Table 6: Comparison of electrical conductivity (EC 1:5 soil extract) and volumetric moisture content determined for different soil depths and above-ground electromagnetic EM38 readings for different land use groups.

Land use	Depth (cm)	EM38 (mS m^{-1}) Vertical	EM38 (mS m^{-1}) Horizontal	EC (mS cm^{-1})	Moisture content (%)
DC-D	0-5	98	73	0.3	9.1
	10-15			0.2	20.1
	30-35			0.2	30.7
SC-D	0-5	176	126	1.3	9.7
	10-15			0.7	20.2
	30-35			0.6	31.4
SC-ND	0-5	298	223	2.0	13.2
	10-15			1.2	19.5
	30-35			1.3	26.0
A	0-5	429	477	9.2	13.2
	10-15			4.5	22.8
	30-35			2.0	26.8

DC-D: double-cropped fields with drainage; SC-D: single-cropped fields with drainage; SC-ND: single-cropped fields without drainage; A: abandoned fields.

Alkalinization: examples from Senegal, Mali and Mauritania

Yield reductions caused by alkalinity have not yet been reported for the Senegal River Basin. However, there is a lot of evidence that alkalinization processes are on-going. Detailed surveys conducted by France's Institut français de recherche scientifique pour le développement en coopération (ORSTOM) in the region of Podor, Senegal, showed that carbonates are accumulating in the topsoil of soils under irrigation. The accumulation rate differed from scheme to scheme but highest values were found for village and private schemes, which have no drainage facilities. Lowest accumulation rates were found in formerly parastatal schemes, which have adequate drainage facilities. Accumulation of carbonates indicates that the internal drainage capacity of the soil is insufficient, i.e. irrigation water is concentrating in the soil profile, which may ultimately result in alkalinization if the buffer capacity of the soil — in terms of calcium ions — runs out. Accumulation of carbonates is, therefore, very alarming.

"Irrigation without drainage in the Sahel will always lead to soil degradation."

Irrigation without drainage in the Sahel will always lead to soil degradation. In the Senegal River Delta, private initiative has lead to a large expansion of the area under irrigation, almost entirely without drainage. Fields are poorly leveled and are usually abandoned after a few years of rice cropping because of weed problems and salinity. As long as there is sufficient land available and there is no government intervention, this process of "shifting irrigation" will continue. Yet these abandoned fields are relatively easy to rehabilitate as the main problem is an excess of easily soluble neutral salts.

The situation in the Senegal River Delta is, however, relatively unique. Soils are often rich in gypsum and have, therefore, a good buffer capacity against alkalinization. In the Senegal River Middle and Upper Valley, and other areas in the Sahel, the buffer capacity of soils against alkalinization is often poor. Accumulation of carbonates in the soil profile as observed in the region of Podor is, therefore, a reason for concern. In contrast to fields affected by neutral sodium chloride salts, alkaline, sodic fields are extremely hard to rehabilitate as it would require huge amounts of acid and gypsum. Very high pH values (pH > 9-10) have been reported in the inland delta of the Niger river in Mali. After 50 years of irrigation, the water table has risen from 30 m depth to the soil surface. The major crop grown, cotton, has been entirely replaced by rice, the only crop that tolerates water-logging. Elsewhere in the Sahel, irrigation is still relatively new, and advanced stages of alkalinity (pH > 9) have not yet been reported. The only other hard evidence the authors have comes from Mauritania (Foum Gleita) where farmers irrigate their crops with water from the Gorgol River, which has a positive residual alkalinity three times as high as that of the Senegal River.

Which crop is best for the Sahel?

As illustrated above, salinity in the Senegal River Delta is to a large extent caused by the capillary rise of salts from the shallow saline water table. This has nothing to do with "soil degradation". It is a natural process, not created by humans.

"Rice will often be the only crop that will do well in saline environments, as the ponded water layer will induce percolation of salts to the subsoil and desalinize at least part of the root zone."

Soils are also often sodic: a result of natural sodification due to the elevated sodium concentration in the water table. Rice will often be the only crop that will do well in saline environments, as the ponded water layer will induce percolation of salts to the subsoil and desalinize at least part of the root zone. With adequate water management (regular surface drainage), good yields may be obtained on highly saline, previously barren soils.

Growing industrial crops such as cotton and sugarcane on relatively heavy soils using furrow irrigation may quickly result in soil salinization as water movement will be almost exclusively upward due to the absence of percolation. Growing rice under ponded conditions will always ensure some degree of downward flow. Care should be taken, however, that this does not induce a steady rise in the water table. This might occur if soils are highly permeable, or if the lateral discharge rate of the water table out of the irrigation scheme is low. In the off-season, capillary rise of salts from a shallow water table may lead to salinization and/or alkalinization of the topsoil.

Soil degradation processes are complex, and a simple answer to the question, "Which crop is best for the Sahel?", is not available. Recommendations will very much depend on the physical and chemical characteristics of the major soil types in an irrigation scheme and should focus on the development of sustainable cropping systems (e.g. rice/non-rice rotations) tailored to local environmental settings.

Outlook

Soil degradation in Sahelian irrigation systems is on-going, due to inherent soil characteristics, the composition of irrigation water and current water management practices. Preventing soil degradation requires insight into: irrigation water quality, soil characteristics, cropping systems, farmers' plot management practices, the condition of irrigation and drainage infrastructure, and groundwater table fluctuations. A range of socio-economic factors may be added to this list. For example, in most irrigation systems in the Sahel, farmers do not own the land they exploit. Effective control of soil degradation involves, therefore, interventions at the plot, irrigation scheme, and policy levels. Field measures to prevent soil degradation include:

- precise leveling to avoid stagnation of water in depressions;
- adequate land preparation to facilitate flushing of salts from the root zone;
- surface water drainage cycles before and during the growing season;
- avoidance of drying fields by evaporation; and,
- soil tillage after the growing season to reduce capillary rise to the root zone.

At the perimeter or regional level it is crucial to install and maintain an adequate drainage infrastructure and monitor water table levels. Drainage water should be disposed of without creating problems elsewhere. Growing rice on highly permeable soils should be discouraged. Installation of subsurface drainage systems to drain the water table artificially is not a realistic option, as this would be extremely expensive and often not very effective because of heavy soil texture. Instead, planting trees may help to reduce water table depth. Good results have been obtained in Australia, where eucalyptus trees have lowered water tables by 7 m in 10 years. WARDA, in collaboration with NARS and ORSTOM, is currently testing simulation models to develop alternative low-cost land and water systems for the Sahel, preventing soil degradation. These systems will avoid concentration of irrigation water in the field, while maintaining the water table at a depth well below the root zone. The models should be able to simulate the impact of perimeter size, distribution of major soil types, water management and density of trees on groundwater table fluctuations.

The Sahelian climate makes the region potentially highly productive, but also fragile. The challenge for the coming years is to help the farmer exploit this potential in a sustainable way.

Towards new high-yielding, weed-competitive rice plant types drawing from *Oryza sativa* and *O. glaberrima* genepools

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A recent breakthrough in hybridizing Asian rice, *Oryza sativa*, with African rice, *O. glaberrima*, gave rise to a major thrust in WARDA's varietal improvement research: the development of weed-competitive upland rices for resource-poor and stress-prone environments.

Average yields on West Africa's two million hectares of upland rice fields are as low as one ton of grain per hectare. Considering that the most commonly grown cultivars can yield up to four tons, the yield gap is substantial. It reflects the multiple stresses that affect the crop and are largely beyond the control of resource-poor farmers. Weed competition is the most important yield-reducing factor, followed by drought, blast, and soil acidity. Traditionally, farmers manage these stresses through long periods of bush fallow. But population growth has led to a dramatic reduction of fallow periods in many areas, aggravating weed pressure and soil infertility.

Despite sustained efforts to improve upland rice cultivars using *Oryza sativa* L., their resistance to weed competition and drought remains poor. In contrast, many African indigenous *Oryza glaberrima* Steud. cultivars are highly weed competitive, and many resist drought, blast and other stresses. However, they have been marginalized by Asian rice, *O. sativa*, which has a higher yield potential. *O. glaberrima*, of which only cultivated forms are known, is now sporadically grown in upland areas for its superior grain quality, and in deep water ecosystems where flood-tolerant landraces have a comparative advantage. The species has never been used systematically in rice breeding because of the sterility barrier with *O. sativa*, its panicle type which has no or few secondary branches, its weak stems that easily lodge (bend over), and its tendency to "shatter" grain. The marginalization of *O. glaberrima* has resulted in a major loss of biodiversity.

> "an exciting area of research [is] the mobilization of African indigenous germplasm and advanced breeding tools to provide Africa's poorest farmers with locally adapted and productive technologies"

The present study, which aims at developing a detailed concept for high and stable yielding upland rice types drawing from traits of African and Asian rice, involved a team of breeders, physiologists, weed scientists and crop modelers. The plant type concepts, once refined and fully validated, will give direction to an exciting area of research, the mobilization of African indigenous germplasm and advanced breeding tools to provide Africa's poorest farmers with locally adapted and productive technologies.

Genetic sources in Africa for weed-competitive rice plant types

Success in crop improvement depends on the available genes for useful traits. Field evaluations of African rice germplasm in 1991 and 1992 showed that many landraces of *O. glaberrima* mature extremely early. In addition the species also possesses many adaptations to traditional shifting cultivation, including early ground cover development through profuse vegetative growth and droopy lower leaves, which help suppress weeds.

Some *O. glaberrima* types produce many tillers and panicles. In experiment I, the *O. glaberrima* accessions CG 14, IG 10 and ACC 102257 had between 220 and 307 tillers m^{-2} (mean 268), and nine *O. sativa* lines of diverse origin had between 119 and 240 tillers m^{-2} (mean 179). *O. glaberrima* is also a rich source of genetic resistance to blast, African rice gall midge, rice yellow mottle virus, root-parasitic weeds and nematodes, and drought.

The most crucial weakness of *O. glaberrima* as a crop is its low yield potential, resulting from its specific panicle type, and tendency to lodge and to shatter grains. All *O. glaberrima* accessions tested had no or few secondary branches on the panicles. In experiment IV, the landrace CG 14 had between 11.0 and 12.2 primary and between 15.2 and 24.0 secondary branches, depending on nitrogen resources. By contrast, the *O. sativa* line WAB 56-104 had 12.2 to 12.6 primary and 37.5 to 41.0 secondary branches. As a result of panicle architecture, most *O. glaberrima* materials produce only 75 to 150 grains per panicle, as compared to 250 or more grains in *O. sativa*. The low yield potential of *O. glaberrima* has motivated many farmers to replace it with *O. sativa* varieties in their cropping systems.

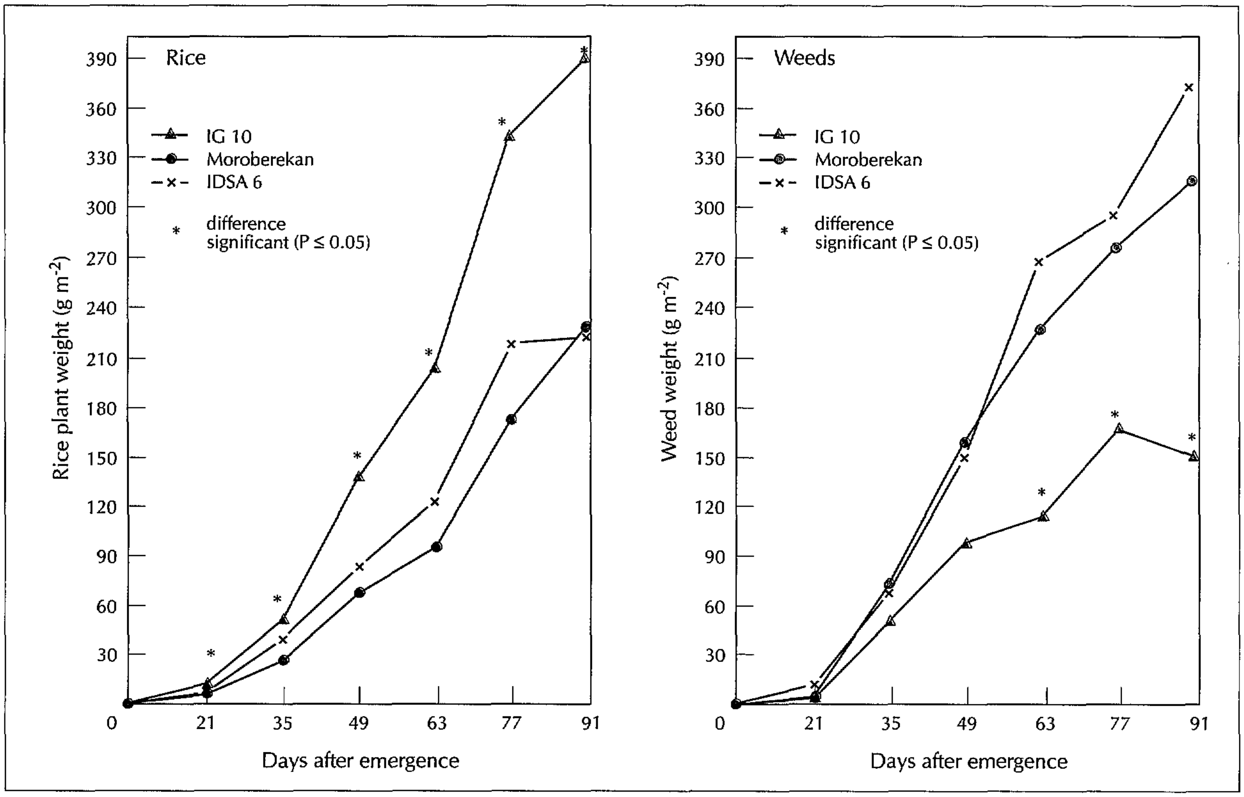
The weed competitiveness of existing *O. sativa* and *O. glaberrima* cultivars

The *O. glaberrima* cultivar IG 10 grew twice as fast as the improved upland rice IDSA 6 and the traditional cultivar Moroberekan, when competing with a natural weed population (Figure 6; experiment II). This rapid growth was associated with a strong suppression of weed growth. Only half the weed biomass was observed at mid-season in the IG 10, *O. glaberrima,* compared to IDSA 6 plots. Consequently, aggregate biomass in the plots was about the same for the three varieties, but weeds accounted for only one-third of biomass in IG 10 plots, and about two-thirds in IDSA 6 and Moroberekan plots. The superior suppression of weed growth by *O. glaberrima* types is thought to be due mainly to vigorous early growth. Seedlings of IG 10 tillered more and earlier than Moroberekan and IDSA 6. This vigor continued with IG 10 developing a greater leaf canopy compared to either Moroberekan or IDSA 6 (leaf area index (LAI) 2.4, 0.7 and 0.8 respectively; SE ± 0.14) at 49 days after emergence (DAE) in the presence of weeds.

The leaf area index of the *O. glaberrima* cultivar at 49 days after emergence was reduced by weed competition by 36% (SE ± 7.4), compared to 33% for Moroberekan and 56% for IDSA 6. Reduction in dry matter and tiller numbers were similar, indicating a marked effect of weeds on the vegetative growth of rice, particularly in the improved variety IDSA 6. At harvest, IG 10 showed considerable yield stability between the clean and weedy plots, with mean yield of 2.63 versus 2.1 t ha^{-1}, compared to Moroberekan (3.9 versus 1.49) and IDSA 6 (3.9 versus 1.4; SE ± 0.254). The weed competitiveness of IG 10 was due more to weed suppression than tolerance.

The weed competitiveness of the most extensively used parents in WARDA's interspecific breeding program was studied in experiment I. The *O. glaberrima* parent, CG 14, competed much better with weeds than the *O. sativa* parent, WAB 56-104 (Figure 7). CG 14 showed superior vegetative growth in clean weeded plots, but had lower yields than WAB 56-104. In the presence of weeds, however, CG 14 produced four times the biomass and eight times the yield

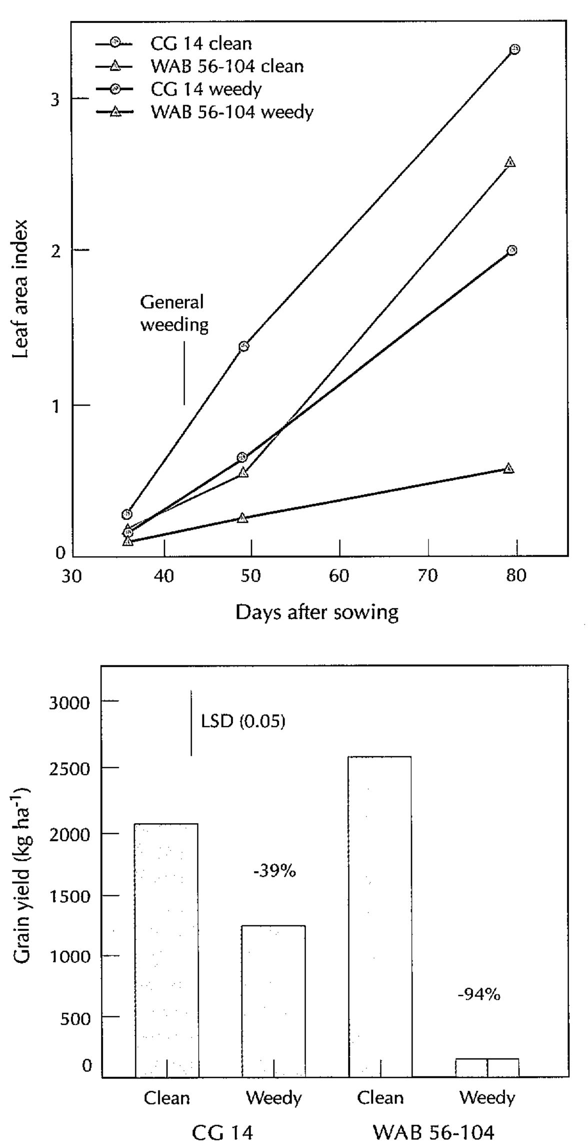
Figure 6: Time courses of rice plant and weed biomass for an *O. glaberrima* (IG 10), and a 'traditional' (Moroberekan) and an improved *O. sativa* (IDSA 6) cultivar. M'bé, Côte d'Ivoire, 1995 wet season.



Weed growth was not controlled after 14 days after emergence.

of WAB 56-104. The grain yield of CG 14 was reduced by weeds by 39%, as compared to 94% for WAB 56-104.

Figure 7: Leaf area index and grain yield of the *O. glaberrima* cultivar CG 14 and the *O. sativa* line WAB 56-104 grown with differential weed management (clean weeding or one single weeding cycle) under non-water-limited upland field conditions. M'bé, Côte d'Ivoire, 1994 wet season.



The LSD (0.05) is based on the factor "weed management".

Generating and testing interspecific hybrids

Hundreds of interspecific progenies were generated and field-tested during the past five years. Many of them had similar or higher yield potential, as compared to both parents and several improved check varieties. But we also noted that the selection pressure for high yield under low input conditions should be increased to improve yield stability.

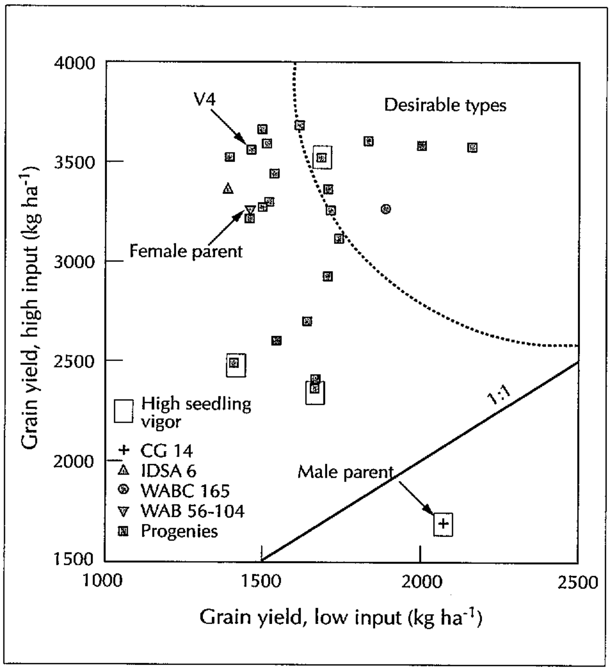
Although only seven out of 48 crosses produced more than five percent fertile seeds in the first generation, a remarkable diversity of plant types evolved. The highest fertility was obtained in F_1 hybrids that had the *O. glaberrima* CG 14, CG 20, T 2, YG 230 or YG 170 as parents. The F_1 plants resembled *O. glaberrima*, including infrequent secondary branching of the panicle, early seedling vigor and a short ligule. Two backcrosses to the *O. sativa* parents raised fertility to 30-65%, and helped combine the *O. sativa* and *O. glaberrima* features. Traits appeared that had been absent even in the parents, such as purple leaf sheath, awns and apiculus.

Morphological intermediates between *O. glaberrima* and *O. sativa* were frequent in some populations, such as WAB 449 (WAB 56-104 x T 2) and WAB 450 (WAB 56-104 x CG 14). Some of these had an intermediate ligule length, a trait that distinguishes the two species (*O. sativa* having a long ligule length; *O. glaberrima*, a short one). Most importantly, some intermediates combined the high yield potential of *O. sativa,* a result of high spikelet numbers caused by secondary branches on the panicle, with useful vegetative traits of *O. glaberrima* such as rapid vegetative growth, droopy lower leaves, high tillering, short duration between 75 to 100 days, and good grain quality.

Using conventional breeding methods, fixation and full fertility was achieved in the course of seven generations, during which useful introgressed traits were retained. Seed shattering was greatly reduced, and the selection of plants with thick culms (stems) solved the problem of lodging. Anther culture was used as an alternative path to achieve early fixation and high fertility. Two-fifths of the regenerated green plantlets were doubled haploids, and the others haploids and polyploids. Some of the F_1 and F_2 doubled haploids had 96-100% fertility. The rapid genetic fixation through double-haploidization has the additional advantage of retaining genes which would otherwise be lost through repeated selection. On the other hand, in a first set of regional trials conducted by Task Forces, many lines succumbed to diseases at some sites, probably due to the expression of many recessive genes. But the most interesting morphological plant types were so far obtained with anther culture.

A subset of progenies from CG 14 (*O. glaberrima*) x WAB 56-104 (improved tropical japonica) crosses was evaluated during 1995 using high-input and low-input management packages. CG 14 was among the top yielders under low inputs, but did not respond to increased inputs (Figure 8). By contrast, WAB 56-104 and the local improved check IDSA6 had low yields under low input, but yields more than doubled under high inputs. Another improved check variety, WABC 165 from Latin America, had relatively high yields in both treatments.

Figure 8: Relationship between grain yields obtained under high and low input management for 22 interspecific progenies, the *O. glaberrima* parent CG 14, the *O. sativa* parent WAB 56-104, and two improved *O. sativa* upland rices. M'bé, Côte d'Ivoire, 1995 wet season.



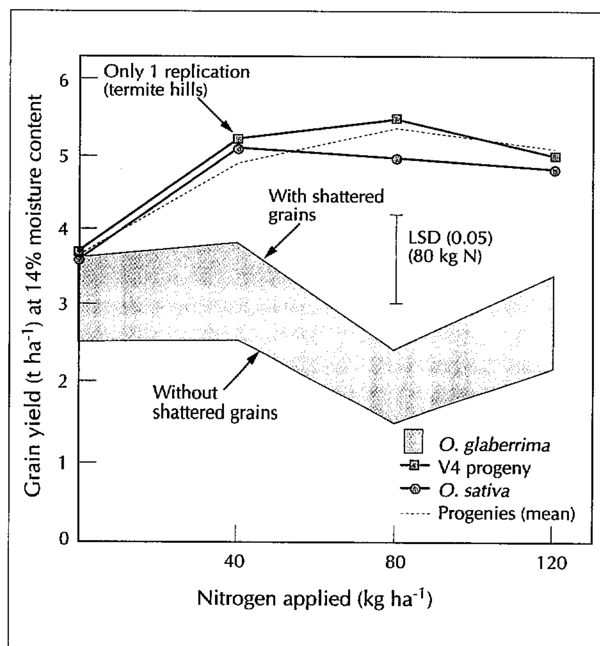
A cluster of interspecific progenies had slightly higher yields than WAB 56-104 and IDSA 6 under both high and low inputs, indicating a high yield potential and a very strong yield response to inputs. A smaller cluster of progenies yielded similarly to WAB 56-104 and IDSA 6 under low inputs, but were less responsive to increased inputs. None of the progenies followed the yield pattern of CG 14 — the *O. glaberrima* parent — probably because none had the glaberrima panicle type which had been selected against. But two progenies (top right in Figure 8 *above*) combined the high yields of CG 14 under low inputs with the high yields of WAB 56-104 under high inputs. These entries, as well as one that had outstanding seedling vigor and good yield potential, will be studied in detail during 1996.

Detailed morpho-physiological characterization of parents and selected progenies

During the 1995 wet season, we initiated a series of detailed growth analyses for selected interspecific progeny and their parents. The results will serve to develop crop models that predict the effect of various trait combinations on yield potential and stability in stress environments, particularly under weed competition. We report here the results of a first such upland experiment (IV), conducted under non-limiting water but variable N resources, for four progeny and their parents, CG 14 and WAB 56-104. Subsequent studies will introduce stepwise additional stress factors such as weed competition and drought, along with an expansion of model sensitivities to these stress factors.

Grain yield and yield components The *O. sativa* parent and the progenies showed very similar yields and yield responses to nitrogen application, the progenies having consistently (across N levels), but statistically not significantly, higher yields (Figure 9). (When comparing pairs of means, however, the progeny V4 significantly outyielded its parents in the 80 kg N treatment.) Yields of the *O. glaberrima* parent did not

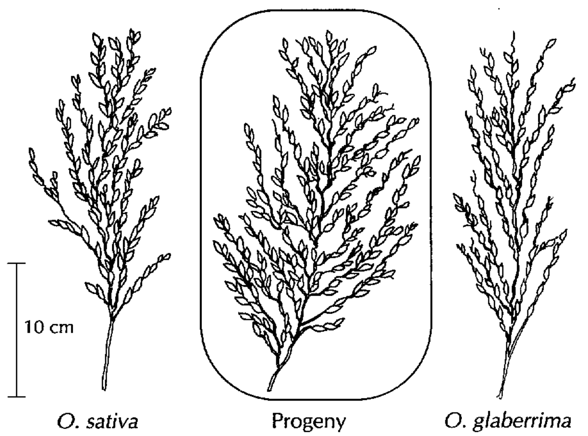
Figure 9: Grain yield as a function of N rate of the *O. sativa* cultivar CG 14, the *O. sativa* line WAB 56-104 and four interspecific hybrids. M'bé, Côte d'Ivoire, 1995 wet season.



respond to N application, probably due to lodging which was total in all treatments but occurred earlier at higher N rates. For all N levels, the *O. glaberrima* parent had the same grain loss of about 1 t ha^{-1} due to shattering (30-40% of the grain produced). The *O. sativa* parent and the progeny did not lodge or shatter. When considering both attached and shattered grains, all parents and progenies had precisely the same yield at zero N inputs (3.7 t ha^{-1}), and varietal differences only materialized as N was applied.

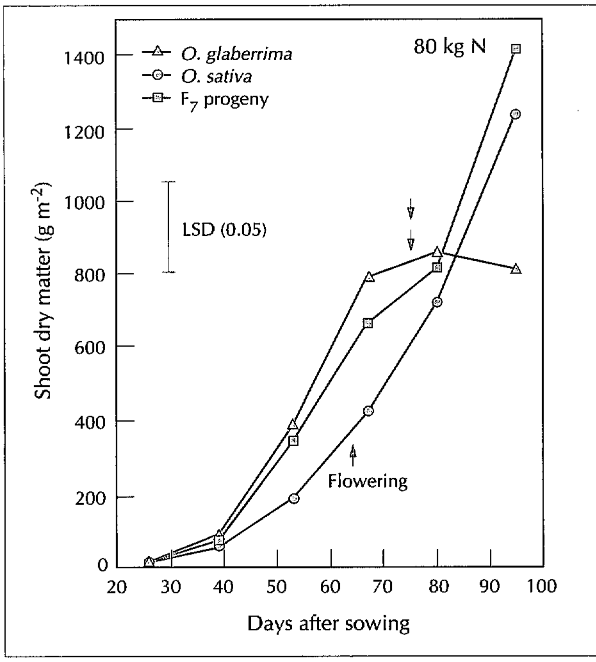
The similarity among the yields of the progeny and of their *O. sativa* parent was partly due to the high incidence of secondary panicle branches (1.53 secondary branches per primary branch in the *O. glaberrima* parent; 3.16 in the *O. sativa* parent; and, between 3.22 and 3.46 in the progenies). The progeny had comparatively open panicles that were mostly larger than those of both parents (Figure 10).

Figure 10: Panicle types observed for the *O. sativa* line WAB 56-104, the *O. glaberrima* cultivar CG 14 and the interspecific hybrid V4 (details in M&M, page 35). M'bé, Côte d'Ivoire, 1995 wet season.



Dry matter accumulation and leaf area growth The *O. glaberrima* parent and the progeny showed superior seedling vigor as compared to the *O. sativa* parent, resulting in rapid biomass accumulation during exponential growth (Figure 11). For the 80 kg N treatment, relative growth rates (RGR) of 18.7% per day were observed for the V4 progeny between 26 and 39 days after sowing (DAS), as compared to 18.4% for the *O. glaberrima* and 14.8% for the *O. sativa* parent. At the onset of linear growth between 39 and 53 DAS, the relative growth rate was 12.0% for V4, as compared to 11.6% for the *O. glaberrima*, and 9.8% for the *O. sativa* parent. Consequently, at any given amount of biomass on the plot, the *O. glaberrima* parent and the V4 progeny grew faster than the *O. sativa* parent. These varietal differences could be largely explained by N uptake and canopy architecture-related light use efficiency.

Figure 11: Time courses of aboveground (shoot) dry matter for the *O. glaberrima* cultivar CG 14, the *O. sativa* line WAB 56-104 and the interspecific F_7 progeny V4 (details in M&M, page 35) in an upland field fertilized with 80 kg N ha^{-1}. M'bé, Côte d'Ivoire, 1995 wet season.



The rapid initial growth of the progeny and their *O. glaberrima* parent was associated with faster leaf growth (Figure 12 *overleaf*). The *O. glaberrima* developed more than twice the leaf area of the *O. sativa* parent under zero-N inputs, and 3.5 times its leaf area in the 80 kg N treatment. The progeny were generally intermediate. Rapid biomass and leaf area growth, as in CG 14 and the progeny, are major components of weed competitiveness. Again, however, we noted that these traits were more strongly expressed in the progeny under high inputs, indicating that more emphasis must be placed on low-input selection environments.

A key to high vegetative growth vigor: specific leaf area Specific leaf area (SLA), which is the leaf surface a plant generates with a given leaf dry matter, was in part responsible for the extremely different LAI observed among genotypes. A high SLA, or "thin" leaves, reduces the physiological cost of leaf area growth, although at the expense of some of its photosynthetic potential. In this study, SLA depended strongly on genotype and growth stage, but not on N resources (Figure 13 *overleaf*). The *O. glaberrima* parent had high SLA through-

Figure 12: Time courses of leaf area index (LAI) observed in an upland field fertilized with 0 and 80 kg N ha^{-1} for the interspecific progeny (WAB 450-24-3-2-P18-HB) and its parents WAB 56-104 (*O. sativa*) and CG 14 (*O. glaberrima*). M'bé, Côte d'Ivoire, 1995 wet season.

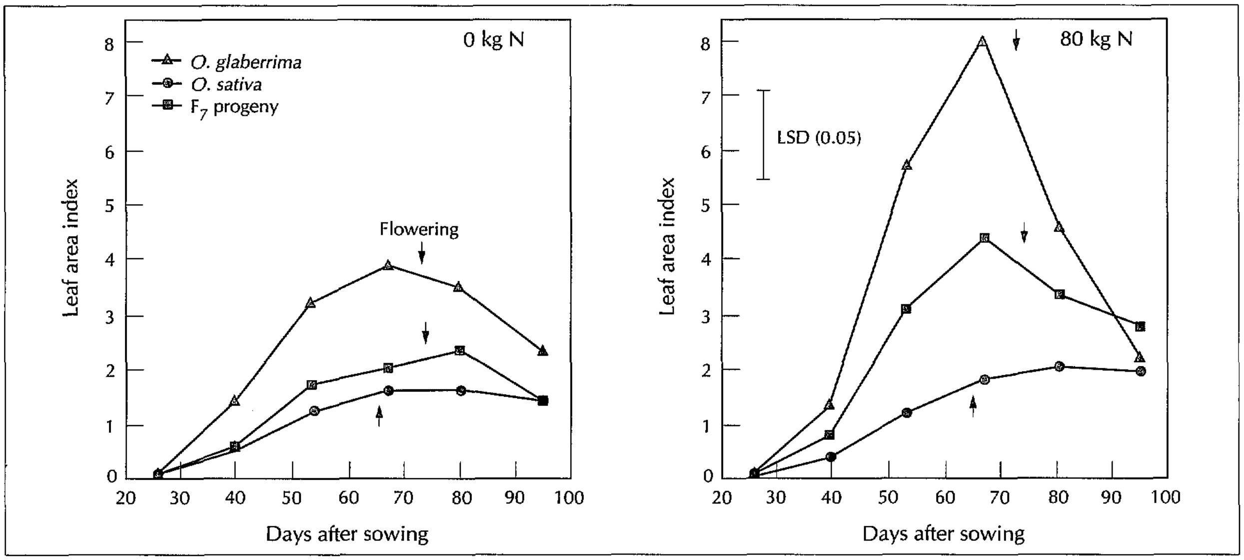
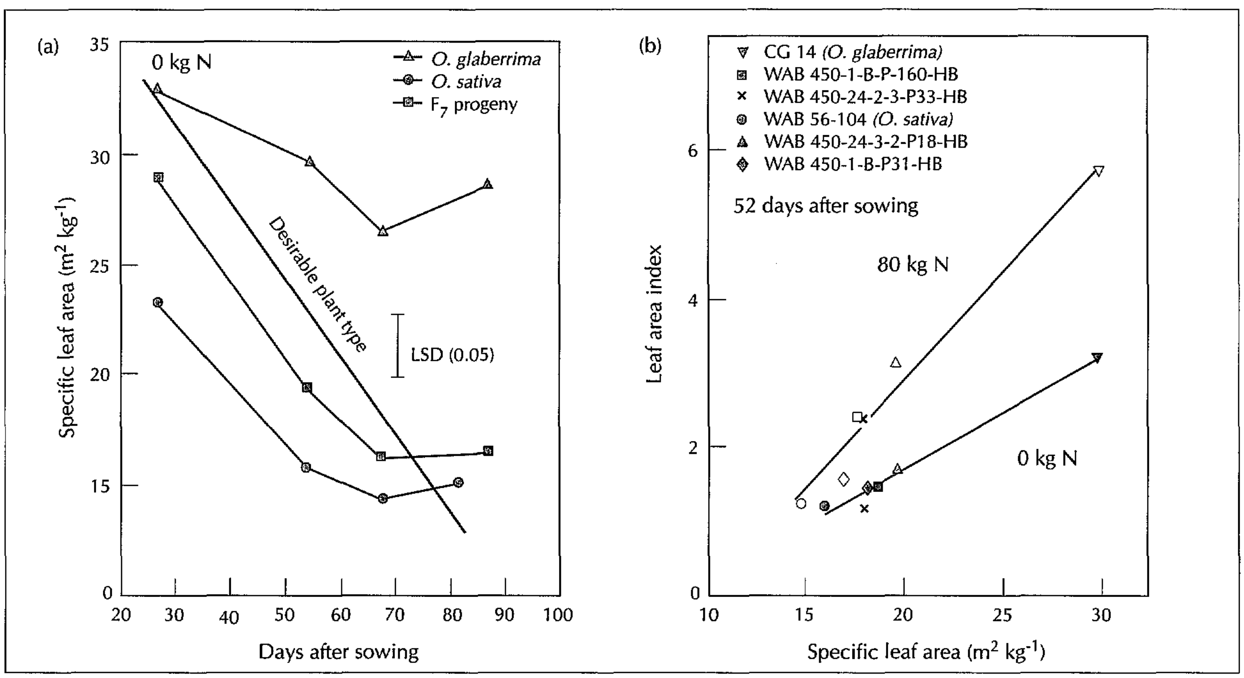


Figure 13: (a) Time courses of specific leaf area (SLA) for the interspecific progeny (WAB 450-24-3-2-P18-HB) and its parents WAB 56-104 (*O. sativa*) and CG 14 (*O. glaberrima*). (b) Relationship between leaf area index (LAI) and SLA across interspecific progenies and their parents, during late vegetative stage in an upland field fertilized with two N levels. M'bé, Côte d'Ivoire, 1995 wet season.



Note: (a) The black line indicates the "ideal" SLA for a high yielding, weed-competitive plant type.

out, whereas the *O. sativa* parent had a much lower initial SLA which even decreased in the course of development, indicating that the leaves were getting thicker. The four progeny had intermediate SLA during early growth stages, followed by a decrease as sharp as that of the *O. sativa* parent.

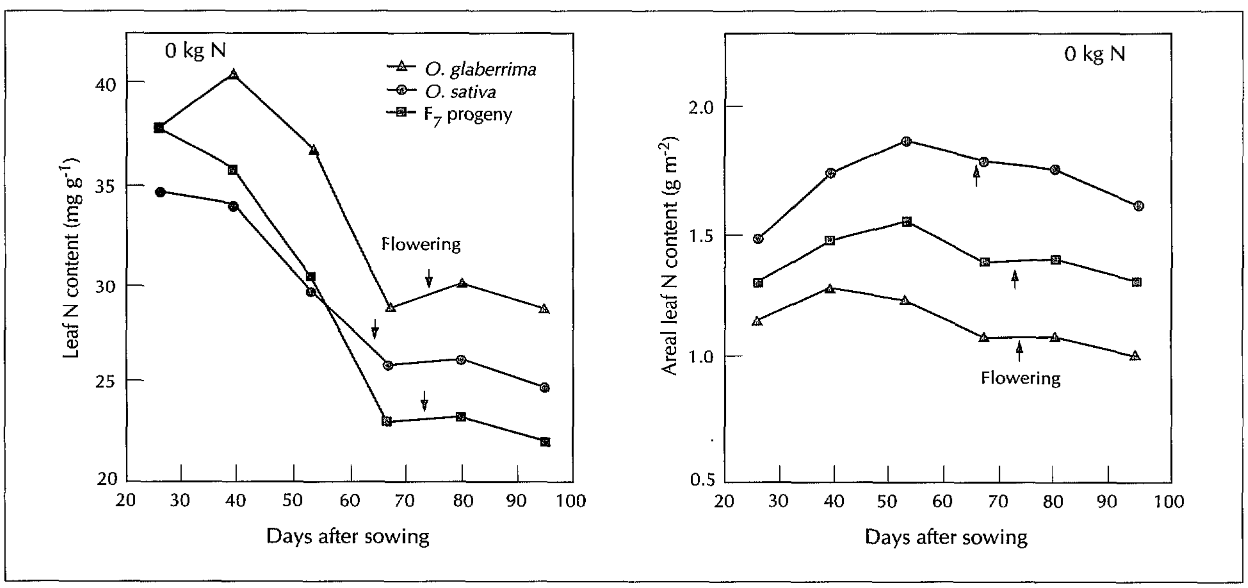
We observed linear correlations between LAI and SLA across genotypes at any given stage (shown for mid-season in Figure 13, page 32). The slope of these relationships depended on N inputs. Genotypes with high SLA produced much leaf area because fewer resources were invested per unit area. This, in turn, enabled a better light harvest and more rapid growth, as confirmed by simulations with the rice growth model ORYZA_1. Experiments II and IV confirmed that high SLA is a common trait in weed competitive *O. glaberrima* landraces. Consequently, particular attention must be paid to this trait in varietal selection, particularly during early growth when weed competition is most intense.

Tradeoffs between leaf area and nitrogen content Leaf N content is a major determinant of crop photosynthesis, and therefore, growth rate, on the basis of a given canopy architecture. There is generally a tradeoff between leaf area and leaf N content if N resources are limited. The best compromise between weed competitiveness and yield potential objectives is achieved if leaf area is maximized during early stages, and leaf N content maximized during reproductive stages. Such patterns are realized in plants that have high SLA during early stages (like *O. glaberrima*), and low SLA during later stages (like *O. sativa*). Figure 13 (page 32) demonstrates the "ideal" phenological pattern of SLA, to which the V4 progeny comes closer than its parents.

The *O. glaberrima* parent CG14 had a very low areal leaf N content, because of its thin leaves (high SLA), although the N content per unit dry weight was high (Figure 14). This resulted in comparatively pale leaves in *O. glaberrima* and some of the progenies, in which dry matter and N were spread over a larger leaf area. Consequently, the pale appearance of *O. glaberrima* in this study was not caused by N deficiency, but by the thin and translucent leaves. It also follows that selection for dark green leaves does not only result in plants with high N content, but also favors thicker leaves (low SLA). This may unintentionally favor plants with poor initial vigor and ground cover, and consequently, poor weed competitiveness. The effects of SLA on photosynthetic rates and drought resistance will be studied during 1996.

Dry matter partitioning A major physiological determinant of plant morphology is how a plant partitions photosynthate among its organs. We found small but consistent differences among the genotypes, confirming that the *O. glaberrima* parent invests more photosynthate in leaf blades during early development, whereas the *O. sativa* parent invests more in stem and leaf sheath growth. The V4 progeny was intermediate. Although the high assimilate partitioning to leaf

Figure 14: Time courses of weight-based and area-based leaf N content for the *O. glaberrima* cultivar CG 14, the *O. sativa* line WAB 56-104 and the interspecific hybrid V4 (details in M&M, page 35) under zero-N inputs. M'bé, Côte d'Ivoire, 1995 wet season.



blades in CG 14 evidently serves to maximize ground cover, this particular trait might be of no value in breeding because the overriding objective of lodging resistance requires the investment of greater assimilates in sturdy stems. In addition, it is technically difficult to screen for specific partitioning patterns.

"We observed in various weed competition experiments that profuse and early tillering is a major varietal determinant of weed suppression."

Tillering The *O. glaberrima* parent CG 14 produced twice as many tillers as the *O. sativa* parent in the zero-N treatment. The progeny had slightly fewer tillers than the *O. sativa* parent, and thus, did not show intermediate behavior. Tillering of both CG 14 and the progenies, however, responded more strongly to N inputs as compared to the *O. sativa* parent. There are clearly tradeoffs between tall, sturdy stems and high tiller numbers, and the present set of progenies are probably excessively on the side of sturdiness and height. We observed in various weed competition experiments that profuse and early tillering is a major varietal determinant of weed suppression. Tallness, on the other hand, primarily increases weed tolerance through "outgrowing". The *O. glaberrima* cultivars IG 10 and CG 14 are highly weed competitive despite their moderate height.

The particular interspecific progenies characterized in this study, although combining many desirable traits from both parents, still lacked the high tillering ability of *O. glaberrima* under low inputs. But other progenies carrying this trait have been identified during 1995 and will be evaluated in 1996. We will also study in more detail the role of tillering in rice/weed competition, particularly the ability of varieties to tiller at very early stages, and to rapidly fill spaces created by weeding at later stages.

Conclusion and outlook

We found strong morpho-physiological evidence for trait introgressions from *O. glaberrima* into an *O. sativa* background. Most of the introgressions are of adaptive value in a resource-limited production environment, particularly in weed-prone upland fields. They include:

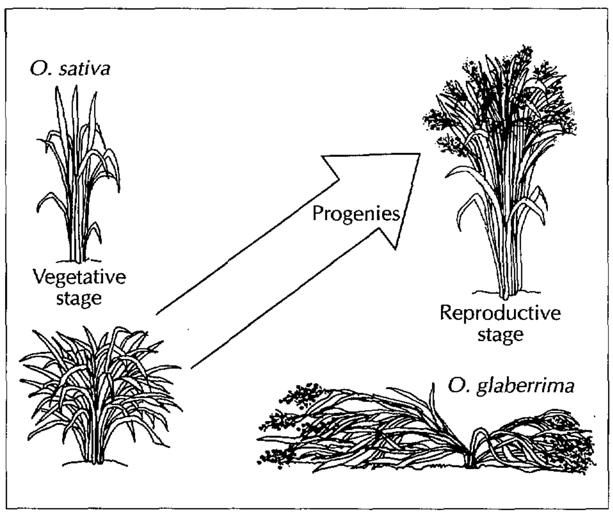
- rapid vegetative growth and leaf area development, at least in part caused by high specific leaf area and partitioning of much assimilate to leaves; and,
- droopy leaves during early growth stages, resulting in a high light extinction coefficient, and thus, high light use efficiency and ground cover.

Combined with useful traits from *O. sativa*, such as large panicles, sturdy stems and erect foliage during reproductive stages, these traits are expected to improve yield stability at a high level of potential yield. More work needs to be done, however, to combine these traits with a high and early tillering ability, and to express them in low-input environments.

Weed competitiveness is not the only adaptation that new plant types can draw from *O. glaberrima*. Although the underlying mechanisms are unknown, it is already evident that the *O. glaberrima* parent in this study, CG 14, is drought resistant. Many *O. glaberrima* landraces resist blast, rice yellow mottle virus and the African rice gall midge. Studies have been initiated to characterize these traits, trace introgressions through molecular markers, and develop models to compose and test environment specific plant type concepts.

The new ideotypes, and the screening tools that we will use to realize them, will emphasize the dynamic expression of morphological traits. Plants will be screened for a droopy, profuse foliage with high SLA during early growth stages, and for erect leaves with much lower SLA during reproductive stages. In other words, during early growth stages the new plant types will resemble *O. glaberrima* and during later growth stages they will resemble *O. sativa* (Figure 15). The interspecific progeny characterized during 1995 indicate that this ambitious objective is indeed feasible.

Figure 15: Basic concept for the development of a weed-competitive, interspecific plant type.



The underlying principle is to realize the weed-competitive traits of *O. glaberrima* during the vegetative stage, and the agronomically valuable traits of *O. sativa* during the reproductive stages.

Materials and method

Parent selection and hybridization:
During 1991-1992, 316 improved and 275 traditional *O. sativa* and 1130 *O. glaberrima* accessions were evaluated for morphological and agronomic traits in an upland field at M'bé, using IRRI's standard evaluation system. Eight *O. glaberrima* parents were selected on the basis of vigor and tiller number, including CG 14 and IG 10. Improved tropical japonica upland rices such as WAB 56-104 and WAB 181-18 were selected as sources for high yield potential. Out of 48 *O. sativa* x *O. glaberrima* crosses, 7 produced fertile grains. The F_1 were backcrossed twice to the *O. sativa* parents, followed by pedigree selection. Traits were fixed after 6 generations. Anther culture was used in a subset of crosses. Anthers were removed from F_2 at booting and placed in a modified N_6 growth medium with 0.5 mg l^{-1} Kinetin, 2 mg l^{-1} 2,4D, 5% maltose and 150 ml l^{-1} coconut milk. After 3-8 weeks, calli were transferred to MS medium. They developed in 3-4 weeks into plantlets which were treated with a hardening chemical to condition them for the transfer to the soil.

Field experiment I:
During the 1994 wet season, 12 *O. glaberrima* and *O. sativa* lines were studied for competitiveness with a natural weed flora on an upland field at M'bé (two-factorial RCB with 3 replications). Weed management was either clean weeding throughout, or one weeding cycle at 43 days after emergence (DAE). Fertilizer inputs were 14 kg N and 20 kg P ha^{-1}. Only observations on two lines, CG 14 and WAB 56-104, are reported.

Field experiment II:
During the 1995 wet season, a detailed study of the interaction between weeds and *O. glaberrima* (IG 10) and improved (IDSA 6) and "traditional" (Moroberekan) *O. sativa,* was conducted. The weed treatments were clean weeding throughout, clean weeding during the first 14 DAE, and weeding once at 28 DAE. Fertilizer inputs were 46 kg N (2-split), 40 kg P and 50 kg K ha^{-1}.

Field experiment III:
During the 1995 wet season, 22 fixed *O. sativa* x *O. glaberrima* progeny derived from conventional breeding and anther culture were evaluated in a yield trial with 4 replications under high and low input management on an infertile upland field. The parents (CG 14 and WAB 56-104) and the improved checks IDSA 6 and WABC 165 were also planted. High input plots were plowed and harrowed. In low input plots, vegetation was slashed and the soil scarified by hand hoe. High-input plots were fertilized with 100 kg N ha^{-1} (3-split), and 36 kg ha^{-1} each of P and K. Low input plots received only 40 kg N ha^{-1} as 2-split. High-input plots were kept weed free, and low-input plots were hand-weeded at 21 and 42 DAE. Seedling vigor was scored at 30 DAE.

Field experiment IV:
During the 1995 wet season, detailed growth and yield analyses of four *O. sativa* x *O. glaberrima* interspecific F_7 progeny and their parents were conducted on a fertile alfisol. The parents were CG 14 (*O. glaberrima,* V1) and WAB 56-104 (*O. sativa,* V2). The progeny were conventionally-bred WAB 450-1-B-P-160-HB (V3), WAB 450-24-3-2-P18-HB (V4), WAB 450-24-2-3-P33-HB (V5) and WAB 450-1-B-P31-HB (V6). The experiment had a two-factorial RCB design with 3 replications (6 genotypes and 4 N rates [0, 40, 80, and 120 kg ha^{-1} as 2-split]). All plots received 100 kg ha^{-1} P and 50 kg ha^{-1} K basally. Moisture was optimal due to supplementary irrigation. Seed was dibbled at 0.25 x 0.25 m. The following parameters were measured every 14 days: LAI and leaf, stem and panicle dry weight from 4 hills; specific leaf area (SLA) of fully expanded blades; tiller number; plant height; and leaf chlorophyll content using SPAD (Minolta), from which N content was also determined. Yield components measurements included the number of primary and secondary branches and grain shattering, based on the number of attached and missing spikelets.

Is lowland rice farming hazardous to human health?

T. Teuscher

Previous research by WARDA to characterize rice production systems in Côte d'Ivoire has indicated that some farmers associate lowland rice cultivation with health hazards. However, the scientific literature on West African water resource developments is non-conclusive with respect to health risks, in particular, those related to vector-borne diseases such as malaria and schistosomiasis (bilharziasis). As all past evaluations were of an experimental nature, comparing a typical village with and without irrigation structures or lowland developments close by, results of these studies are necessarily time- and site-specific. Some studies observed reductions; others, no change; and a few, increased frequencies, of vector-borne diseases among farm families cultivating lowland and irrigated areas. It was recognized that the health risks are not only related to the environmental changes induced by the development projects, but also to the household economic impact of the new cultivation systems.

"some farmers associate lowland rice cultivation with health hazards. However, the scientific literature on West African water resource developments is non-conclusive with respect to health risks, in particular, those related to vector-borne diseases such as malaria and schistosomiasis (bilharziasis)."

In order to improve strategic planning with respect to lowland rice cultivation, a multidisciplinary Health Research Consortium, based at WARDA headquarters and main research center at M'bé, Côte d'Ivoire, was created. The Consortium, which consists of six regional research institutions, became operational in March 1995. The first three-year project phase is financed by the International Development Research Centre (IDRC) of Canada, the Danish Agency for International Development (DANIDA) and the Government of Norway.

The Consortium's milestones

In 1995, the Consortium developed a multidisciplinary research protocol to evaluate the importance of vector-borne diseases related to irrigation and lowland rice farming practices, and to make comparisons with endemicity levels commonly found in an ecological transect through West Africa. Preliminary studies to provide the baseline for a population-based sampling were also begun.

In 1996 and 1997, multidisciplinary studies and the mapping of human health risks within the context of West African agro-ecosystems will be carried out. The Consortium's first phase will close with the development of a coherent multisectoral (agriculture, health, social welfare) intervention strategy that will reconcile agricultural development objectives with subsistence farmers' welfare.

During the second project phase, planned for 1998 to the turn of the century, the Consortium will carry out operational research to evaluate the processes of delivery and the impact of such interventions.

Working hypotheses

Two main hypotheses are to be tested by the Consortium during the first project phase. They are:

- Does the promotion of lowland rice cultivation result in an increased frequency of vector-borne diseases in resident smallholder farming populations living in rural, endemic areas?
- Does the intensification of lowland rice cultivation through improved water management increase disease risk in such populations?

Malaria and schistosomiasis and lowland rice cultivation

As malaria and schistosomiasis are most strongly associated with stagnant water, these two diseases were selected as indicator diseases of major importance. Across the three major ecological zones of West Africa — the Sahel, the sudan-savanna zone and the humid forest — the whole spectrum of malaria in Africa is represented.

"Across the three major ecological zones of West Africa — the Sahel, the sudan-savanna zone and the humid forest — the whole spectrum of malaria in Africa is represented. "

Low malaria transmission is found in the Sahel in Mali. Outside the irrigated perimeter, most residents are susceptible to clinical malaria illness only during and following the annual rains. Meanwhile, in the humid forest, year-round malaria transmission occurs, and 60% of the resident population is infected with malaria parasites without showing clinical signs of disease.

Schistosomiasis, on the other hand, is focally present in all three ecozones. In Mali, the occurrence of urinary and intestinal schistosomiasis is strongly associated with water resource developments, while in the more humid Côte d'Ivoire this association is less clear.

In the quasi-experimental setting of the Sahel, the influence of different degrees of intensified rice cultivation on vector dynamics and disease will be the main thrust of the Consortium research program. Our work is focused on the Office du Niger irrigated rice scheme. Located along the Niger River in Mali, this is the oldest and largest irrigated rice area in the Sahel, dating from the early 1930s and currently covering more than 50 000 hectares. We will determine whether the very high number of mosquitoes encountered within the scheme in fact results in increased malaria transmission and malaria disease, in comparison to populations living outside the irrigated areas.

The impact of two annual irrigation cycles for rice double-cropping on mollusc populations and their transmission potential for human schistosomiasis will also be compared to mollusc populations exposed to a single annual irrigation cycle.

Socio-anthropological studies will attempt to describe the preventive behaviors provoked by the different degrees of endemicity and levels of nuisance of these disease vectors, and will outline acceptable household-based strategies aimed at reducing the number of disease episodes. However, as large-scale water resource developments have often site- and time- specific characteristics, a second, population-based, study will be carried out in Côte d'Ivoire.

"The goal is to improve our understanding of the risks for serious malaria illness."

These studies will provide representative estimates of the general health impact in populations living in West African lowland rice growing environments in the sudan-savanna and forest zone. Smallholder rural farming populations in these zones have been stratified into populations exposed to lowlands with two annual rice crops (intensified cultivation) and lowlands with one annual rice crop. The frequency of newly occurring malaria episodes will be estimated over 12 months in approximately 1500 residents within each of the six agro-ecological strata. These results will be compared to the frequency of malaria disease in populations exposed only to uncultivated lowlands. The goal is to improve our understanding of the risks for serious malaria illness. The duration (epidemic, seasonal, year-long), and the level of the average exposure to infective mosquito bites (< 10 or >100 infective bites per person per year) are considered to be important determinants for the existence of distinct clinical malaria-related syndromes, such as cerebral malaria or severe malaria anemia.

The distribution of the frequency and intensity of schistosomiasis infection within the same populations will also be mapped over a 12-month period. In all settings, the impact of agro-ecosystem-related nuisances, such as the resurgence of blackflies or of large rice-field-related culex (mosquito) populations, will be simultaneously evaluated and simple interventions pilot-tested. Complementary socio-economic studies will describe the relationship between income from rice cultivation and health status, as well as health-seeking behavior. These initial studies will also permit the documentation of other perceived health hazards related to lowland rice cultivation.

Reducing human health risks

The multidisciplinary nature and the policy orientation of the Consortium studies will aid the development of intervention strategies to reconcile agricultural developments with human health goals. The data will indicate that, in some situations, only multi-sectoral interventions aiming at improving the socio-economic environment of smallholders will successfully address eventual development-project-related concerns for human health. Our research will guide the formulation of these intervention strategies and their deployment addressing priority areas of concern to resident farming communities.

The strength of these studies lies not only in quantifying the agro-ecological risk factors which determine levels of vector-borne transmission and disease, but the utilization of a multi-disciplinary approach from within an institution — WARDA — engaged in strategic planning. Therefore a comprehensive risk characterization and quantification is presently being undertaken, considering risks with regard to behavior, linked to agricultural activities and cultural perceptions, preventive household activities, perception of risks and the determination of resources allocated to their treatment, as well as geographic drug resistance patterns or drug consumption at home, to name just a few major explanatory variables for disease.

This first project phase will also describe farmers' perceptions on incentives to review current agricultural practices and their attitude with respect to water management or water resource development activities. The project is also contributing to a typology of rice cultivation systems which will assess the potential of each system to increase public health hazard. This is done through ecological studies at the WARDA main research center, investigating in detail the impact of agricultural practices such as seeding type and density on mosquito larva dynamics.

The studies aim to provide a quantitative answer to the question: is it lowland cultivation *per se* or, lowlands with partial or total water control, that constitute a significant health risk for vector-borne disease among resident populations?

The WARDA Health Research Consortium

Consortium members:

In Mali

- Ecole nationale de médecine et pharmacie, Département de l'epidémiologie des affections parasitaires, Malaria Research Training Center, Bamako
- Institut d'économie rurale, Programme riz, Bamako
- Institut national de recherche en santé publique, Programme national de lutte contre les schistosomiases, Bamako.

In Côte d'Ivoire

- Centre universitaire de formation en entomologie médicale et vétérinaire, Bouaké
- Institut Pierre Richet, OCCGE, Bouaké
- West Africa Rice Development Association (WARDA), Bouaké

The social science unit of the University of Bouaké is in the process of becoming a Consortium member. It will add expertise in social science studies and anthropology.

Associated international institutions:

- WHO/FAO/UNEP/UNCHS Panel of Experts on Environmental Management for Vector Control (PEEM), Geneva, Switzerland
- International Development Research Centre (IDRC), Ottawa, Canada.

Scientific Advisory Committee:

- Danish Bilharziasis Laboratory, Charlottenlund, Denmark
- London School of Hygiene and Tropical Medicine, London, UK
- Institut français de recherche scientifique pour le développement en coopération (ORSTOM), Paris, France
- Prince Léopold Institute for Tropical Medicine, Anvers, Belgium.

Financed by:

- International Development Research Centre (IDRC), Ottawa, Canada
- Danish Agency for International Development (DANIDA), Copenhagen, Denmark
- Government of Norway, Oslo, Norway

Continuum rice program

Staple food production and consumption patterns in West Africa are currently undergoing a period of dramatic change. The most prominent elements of this change are:

- the gradual substitution of traditional coarse grains by rice, particularly in densely populated and urban areas;
- the emergence of Nigeria as the region's dominant rice producer and consumer, overtaking the traditional rice countries on the west coast;
- the increasing importance of rainfed lowland rice production relative to upland rice, which has in many areas reached its ecological limits of intensification; and,
- the local transition of labor to land-limited, intensified production systems.

These changes have resulted in an 8.3% annual growth rate during the last decade of rice production in the region, a far higher growth rate than that of any other staple crop. The source of the increases in rice production, however, carries danger signals that such growth is probably not sustainable. Regional rice yields, which average only 40% of the world mean, have risen at only 1.9% per year since 1983. Consequently, the bulk of production increases were due to area expansion.

Most of the recent increase of rice production and cultivated areas falls into the upland/inland valley swamp continuum environments, located in the savanna and forest zones of West Africa. In the continuum, which typically consists of lowland, hydromorphic and upland ecosystems in close association, rice is usually grown with low management inputs in small fields. These fields occupy narrow segments of toposequences, and depend on rainfall and water movements within small watersheds. This complex and highly diverse environment can only be understood through an integrated multidisciplinary approach that carefully considers the scale specificity of biophysical phenomena on the one hand, and the diversity of farmers' objectives on the other hand. WARDA's largest research program, the Continuum Program, has the challenging task of providing generic solutions to the constraints to rice production in a diverse and complex environment, which is undergoing a rapid transition from extensive to intensive cultivation.

The Continuum Program is grouped into five thematic projects that cut across the different ecosystems constituting the continuum:

- agro-ecological and socio-economic characterization;
- improvement of cropping systems;
- improvement of soil fertility;
- integrated pest management (IPM); and,
- varietal improvement.

Each project involves a range of disciplines, and includes problem-oriented subprojects with explicit output projections.

Research during 1995 built on the achievements of previous years, namely, a technical breakthrough in crossing the African indigenous rice species *Oryza glaberrima* with Asian rice, *O. sativa*; and the agro-ecological and socio-economic knowledge gained in WARDA's increasingly decentralized research at key sites in the region. New disciplinary and technical capacities were developed in the areas of systems research, in particular: crop and hydrological modeling; the use of geographic information systems (GIS) in collaboration with the Inland Valley Consortium (IVC); the characterization of rice germplasm through isozyme fingerprinting; and, the development of three on-farm and one on-station benchmark watersheds serving as multi-disciplinary, life-size field laboratories.

The most important highlight of research in 1995 was the development and eco-physiological characterization of new stable interspecific rice hybrids. The growth vigor and yield potential of *O. glaberrima* x *O. sativa* progenies exceeded all expectations. This, as well as the mounting evidence of accessible genes in *O. glaberrima* for many other crucial adaptations, prompted us to make interspecific breeding a centerpiece of WARDA's research in the foreseeable future. It is now probable new plant types based on *O. glaberrima* x *O. sativa* crosses will provide a viable answer to many of the yield-reducing constraints in low-management rice production systems in the upland, hydromorphic and rainfed lowland ecosystems.

The second conceptual centerpiece of continuum research is the sustainable intensification of lowland rice-based production systems, in conjunction with the agro-ecological stabilization of over-exploited uplands. These two complementary objectives require the full integration of crop- and resource-management research with varietal improvement, and of on-station research with decentralized, collaborative on-farm research.

In 1996, we will further consolidate continuum research in the principal areas of high potential impact, and intensify on-farm and farmer-participatory research. Priority setting will be based on new *ex ante* and *ex post* mechanisms to evaluate the impact of research.

CHARACTERIZATION OF CONTINUUM RICE-GROWING ENVIRONMENTS

In order to develop appropriate production technologies for rice environments as diverse as those in the humid and sub-humid zones of West Africa, the applied research we do must be backed by an unusual investment in characterization research.

The main objectives of characterization are priority setting and the assessment of impact probabilities, as well as direct multidisciplinary backstopping to technology development. During the past five years, characterization research for the continuum has focused on production constraints from various disciplinary angles: production and policy economics, cropping systems agronomy, soil fertility, pest control and germplasm diversity.

Major progress has been made in the understanding of farm-level determinants of production, including agronomic yield gaps caused by pests and soil infertility, labor requirements and availability, gender roles in different types of production systems, and the role of farmer education. The Inland Valley Consortium (IVC) provided this research with a regional approach, based on key research sites in eight countries. Much of WARDA's continuum characterization research is now being carried out at three benchmark watersheds in Côte d'Ivoire, which also serve as sites for the testing of new technologies.

During 1995, we sought to improve our quantitative grasp of the spatial and temporal variability of environments, both at the micro (toposequence) and macro (regional) scale. The hydrological, soil-physical and chemical characteristics of inland valley toposequences were studied in detail. Data and modeling concepts were generated that will ultimately enable the prediction of natural resource flow in small watersheds as a function of land-use patterns. Meanwhile, the first comprehensive datasets on varietal performance under farmer management came in from the key sites, confirming that some of WARDA's new rices are well suited to a variety of upland environments.

In 1996, we will continue to strengthen on-farm research at benchmark sites. A number of preliminary models will become available to test different rice plant types in different climatic and hydrological environments, and to predict scale effects on water flow in watersheds. This research will be directly coupled with applied varietal improvement and cropping systems research. Characterization research will be transformed from a "stand-alone" project into systems research components associated directly with applied research projects.

The V1 on-station watershed at M'bé: a life-size laboratory for natural resource flow

N. van de Giesen

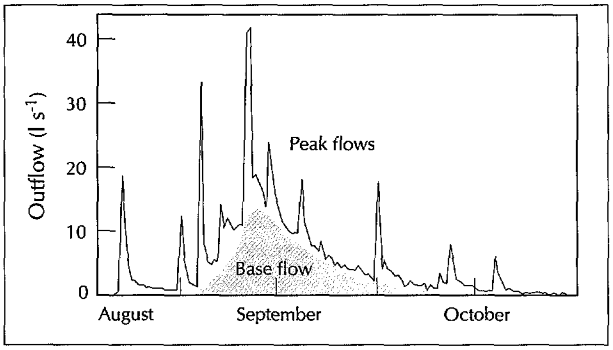
WARDA's concern with sustainable development of the continuum includes the effects, both positive and negative, that interventions in one part of the landscape have on the rest of the watershed. In as far as these interactions are biophysical, they are mainly associated with the flow of water and nutrients. With a systems approach, the movement of water and nutrients can be modeled at the watershed level. A watershed model will not only describe actual resource flows but will help to predict changes which would occur under different land-use scenarios. With its descriptive and predictive capacities, a watershed model would be a very productive instrument for the testing and extrapolation of technologies by the Inland Valley Consortium (IVC).

With the V1 valley watershed, at the WARDA main research station near Bouaké, Côte d'Ivoire, we have a unique research instrument to study water and nutrient movement through the continuum landscape. Although the watershed has an area of only 130 ha, it contains all landscape elements typical for the region: deeply drained uplands, iron pans, sandy slopes with shallow impermeable layers, and a clayey valley bottom. Present land use is extensive and the vegetation consists mainly of grassy fallow on slopes and uplands, and a gallery forest in the valley bottom. Because the watershed lies almost completely within the station, it is possible to intensify the land-use and to monitor the induced changes in water and nutrient availability. Before land-use changes take place, WARDA and IVC scientists will closely measure and model the present resource flows.

During 1995, we focused on movement and storage of water. Rainfall, groundwater levels, and outflow from the valley bottom were measured in detail. The total rainfall in 1995 was 820 mm which is equal to 1 000 000 m^3 of water, for the given surface. Total outflow from the valley was 33 000 m^3 or only three percent of the total rainfall. Outflow started in August, after more than half the total rainfall had fallen.

The daily outflows from the valley bottom (Figure 16) can be divided into base flow, which rises and falls slowly; and peak flows, which occur immediately after rainstorms. Groundwater levels show that the period with peak flows coincides with the time during which the valley bottom was saturated with water. All rain falling on the saturated valley bottom quickly moved to the outlet. Further analysis of groundwater levels indicates that the base flow was caused by relatively slow shallow groundwater flow through the slopes to sources at the edge of the valley bottom.

Figure 16: Daily outflows from V1 valley during 1995 rainy season.



Although outflow represents only a small part of the water balance, it is a crucial part because it determines the amount of water available for irrigation and the amount to be drained during peak flows. The V1 watershed will therefore provide valuable insight to the impact of land-use changes on the water resources of the continuum landscape.

Materials and method

Rainfall was measured with four standard raingauges, distributed over the watershed. Run-off was measured with a 1.5' H-flume, installed in an interceptor canal at the valley outlet. Groundwater and surface water heights were measured with one longitudinal and four lateral piezometer lines.

Towards a typology for the spatio-temporal variability of drought in West Africa

A. Audebert (CIRAD)

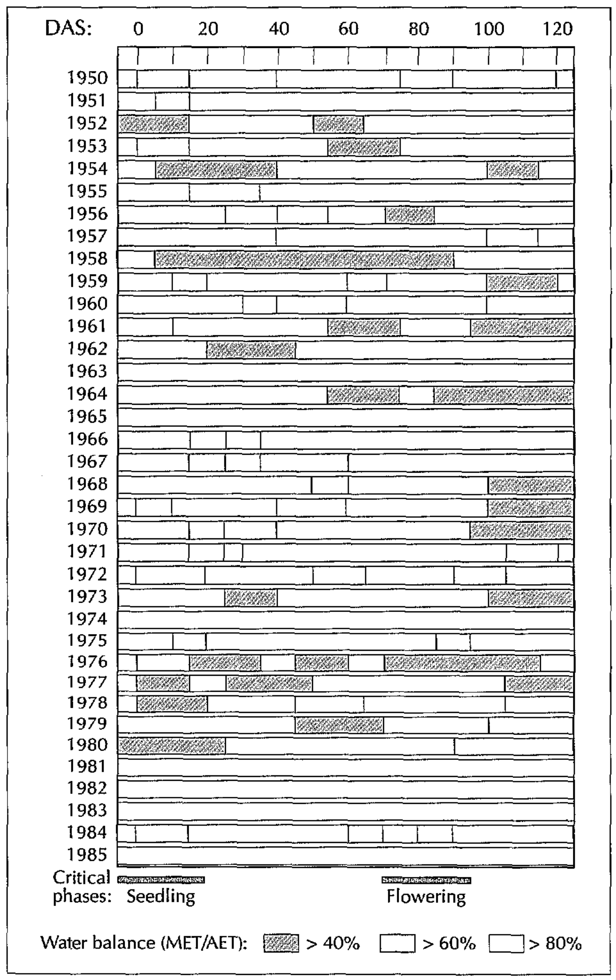
Past agro-climatic studies for West Africa, for example by CIRAD, AGRYMET, and ICRISAT, have identified zones and seasons suited to different rainfed crops. Modeling studies at CIRAD have matched the crop duration of some upland rice varieties with mean local rainfall patterns, and a recent study at WARDA, using the phenological model RIDEV, performed an agro-climatic zonation of the Sahel region with respect to the temperature sensitivity of irrigated rice. Similar studies have now begun at WARDA in collaboration with CIRAD to assess the spatio-temporal distribution of drought risks for upland rice in the savanna zone, where rainfall patterns are extremely variable and represent a major source of yield variations.

During 1995, a first such study was conducted using the model SARRA (CIRAD), which is based on the water balance approach. Considering the difficulty of gathering such data (namely, potential evapotranspiration), we have used available data from four sites in the southwestern region of Burkina Faso. These sites cover a gradient of 2° latitude, from 11°N (Bobo-Dioulasso) to 9°N (Batie). For each of these sites, 35 years of data are available. The critical limit for available water has been set at 30 mm.

The average total rainfall on this gradient (1092 mm) is not significantly different from one site to another. These rainfall patterns follow a monomodal curve centered between the end of August and early September.

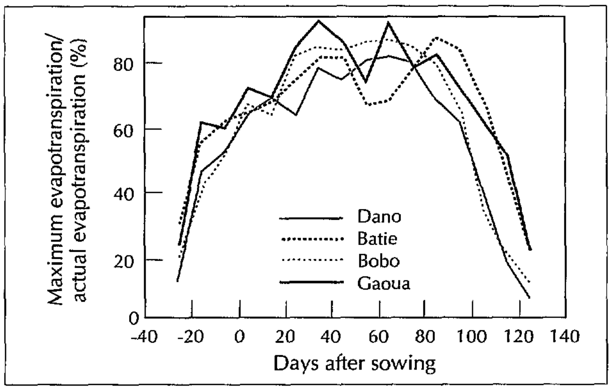
The study of the coefficient of water balance of the crop (ratio of the maximum evapotranspiration on actual evapotranspiration — MET/AET) (Figure 17) shows that over a 35-year

Figure 17: Coefficient of water balance for the rice crop at Batie, Burkina Faso, from 1950 to 1985.



period there was a very high temporal variability in the periods of drought. These can be found at any given time in the cycle of the plant with different durations and intensities. These results do not appear in curves of frequential analysis at 80% (Figure 18) because of data suppression.

Figure 18: Curves of frequential analysis (80%) of the rate of water balance in southwestern Burkina Faso



This study will continue with a view to developing a map of drought risks for the rice (period, duration and intensity) in West Africa. This will considerably help breeders target new rice varieties for specific drought environments.

Materials and method

Entry variables of the model (SARRA) are rainfall, potential evapotranspiration (PET), the critical nutrient status of the soil, cropping coefficients, date of planting, rate of root growth and depth of rooting. The SARRA model allows us to estimate from these variables the water balance of the crop. Dates of planting integrated in the model are the dates currently recommended.

Micro-variability of rice performance under different hydrologies

A. Audebert (CIRAD)

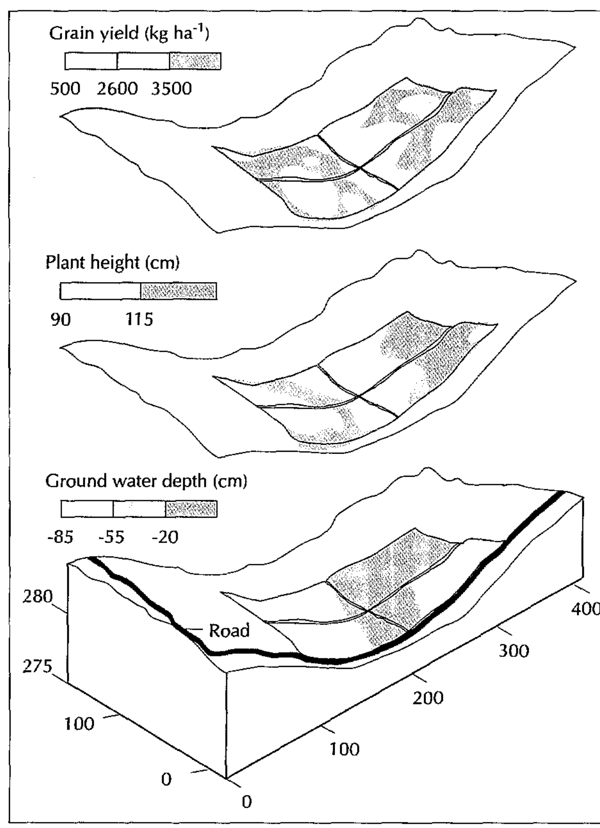
Frequently, farmers use the same rice variety on the whole toposequence (upland, hydromorphic zone and lowland) regardless of the hydropedological conditions typical of each situation. A good understanding of the spatial distribution of constraints along the continuum is a prerequisite to developing more efficient forms of land use. Physiological models of crop water use and growth can then be combined with spatial models of resource flows to test the fit of new varieties to different inland valley settings.

In 1995, we blank-cropped a newly cleared plot to demarcate the major homogeneous zones of the crop, using geostatistical methodologies. This survey has thus helped to perform a hydrological and agronomic characterization of the site. The determination and demarcation of the main areas of the continuum using the watershed level, were made through hydrological (groundwater table) and agronomic studies.

The site selected, two hectares in size, comprises two slopes on either side of a thalweg (line connecting lowest points of a valley bottom) at the WARDA main research farm at M'bé, Côte d'Ivoire. The rice variety used was IDSA 6, a tropical japonica variety adapted to a wide range of conditions, with the exception of waterlogging. The site is part of a granite-gneiss formation. The two continua facing each other, on both sides of the thalweg, show a terraced hydropedological structure. The groundwater table shows fluctuations correlated with rainfall and the morphology of the watershed.

By working out the average depth of the groundwater table throughout the cropping season, one can determine three distinct zones corresponding to the different rice-growing environments (Figure 19). All measured variables, both

Figure 19: Spatial overlay of ground water level and performance characteristics of rice in an inland valley segment



agronomic and hydrological, showed a consistent spatial distribution. Moreover, there exists a good correlation between characteristics of the crop: morphology (height) and yield (kg ha^{-1}) with the level of the water table. Discrepancies noted on the production map are mainly due to termite hills.

Materials and method

Four 0.5 ha plots were selected and their topography studied at 5 m intervals. After plowing (at a depth of 15-20 cm), and heavy fertilizer application (150 kg ha^{-1}) and chemical weeding (Ronstar), variety IDSA 6 was planted under upland conditions. The depth of the water table was measured weekly throughout the cropping season with three transects of 6 piezometers. Agro-physiological measurements were made on 36 georeferenced micro-plots, scattered over the site. Results were statistically studied and represented spatially after kriging.

Scale effects on surface run-off on a continuum toposequence

N. van de Giesen

For the management of the natural resources of the continuum landscape, it is necessary to understand not only the availability and movement of water and nutrients at the plot and field level, but at the slope and watershed level as well. Moving from field to watershed level, one has to account for effects of scale. Such effects of scale are a central theme in contemporary water resources research. For any given point in space, current knowledge enables us to calculate the distribution of rainfall among run-off, infiltration, percolation and evapotranspiration. It is not clear, however, how to aggregate an assembly of points to predict the movement of water through a complete landscape. A straightforward integration of points is hampered by the presence of high spatial variability of soil properties and by the non-linear dynamics of water flowing from one point to the next.

Because understanding the hydrological behavior of the continuum landscape as a whole is crucial for the efficient and sustainable management of its resources, WARDA and the Agronomy Department of Wageningen Agricultural University in the Netherlands initiated a series of experiments aimed at understanding the effects of scale on surface run-off. In 1995, run-off from plots with different slope lengths was measured on an experimental toposequence.

Some typical results are given in Table 7, showing the run-off reducing effects of vegetation during the fallow period. Vegetation prevents the formation of a surface crust such as found in the bare fallow plots. In addition, vegetation slows down the movement of surface water, thereby extending the ponding time and infiltration surface. Table 7 also shows the pronounced effect of slope length on total run-off with longer plots giving relatively less run-off.

Table 7: Effects of fallow treatment and plot size on run-off totals from upland plots for four rainstorms in the 1995 season. Vegetated fallow is average of cropped and weedy fallow.

	Fallow		
	vegetated	**bare**	**Average**
Date: 23-05-95	Total rainfall 31.5 mm		
Size: 1 m^2	3.9 mm	16.8 mm	10.4 mm
Size: 10 m^2	0.3 mm	9.2 mm	4.8 mm
Date: 05-07-95	Total rainfall 36.0 mm		
Size: 1 m^2	15.3 mm	14.6 mm	15.0 mm
Size: 10 m^2	7.2 mm	2.0 mm	4.6 mm
Date: 05-08-95	Total rainfall 21.0 mm		
Size: 1 m^2	5.6 mm	3.8 mm	4.7 mm
Size: 10 m^2	3.7 mm	1.7 mm	2.7 mm
Date: 13-09-95	Total rainfall 41.5mm		
Size: 1 m^2	19.6 mm	8.5 mm	14.0 mm
Size: 10 m^2	13.4 mm	14.0 mm	13.7 mm

Two mechanisms give rise to these scale effects. The first is the longer opportunity time for water to infiltrate on the larger plots. The second is that, given the spatial variability of soil surface parameters, the chance that run-off will run onto a zone of high storage or infiltration capacity is higher in the long plots. The relative importance of these two mechanisms will be determined in 1996 by measuring in detail the dynamics of the run-off process during rainstorms. Once the mechanisms are understood, a watershed scale model will be developed with the aid of data collected in the V1 experimental watershed at M'bé, Côte d'Ivoire. The hydrological data gathered at the key sites will subsequently serve to test and calibrate the model for other parts of the region.

Materials and method

Run-off measurements were made under bare, cropped, and weedy fallow and on the upland and hydromorphic parts of the toposequence, for a total of six sites. At each site, two differently sized run-off plots were installed along the slope. One plot had the standard dimensions of 0.8 x 1.25 m, while the second plot had the same width of 0.8 m but a length of 12 m. Run-off was collected at the bottom of each plot and measured after every rainstorm. For more information on the site, *see*: Managing native soil nitrogen on the continuum toposequence, page 51.

CROPPING SYSTEMS RESEARCH

Farmers are currently intensifying their rice-based cropping systems in the environments of the upland-inland valley swamp continuum. Production objectives are increasingly short-term and tend to degrade the resource base. New technical options are needed to stop, and possibly reverse, this degradation process while increasing productivity.

Small-scale subsistence farmers grow a single crop of upland rice in rotation with forest or bush fallow. Under low population pressure and with long fallow periods, this slash-and-burn shifting cultivation has been able to maintain crop yields at a low but sustained level. Demographic pressure is now forcing farmers to reduce fallow periods in many areas, resulting in deforestation, soil nutrient depletion, soil physical degradation, and rapid weed infestation of the land. Purchased inputs may partly compensate for some of these negative effects but are unlikely to be used on subsistence crops. Continuous crop production in the same field with inclusion of weed-suppressing leguminous cover crops may allow ecological and economic stabilization of intensified upland rice-based systems.

A rapidly growing demand for rice, and a changing economic and policy environment, are currently accelerating the intensification of lowland cultivation. Diagnostic work conducted in 1994 indicates that most intensified lowland systems show a negative balance for major plant nutrients. External inputs are inefficiently used and systems internal resources are not or insufficiently exploited. To ensure a sustainable intensification of lowland cultivation, activities started in 1995 focus on the evaluation of improved weed and resource management options for crop diversification, and the development of decision tools for a range of location-specific bio-physical and socio-economic conditions.

Current land use and resource management practices result in both the under-utilization and the over-exploitation of resources in different ecosystems of an inland valley. A strong bio-physical and socio-economic interdependence of the ecosystems in inland valleys calls for a multi-scale approach that results in the stabilization of uplands while intensifying the more robust lowlands. The development of cropping options that optimize resource use involves the evaluation of land use systems and the quantification of water and nutrient flows for different resource management scenarios. Technical options are developed at plot scale, validated at field and watershed scale (physical interactions), and transferred at household or village scale (socio-economic interactions). Activities are carried out at three WARDA key sites in Côte d'Ivoire in collaboration with the Inland Valley Consortium (IVC) and the technology transfer research project (RADORT).

On-farm field research laboratories in Côte d'Ivoire

M. Dingkuhn, R.Diallo and M. Mohaman

The successful development of technologies for agricultural production systems requires an intensive interaction between researchers and farmers during the various stages of research. These stages include: environment and system characterization, setting of priorities and technical objectives, evaluation of the performance and socio-economic fit of new technologies, and their local adaptation and transfer.

In order to achieve these objectives at the regional scale, WARDA has developed extensive collaborative links and networks with national agricultural research systems (NARS) through the Task Forces and the Inland Valley Consortium (IVC), and national development programs and non-governmental organizations (through the IVC and the new technology transfer research project, RADORT).

However, there is also a need for on-farm benchmark sites which serve as life-size laboratories for the researcher on a day-to-day basis, enabling efficient shuttle research between controlled and "real life" environments. Côte d'Ivoire, the host country of WARDA's main research station at M'bé, offers ideal conditions for this: diverse agro-ecological zones ranging from humid forests to harmattan (dry, dusty land winds) -prone savannas; diverse ecosystems including irrigated, rainfed lowland and upland systems; land-limited peri-urban and labor-limited rural systems; and diverse ethnic and historical backgrounds of rice cultivation. In addition, an excellent national infrastructure and a high degree of political stability allow for a long-term perspective and technically efficient on-farm research.

During 1995, the implementation of a multi-site on-farm field laboratory system in Côte d'Ivoire neared completion, and the underlying concepts were refined. The key site activities are listed in Table 8, and locations are shown in Figure 20 (pages 46 and 47). The core of the network is three benchmark watersheds located in a bimodal humid forest environment with moderate rainfall (Gagnoa), a monomodal high-rainfall humid forest environment (Danane) and a monomodal moist-savanna environment (Boundiali) (Figure 20a). The sites have been selected in collaboration with the IVC on the basis of their agro-ecological representativity and the local importance of rice production (Figure 20b), which will permit the extrapolation of research results to other sites. Each of these small watersheds encompasses several first and second order valleys, several villages, and diverse upland and lowland rice- based production systems. WARDA maintains

Table 8: Research activities that are currently on-going (X), planned (P) or completed/terminated at various on-farm key sites in Côte d'Ivoire.

	Characterization			
	(Biophysical)		(Socio-economic)	
	Agro-ecological zone	Yield gap	Village	Household
Collaborators	IVC	—	IVC	IVC
Benchmark watersheds:				
Boundiali/Pondiou	X	X	X	T
Danane/Yotta	P	X	X	X
Gagnoa/Guessiho	X	X	X	T
Peri-urban sites:				
Bouaké	P	P	—	P
Korhogo	P	P	—	P
Other sites:				
Man	—	—	—	—
Odienne	—	—	—	—
Touba	—	T	X	T
Ferkessedougou	—	—	—	—

Note: Yield gap analyses use superimposed researcher managed plots; IVC = Inland Valley Consortium.

Table 8 (cont):

	Technology testing (researcher-management)								
	CRET-ul	CRET-II	Partic. breeding	Iron toxicity	Drought	Acidity	Blast	RYMV	Improved fallow
Collaborators	IDESSA	IDESSA	—	TF	TF	TF	TF	TF	TF
Benchmark watersheds:									
Boundiali/Pondiou	—	—	X	—	—	—	—	—	X
Danane/Yotta	—	P	X	—	—	—	—	—	X
Gagnoa/Guessiho	X	P	P	—	—	—	—	X	X
Peri-urban sites:									
Bouaké	X	P	—	—	X	—	—	—	—
Korhogo	X	P	—	X	X	—	X	—	—
Other sites:									
Man	X	—	—	—	—	X	X	—	X
Odienne	X	—	—	—	—	—	—	—	—
Touba	X	—	—	—	—	—	—	—	—
Ferkessedougou	X	—	—	—	—	—	—	—	—

Note: CRET-ul = coordinated replicated evaluation trials — upland; CRET-II = coordinated replicated evaluation trials — lowland; Partic. breeding = participatory breeding; TF = Task Forces.

a small team of field technicians at each of the sites, as well as electronic weather stations which have been integrated into the national agro-meteorological service ANAM.

The research activities conducted in the three watersheds fall into four categories: agro-ecological characterization (the analyses of yield gaps and natural resource dynamics); socio-economic characterization (household and village level); researcher-managed technology development and testing; and, farmer-managed technology testing (Table 8). A systems approach is being developed to link these activities together, and to interpret and extrapolate the results on the basis of

Table 8 (cont):

	Technology testing (farmer management)		
	OFT-ul	**OFT-ll**	**Improved fallow**
Collaborators	IDESSA	IDESSA	TF
Benchmark watersheds:			
Boundiali/Pondiou	X	P	P
Danane/Yotta	X	P	X
Gagnoa/Guessiho	X	P	X
Peri-urban sites:			
Bouaké	X	P	—
Korhogo	—	P	—
Other sites:			
Man	—	—	—
Odienne	X	—	—
Touba	X	—	—
Ferkessedougou	—	—	—

Note: OFT-ul = upland on-farm varietal trials; OFT-ll = lowland on-farm varietal trials; TF = Task Forces.

the temporal and spatial variability of the environment, the diversity of farmers' objectives and consumers' preferences, and, the competition for land and labor among different crops and cropping systems. The Ivorian national Institut des savanes (IDESSA) and WARDA work closely together at the benchmark sites, particularly in the area of on-farm technology testing.

A second set of benchmark areas has been selected to develop options for the sustainable intensification of lowland agriculture along the peri-urban to rural gradient. In these environments, a rapid transition from labor to land limited production can be observed, requiring different technical solutions for highly market-oriented systems. Preliminary surveys conducted in 1995 led to the selection of Bouaké and Korhogo as two contrasting benchmark sites. Figure 20c, shows the physical accessibility of urban markets in these two areas, which is a major determinant of intensified agriculture. We will also collaborate with a complementary peri-urban project at Kumasi in Ghana.

A few additional key sites in Côte d'Ivoire are used to test technologies in specific environments which do not seem to be fully represented by the three watersheds and two peri-urban sites. Activities and infrastructural investment for research at these sites will be kept at a minimum, and their eventual transfer to the main sites is likely.

Figure 20a: Location of WARDA's various on-farm benchmark research sites in Côte d'Ivoire, as related to major environment properties. (a) Major agro-ecological zones.

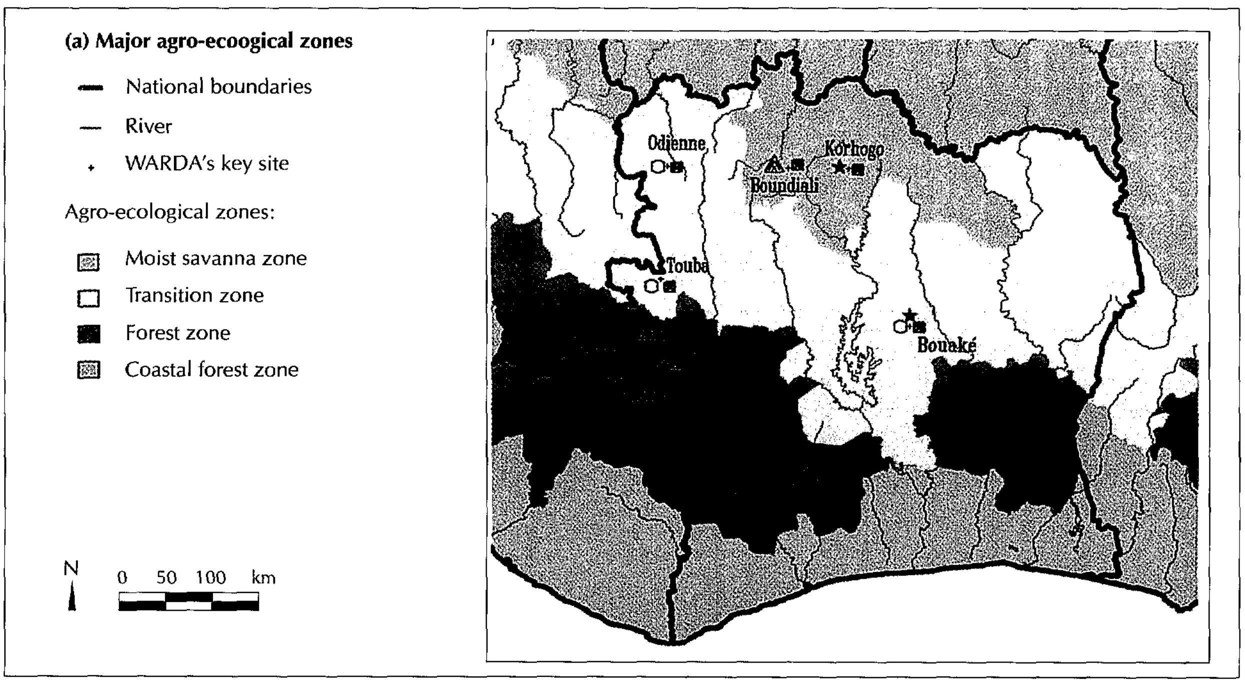


Figure 20b, c: Location of WARDA's various on-farm benchmark research sites in Côte d'Ivoire, as related to major environment properties. (b) Importance of rice relative to other crops. (c) Accessibility of urban markets (> 100,000 inhabitants) on the basis of distance, road quality and time to reach the nearest road in the dry season. Data were provided by the USAID-REDSO office in Abidjan.

(b) Importance of rice relative to other crops

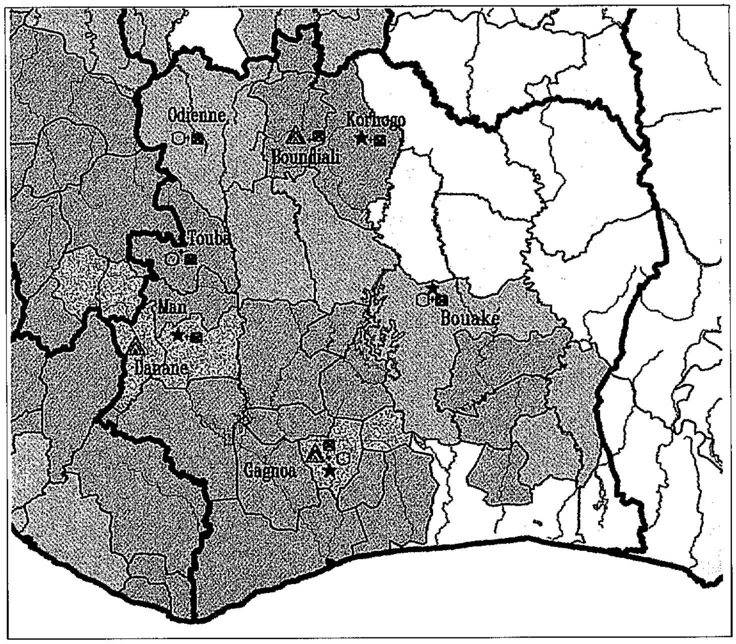
- National boundaries
- Sub-region boundaries
- River
- WARDA's key site
- Watershed level
- CRET
- Specific stresses: Iron toxicity; drought (Korhogo); soil acidity (Man); RYMV (Gagnoa, Sakassou)
- On-farm varietal trials

Rice as a percentage of agricultural units

- 0
- 0.00-0.05
- 0.05-0.50
- 0.50-1.00
- 1.00-5.00
- 5.00-10.00
- > 10.00

N

0 50 100 km



(c) Accessibility of urban markets

- National boundaries
- Railway
- Road

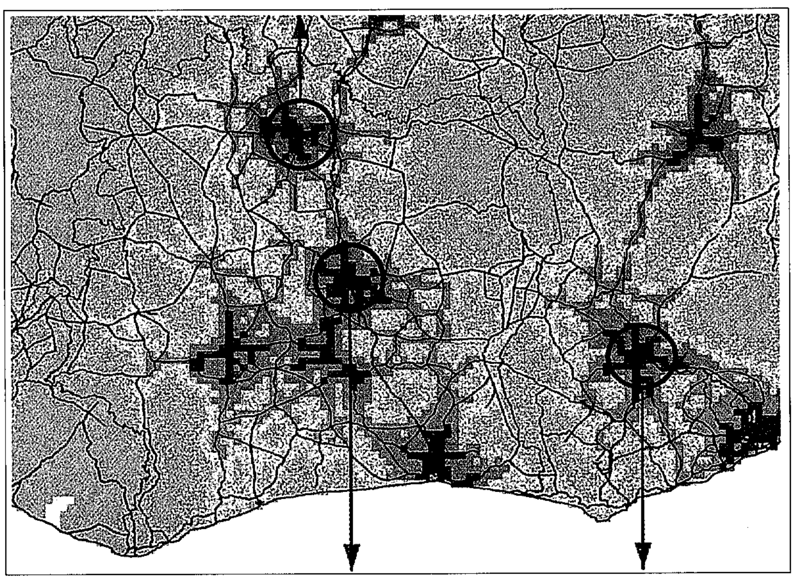
Market accessibility,
Dry season; cities over 100 000

Travel time:

- 0 to 1 hour
- 1 to 3 hours
- 3 to 6 hours
- 6 to 10 hours
- 10 to 20 hours
- More than 20 hours

0 50 100 km

Korhogo (WARDA)



Bouaké (WARDA) Kumasi (ODA)

In summary, we are moving major components of our applied research to on-farm benchmark sites that are sufficiently accessible from the main research station at M'bé to permit shuttle research between the research station and farmers' environments. This system is complementary to the existing regional research networks, because it operates at the scale of households, villages and small watersheds. This is where technology adoption is decided, based on systems properties and externalities that are only manifest at this scale. In 1996, we will consolidate our "on-farm field laboratory" approach and expand our systems research tools, such as models, to extrapolate research findings from the micro to the macro (regional) scale.

Differential response of rice ecotypes to weeds, nitrogen, and hydrology

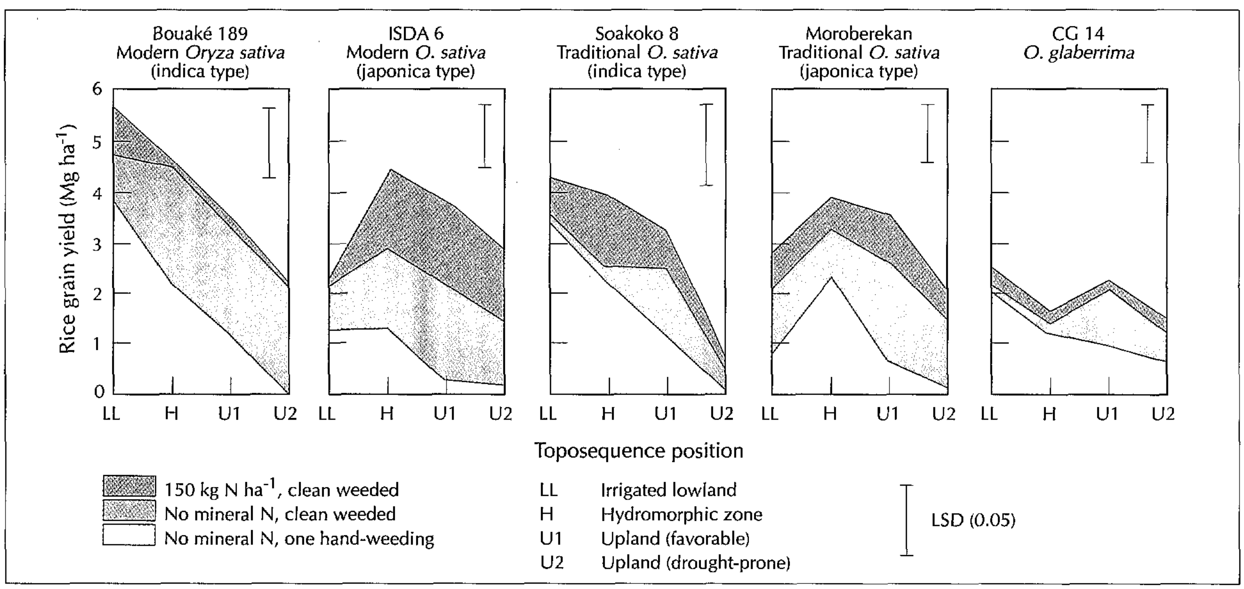
M. Becker, D.E. Johnson (NRI), N. van de Giesen, A. Audebert (CIRAD) and M. Dingkuhn

Crop performance of different rice ecotypes and their yield response to management interventions is likely to vary with hydrology. We characterized varietal performance of modern and traditional *Oryza sativa* (both indica and japonica types) and *O. glaberrima*, along a hydrological gradient and at different levels of crop management. A trial was laid out in a split plot with three replications at the WARDA research farm during the 1995 wet season. Five rice ecotypes were established on four toposequence positions (ranging from irrigated lowland over the hydromorphic valley fringe, to favorable and drought-prone upland zones) and at three management levels. Toposequence positions differed regarding soil texture and hydrology.

The trial was established in a split plot design at four levels of the toposequence (irrigated lowland, hydromorphic valley fringe, favorable upland, drought-prone upland). The upland ecologies were characterized by loamy sand and a water table depth of 98 cm and 172 cm for the lower and upper position, respectively. A sandy clay loam dominated the hydromorphic (38 cm water table depth, 32% average volumetric soil moisture content) and lowland environments. The three main plot treatments were: one hand-weeding, clean weeding, and clean weeding plus mineral fertilizer N application. Sub-plot treatments were composed of five cultivars: Bouaké 189 (modern indica), Souakoko 8 (traditional indica), IDSA 6 (modern japonica), Moroberekan (traditional japonica), and, CG 14 (*O. glaberrima*). Leaf area index (LAI) and leaf chlorophyll content (SPAD) were determined at flowering stage of rice. Weed biomass and species composition were recorded at 28, 56, and 84 days after sowing (DAS).

The rice ecotypes responded differentially to the combinations of ecosystem and crop management (Figure 21). Indica-type *O. sativa* cultivars yielded highest in the irrigated lowland, and tropical japonica types in the hydromorphic and upland ecosystems. *O. glaberrima* (CG 14) showed no apparent response to hydrology. Within each cultivar, grain

Figure 21: Differential response of rice ecotypes to weeds, nitrogen and hydrology, M'bé, Côte d'Ivoire, 1995 wet season.



yields were closely associated with leaf area index (LAI), values being highest in the lowland and lowest in the drought-prone upland environments. The *O. glaberrima* cultivar produced much less grain per unit LAI than *O. sativa* cultivars. Across varieties, lowest yields were observed in the drought-prone upland ecology (water table > 1.7 m, average volumetric soil moisture < 18%). In this toposequence position, weed growth in later stages of crop growth was greatest, and rice LAI and leaf chlorophyll content were lowest. Modern-type cultivars tended to respond more to crop management than traditional ones. Significant response to mineral N application was limited to the irrigated lowland for improved indicas, and to the hydromorphic and favorable upland ecosystems for japonica types. Leaf chlorophyll content responded to N nutrition and was lowest in weedy plots of the upland ecosystems with poor sandy soils (U2). Grasses were the dominant weeds across the toposequence (*Digitaria horizontalis* in the upland, *Leersia hexandra* and *Eleusine indica* in the hydromorphic, and *Echinochloa crus-pavonis* in the lowland ecosystems). The traditional tropical japonica Moroberekan and *O. glaberrima* had lower weed weights than modern cultivars in the hydromorphic zone. The indica cultivars had higher weed weight than japonicas in the upland ecologies. This appears to be related to LAI, which was higher in japonica than in indica types. The effect on grain yield of improved weed control was substantial at all positions of the toposequence. Across cultivars, yields were very low in the upland positions with poor weed control. Across sativa cultivars, potential yields were high in the hydromorphic environment with a strong response to both weed control and N application.

The use of modern-type *O. sativa* rices is widely recommended in West Africa. A superior crop performance over traditional type varieties, however, is expressed only under improved crop management and in the respective hydrological niches of the ecotypes. New rice breeding strategies may be needed for non-irrigated ecosystems where crop management is usually poor. Weed competitiveness, and phenotypic plasticity with regards to variable hydrology are essential traits of future improved varieties for unfavorable environments under low-input management. Reducing management requirements through better varieties may be of particular relevance in hydromorphic environments where potential yields and the sensitivity of cultivars to management interventions are very high.

Optimizing crop management on the continuum toposequence

M. Becker and D.E. Johnson (NRI)

For farmers, the available agronomic management options to increase rice yields in any given hydrological situation involve: varietal choice; method and density of seeding/planting; fertilizer use, with N featuring prominently; and, crop protection (mainly weed control). The most appropriate combination of options is likely to vary with the ecosystem or position on the toposequence. Nevertheless, extension recommendations in West Africa are surprisingly similar among countries and across agro-ecological zones and hydrologies (namely, "modern" varieties, medium dense spacing, 50-100 kg mineral fertilizer N ha^{-1}) despite the varied circumstances.

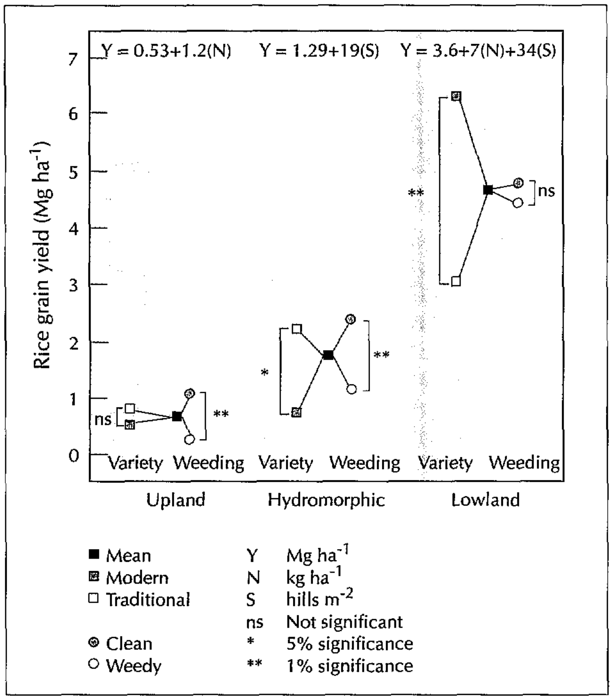
A two-year field experiment was conducted at the WARDA main research farm at M'bé (forest-savanna transition zone), Côte d'Ivoire during the 1994 and 1995 wet seasons to quantify the relative impact on yield of a range of management options in relation to hydrology. The experiment was laid out at three locations on the toposequence (upland, hydromorphic zone, lowland) in a four-factorial design. Factors included variety (two levels), weeding (two levels), N rate (four levels) and spacing (three levels).

Two types of varieties (traditional versus modern), two weeding regimes (hand weeding at 28, 56, and 84 days versus one hand-weeding at 28 days), three plant spacings (8, 16, and 24 hills m^{-2}), four mineral fertilizer N rates (0, 50, 100, and 150 kg ha^{-1}), and their interactions were studied at three positions of a continuum toposeqence (upland, hydromorphic zone, irrigated lowland). Soils ranged from loamy sand in the upland to sandy clay in the lowland. PK was basally applied at 50 kg ha^{-1}. Treatments were laid out a split plot design (variety, spacing, and N rate in the main plot, weeding regime in the sub-plot) using three replications.

The highest yields were observed in the irrigated lowland ecosystem (Figure 22 *overleaf*). The modern semi-dwarf variety Bouaké 189 responded significantly to mineral fertilizer application up to 100 kg N ha^{-1}. Dense spacing further increased this yield advantage over the traditional-type varieties (Iguape Cateto in 1994 and Moroberekan in 1995). Additional weeding did not increase yields though modern varieties had a lower weed weight than the traditional (36 versus 55 g m^{-2} at 28 days). A higher yield in modern than in traditional varieties could be attributed to their increased tiller number (228 vs 163 tillers m^{-2}) and harvest index (0.49 vs 0.44) and their input responsiveness (average N use efficiency of 16 vs 7 kg grain kg^{-1} N applied).

The hydromorphic environment was characterized by a strongly fluctuating water table during the growing season (volumetric soil moisture content varying between 13 and 46%) and strong weed pressure (mainly *Echinochloa, Ageratum,* and *Digitaria*), which further increased in the second year of cropping. Dry weed biomass increased significantly with N application (17 g m^{-2} with no N input versus 53 g m^{-2} at 150 kg N ha^{-1}) and wide plant-spacing (28 g m^{-2} at 25 hills vs 45 g m^{-2} at 8 hills m^{-2}). Grain yield increased with dense plant-spacing but did not respond to mineral N application. Traditional varieties outyielded modern varieties

Figure 22: Differential response of rice grain yield to management interventions along the continuum toposequence (field experiment, wet season 1995).



and dense spacing further increased this yield advantage. These higher yields are partly attributable to better weed competitiveness due to increased plant height (142 versus 107 cm) and higher leaf area index (2.6 versus 2.0) at maximum tillering stage.

Upland rice yields were generally low (620 kg ha^{-1} in average), regardless of variety, N rate, or plant spacing. Additional weeding was the only management intervention that significantly increased yield in 1995. Weed flora were dominated by the grass, *Digitaria horizontalis*. Similar to the hydromorphic environment, weed pressure in the upland was higher in 1995 than in 1994 and significantly increased with N application and wide plant-spacing. Additional weeding gave a significant yield advantage in the upland and the hydromorphic ecosystems in 1995, and only in the hydromorphic ecosystem in 1994 (the first year of cultivation after eight years of bush fallow). Farmers are likely to encounter more weed problems in the upland and the hydromorphic ecosystems with increased rice cropping intensity and with mineral N application. Improving plant stands will significantly reduce weed growth.

The effectiveness of agronomic management options varied widely across the positions of the toposequence studied. This variability is likely to be even greater across sites in different agro-ecological zones, soil types, and farming systems. Crop simulation tools are being elaborated to assist in the required reassessment of extension recommendations and their extrapolation domains. New rice breeding strategies may be needed for non-irrigated environments where water resources are good but weed pressure is high as in the hydromorphic zone.

Developing crop options for residual moisture-use in rainfed lowlands

M. Becker and D.E. Johnson (NRI)

In most cultivated inland valley swamps, a single crop of rainfed lowland rice is grown. One way to intensify and diversify these systems is to use the residual soil moisture, which is frequently available after rice harvest, for off-season crop production. The impact of this type of intensification on total production and labor productivity as well as on sustainability indicators such as soil parameters, nutrient balance, and rice pest dynamics is being studied in a long-term experiment at WARDA's research farm at M'bé, Côte d'Ivoire.

Different types of dry season vegetation were established on soil residual moisture after harvesting a uniform crop of rainfed lowland rice in October 1994. During the dry season, the water table receded at an average rate of 5 mm day^{-1} and reached its lowest level of 62 cm by late March 1995. Maize, cowpea, and sweet potato were established on 80- or 40-cm-wide ridges and harvested in March (maize, cowpea) and May (sweet potato). Ridging was also used as sub-treatment in the weedy fallow control plots. After the onset of the rains, manual tillage, and land leveling, an improved lowland rice variety (Bouaké 189) was transplanted in early July, receiving two mineral N application rates (0 and 100 kg N ha^{-1}). Grain yield and pest incidence were determined and nitrogen balances were established (Table 9).

Dry season crops increased systems total caloric output and significantly reduced weed pressure in 1995. Low weed weight in intensified systems may be attributed to weed suppression by the off-season crop (particularly sweet potato), but also to the practice of ridging. There are, however, indications that the experimental system may not be sustainable. Dry season cropping is highly labor demanding due to the building of ridges. Soil pH and exchangeable phosphorus tended to decline in the intensified systems, although this was not statistically significant after one cropping cycle. Rice grain yields were significantly lower after a dry season food crop than after a weedy fallow (5.3 versus 6.0 Mg ha^{-1}). Nitrogen balances were negative throughout and applied mineral fertilizer N compensated the second rice crop's N deficit only in the weedy fallow control and the cowpea treatments. No effects of dry season cropping

Table 9: Using soil residual moisture to intensify rainfed lowland rice-based systems.

Wet season 1994	Dry season 1995 —Residual moisture crop—		Wet season 1995 — Lowland rice —		Total 1995
Uniformity crop	**Species**	**Weed dry matter ($g\ m^{-2}$)**	**Fertilizer N input ($kg\ N\ ha^{-1}$)**	**Rice grain yield ($Mg\ ha^{-1}$)**	**Nitrogen balance[a] ($kg\ N\ ha^{-1}$)**
			0	5.70	-83
	Weeds	302	100	6.23	+10
	(+Ridges)	284	0	5.91	-86
Rice	Maize	196	0	4.73	-95
(5.0 Mg ha^{-1})			-100	5.71	-1
	Sweet potato	79	0	5.34	-98
			100	5.99	-4
	Cowpeas	227	0	4.94	-79
			100	5.32	+14
	LSD (0.05)	54	—	0.35	16

Note: [a] Fertilizer N applied minus N removed with crop produce.

on rice insects and diseases were observed, as overall pest pressure was very low in 1995.

In conclusion, rainfed lowland rice-based systems can be intensified and diversified by using residual soil moisture available after rice harvest. However, current nutrient application rates and crop and soil management strategies may need to be modified to assure long-term sustainability. Labor availability and productivity for different options of non-irrigated dry season food crop production require further investigations. This will be studied in detail in the framework of a newly initiated research project on the sustainable management of peri-urban lowlands.

Managing native soil nitrogen on the continuum toposequence

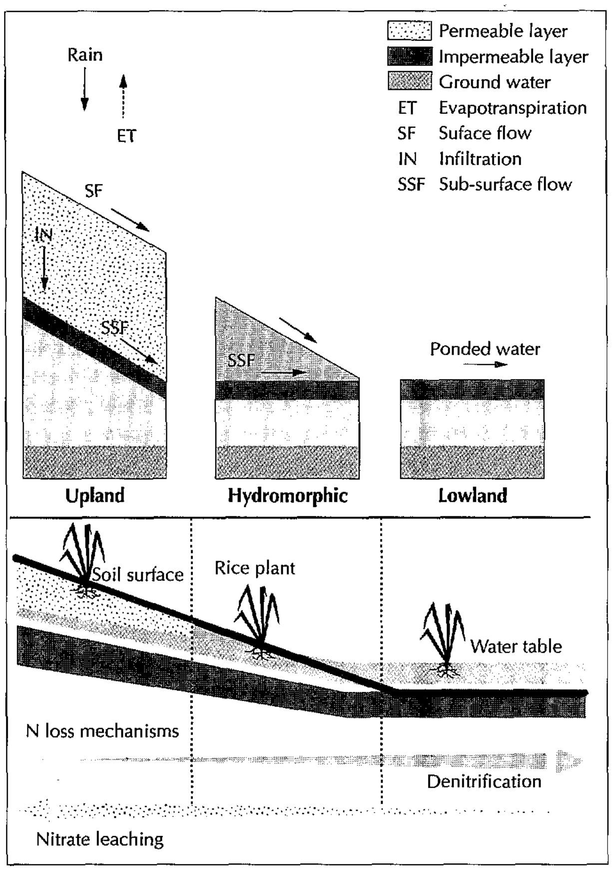
A. Engels, M. Becker and N. van de Giesen

Intensification of low-input smallholder rice farming systems in inland valleys calls for a more efficient use of the systems' internal resources such as soil moisture and native soil nitrogen. Amounts of mineral and thus plant-available soil N, particularly nitrate, are tightly coupled to soil moisture and water movements, and are therefore likely to vary in space and time. When high amounts of nitrate in the soil are not matched with plant N uptake, the potential for N losses is increasing. Efficient use of native soil N through the development of improved soil and crop management practices requires a quantitative understanding of N and water dynamics and their underlying processes.

A German-funded (BMZ/GTZ) collaborative research project was initiated in 1995 between WARDA, the University of Giessen in Germany and Wageningen Agricultural University in the Netherlands. Detailed studies on seasonal patterns of water and N dynamics, with particular reference to the extent and the mechanisms of N losses, are being undertaken on a model toposequence on the WARDA research farm at M'bé. Three types of vegetative cover during the dry-to-wet transition (bare fallow, weedy fallow, and maize crop) are being compared for soil N conservation (randomized block with three replications). Studied water components include rainfall, evapotranspiration, soil moisture, infiltration, surface runoff, subsurface flow, and water table and ponded water depth. Components of the N cycle involve weekly quantification of ammonification, nitrification, nitrate leaching (lysimeters), and *in situ* denitrification (modified acetylene inhibition method, using incorporated calcium carbide).

Preliminary results indicate a flush of mineral soil N (mainly nitrate) occurs during the dry-to-wet transition period, with higher amounts being found in the top soil of the hydromorphic and lowland (69 and 40 kg N ha^{-1}, respectively) than in the upland ecologies (29 kg N ha^{-1}) (Figure 23 *overleaf*). Little soil nitrate was found after the onset of the main rainy season, when the toposequence was planted to rice. In the upland, rate that had not been immobilized in the biomass of growi..g plants was mainly leached out of the rooting zone and probably translocated with infiltration and subsurface flow water to the lower parts of the toposequence, where *in-situ* measured denitrification was highest (Ca-carbide acethylene-inhibition method).

Figure 23: Mechanisms of native soil nitrogen losses from three types of vegetative cover on a wet-to-dry transition.



We conclude that in the absence of soil N conservation measures (e.g. nitrate-catching crops), large amounts of native soil N are being lost, with leaching being the dominant process in the upland, and denitrification being the more important loss mechanism in the lowland ecosystems. The complexity and interactions of the underlying processes call for the use of systems research tools. Development of water-N models at the toposequence and watershed levels will assist in the development of technical options that improve the management of native soil N for rice production on the continuum.

Upland rice yield and resource-base quality as affected by cropping intensity

M. Becker and D.E. Johnson (NRI)

Increased demand for land is forcing many farmers to intensify their upland rice-based systems. Current trends indicate a gradual shift from bush fallow rotation or shifting cultivation systems towards sedentary agricultural production. However, farmers are not adapting crop- and resource-management practices to the new intensified land-use systems, which may threaten their sustainability by reducing resource-base quality, and affecting yield potential and systems productivity.

Diagnostic field trials were conducted in three of the agro-ecological zones of Côte d'Ivoire in 1994 and 1995: at Gagnoa in the forest zone; Touba in the transition zone; and, Boundiali in the savanna zone. Traditional extensive upland rice production systems were compared with intensified cropping in 191 farmers' fields. Weed species composition and dry biomass, and rice grain yield were determined under farmers' management, as well as in three superimposed researcher-managed subplots (hand weeding at 28, 56, and 84 days; 30 kg mineral fertilizer N application; and, a combination of both). Soil samples (0-20 cm), taken at the start of the cropping season, were anaerobically incubated in the laboratory and extracted after 1 and 3 months for soil exchangeable ammonium (2N KCl) to determine potential soil nitrogen-supplying capacity. Yield gaps were attributed to weeds and nitrogen, based on yield response to researchers' management in intensified systems.

Current land-use intensification is likely to increase total upland rice production in the short-term, but it results in a significant plot-level yield reduction. Intensification-induced yield loss was higher in the forest (41%) than in the transition (31%) or the savanna zones (20%), and appeared to be related mainly to increased weed infestation (72% more weed biomass) and a 28% reduction in soil N-supplying capacity. The relative importance of yield-affecting factors varies by agro-ecological zone. Weeds seem to be the dominant factor responsible for yield loss in the forest (68% of the yield gap) and appear to play a lesser role in the savanna. Short fallow fields in the forest zone were dominated by broadleaf species (e.g., *Chromolaena odorata*), whereas grasses (*Imperata, Digitaria*, and *Andropogon*) dominated the intensively cultivated fields in the transition and the savanna zones. Crop intensification generally reduced soil N-supplying capacity. This reduction was strongest in the transition zone where N supply accounted for 44% of the yield gap. Rice pests and changes in soil physical parameters may have played a significant role in the observed yield decline. This may be particularly true for the savanna zone, where more than 30% of the yield gap could neither be explained by weeds nor by N supply (Table 10 *opposite*).

Table 10: Impact of intensification of upland rice-based systems on resource based quality and yield loss (diagnostic on-farm trials, Côte d'Ivoire, 1994 and 1995).

Parameters	— Forest zone — Extensive n = 29	Intensive n = 39	— Transition zone — Extensive n = 16	Intensive n = 18	— Savanna zone — Extensive n = 28	Intensive n = 35	Across agro-ecological zones n = 173	
Observations							Intensification-induced changes:	
Yield (Mg h^{-1})	1.68	0.98	1.82	1.22	1.63	1.31	Yield	-38%
Weed weight (g m^{-2})	156	302	259	372	368	394	Weed weight	+72%
N supply (mg kg^{-1})	72	57	108	62	72	69	Soil N supply	-28%
Yield gap							Yield gap attributable to:	
— due to weeds (%)	68		38		44		Weeds	54%
— due to N (%)	28		44		24		N supply	31%
— unaccounted (%)	4		18		32		Others	18%

Extensive systems: > 8 years of bush fallow (forest); first crop after fallow (transition and savanna). Intensive systems: < 5 years bush fallow (forest); rice after > 3 years of cultivation (transition and savanna).

We conclude that long-term upland rice productivity cannot be sustained under current intensification practices. Improved management strategies target the stabilization of upland rice-based systems, aiming primarily at reducing weed pressure and improving soil N supply. Technical options are likely to vary with agro-ecological zones.

Incorporating leguminous species into upland rice fallow systems

M. Becker, D.E. Johnson (NRI) and A. Audebert (CIRAD)

The intensification of upland rice systems in recent years has led to a decline in the duration of the fallow periods which are relied upon to maintain productivity. To address this threat to sustainability, multi-purpose legume cover crops may be introduced to control weeds and erosion, and increase organic matter and soil nitrogen supply capacity. During 1995, we sought to identify suitable legume species for the major rice growing ecologies and to determine appropriate fallow management practice on the basis of existing rice-based cropping systems. Improved management of legume fallows depends on when the fallow is sown (to optimize legume establishment while minimizing competition with the rice crop), how the fallow is cleared in preparation for rice, and how a direct economic benefit can be derived from the fallow species.

The effect on crop and weed growth of the removal, burning, mulching or incorporating fallow residue prior to the rice crop was compared for the legume fallow species *Calopogonium, Canavalia, Mucuna, Puararia, Vigna, Centrosema,* and natural weed population. In a second experiment, the timing of fallow establishment, in relation to the rice, was examined for the legumes *Tephrosia, Stylosanthes,* and *Calopogonium.* In each experiment, rice and weed growth were recorded. 1995 was the first year of these experiments.

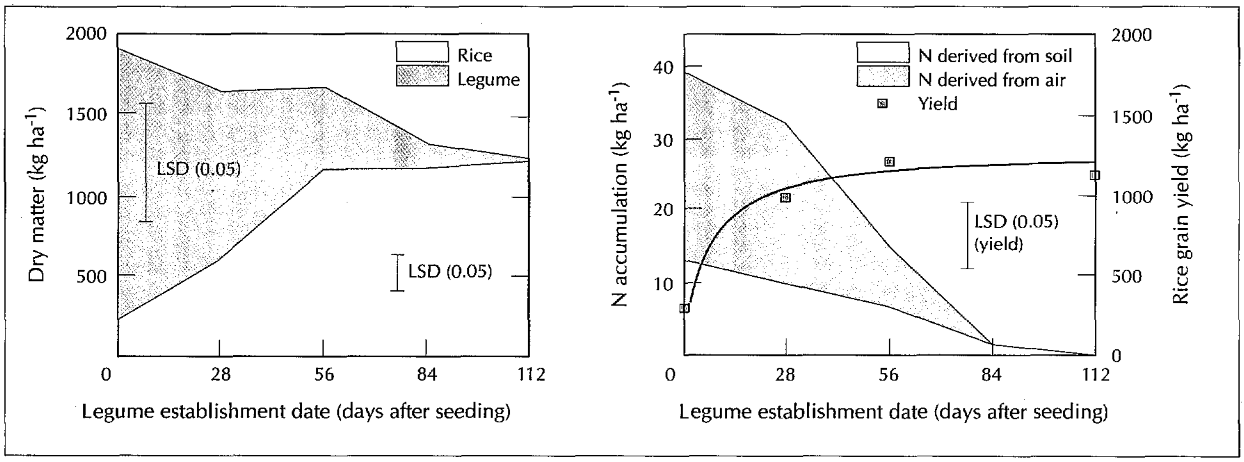
Across species, the legume fallow vegetation accumulated more than three times the N compared to the weedy fallow, while at the end of the fallow period the legume vegetation contained only one-fifth of the weed biomass of the weedy fallow (Table 11). Rice grain yields after the legumes were significantly higher than following the weedy fallow. Across fallow management treatments, at 28 days after sowing (DAS)

Table 11: Impact of fallow vegetation and residue management on upland rice.

Parameters	Dry season vegetation Weedy fallow	Legume fallow	LSD (0.05)
N accumulation (kg ha^{-1})	26	81	17
Dry weed biomass (g m^{-2})	126	21	26
Rice grain yield (Mg ha^{-1})			
— residues removed	0.34	0.88	0.38
— residues burnt	0.40	0.93	ns
— residues mulched	0.29	1.05	0.55
— residues incorporated	0.26	1.15	0.34
Mean of treatments	0.32	1.01	0.33
LSD (0.05)	ns	0.33	

weed growth in the rice was lower when the vegetation had been removed prior to sowing the rice, compared to when it had been burnt, mulched or incorporated (32, 67, 57 and 76 g m^{-2}, respectively $LSD_{0.05}$ 22). The removal of the fallow vegetation is likely to have reduced the quantity of weed seeds remaining on the site. In the second experiment, across the legume species, sowing of the legumes at the same time as the rice resulted in the best ground cover and highest N accumulation (39 kg N ha^{-1}) in the fallow biomass at the onset of the dry season, but led to very low rice yields due to inter-specific competition. There were no differences in rice yields when the legumes were sown at 28, 56 or 120 days after the rice, but legume N accumulation up to the rice harvest increased with the earliness of establishment (Figure 24). The presence of legumes reduced natural weed growth in the rice at 56 and 84 DAS. Models are now being developed, as optimal dates for legume establishment are likely to vary with rice cultivar, legume species and ecosystem. In 1996, a number of the most promising legume species will be grown on farmers' fields in the different agro-ecologies.

Figure 24: Effect of legume establishment date, as sown into an upland rice crop, on total dry matter production, legume N accumulation, and upland rice grain yield.



SOIL FERTILITY MANAGEMENT RESEARCH

Rice cultivation in West Africa occurs in a wide variety of soils ranging from strictly waterlogged (inland swamp) to well drained upland soils. The soil fertility problems of uplands are more diverse and complex, and are further complicated by water shortages, and rapid decline in organic matter and nutrient reserves. Most soils are deficient in nitrogen and phosphorus. The acid uplands in the humid forest zone are acutely deficient in P, and P deficiency is a major constraint to rice production. On the other hand, rice yields on the uplands in the savanna and forest-savanna transition zone suffer more from N than P deficiency. Nutrient deficiencies in rainfed systems tend to be less serious in drought-prone environments, where water stress frequently prevents exhaustive use of native soil fertility.

Because of the prevailing undulating topography, the uplands are prone to the loss of soil fertility through erosion and leaching. By contrast, the lowland soils in the valley bottoms of inland valleys are relatively robust. Because of flat topography there is little loss of soil fertility due to soil erosion. In fact, lowlands receive soil nutrients through surface and interflow, as well as sediment deposit, from the uplands. Because of the flow of nutrients such as potassium, calcium and magnesium to the lowlands from uplands, the deficiency of these nutrients are rare in the lowlands. However, the interflow of ferrous iron into the lowlands is a cause of concern because it can cause iron toxicity to rice growing in the lowlands. Zinc deficiency is more prevalent in lowland than in upland rice.

During 1995, WARDA's soil fertility research continued its focus in the diagnosis of nutrient disorders affecting the rice crop along the continuum. We also continued our research efforts in identifying genotypes of rice tolerant of iron toxicity in the lowlands and P deficiency in acid uplands. An inter-disciplinary approach is being used to develop integrated management methods for problem soils, combining varietal choice with improved crop- and resource-management methods. Consequently, applied soil fertility research is now increasingly conducted at national agricultural research system (NARS) sites and on-farm key sites in different agro-ecological zones in Côte d'Ivoire and Nigeria, backed by on-station strategic research.

Varietal responses to residual P in an Ultisol in the humid forest zone

K.L. Sahrawat and M.P. Jones

Phosphorus deficiency is the major nutrient disorder in the acid uplands of West Africa's humid forest zone. In these soils the availability of native and applied P to the crop is reduced by reactions of soluble P with aluminum and iron oxides. Our approach to improving the productivity of rice on Ultisols is based on the integration of genetic tolerance to P deficiency and crop management.

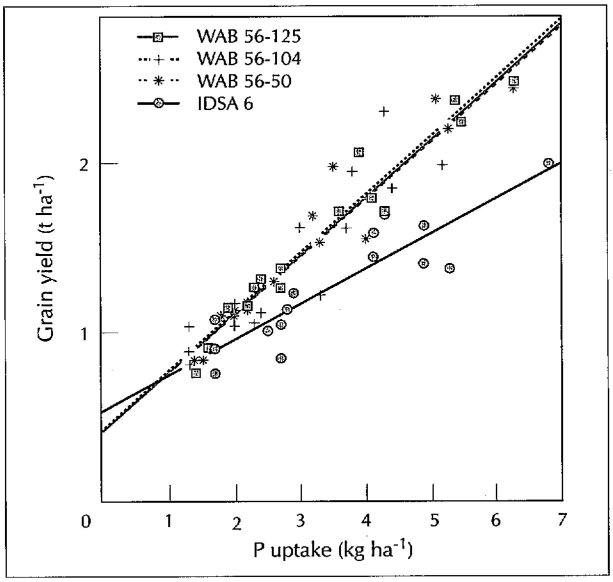
In 1994, we reported on the response of four upland rice cultivars to fresh (wet season 1993) and to residual P (wet season 1994). During 1995, the experiment was repeated at the same site, but without any fresh application of fertilizer P, to study the response of the four cultivars to the residues two years after the initial P application.

All test cultivars showed a significant response of grain yield to P application during the first and second years although the response to residual P in the second year was weaker (Figure 25). In the third year (1995) the response to the residual P was still significant from P applied at 135 and 180 kg P ha^{-1}. Consequently, in these highly acid soils, fertilizer P applied in excess of the crop requirement has significant residual effects up to two years after application. However, the apparent recovery of applied P by the crop does not exceed 6% for the first crop or 10% for three crops.

The agronomic P efficiency of the four cultivars, averaged over five rates of P, and based on cumulative P response during the three years was highest for WAB 56-125 (25 kg grain/kg P) and lowest in IDSA 6(13 kg grain/kg P). The local improved check IDSA 6 had also the lowest physiological P-use efficiency, indicating that WARDA's improved cultivars produced significantly more grain per unit of P absorbed. Superior P-use efficiency of the WAB lines was due to a higher P harvest index (0.71-0.74) or fraction of P translocated to grain, than IDSA 6 (0.62).

These results indicate that the higher P efficiency of the WAB lines is related to lower internal P requirements compared to IDSA 6. They also indicate that it is possible to breed cultivars for higher P efficiency. These traits are only expressed when the the materials are evaluated on acid soils acutely deficient in P. During 1996, we plan to evaluate the *O. glaberrima* and *O. glaberrima* x *O. sativa* progenies for tolerance to soil acidity and P deficiency.

Figure 25: Relationship between grain yield and P uptake of upland rice.



Materials and method

The experiment was conducted near Man in the humid forest zone of Côte d'Ivoire. Phosphorus was applied only once in 1993 as triple superphosphate at five rates (0, 45, 90, 135 and 180 kg P ha^{-1}) in an Ultisol (pH 4.9; organic C 1.35%) low in extractable P (2.7 ppm Bray-1 extractable P). The experiment had a two-factorial randomized complete block design with four replications. Two factors were compared: P application in the first year (1993), and cultivars (WAB 56-125, WAB 56-104, WAB 56-50 and IDSA 6).

Characterization of grey soils on lower slopes developed on granite and gneiss parent material

S. Diatta and K.L. Sahrawat

The upland/lowland swamp continuum is one of WARDA's priority research areas. It includes upland, hydromorphic and lowland zones. It is necessary to fully understand its pedological structure, as well as its water status, for rice cropping along the toposequence. We studied the spatial distribution of physical and chemical properties of grey sandy soils of the hydromorphic zone at 20 cm depth in two inland valleys in the forest-savanna transition zone in Côte d'Ivoire.

Mapping of the soil properties (Figures 26 and 27) highlights three parts roughly parallel to the valley contour lines: an upstream zone; an intermediate zone; and, a downstream zone located near the valley bottom.

The upstream zone is characterized by relatively high contents in clay, organic carbon, calcium, magnesium, potassium, and by high values of cation exchange capacity (CEC). These values increase with depth, with the exception of available phosphorus, which is more concentrated on the surface (0-20 cm). The spatial variability of nutrient contents is high in this zone. Available P is found in high concentrations.

The intermediate zone has low contents in clay, organic carbon, calcium, magnesium, potassium, along with low CEC. This is a depleted area with strong vertical- and side-leaching. Available phosphorus remain high in this zone, which confirms the low mobility of this nutrient in the soil.

The downstream zone contents in clay, organic carbon, calcium, magnesium, potassium, as well as the CEC values, are higher than in the intermediate zone. However, these values remain low in comparison with those recorded in the upstream zone. Spatial variability is moderate, with peaks corresponding either to lobes of the lowland or the presence of termite hills.

Results show that hydromorphic soils are heterogenous, and have confirmed the existence of an intermediate zone with physical and chemical characteristics different from those found in upstream and downstream areas. This zone is a physical and mineral discontinuity between the upstream and downstream portions of the site. Rice yields are low in this area compared to upstream and downstream areas. In the downstream zone, high yields are basically due to the presence of the water table, while in the intermediate zone the table is deeper and does not compensate for the water deficit of very sandy soils. Only perennial fruit crops could

Figure 26: Spatial distribution of organic carbon content at the depth 0-20 cm, M'bé, Côte d'Ivoire.

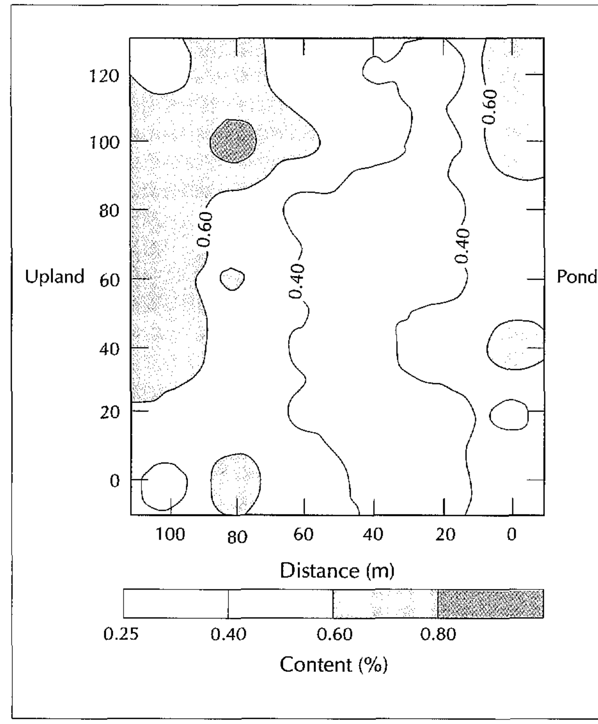
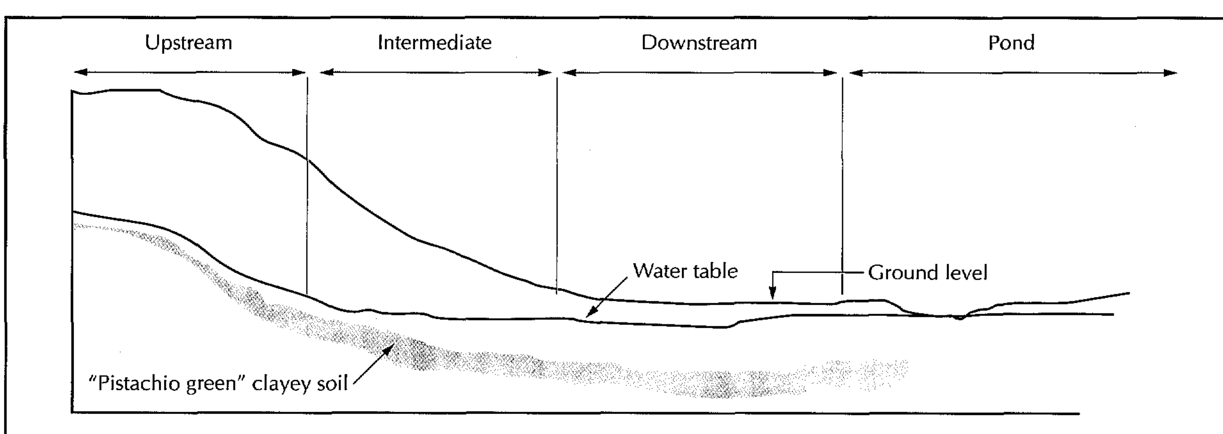


Figure 27: Distribution of grey sandy soils along the zones of the toposequence, M'bé, Côte d'Ivoire.



be considered to be grown in this zone. On the basis of results obtained, future research will focus on the dynamics and flow of mineral elements along the toposequence.

Materials and method

Two one-hectare sites were selected along an inland valley at M'bé, Côte d'Ivoire, and were stratified. Soil samples were taken at four depths (0-20, 20-40, 40-60, 60-80 cm) following a 5 x 5 m grid. Standard analysis (granulometry, pH, carbon, nitrogen, available phosphorus, exchangeable base and CEC) were made.

Iron deficiency in upland rice caused by the liming action of ash

K.L. Sahrawat

Iron deficiency, or iron chlorosis, is a nutrient disorder that commonly occurs in plants growing on calcareous and high pH soils. However, it can also be induced in soils rich in iron and with pH in the acidic range, by the liming action of ash introduced by the burning of residues or vegetation. The problem can be severe in patches in and around the heaps of ash, and is a major source of crop heterogeneity. Iron deficiency may be encountered under slash and burn cultivation of upland rice in West Africa.

We have observed typical iron deficiency symptoms on young rice plants growing on light-textured, well drained upland soils at the WARDA farm at M'bé, Côte d'Ivoire. The occurrence of the disorder has generally been confined to those fields where residues were burned during the dry season prior to planting of rice crop during the rainy season following (June-October).

The iron deficiency symptoms in the rice plants appeared as interveinal chlorosis, or bleaching, of the youngest leaves. The symptoms spread to the older leaves with increasing severity of the disorder.

The disorder was transient and persisted until the patches of soil, loaded with ash, were diluted by flooding with rain water. To confirm the occurrence of iron deficiency, soil and plant samples were collected from patches in the field planted to upland rice. Samples were collected from areas showing normal rice growth and those affected by iron deficiency.

The results on the analyses of soil and plant samples revealed striking differences in soil pH and total iron content of the plant tissue. The pH of the soil samples collected from patches showing iron deficiency ranged from 8.6 to 9.0, while the pH in the soil samples with normal rice growth, was in the plant tissue of the healthy and affected rice plants in the range of 6.0 to 6.5.

The top three leaves of the rice plant from the affected areas contained total iron ranging from 35 to 45 mg Fe kg^{-1} of dry weight. Plant samples from normal growth areas contained total iron in excess of 120 mg kg^{-1} (from 125 to 210 mg kg^{-1}). The nitrogen, phosphorus, potassium and zinc content of leaves was not affected by the disorder.

Evidently, iron deficiency in the rice plants was induced by liming as a result of burning of the residues in heaps. The land was well drained and the soil did not get waterlogged until late in the season. The high soil pH would not have caused iron deficiency in the rice plants had the soil been waterlogged. Waterlogging of the soil can alleviate iron deficiency by diluting the ash through dispersion and mixing, and more importantly, by mobilizing ferrous iron in soil solution. In some plants, iron chlorosis was eventually alleviated by waterlogging.

Under severe ash-induced iron deficiency caused by the combination of liming by ash and well-drained soil, the crop may have to be resown after plowing. But the overall quantitative importance of iron deficiency in West African soils is low due to the high content of reducible iron in most soils.

Materials and method

The variety, IDSA 6 was direct-seeded and received 200 kg of 10-18-18 (N-P-K) as basal application.

Varietal and seasonal differences in yield reductions caused by iron toxicity

K.L. Sahrawat, B.N. Singh and M. Dingkuhn

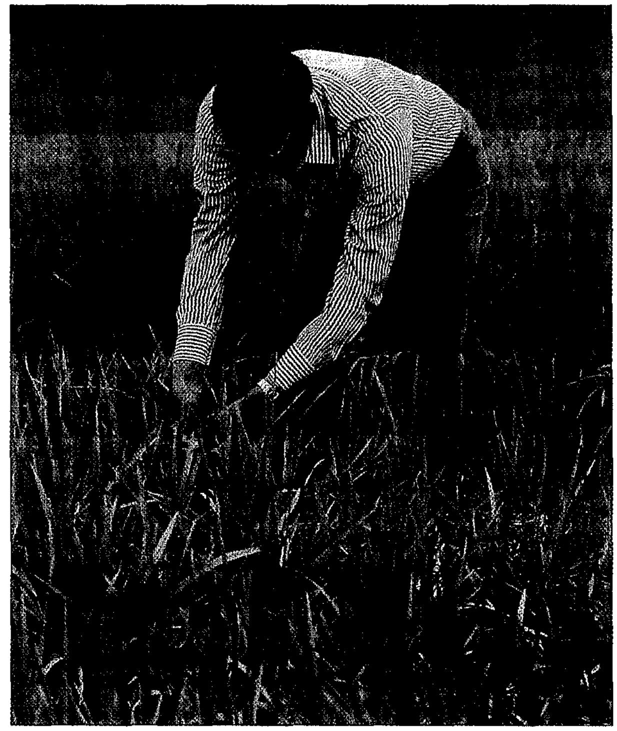
Iron toxicity, a physiological stress caused by excess soluble iron (Fe^{++}) under waterlogged conditions, is a major yield-reducing factor in rainfed and irrigated lowlands. Varietal tolerance is the most cost efficient means to control this condition. As with other stresses caused by excess cations, such as salinity, iron toxicity is likely to depend on transpiration water flow, which in turn depends on local and seasonal climate. This, as well as the strong interactions with soil fertility described in the 1994 WARDA Annual Report, reduces the replicability and extrapolation of varietal performance data.

During 1995, we tested 10 advanced iron-toxicity-tolerant selections, one susceptible check (Bouaké 189), and one traditional tolerant check (Suakoko 8) during the wet and dry seasons at Korhogo in northern Côte d'Ivoire, an iron-toxic hotspot. The wet season at WARDA's main experimental station at M'bé served as the non-toxic reference environment. Management of water, weeds, and nutrients followed the recommended optimum.

The highest grain yields were observed at the M'bé reference site, where they averaged 6.9 t ha^{-1}. Suakoko 8 had yields of only 5.3 t ha^{-1}, as a result of its tall-traditional morphology. Mean yields were lower by 1.6 t ha^{-1} (23%) during the wet season at Korhogo, and by 2.7 t ha^{-1} (39%) during the dry season at Korhogo despite higher solar radiation. In 1996, we will study whether the stronger yield reductions in the dry season were caused by higher transpiration, resulting in the uptake of more iron by the plant, or by a higher concentration of Fe^{++} in the soil.

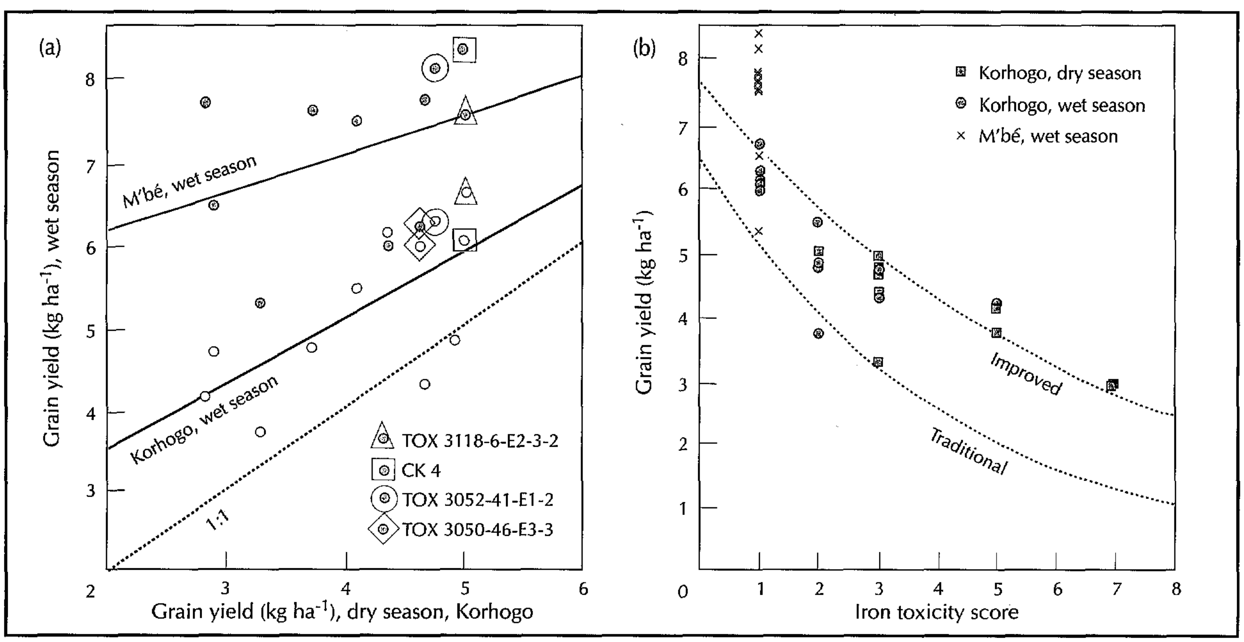
An encouraging observation is the very good performance of some of the highest yielding materials in all three environments, indicating that varietal tolerance to iron toxicity does not necessarily incur trade-offs in terms of yield potential (Figure 28a). This, as well as the high correlation ($R = 0.85^{***}$, $N = 33$; Figure 28b) between leaf-symptom-based iron toxicity scores and grain yield across environments and genotypes (except Suakoko 8), will permit rapid progress in the selection of yet better materials.

During 1996, we will seek to establish relationships among soluble iron concentrations in the substrate, soil fertility and plant-nutritional parameters, climate, leaf toxicity symptoms, and grain yields. This will help us develop rapid methods to assess yield reductions caused by iron toxicity in different environments, formulate robust models to estimate the



Checking iron toxicity in rice

Figure 28: (a) Grain yield of 12 rice varieties in the wet season at M'bé, and the iron-toxic site of Korhogo, Côte d'Ivoire, as compared to grain yields observed during the dry season at Korhogo. (b) The relationship between grain yield and leaf-symptom-based iron toxicity scores across the environments, for 11 improved high-yielding lines and one tall-traditional check.



potential impact of improved technologies for the region, and develop appropriate varietal and management technologies for the diverse lowlands affected by iron toxicity.

Materials and method

All plots (12 m² at M'bé, 24 m² at Korhogo) received a basal application of 20-36-36 kg ha^{-1} N-P-K, and a further topdressing of 80 kg ha^{-1} of N as urea in two splits. All three experiments had a randomized complete block design with four replications.

Physiological adaptations to iron toxicity

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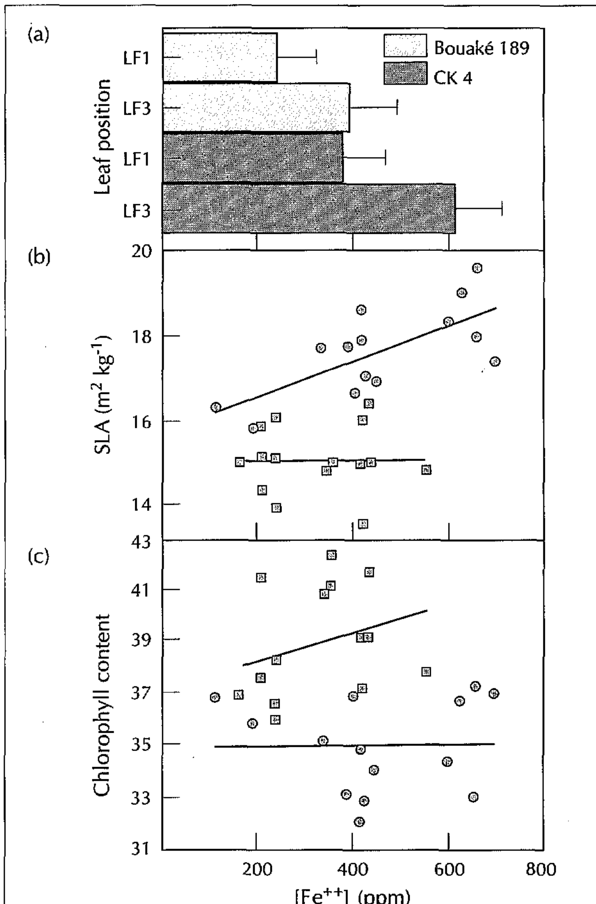
Iron toxicity is the most common chemical stress in lowland rice systems in West Africa. Under reduced soil conditions, high concentrations of Fe^{++} accumulate in the soil solution and floodwater, which are taken up by the plant. The soluble iron accumulates in leaves and causes severe yield reductions, associated with leaf discoloration and poor growth. Our understanding of the physiological mechanisms of these yield reductions is still incomplete.

At an irrigated, iron toxic site at Korhogo in northern Côte d'Ivoire, we investigated the relationship between leaf iron accumulation and two parameters relevant to carbon assimilation: specific leaf area (SLA) and chlorophyll content. Effects of leaf age were taken into account by collecting separately the youngest and third-youngest leaf of the main culms during the late vegetative stage. Test varieties were Bouaké 189 (susceptible) and CK 4 (tolerant).

Leaves of the two test varieties responded differently to iron toxicity. While older leaves generally contained more iron than young leaves — probably a function of transpiration history — the concentrations were much higher in Bouaké 189 than in CK 4 (Figure 29a). The latter, tolerant variety, therefore, absorbed less iron or transported less to the leaves. Accumulation of iron in the leaves of Bouaké 189 was associated with a significant increase of SLA, which is the leaf area produced with a given amount of dry weight. Consequently, iron-stressed leaves were thinner than non-stressed leaves (Figure 29b). The tolerant check CK 4 showed no such response. CK 4 had a significantly higher leaf chlorophyll concentration than Bouaké 189 under iron toxic conditions, indicating a higher photosynthetic potential (Figure 29c). Taking observations on both SLA and chlorophyll content into account, it is seen that any given amount of iron present in the leaves reduced photosynthetic rates more strongly in Bouaké 189 than in CK 4.

In summary, CK 4 owes its superior performance under iron toxic conditions partly to avoidance (less iron accumulation in leaves) and tolerance (superior photosynthetic potential under iron toxic conditions). In 1996, we will further investigate both mechanisms, with the objective of developing more efficient tools for selecting Fe^{++} tolerant rice varieties.

Figure 29: Differences in specific leaf area (SLA) and areal chlorophyll content (arbitrary units) as related to leaf iron content for two rice varieties grown under iron toxic conditions. LF1, youngest fully expanded leaf; LF3, third leaf position from top.



(b) ◎ Bouaké 189; SLA = 0.00427 [Fe^{**}]+15.70; n = 16; r^2 = 0.50
▣ CK 4; SLA = 0.0001 [Fe^{**}] + 15.009; n = 16; r^2 = 0.0002
(c) ◎ Bouaké 189: [Chl] = 0.00043[Fe^{**}]+34.683; n = 16; r^2 = 0.003
▣ CK 4: [Chl] = 0.00563[Fe^{**}]+37.144; n = 16; r^2 = 0.096

Materials and method

The experiment had a randomized complete block design with four replications. All measurements were conducted during a single day during the wet season during the late vegetative stage of the crop, based on four leaves from as many hills per plot. SLA was measured by portable leaf area meter and subsequent drying and weighing. Iron concentrations were measures by AAS and areal chlorophyll content by SPAD chlorophyll meter.

INTEGRATED PEST MANAGEMENT RESEARCH

Biotic stresses in West African rice systems are, in many cases, indigenous to Africa. They are enhanced by abiotic stresses that weaken the plant and render it susceptible. For some of the major pests and diseases of lowland rice, such as rice yellow mottle virus (RYMV) and the African rice gall midge (ARGM), no genetic resources for strong resistance are available in other continents, and solutions must build entirely on indigenous resources. In the case of many weed and insect problems, established chemical control methods are not suited to local conditions, due either to the non-availability of chemical inputs, or out of ecological consideration. In fact, research at WARDA during the past years has shown that natural control mechanisms, such as predators or parasitoids, are still fairly intact in many West African rice environments, and are probably responsible for a comparatively low insect pest pressure. Consequently, the main objectives of WARDA's integrated pest management (IPM) research are: to stabilize the fragile natural mechanisms of pest control as rice systems are intensified; and, to develop varieties with stable resistance to pests and diseases, particularly those that tend to escape cultural and ecological control mechanisms.

During 1995, research focused on the integrated management of regionally important pests, in particular, weeds, RYMV, leaf and neck blast, ARGM, and root nematodes. Significant progress was made in the analysis of interactions between the natural weed flora and useful predator populations; the selection of weed-competitive parent materials for interspecific rice crosses; the selection of genetic sources of RYMV-resistance both within *O. sativa* and *O. glaberrima*, and the successful field-testing of promising resistant progenies; the agro-ecological characterization of parasitic nematodes, and the identification of resistant *O. glaberrima* landraces; and the agro-ecological characterization of ARGM.

Major knowledge and research gaps remain. In 1996, research will therefore be intensified in the development of genetic resistance to ARGM, which, due to the apparent lack of good donors within *O. sativa*, will also use *O. glaberrima* sources. The search and breeding activities for RYMV-resistant or -immune lowland rices continue, as will research on the regional genetic diversity of the blast pathogen. The major challenge for the years to come will be to combine resistances to major stresses in a single, low-management plant type. This plant type will draw most of its biotic and abiotic stress resistance from *O. glaberrima*, and its yield potential from *O. sativa*.

The rice yellow mottle virus epidemic: new replacement varieties as a short-term solution

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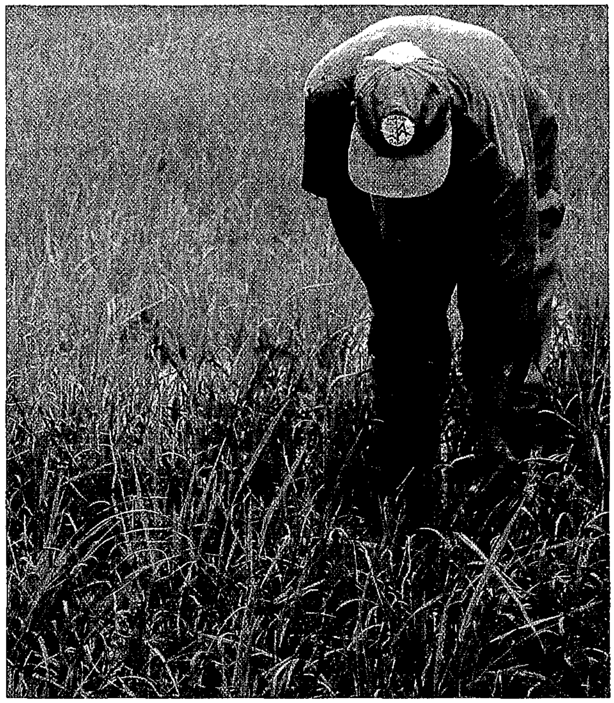
The rice yellow mottle virus (RYMV) disease is spreading rapidly in lowland ecologies in Africa. The disease has been observed in most sub-Saharan African countries, and severe yield losses have been reported in irrigated rice systems in Mali, Niger, Côte d'Ivoire and Madagascar. The disease can be locally severe in all the three major agroclimatic zones of West Africa: the Sahel, the savanna, and the humid forest zones. The most commonly grown lowland rice varieties — BG 90-2, IR 1529-680-3, Jaya, and Bouaké 189 — are introductions from Asia and highly susceptible to RYMV.

Many tropical upland japonica lines are resistant to RYMV, but their yield potential is low, as compared to lowland adapted indica varieties. Screening for genetic donors for breeding RYMV resistance began at Rokupr, Sierra Leone, in 1975, and at the International Institute for Tropical Agriculture (IITA) in Ibadan, Nigeria, in 1978. Hybridization work started in 1982 at Ibadan, using upland materials such as Moroberekan, OS 6, and LAC 23 as genetic donors. In 1983, CT 19, an indica semi-dwarf line from India, was identified as a new donor having better genetic compatibility with indica materials. Yield evaluation of recombinant lines began in 1987. Stable progenies with genes from OS 6, CT 19 and LAC 23 are now available, combining RYMV resistance with the high yield potential required in lowland ecologies.

During the 1995 wet season, WARDA researchers and the Lowland Rice Breeding Task Force evaluated observational nurseries, advanced yield trials and elite varietal trials across the region. The 31 improved lines from 14 crosses had been previously selected based on their yield potential and resistance to RYMV under artificial inoculation in screenhouses at Ibadan. These multi-location trials, although providing valuable information on varietal performance across the region, did not achieve a conclusive field validation of the entries' RYMV resistance. This was due to the fact that RYMV incidence is extremely variable and can be neither predicted nor induced. The disease also seems to be more frequent in farmers' than in researchers' fields. Another confounding factor was the massive occurrence of African rice gall midge (ARGM) at Ibadan, which reduced yield levels to less than half of the varieties' potential.

On the basis of the data obtained in all regional yield trials in the past four years, some of which did show RYMV infestation (e.g. in Mali and Cote d'Ivoire), three elite lines have been identified. These are WITA 7 (TOX 3440-171-1-1-1-1-1), WITA 8 (TOX 3440-176-1-2-1), and WITA 9 (TOX 3058-28-1-1-1). The first two lines are based on a cross of Tox 891-212-1-201-1-105 with TOX 3056-5-1 (1987 at IITA), whereas WITA 9 resulted from cross between IR 2042-178-1 and CT 19 (1984 at IITA). WITA 7 and 8 derive their RYMV resistance from CT 19 and OS 6, respectively, while WITA 9 derives it from CT 19 only.

WITA 7 through 9 are our current "best bets" for RYMV-affected areas. WITA 9 is of short stature and best suited to fully irrigated systems, whereas WITA 7 and WITA 8 are slightly taller and are adapted to both rainfed and irrigated lowlands. The three lines showed good RYMV resistance under inoculated conditions at Ibadan, and showed field resistance at Gagnoa, Sakassou and M'bé, Côte d'Ivoire; Rokupr, Sierra Leone; and Niono, Mali. Their yield potential at different locations, RYMV score, plant height, and flowering is given in Table 12. Grains of WITA 7 and WITA 9 are long and slender (comparable to the commonly cultivated but RYMV-susceptible Bouaké 189), and WITA 8 grains are long and bold (comparable to IR15 29-680-3 and Jaya).



WARDA reasearcher examining rice infected with RYMV

Table 12: Grain yield (t ha^{-1}) and other agronomic traits of selected RYMV-tolerant lines in regional trials.

Designation	Rokupr, Sierra Leone			Ibadan, Nigeria			Gagnoa, Côte d'Ivoire		M'bé, Côte d'Ivoire			Camp Penal, Côte d'Ivoire	Niono, Mali
Year	**93**	**94**	**95**	**93**	**94**	**95**	**93**	**94**	**93**	**94**	**95**	**93**	**94**
WITA 9 (TOX 3058-28-1-1)	2.9	3.4	3.4	4.6	4.6	2.6	4.4	1.3	8.8	3.9	3.5	3.7	9.0
WITA 7 (TOX 3440-171-1-1-1-1-1)	2.2	3.5	4.6	4.6	4.9	2.7	4.5	2.6	8.7	3.8	2.8	4.1	7.8
WITA 8 (TOX 3440-176-1-2-1)	2.5	3.2	3.0	4.0	5.1	2.7	4.4	2.2	7.1	3.2	3.1	3.9	8.5
ITA 306	3.1	3.6	3.1[c]	4.6	4.6	2.1	4.2	1.4	6.9	3.9	4.2[c]	2.8	8.5
Bouaké 189[a]	—	—	—	—	—	2.3[c]	6.0	2.4	—	4.8	3.2	2.8	8.1[b]
SE	0.2	0.4	—	0.3	0.3	0.2	0.7	0.2	0.4	0.7	—	—	0.8
CV (%)	13.7	17.4	—	11.1	10.1	12.9	13.9	17.4	8.5	31.9	34.7	—	18.0

Table 12 (cont):

Designation	Plant height (cm) Ibadan	Days to 50% flowering in g at Ibadan	RYMV (SES 1-9) Ibadan, 1995 wet season
WITA 9 (TOX 3058-28-1-1)	95	90	1
WITA 7 (TOX 3440-171-1-1-1-1-1)	126	102	3
WITA 8 (TOX 3440-176-1-2-1)	121	97	3
ITA 306	106	95	7
Bouaké 189[a]	128	105	7
SE	1.8	0.5	—
CV (%)	2.8	0.9	—

[a] Local check; [b] BG 90-2; [c] ITA 230.

During 1996, RYMV resistance of three elite lines will be evaluated under artificial inoculation at M'bé, based on a replicated yield loss study. On-farm field tests will also be carried in hot spots in Mali, Niger, and Côte d'Ivoire. If these trials confirm a satisfactorily broad resistance of these lines to RYMV, they will be propagated in affected zones in collaboration with national agricultural research systems (NARS) and development programs.

Survey of rice insect pests of Côte d'Ivoire, Guinea and Guinea-Bissau

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With rice cropping intensification, insect populations and insect-caused plant damage are expected to increase. To quantify such changes, baseline data are needed before intensification occurs. To obtain such baseline data and to select priority areas for pest management research, surveys were conducted in Côte d'Ivoire, Guinea and Guinea-Bissau during the 1995 wet season. Farmers' fields were systematically sampled using a sweep net to collect canopy insects and predacious spiders. Visual observations were made to determine the extent of plant damage due to insects and the percentage of plants showing typical rice yellow mottle virus (RYMV) symptoms. The various ecologies surveyed are shown in Table 13.

More than 30 known, and numerous unidentified, insect species were collected in sweep net sampling. Populations of representative pest species varied by climatic zone, ecology and country (Figure 30). Of the pest species, adults of the stem borer, *Diopsis longicornis* were abundant in all collection sites but were more abundant in the savanna and lowland than in the forest and the upland. They were most abundant in Guinea. Populations of the white leafhopper, *Cofana spectra,* and the spittlebug, *Locris maculata,* were low in Côte d'Ivoire and Guinea-Bissau, while high in Guinea. The green leafhopper, *Nephotettix* spp. was most abundant in Guinea-Bissau. *Chaetocnema* spp., potential vectors of RYMV, were abundant in all climatic zones and ecologies, except for the lowland in Côte d'Ivoire, where none were collected. Of the predatory species, canopy dwelling spiders, mostly *Tetragnatha* spp., were extremely abundant in the lowlands in Guinea-Bissau.

Whitehead incidence due to stem borer damage was sufficiently high to cause yield losses at all locations in Côte d'Ivoire (Table 13). In Côte d'Ivoire, caseworm damage was most severe in the lowland, while termite damage only occurred in the upland. African rice gall midge (*Orseolia oryzivora*) damage was most common in the lowlands. In Guinea, 25% of sampled fields were infested, but percent tiller infestation was low. It was widespread on the coastal plain (savanna) but was not found in the humid forest zone. In Guinea-Bissau, galls were observed in 77% of sampled fields. Damaged tillers per field ranged from 0 to 13% with a mean of 2%. Gall midge parasitism by *Platygaster diplosisae* and *Aprostocetus procerae* averaged 3.2% and 8.9%, respectively. These parasitism levels are too low to explain the low levels of gall midge damage.

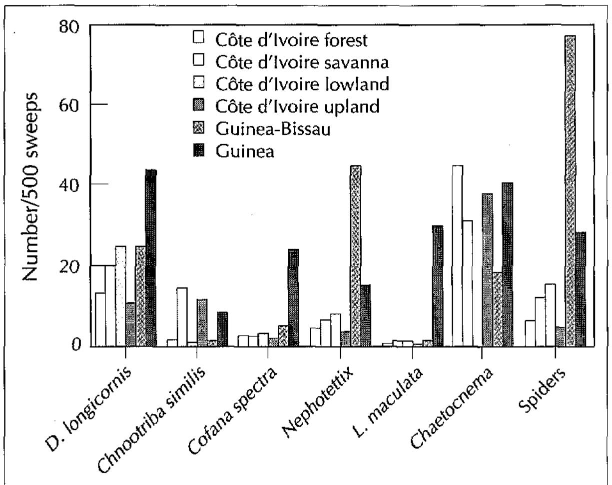
In comparison to Nigeria where the gall midge is a serious pest, the low incidence in Guinea and Guinea-Bissau is possibly due to: the low populations (in southern Guinea only) of the alternate host, *Oryza longistaminata,* on which

Table 13: Plant damage caused by rice insects and rice yellow mottle virus (RYMV) as based on visual observations in surveys.

	Stem borer damage (%) Deadhearts			Stem borer damage (%) Whiteheads	Caseworm damage (%)	Defoliation (%)[b]		Gall midge (%)			Termite damage (%)	RYMV (%)
Ecologies	C.I.	G.	G.B.	C.I.	C.I.	G.	G.B.	C.I.	G.	G.B.	C.I.	C.I.
Upland	7.7	—[a]	—	6.3	0.0	—	—	0.2	—	—	0.4	0.1
Lowland	9.6	5.2	2.3	7.0	22.8	4.3	5.3	1.6	0.9	2.0	0.0	1.5
Savanna[c]	9.9	4.0	—	6.0	6.8	4.4	—	0.9	1.3	—	1.0	0.8
Forest[c]	7.4	7.8	—	7.6	34.2	4.0	—	0.6	0.0	—	0.1	0.5
Mangrove swamp	—	—	1.8	—	—	—	3.5	—	—	1.0	—	—

Surveys conducted in Côte d'Ivoire (C.I.) 14-21 July, in Guinea (G.) 18-25 September, and in Guinea-Bissau (G.B.) 7-14 October 1995.[a] No samples taken; [b] Much of the defoliation was caused by caseworm (*Nymphula* sp.) and crickets (*Euscyrtus* sp.); [c] Côte d'Ivoire savanna and forest ecologies consist of both lowland and upland fields while Guinea and Guinea-Bissau are only lowland fields.

Figure 30: Population of insect pests, *Diopsis longicornis, Chnootriba similis, Cofana spectra, Nephotettix* spp., *Locris maculata, Chaetocnema* spp. and predacious spiders, as based on sweep-net counts in surveys conducted in forest, savanna, upland and lowland fields in Côte d'Ivoire, and in lowland fields in Guinea and Guinea-Bissau.



the midge passes the dry season; the extensive planting of traditional varieties, which may have some levels of resistance; and, the minimal use of inorganic N fertilizer. Levels of stem-borer-caused whitehead and caseworm damage in Côte d'Ivoire are high, and they are expected to increase with further intensification. This suggests that research should be targeted toward the management of these pests.

Materials and method

The surveys were conducted 14-21 July, 18-28 September, and 7-14 October, 1995, in Côte d'Ivoire, Guinea and Guinea-Bissau, respectively. In Guinea and Guinea-Bissau, only pre-flowering and hydromorphic/lowland fields were sampled, as the main objective of the survey was to obtain gall midge data. Thus, upland fields were not sampled and no data on whiteheads were taken. In Côte d'Ivoire, all fields observed along the selected route were sampled. In Guinea, with extensive rice areas, fields were selected at 50 km intervals along a route. In Guinea-Bissau, with fewer fields than Guinea, a distance of 25 km was maintained between sample sites. In all surveys, 500 sweeps with a 38 cm diameter sweep net were taken per farmer's field. For visual observations, 100 hills along a transect were examined per field in Côte d'Ivoire while in Guinea and Guinea-Bissau 30 to 50 hills were examined at equal intervals along 3 to 5 parallel transects across sampled fields. Termite damage and RYMV infection were recorded only in the Côte d'Ivoire survey. To determine percent gall midge parasitism in Guinea-Bissau, random samples of about 50 galls (emerged and unemerged) were dissected at 12 sites.

Seasonal abundance of African rice gall midge and its natural enemies at Ibadan under conditions of constant host plant availability

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Outbreaks of *Orseolia oryzivora,* the African rice gall midge (ARGM), have increased markedly in the last two decades. Improving integrated management of this key pest requires a better understanding of its ecology, and that of its natural enemies. To this end, the abundance of ARGM galls, levels of parasitism and predation within them, and abundance of potential ARGM predators, were monitored on irrigated rice plots planted at monthly intervals in a "rice garden" experiment at Ibadan, Nigeria.

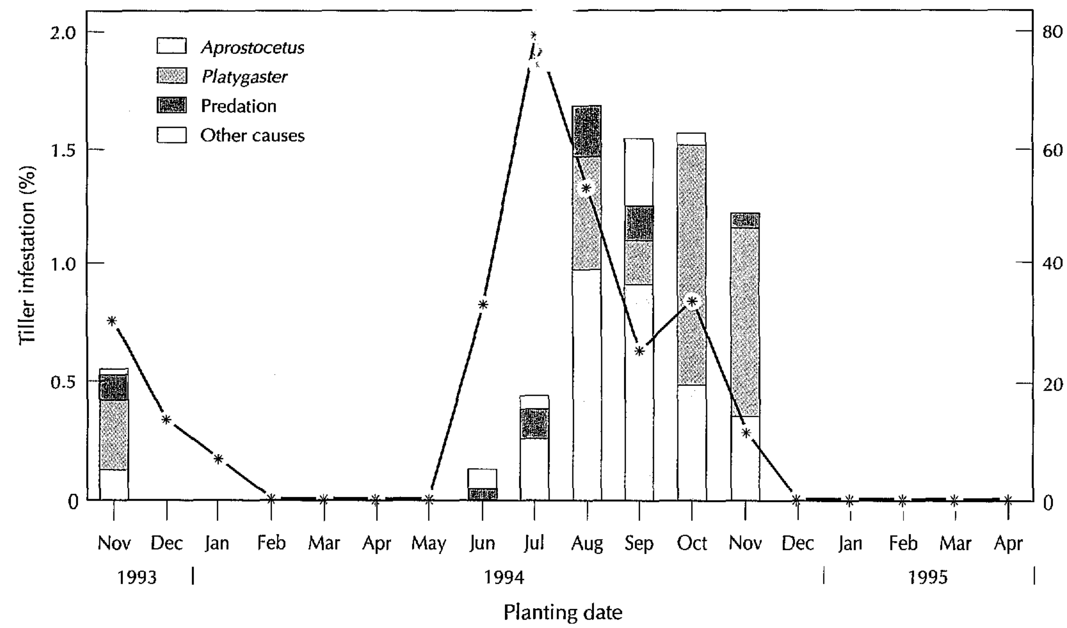
Outbreaks of ARGM are associated with wet conditions, so the build-up of galls during the wet season (April to October) was expected (Figure 31 *overleaf*). But the long lag between the end of the rains and the disappearance of galls in February was not. ARGM was probably able to reproduce through this dry period because low night temperatures, typical of the harmattan season, produced dew on the leaves, allowing some eggs and newly hatched larvae to survive. This explains how, on farmers' fields, ARGM can switch from rice crops harvested after the rains, to perennial *Oryza longistaminata*, a key host for dry-season survival.

Once parasites had arrived in the rice garden, there was a source of ARGM parasites close to each new rice plot, because of the monthly plantings. Under these conditions, both *Platygaster diplosisae* and *Aprostocetus procerae* were effective natural biological control agents. They showed a strong response to increasing host density and produced high mortality at low ARGM infestation levels (Figure 31). This suggests, that under farmers' conditions, the effectiveness of parasites is limited by inadequate sources of these parasites close to rice fields, rather than by innate deficiencies in their searching abilities once in the crop. In contrast to parasitism, predation of pupae within galls was low, and showed no response to host density.

Predators of ARGM eggs and adults (life-stages not protected within galls) must invade the crop early to be effective, because ARGM can only damage plants prior to panicle initiation. The numbers of potential ARGM predators were generally low in early sweep net samples (Table 14 *overleaf*). The main exceptions were tetragnathid spiders, damselflies (Zygoptera) and long-horn grasshoppers (Tettigoniidae).

Based on these results, studies in 1996 will emphasize the role of natural biocontrol agents and weather on ARGM egg and larval survival. We will also continue the evaluation of

Figure 31: Relationships between transplanting date, ARGM infestation level (line) and parasitism and predation levels within galls (bars) at 60 days after transplanting.



Parasitism and predation were only determined if galls exceeded 7 per 100 hills. Parasitism due to *Platygaster diplosisae* and *Aprostocetus procerae* was separated.

Table 14: Numbers of potential ARGM predators in sweep net samples.

Predator group	Number per 360 sweeps	Potential predator of ARGM eggs (e) or adults (A)	Predator group	Number per 360 sweeps	Potential predator of ARGM adults (A)
Insects:			**Spiders:**		
Anisoptera	1.6	A	Tetragnathidae	138.1	A
Zygoptera	58.0	A	Thomisidae	10.9	A
Tettigoniidae[a]	39.0	e	Salticidae	5.9	A
Gryllidae	2.1	e	Others	5.3	A
Heteroptera[b]	42.7	e			
Dermaptera	0.0	e			
Neuroptera	0.1	e			
Carabidae	0.0	e			
Staphylinidae	0.3	e			
Coccinellidae[c]	3.1	e			
Formicidae	0.6	e			

Samples taken at 15, 30 and 45 days after transplanting; 120 sweeps on each occasion. Figures are averages for a year (12 monthly plantings). [a] *Conocephalus* sp.; [b] Mostly phytophagous; specimens currently being checked to identify potential ARGM egg predators. [c] Excluding the phytophagous species *Chnootriba similis.*

the rice germplasm collection to identify cultivars which can be used as parents in the breeding of ARGM resistant cultivars.

Materials and method

Variety: ITA 306; design: RCBD with four replications; plots: 5 x 10 m; plant spacing: 20 x 20 cm; standard fertilizer and weeding regime; gall and tiller counts and sweep-netting at 15 day intervals from 15 to 90 days after transplanting on each plot; sample of 50 galls from a planting dissected to determine parasitism and predation levels whenever gall density exceeded 7 per 100 hills. Both emerged and unemerged galls sampled to prevent overestimation of parasitism levels.

Activity of spiders and predacious insects on the continuum toposequence

E.A. Heinrichs, D.E. Johnson (NRI) and A.K. Traoré

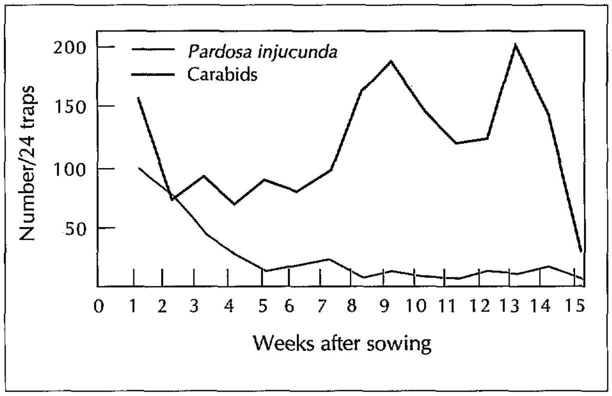
Predacious arthropods, such as spiders and insects, are important in the regulation of rice insect pest populations. In characterizing continuum environments, we are determining the species of predacious arthropods, their abundance within a crop season, and their activity as affected by toposequence site, rice variety and weeding regime.

Continuing of a multi-year study on the continuum toposequence at M'bé, Côte d'Ivoire, in 1995 we determined the activity and abundance of canopy-dwelling and ground-dwelling predacious arthropods. This summary reports on the activity of ground-dwelling predators.

Spiders made up 13%, and insects 87%, of the arthropods collected. *Pardosa injucunda* and *Wadicosa oncka* were the most abundant spiders, making up 74% and 16% of the total spiders collected, respectively. Of the insects collected, 86% were potential predatory species, with ants making up 84%, and the carabid (ground beetle) species, *Pherosophus cineticolis,* making up 2%.

Activity of the spider *P. injucunda* and the carabid *P. cineticolis* was high immediately after planting. Spider activity continued to about 14 weeks after sowing, while that of the carabid dropped to a low level by five weeks after sowing (Figure 32). Spider activity was high at all toposequence sites but was highest on the hydromorphic 2 site (Table 15, *bottom of page*). Carabid activity was highest next to the valley

Figure 32: Numbers of the ground-dwelling predatory spiders, *Pardosa injucunda,* and the ground beetles of the family Carabidae, caught in 24 pitfall traps at indicated weeks after sowing.



Data are a combination of two rice varieties, IDSA 6 and Bouaké 189, and four continuum toposequence sites, upland 1 and 2, and hydromorphic 1 and 2.

Table 15: Effect of toposequence sites and weeding regimes on arthropod populations in the upland rice variety, IDSA 6. M'bé, Côte d'Ivoire, wet season 1995.

Treatment	Weeds ($g\ m^{-2}$)	Arthropod activity (Number)[a] Spider *Pardosa injucunda*	Carabid *P. cineticolis*	Ants
Toposequence site:				
Upland 2 (drought-prone)	192	202b	16c	3162a
Upland 1 (favorable)	176	244ab	20c	2470a
Hydromorphic 2 (dry)	93	342a	58b	1482b
Hydromorphic 1 (wet)	87	156b	115a	237c
Weeding regime:				
Hand-weeded 1 x at 28 DAS	137	380a	65ab	2896a
Herbicide	—a	268b	85a	2073a
Herbicide + 150 kg N ha^{-1}	—a	306b	59b	2382a

[a] Means with common letters are not significantly different at the ($P < 0.05$) by Duncan's multiple range test on $\sqrt{n} + 1$ transformed data. Numbers represent the total collected in 18 traps in the toposequence sites and 24 traps in the weeding regime over a 15 week period. [b] Insignificant weed weights due to herbicide application.

bottom in the hydromorphic 1 site, and ant activity was highest at the drought-prone upland 2 site. The treatment with the most weeds (hand-weeded once) had the most spider activity, while the herbicide treatment had the most carabid activity.

Results indicate that activity of predacious arthropods in upland rice is high as soon as rice plants emerge. The various predatory species have their ecological niche on the toposequence at which they are most active. Their activity should be maintained as upland crop production systems are intensified and input levels increased.

Materials and method

Treatments are given in Table 15 *(previous page)*. Activity (movement) of ground-dwelling predators was determined by the aid of pitfall traps. Pitfall traps, consisting of 8.5 cm diameter plastic containers containing a preservative solution, were placed in the soil with the top of the container at soil surface. Traps were emptied and refilled with solution twice weekly beginning at sowing and continuing to harvest (15 weeks).

Plant parasitic nematode diversity and distribution along a continuum toposequence

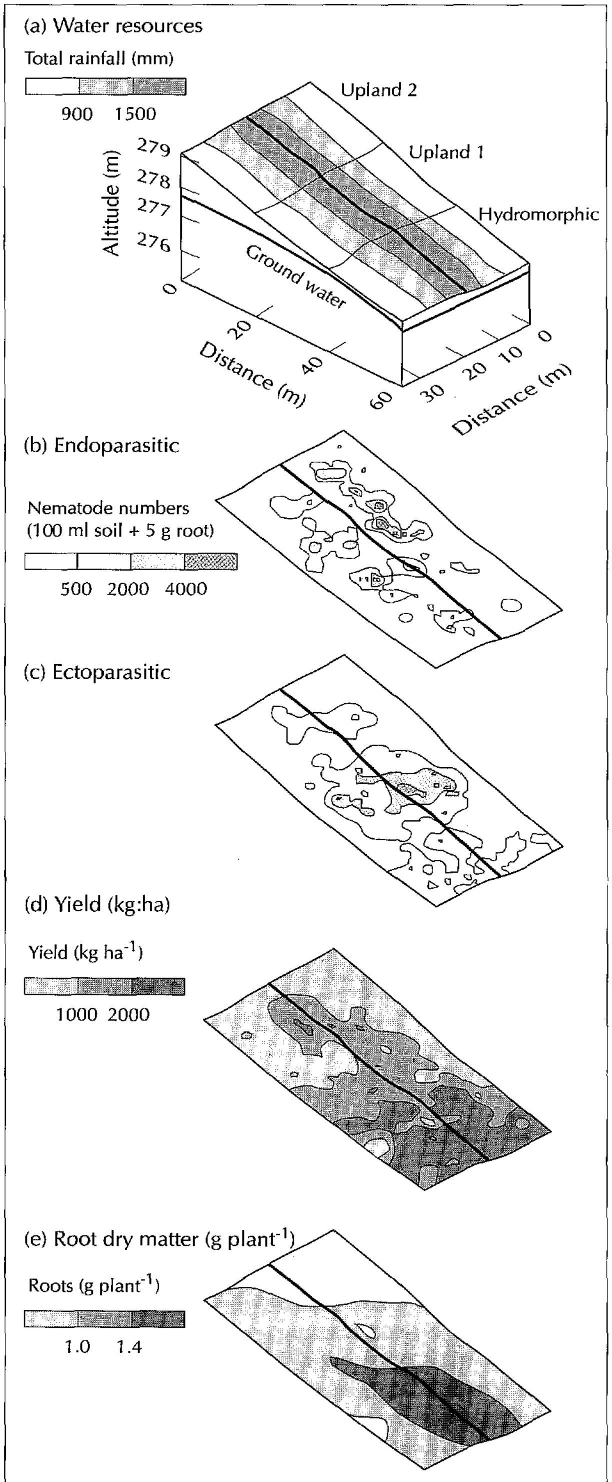
D. Coyne (NRI) and A. Audebert (CIRAD)

Recent research at WARDA has indicated that rice parasitic nematodes affect grain yield in the various ecosystems along the continuum toposequence, both on researchers' and farmers' fields. Hydrology may be a major determinant of the extreme micro-variability of nematode incidence, but the available information is insufficient to explain or predict this variability.

As root parasites, nematodes disrupt water and nutrient translocation within the plant. At worst, they may destroy the whole root system, but more commonly, the extent of damage is less severe and depends on numerous environmental factors. With the increasing water stress along the toposequence, nematodes hold the potential to multiply any crop damage under reduced water availability.

In order to determine the effects that different soil moisture availability may have on the nematode diversity and crop development, a trial was established on a typical valley slope at M'bé, Côte d'Ivoire, towards the end of the 1995 wet season. A sprinkler irrigation line was installed along the center of the trial, from the upland through the hydromorphic zones, delivering increasingly less water with distance from the line. Two perpendicular water gradients were thus enforced, supplying a range of topsoil moisture and ground water variation across the trial (Figure 33a).

Figure 33: Plant parasitic nematode densities, root development and grain yield on a continuum slope.



Final nematode populations, at crop maturity, were categorised into two groups based on their feeding mode (Figure 33b and c, *opposite*). The groups reached greatest densities in two respective areas: ectoparasites (*Helicotylenchus dihystera, Scutellonema clathricaudatum, Paratrichodorus minor, Tylenchus* spp., Criconematids) in the lower upland, and endoparasites (*Pratylenchus zeae, Meloidogyne* spp., *Heterodera sacchari*) in the upper upland. Ectoparasites developed better under greatest irrigation, while endoparasites became more populous in areas receiving intermediate irrigation. Rice yield, root dry matter (Figure 33d and e, *opposite*) and overall nematode occurrence were positively related to water availability. The two groups of nematodes however, assume separate defined distributions within the continuum, which was found to be further defined at the species level.

West African rice farmers face widely heterogeneous growing conditions. By dividing the trial area into a number of distinctive water availability regimes simulating this diversity, the interrelationships of parasitic nematodes and their effects on rice crop development will be better understood.

Materials and method

The trial area was sown to rice for the third consecutive year. Hills were spaced 25 cm apart using five seeds per pocket of the cultivar IDSA 6. Nematode densities and crop development were determined from 360 individual hills. Plants were irrigated for a total of 34 hours, delivering 1420 mm to those plants closest to the sprinklers and 0 mm to the furthest. Sprinklers were spaced at 4.5 m intervals. Rainfall measured 482.4 mm. Irrigation was conducted in order that water stress was prevented in those plants closest to the irrigation line.

Weed competitiveness in upland *Oryza sativa* and *O. glaberrima* rices

M.P. Jones, D.E. Johnson (NRI) and T. Koupeur

Weeds are a major limiting factor of upland and hydromorphic rice production in West Africa. Farmers of rainfed rice rely largely on hand-weeding as the main weed control method. However, due to limited availability of labor, weeding of the crop is often delayed or inadequate, and crop losses due to weeds are severe. Such losses may be reduced by the use of weed-competitive cultivars.

Our reports of 1994 indicated that there were substantial differences in the response of different rice varieties to weeds, with certain varieties being less affected by competition than others. Weed competitiveness appeared to be related to rapid vegetative growth, which in turn was associated with high tillering ability. Two experiments were conducted during 1995 to identify rice cultivars that can compete with weeds, and to determine the contribution of tillering and leaf formation in upland rice varieties.

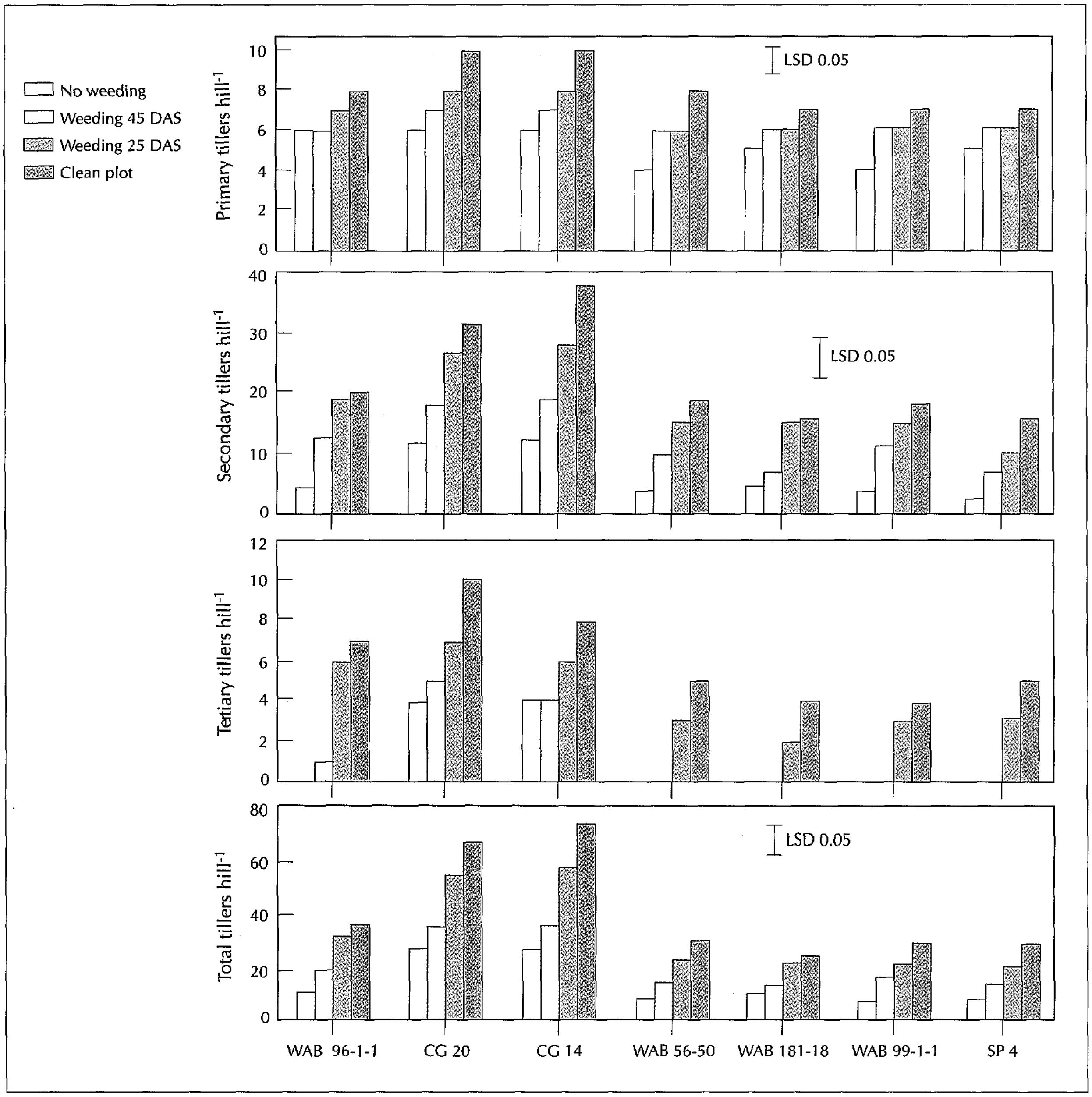
In the first experiment, seven *O. sativa* and *O. glaberrima* cultivars were selected, each differing strongly in terms of tillering capacity, canopy architecture and plant height. The cultivars were grown in a factorial combination with four levels of weeding: weed free, hand-weeding once at 25 days after sowing (DAS), hand-weeding once at 45 DAS, and no weeding. The second experiment comprised an *O. glaberrima* — IG 10, and three *O. sativa*, grown under three levels of weed control.

The *O. glaberrima* cultivars — CG 14 and CG 20, and improved *O. sativa* varieties — WAB 56-50, WAB 181-18, WAB 99-1-1 and WAB 96-1-1, are of intermediate stature, with plant height varying between 90 and 115 cm. The traditional *O. sativa* variety SP4, is tall with a plant height greater than 130 cm. There were significant differences in weed biomass among varieties at 45 days after sowing and at harvest. The *O. glaberrima* varieties, CG 14 and CG 20, had the lowest weed weights during the vegetative stage of growth and at harvest, followed by an improved *O. sativa*, WAB 96-1-1. The other improved and traditional *O. sativa* varieties had higher weed biomass. The varieties with the lowest weed biomass, CG 20, CG 14 and WAB 96-1-1, showed rapid vegetative growth (seedling vigor), had the largest number of primary, secondary and tertiary tillers, and had droopy lower leaves within 30 to 45 days (Figure 34 *overleaf*). The total number of tillers at different levels of weeding was the result of differences in the emergence of primary, secondary and tertiary tillers. The decrease in tiller number due to weed infestation was found to be more marked in the *O. sativa* cultivars with compact plant type and erect leaves, namely: WAB 56-50, WAB 181-18, WAB 99-1-1, and SP 4. In these varieties, tertiary tillers were not produced at high levels of weed infestation, and fewer secondary tillers were produced.

In the second experiment, significant differences in weed growth were observed between 35 and 49 days after emergence (DAE). The growth rate of weeds was lowest in the *O. glaberrima* IG 10 (3.4 g m^{-2} day), compared with that for Moroberekan, IDSA 6 or ITA 257 (respectively, 6.1, 5.9, and 7.4 g m^{-2} day, SE ± 0.8). These differences were attributed to the vigorous early growth and tillering of IG 10 compared to the three *O. sativa* cultivars tested. At 21 days after emergence, in treatments that had not been weeded, only IG 10 and IDSA 6 had begun tillering, and IG 10 had almost twice the leaf area of the *O. sativa* cultivars. During the subsequent 14 days, IG 10 tillered at a rate of 4.8 tillers m^{-2} day, compared to 1.4, 1.2 and 0.3, SE ± 0.80, for Moroberekan, IDSA 6 and ITA 257, respectively.

The results illustrate the vigorous vegetative growth of certain *O. glaberrima* lines and their ability to maintain tiller production despite severe weed competition. In 1996, field studies on the effects of weed competition on rice will include *O. glaberrima* x *O. sativa* crosses.

Figure 34: Effect of weed infestation on tillering of rice varieties



Materials and method

Experiment 1:
A split-plot design with weeding regime as main-plot and varieties as sub-plot and five replications were used; the varieties were grown in factorial combination with four levels of weeding as indicated above. Land was prepared by shallow hand cultivation and three rice seeds dibbled and later, thinned to one seedling per hill, spaced 25 cm apart. The compound fertilizer 20-36-36 kg N-P-K ha^{-1} was basally applied followed by two additional split applications of 40 kg N ha^{-1} at 35 and 70 days after sowing.

Experiment 2:
Factors variety x weed control, 6 replicates. 46 kg N, 40 kg P, 50 kg K ha^{-1}.

Genetic sources for resistance to rice yellow mottle virus

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Rice yellow mottle virus (RYMV) is the most important yield-reducing factor in the irrigated rice environments of Mali and Niger, where rice is intensively produced on nearly 60 000 hectares. Total losses have been reported for some irrigation schemes near Niono and Selingue. The exclusive cultivation of highly RYMV-susceptible indica varieties in these systems, such as BG 90-2 and IR 1529-680-3, have raised the concern that rice production in the Sahel might face disaster. The large irrigation schemes in Senegal and Mauritania have so far been spared by RYMV, but they also rely entirely on susceptible varieties such as Jaya.

The present study, which is part of an inter-disciplinary effort at WARDA and its national partners in the Integrated Pest Management Task Force, aims at identifying materials currently available to national agricultural research systems (NARS) that might either serve as short-term replacements of the existing susceptible varieties, or could serve as donors for RYMV resistance in WARDA's ongoing breeding programs.

During 1995, 97 varieties and lines were jointly selected by task force members for analysis of their agronomic properties and resistance to RYMV under both natural and artificial inoculation. The nursery included two resistant checks (Fofifa 62 and Moroberekan) and three widely cultivated susceptible checks (BG 90-2, Jaya and Bouaké 189). The nursery was planted in the field at two hotspots in Côte d'Ivoire and three in Mali, and at WARDA's research station at M'bé under artificial inoculation. We report here the ranking of the top 27 entries and the three susceptible checks, based on an aggregate index of observations on disease expression made under artificial inoculation (Table 16).

Table 16: Top-ranking rice yellow mottle virus-resistant lines.

Rank		Performance index[a]	Ecotype
1	VILLAGUAY	91.1	[b]
2	Fofifa 62 (resistant check)	94.7	Upland
3	IR 47686-31-1-1	103.1	Upland
4	CNA 762069	107.8	Upland
5	IRAT 133	108.5	Upland
6	WABIS 18	117.8	Upland
7	ITA 175	121.7	Upland
8	P 5589-1-13P-4	123.2	Upland
9	IR 47686-15-1-1	128.8	Upland
10	WABIS 675	130.1	Upland
11	TOX 1010-6-9-3-201	130.1	Upland
12	WABIS 844	131.7	Upland
13	IRAT 161	133.7	Upland
14	TOG 6569 *(O. glaberrima)*	133.7	Upland
15	Moroberekan (resistant check)	137.7	Upland
16	056 (FARO 11)	143.1	Upland
17	LAC 23	144.0	Upland
18	IRAT 216	157.0	Upland
19	TOX 1768-3-1-1-101-3	161.6	Upland
20	ITA 305	165.1	Upland
21	LINEA 554	170.5	[b]
22	ITA 257	170.7	Upland
23	TOX 1010-6-3-4	174.2	Upland
24	LINEA 148	177.8	[b]
25	ITA 235	179.5	Upland
26	TOX 1889-22-103-1	184.0	Upland
27	ITA 212	354.0	Irrigated
	Jaya (susceptible check)	435.3	Irrigated
	Bouaké 189 (susceptible check)	438.6	Irrigated
	BG 90-2 (susceptible check)	461.1	Irrigated

[a] The performance index for each variety is comprised of the following variables: incidence and severity of RYMV infection, tiller reduction, plant height reduction at 27, 41, 55 and 69 days after transplanting (DAT), rate or reduction of panicle exsertion and grain filling at 90 DAT, and 1000 grain weight. [b] Not provided.

Fourteen entries ranked higher than the resistant check Moroberekan, and one higher than Fofifa 62. Serological tests showed that five of these entries, namely Fofifa 62, IRAT 161, IRAT 163, WABIS 18 and IR 47686-15-1-1, were immune to the virus. As expected, the three susceptible checks ranked among the lowest. However, none of the highly resistant entries qualified as potential replacement for the currently cultivated lowland materials, because they were generally upland adapted, low tillering tropical japonica, or, in one case, *O. glaberrima* materials (TOG 6569). These genotypes will therefore be considered as possible donors for RYMV resistance in WARDA's lowland rice breeding activities. One of them, IRAT 161, is already being used in WARDA's lowland rice breeding program.

The present study demonstrates that no RYMV resistant, high yielding indica rice varieties are currently available to NARS in the region, although a large number of excellent but genetically distant donors for resistance exist (tropical-japonica or *O. glaberrima*). Our best bets for a short-term solution to the RYMV epidemic in the Sahel are therefore the partially resistant high yielding breeding lines that are currently evolving from WARDA's lowland rice breeding activities, such as WITA 9. During 1996, these will be exposed to the local RYMV inoculum at various sites in the region under both artificial and natural infestation. This will help us assess the risks associated with the transfer of the new lines to production systems that may harbor different pathogen strains, and help predict the yield reductions under heavy infestation.

Materials and method

During the 1995 wet season, 97 rice cultivars were grown in a screenhouse at M'bé, and inoculated with the local RYMV isolate at 13 and 50 days after transplanting. Entries were ranked on the basis of RYMV symptom incidence, severity, and the reduction in tiller number, plant height, panicle exsertion, number of filled grains, and 1000 grain weight.

Reaction of nine rice cultivars to cyst nematodes and weeds

D. Coyne (NRI); B. Thio, Institut national des recherches agronomiques (INERA), Burkina Faso; and B. Fofana

With intensification of rice production, biotic constraints become increasingly severe, particularly weeds. Moreover, a crop under stress from any given constraint is further predisposed to additional problems. Cultivars with multiple pest resistance offer substantial benefits under more intensive cropping conditions. The sugar cane cyst nematode, *Heterodera sacchari,* is found throughout West Africa and is particularly pathogenic to upland rice, causing severe chlorosis and stunted growth. Nematode reproductive rates can be very high, but depend on host suitability and environment. *Oryza sativa* cultivars differ in their susceptibility to the nematode. The reaction to *H. sacchari* of *O. glaberrima* is unknown, although it is resistant to some other parasitic nematodes.

In 1995, we assessed cyst nematode development in nine rice cultivars under two weed management strategies (Table 17). In an area infested with the nematodes and natural populations of the weeds, in order of importance, *Eleusine indica, Digitaria horizontalis, Euphorbia heterophylla* and *Ageratum conyzoides,* we compared the response of three traditional and three improved *O. sativa* and three *O. glaberrima* cultivars. Mature cysts were recovered from plots at harvest, counted, and the average fecundity per plot established. Weed biomass was determined for the low weed management treatment at the same time.

We observed significant differences in the fecundity of nematodes between cultivars ($P = 0.018$). In particular, all three *O. glaberrima* cultivars showed extremely low numbers of eggs in the cysts. Nematode response to weed management was also highly significant ($P = 0.027$), with total egg production much greater in weed-free treatments (4.17 vs 2.31 ± 0.57 SE). The three *O. glaberrima* and two of the traditional *O. sativa* cultivars significantly suppressed weed growth.

We can conclude that *O. glaberrima* cultivars resist both cyst nematodes and weeds. Previous research at WARDA showed that this species is also a major potential source of resistance to rice yellow mottle virus, blast, African rice gall midge, parasitic weeds and drought. *O. glaberrima* might therefore

Table 17: Reaction of cyst nematode development on nine rice cultivars.

Cultivar	Varietal type	Eggs per cyst[a]	Eggs ml^{-1} soil[a]	Weed biomass ($t\ ha^{-1}$)
WAB 96-1-1	*Oryza sativa* improved	55.8	30.0	2.7
WAB 56-104	*O. sativa* improved	75.9	71.7	3.7
WAB 56-50	*O. sativa* improved	51.7	23.3	2.5
Digba Youho	*O. sativa* traditional	72.8	54.8	2.7
G 5	*O. sativa* traditional	45.5	29.0	1.9
YS 236	*O. sativa* traditional	71.6	40.0	1.5
IG 10	*O. glaberrima*	9.8	3.8	0.9
ACC 102257	*O. glaberrima*	17.8	0.9	1.8
CG 14	*O. glaberrima*	30.2	4.4	2.0
LSD (0.05)		38.7	40.1	1.1
CV (%)		66	106	28

[a] Means of clean-weeded and single-weeded treatments combined.

provide the much needed multiple stress resistance for rice grown in resource-poor environments. In 1996, we will study the inheritance of these traits in the improved and better yielding *O. sativa* x *O. glaberrima* progeny recently developed at WARDA.

Materials and method

Conducted during 1995 dry season under irrigated upland conditions at M'bé, Côte d'Ivoire, in a RCB design: two treatments of weed-free and one hand-weeding at 43 days after sowing (DAS), replicated three times. Phosphate applied (20 kg ha^{-1}) after ploughing; urea applied (14 kg ha^{-1}) 43 DAS.

Insect populations as affected by density of plants in transplanted and direct-seeded lowland rice

E.A. Heinrichs and I. Oyediran

Plant density has been reported to affect rice insect populations and subsequent plant damage. Dense plantings change crop growth, crop development and the microclimate which in turn affect rice insect pests and their natural enemies. Sparse plantings encourage weed growth which may indirectly affect insect abundance. Dense planting is reported to cause an increase in certain insect species, and a decrease in others. Previous studies at WARDA (*see* Annual Report 1993) have shown that close spacing (10 x 10 cm) in transplanted rice increases caseworm defoliation and whiteheads caused by stem borers. Because of the high cost of labor for transplanting there is an interest in shifting to direct seeding rice by hand broadcast.

In order to compare the relative abundance of insects and insect damage in transplanted and direct-seeded rice, tests were conducted in 1993, 1994 and 1995.

Adult populations of the stem borer, *Diopsis longicornis*, as based on sweep net counts, were similar in transplanted and direct-seeded plots and were highest in the most dense plantings (14 x 14 cm and 120 kg seed ha^{-1}). In 1993 *D. longicornis* adults and percentage deadhearts (Table 18) were both highest in the 14 x 14 cm spacing. Percentage of tillers with whiteheads was similar in the three transplant spacings in 1994. In 1993 and 1995, percentage whiteheads was highest in the 120 kg ha^{-1} direct-seeded plots. Yields in all treatments were similar ranging from 4 to 5 t ha^{-1} in 1993 and 1994 and 3 t ha^{-1} in 1995 (Table 18).

Plant density studies will be continued in 1996 to determine the effect of plant density on rice yield, insect pests, weed populations, and populations of larvae of the malarial mosquito vector, *Anopheles gambiae*.

Table 18: Effect of direct-seeding seed rates and spacing of transplanted seedlings on rice stem borer damage. Lowland, M'bé, Côte d'Ivoire 1995.

Treatment	Hills or seeds (m^{-2})	93	94	95
		Deadhearts[a] (%)		
14 x 14 cm	51	24.1a	6.2a	13.4a
20 x 20 cm	25	18.8b	5.9a	14.0a
30 x 30 cm	11	19.3b	6.3a	13.6a
120 kg ha^{-1}	400	15.8b	5.7a	15.1a
90 kg ha^{-1}	300	16.5b	5.8a	14.4a
60 kg ha^{-1}	200	15.4b	4.7b	13.9a
		Stem borer infested stems[a] (%)		
14 x 14 cm	51	18.3ab	7.2ab	12.1a
20 x 20 cm	25	21.4ab	5.6ab	7.5b
30 x 30 cm	11	26.5a	6.9ab	12.3a
120 kg ha^{-1}	400	13.6ab	7.4a	7.5b
90 kg ha^{-1}	300	13.5ab	5.3ab	9.3ab
60 kg ha^{-1}	200	7.6b	4.5b	7.5b
		Yields[a] (kg ha^{-1})		
14 x 14 cm	51	4088a	3773bc	3762a
20 x 20 cm	25	3833a	4283bc	2071b
30 x 30 cm	11	3089a	5202a	2635b
120 kg ha^{-1}	400	3943a	4635ab	2839ab
90 kg ha^{-1}	300	4022a	3368c	2700ab
60 kg ha^{-1}	200	4154a	4162bc	2903ab

[a] In a column, mean values with the same letter are not significantly different from each other at ($P < 0.05$) by Duncan's range test.

Materials and method

Treatments consisted of three transplanting spacings: 14 x 14 cm, 20 x 20 cm and 30 x 30 cm, and three direct-seeding seed rates; 120 kg ha^{-1}, 90 kg ha^{-1} and 60 kg ha^{-1}. Stem borer damage was recorded by visually observing the number of deadhearts and whiteheads, and data reported on a percent tillers infested basis.

Effect of fallow period and weed management on natural enemies of upland rice insect pests

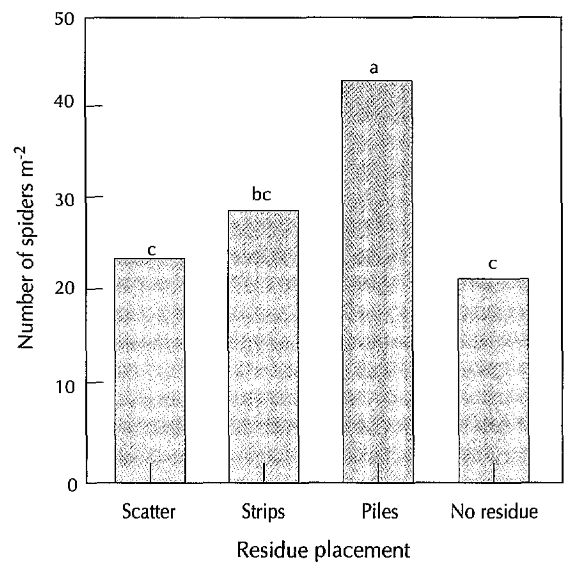
J.V.K. Afun, A. Russell-Smith (NRI), D.E. Johnson (NRI), and E.A. Heinrichs

Effective management of rice insect pests involves the manipulation of biotic population-regulating factors, for example, natural enemies such as predators, parasites and pathogens. Although it is well known that high weed populations have detrimental effects on rice, their presence may enhance activity and populations of predatory arthropods. Therefore, we sought to identify weed management regimes that maintain natural enemy populations without an adverse effect on yield. To investigate the effects of cropping intensification and weed management on insect pests and predators, surveys were conducted in farmers' upland rice fields in the forest and savanna zones of Côte d'Ivoire and on the WARDA main research station at M'bé.

Chromolaena odorata was the major weed in the forest zone, while *Pennisetum polystachion, Hackelochloa granularis* and *Imperata cylindrica* dominated in the savanna zone. Weed dry weight was significantly lower in the long-fallow (> 5 years) fields. The short-fallow (< 5 years) fields had higher proportions of grass weeds, particularly in the savanna. These fields were associated with significantly higher numbers of the insect pests, *Cofana* spp. and grain-sucking bugs. The flea beetles, *Chaetocnema* spp., leaf beetles and termite numbers were higher on long-fallow fields, which were characterized by greater proportions of broadleaf weeds. Predators found during the survey were: spiders, mostly lycosids and araneids; a wide range of ant species; carabids (ground beetles); and, cicindelids (tiger beetles). In both zones, spiders were the most common predators, and these were more abundant in long-fallow fields.

Dominant weeds in the weeding regime experiment were the grasses *Digitaria horizontalis* and *Eleusine indica*, while leafhoppers, plant hoppers and the grain suckers, *Stenocoris* sp. and *Aspavia* spp., were the main pests. Predators included ground and canopy spiders, ants, carabids, staphylinids (rove beetles), reduviids (assassin bugs) and nabids (damsel bugs). While partial or complete weed control had lower predator numbers than no weedings, grain yield was negligible in the latter (Table 19). There were no clear relationships between pest populations and weed density. Significantly higher populations of spiders were found where weed residue was piled than where it was scattered, placed in strips, or removed (Figure 35).

Figure 35: Effect of weed residue management on spider populations.



Scattered = residue randomly distributed; Piles = 1 pile 10 m^{-2}; Strips = 1 strip every 5 rows of rice; No residue = all trash removed from plot. Values are means over the season.

These studies show that partial weeding and residue management can maintain or enhance predator populations. Further studies are required to elucidate the relationships, particularly with respect to rice yields and the role of weed mangement in regulating pest populations.

Table 19: Effect of weeding regimes on weed dry weight, grain yield and predator populations.

Weeding period[a]	Weed weight m^{-2}	Yield g m^{-2}	No. of predators m^{-2} Spiders	No. of predators m^{-2} Reduviids
0-100	1.7	1058	10.0	0.3
14-35	83.5	359	13.6	0.8
28-49	107.2	554	17.0	1.5
No weeding	517.7	0	27.1	4.8
Mean	177.5	493	16.9	1.9
LSD	78	117	7.8	1.6

[a] Days after emergence.

GERMPLASM IMPROVEMENT RESEARCH

For the farmer, the use of better-adapted varieties is the most cost-efficient way of overcoming biophysical and labor constraints to rice production. Varieties that resist the major yield-reducing stresses in a given environment require fewer management interventions, and provide higher returns to crop- and resource-management inputs. In West Africa, this is of particular importance since most production systems are limited by labor availability and are prone to multiple stresses. Upland rice is frequently affected by drought (savanna zone), soil acidity (forest zone), blast disease, and weeds, particularly in areas where population pressure has led to a reduction in fallow length. Rainfed lowland and hydromorphic environments are also affected by weeds and drought, but a number of ecosystem-specific stresses dominate locally: rice yellow mottle virus, gall midge, iron toxicity, floods, and, under drought conditions, blast disease.

WARDA's germplasm improvement project for the continuum is grouped into sub-projects addressing upland/hydromorphic and lowland systems, and, within these, into several breeding itineraries dedicated to specific stress environments. These breeding activities involve the scientists from complementary disciplines, such as physiology, plant pathology, or production economics.

In 1995, we greatly expanded our on-farm and regional, multi-location tests of rice germplasm, with the regional breeding Task Forces playing a key role. Major progress was made in the development and eco-physiological characterization of inter-specific hybrids, based on crosses between *O. sativa* and *O. glaberrima* rices. These genotypes are being bred on the basis of an innovative plant type concept, the "low-management plant types", which will help save labor through improved weed competitiveness and multiple stress resistance in upland rice environments. Progress was also made in conventional breeding activities. For major stresses such as iron toxicity and rice yellow mottle virus, resistant and high-yielding genotypes are now available and will be tested on-farm.

We also developed further our technical capacity to employ systems research tools to validate our plant type concepts, and to better understand the synergies and tradeoffs between different adaptations to the environment. In 1996, crop growth models will be used to explore the scope for expanding the low-management plant concept from the uplands to adverse lowland environments, and interspecific progenies will be systematically characterized for their adaptations to lowland-specific stresses.

Field performance of anther-culture-derived progenies of wide crosses

M.P. Jones, S. Mandé, H. Sehi and K. Aluko

The goal of WARDA's upland rice breeding program is to develop improved high and stable yielding rice varieties for distinct levels of management (high- and low-input production systems) by crossing traditional with improved rice varieties. While initial activities focused on the widely cultivated japonica group, we are now increasingly using wide crossing among indica, japonica and *O. glaberrima* types. These activities, initiated in 1992, are being supported by the Rockefeller Foundation. Improved anther-culture-based doubled haploid breeding methods were developed, which helped overcome the sterility barriers and enabled rapid fixation of progenies. Since 1994, androgenesis has also been applied to several advanced breeding lines of F_4 to F_6 generations derived from wide hybridization to complete their fixation while conserving the potential of the lines.

In 1995, more than 200 progenies of spontaneous doubled haploid (DH) fertile lines of japonica x *O. glaberrima* and 600 japonica x indica lines were evaluated in the field in observational and replicated yield trials to study their fertility, genetic stability, and agronomic traits.

Most of the anther-cultured-derived populations were homogeneous. Nevertheless, of the 800 lines derived from different calli observed over two planting seasons, 22 or 3%, displayed heterogeneity within the DH2 progeny. This phenomenon can be explained by:

- chromosomal abnormalities, most likely due to eneuploidy of the DHo plant, since no morphological or developmental problems were noticed, or,
- outcrossing of the DHo plant by contaminant pollen, particularly in populations with high partial sterility.

About 3% of the doubled haploid lines which appeared unstable over the selfing generations were normally fertile at DHo generation, thus suggesting a resurgence of recessive heterozygous mutation. Stable potential sterility of more than 20% was observed in 36% of the DH lines derived from crosses involving distant varieties, and 4% from closely related varieties (Table 20 *overleaf*). This problem may be due to chromosomal abnormality mentioned above, or to a fixation of F_1 gametophytic developmental genes or F_2 sporophytic sterility genes. This may hinder the agronomic

Table 20: Percentage of partially sterile doubled haploid lines recovered from anther culture of intraspecific, intersubspecific and interspecific crosses.

Crosses	Partial sterility in two generations (%)	Partial sterility in one generation (%)
Intraspecific	4	15
Intersubspecific	6	20
Interspecific	36	45

utilization of the anther-cultured lines derived from distant F_1 hybrids.

A replicated yield trial was conducted in 1995 to compare both the yield potential and agronomic characteristics of 10 anther-cultured-derived lines and an improved high yielding japonica — WABC 165, and an *O. glaberrima* variety — CG 14, under high- and low-input production systems. Under high inputs, most of the anther-cultured-derived lines matured earlier and had shorter plant stature than the check varieties (Table 21). Several lines were rated excellent in phenotypic acceptability and spikelet fertility. Under low-input conditions, maturity was delayed by 8 to 15 days. Plant height was reduced and tiller numbers were extremely low. Many of the anther-cultured lines were short-statured and had erect leaves with sturdy culms.

Most of the anther-cultured lines significantly outyielded the standard checks/parents under high-inputs while only one line — WAB 651-B-A263, significantly outyielded the checks under low-input conditions. The stability of yields of the anther-cultured-derived lines in terms of phenology and yield is evident in their consistent performance across replications under both high- and low-input conditions. This indicates that the traits of the anther-cultured lines have been fully fixed through anther culture. Promising anther-cultured lines with high yield potential will be evaluated for their reactions to biotic and abiotic stresses during 1996.

Materials and method

Observational yield trials were conducted under high-input conditions with a modified augmented design in which a check variety is surrounded by eight test entries. The replicated yield trials were conducted under low- and high-input conditions.

Table 21: Replicated yield trial: early duration, high and low inputs.

AC lines	Duration (days) High input	Duration (days) Low input	Ph. Accept High input	Ph. Accept Low input	Height (cm) High nput	Height (cm) Low input	Panicle m^{-2} High input	Panicle m^{-2} Low input	Yield (kg ha^{-1}) High input	Yield (kg ha^{-1}) Low input
1 WABC 165 (check)	102	112	3	2	130	111	191	25	2287	558
2 WAB 651-B-A146	106	128	7	4	102	86	207	39	828	435
3 WAB 651-B-A263	105	122	5	4	114	85	197	50	2611	832
4 WAB 450-4-1-A2	95	110	4	3	112	94	127	29	2656	319
5 WAB 450-4-1-A3	94	104	4	4	117	82	156	28	2311	356
6 WAB 450-4-1-A4	95	111	4	3	117	94	168	14	2399	321
7 WAB 450-4-1-A6	95	106	4	3	109	67	163	18	2976	371
8 WAB 450-4-1-A8	95	111	3	3	117	97	156	20	2524	310
9 WAB 450-4-1-A9	94	110	5	3	114	93	163	37	2447	387
10 WAB 450-4-1-A11	95	105	4	3	110	93	181	21	1882	547
11 WAB 450-4-1-A26	95	110	3	3	113	103	179	26	2910	513
12 CG 14 (check)	106	114	5	4	117	118	289	93	1137	712

Low: 40 kg N ha^{-1} applied as 2 splits after manual weeding at two dates; soil preparation by hand hoe. High: 20-36-36 kg N-P-K ha^{-1} basal application and two additional split applications, each of 40 kg N ha^{-1}. Chemical weeding with Ronstar pre-emergence herbicide and manual clean weeding throughout the season; harrow by tractor.

Performance of WARDA upland rice varieties in farmer-managed trials in Côte d'Ivoire

M.P. Jones and R. Diallo

During the past four years, WARDA and the Insitut des savanes (IDESSA), the national agricultural research program of Côte d'Ivoire, tested five "best bet" upland rice lines in farmer-managed trials. The objective was to verify the performance and acceptability of new varieties which had previously shown superior performance on-station.

At each of five sites representing different agro-ecological environments, 25 farmers were asked to plant six improved upland rice varieties along with the local check, following a pre-determined plot layout, which included one non-fertilized plot per variety, and one plot fertilized according to official recommendations. Apart from laying out the plots and providing the seed and fertilizer, the scientists' role in these trials was limited to monitoring crop performance and stresses such as drought and diseases, as well as conducting surveys on farmer perception of the test varieties.

The test varieties included three morphologically different short-duration selections from one common cross (WAB 56-50, -104, and -125), one medium-duration progeny from a different cross (WAB 96-1-1), a selection from a Latin American upland rice line (WABC 165), the local improved check IDSA 10, as well as the site-specific local traditional checks (Table 22 *below and overleaf*). The local checks had generally a longer duration than the improved lines. Due to a number of constraints, not all entries could be planted at all sites in all years, and the target number of 25 farmers per site could not always be attained during the earlier trials. Results for a fifth site, Bouaké, are not included in Table 22 because of a devastating drought.

Table 22: Results of farmer-managed varietal trials at four sites in Côte d'Ivoire, conducted jointly by researchers of WARDA and IDESSA.

	1993		1994		1995		Mean yield	
	-N	+N	-N	+N	-N	+N	-N	+N
Boundiali								
WAB 96-1-1	—	—	1217	1564	1576	1993	1397	1779
WABC 165	1268	1648	1084	1346	1563	1866	1305	1620
WAB 56-125	967	1498	—	—	1348	1803	1158	1651
IDSA 10	1094	1536	1085	1442	1274	1465	1151	1481
WAB 56-104	922	1301	—	—	—	—	922	1301
WAB 56-50	—	—	1177	1486	1205	1483	1191	1485
local cultivar	901	1169	1048	1301	1392	1668	1114	1379
LSD (0.05)	251		226		222			
No. of farmers	24		25		25			
Touba								
WAB 96-1-1	—	—	1191	1331	1988	2167	1590	1749
WABC 165	1457	1851	641	781	1896	2163	1331	1598
WAB 56-125	1481	1826	—	—	1254	1455	1368	1641
IDSA 10	1380	1754	961	1175	1073	1258	1138	1396
WAB 56-104	1459	1731	—	—	—	—	1459	1731
WAB 56-50	—	—	1031	1211	1723	1938	1377	1575
local cultivar	1679	1981	1029	1196	1304	1506	1337	1561
LSD (0.05)	208		111		223			
No. of farmers	24		25		25			(cont.)

Yields are expressed as kg ha^{-1}. Fertilizer regimes are indicated by -N (no fertilizer applied) and +N (fertilizer application as recommended by local authorities).

Table 22 (cont.):

	1994 -N	1994 +N		1994 -N	1994 +N
Gagnoa			**Odienne**		
WAB 96-1-1	1570	1844	WAB 96-1-1	—	—
WABC 165	1220	1512	WABC 165	1063	1459
WAB 56-125	—	—	WAB 56-125	1372	1794
IDSA 10	1206	1452	IDSA 10	1341	1791
WAB 56-104	—	—	WAB 56-104	1404	1893
WAB 56-50	1395	1666	WAB 56-50	—	—
local cultivar	1459	1651	local cultivar	—	—
LSD (0.05)	195		LSD (0.05)	195	
No. of farmers	25		No. of farmers	25	

Yields are expressed as kg ha^{-1}. Fertilizer regimes are indicated by -N (no fertilizer applied) and +N (fertilizer application as recommended by local authorities).

Yields were generally between one and two tons per hectare, due to weed competition, drought and other stresses. In all but one environment (site x year), however, yields differed significantly ($P < 0.05$) among varieties. One of WARDA's new lines, WAB 96-1-1, ranked first in all of the ten site x year x fertilizer environments where it had been tested. The local traditional check ranked first in only one environment (Touba, 1995), and the local improved checks in none. The recommended fertilizer dose generally increased yields by 20% to 50%, relative to the farmers' common practice of applying no fertilizer at all. In all environments, the highest yielding entry under non-fertilized conditions also gave the highest yields if fertilizer was applied.

Farmers' evaluation of the new lines was mostly positive, but there were also critical comments. For example, some farmers found it difficult to obtain pure white rice from WAB 96-1-1 if traditional milling technologies were used. Delayed harvesting also caused some losses due to grain shattering in this line.

IDESSA and WARDA are now jointly analysing the data to evaluate the suitability of the test entries for official release by the national authorities. The present set of entries will be tested on-farm once more during 1996, and then replaced by a new generation of elite lines from WARDA's upland rice breeding program. The selection of the new lines will take fully into account the lessons learned from the current set of on-farm trials, and give a higher emphasis to grain quality characteristics. We will also initiate a farmer-participatory breeding program at the same sites, which involves farmers in an earlier stage of varietal selection.

Performance of *Oryza sativa* and japonica x *O. glaberrima* lines under high and low inputs

M.P. Jones, M. Dingkuhn, K. Aluko and S. Mandé

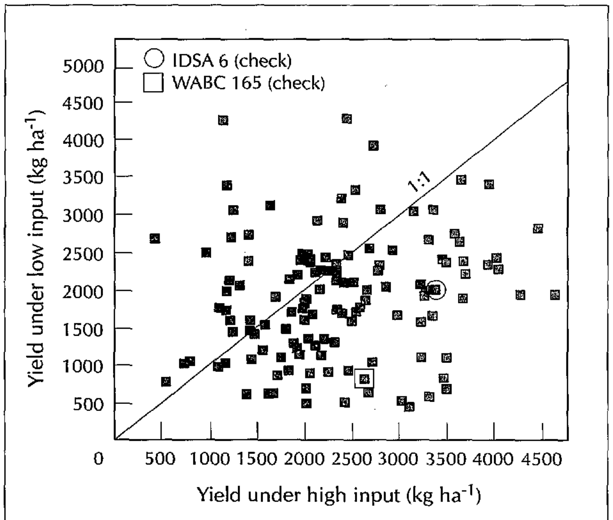
Farmers cultivating upland and hydromorphic rice in West Africa usually harvest less than one ton grain per hectare because their crops are affected by multiple constraints such as weed competition, drought, blast disease, soil acidity, and low-input cultural practices. Population pressure has significantly reduced fallow periods and aggravated many of these constraints.

Intraspecific breeding programs have been active for more than three decades to improve the performance of the commonly grown tropical japonica varieties which have limited resistance to many of the stresses that affect upland rice in the region. Although advanced selections from these breeding programs mostly outperform farmers' traditional varieties in on-station trials under relatively high-input conditions, they perform poorly when cultivated under the low-input systems that characterize upland farming in West Africa. In an effort to break this pattern, WARDA initiated an interspecific hybridization program in 1992 to introgress some important traits between *O. sativa* japonica types and *O. glaberrima*. *O. glaberrima* types are highly weed competitive due to early vigor and ground cover. Many also resist drought, blast and other stresses.

WARDA's breeding program for upland rice is based on two interactive selection itineraries, one under low levels and the other under high levels of management and inputs. The management levels differ in fertilizer inputs, weeding regimes and soil preparation.

During 1995, 133 newly fixed interspecific japonica x *O. glaberrima* progenies were evaluated in observational and replicated yield trials against two improved *O. sativa* standard check varieties — IDSA 6 and WABC 165 — under low- and high-input conditions at M'bé, Côte d'Ivoire. In the observational yield trials, 57 interspecific progenies outyielded the best standard check variety, IDSA 6, under low-input conditions. The highest yielding entries were WAB 450-24-3-3-P18-HB, WAB 450-24-3-P38-1-HB, and WAB 450-11-1-P40-HB (Figure 36). Under high input conditions, 18 interspecific lines outyielded IDSA 6. The top yielders were WAB 450-11-1-1-P5-HB and WAB 450-11-1-1-P1-HB. There was little similarity in yield ranking of the varieties between the low-input and high-input systems, indicating that varietal requirements for the two systems are different. Several entries that gave fairly high yields under low input gave lower yields under high input due to severe lodging. However, two entries, WAB 450-11-1-P40-1-HB and WAB 450-1-B-P-136-HB, gave stable yields of about 3.5 t ha^{-1} under low- and high-input levels. Other promising stable yielders that gave yields in excess of 3 t ha^{-1} were WAB 450-24-P-5-P4-HB and WAB 450-11-1-1-P26-HB.

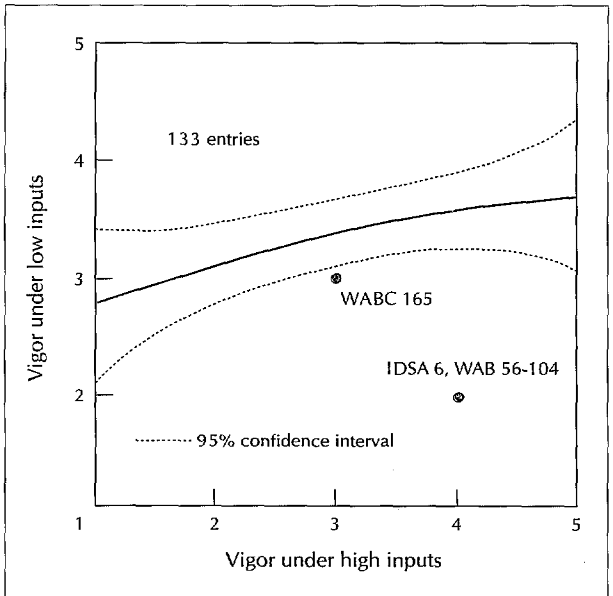
Figure 36: Yield distribution of entries in observational yield trials of newly fixed *O. sativa/glaberrima* lines.



Similar to the observational yield trials, the sativa/glaberrima progenies in the replicated yield trials responded to fertilizer input levels in the same way as the *O. sativa* cultivars. Under high-input conditions, 11 of the 22 progenies evaluated were top yielders, with average grain yield between 3.4 to 3.8 t ha^{-1} . Under low-input management, 16 of the newly fixed progenies outyielded the *O. sativa* check cultivar and had grain yield similar to or higher than the *O. glaberrima*, indicating superior adaptation to low-input conditions. The new progenies responded to inputs by increasing their number of panicles. The high transgressive yields observed in the progenies in both low- and high-input conditions resulted in part from large panicles with many secondary branches inherited from the *O. sativa* parent. In addition, most of the progenies showed transgressive segregation with larger panicles than either of their parents. For example, some progenies had more primary and more secondary branches than either parent.

Of the 133 entries, 10 progenies showed superior seedling vigor under both high- and low-input conditions as compared to the *O. sativa* standard check varieties. A further 18 and 14 varieties gave high seedling vigor under high- and low-input conditions, respectively, suggesting that only a limited number of progenies retain their vegetative vigor under both levels of management. Figure 37 shows that the relationship across genotypes between vigor under high and low inputs is weak, and that high vigor under high input is, in most cases, associated with a much lower vigor under low input. High vegetative vigor in the progenies was associated with faster tillering and leaf growth, a trait inherited from the *O. glaberrima* parents. Further studies in 1996 will evaluate the reactions of the new progenies to biotic and abiotic stresses.

Figure 37: Seedling vigor at 30 days after emergence, for 130 *O. sativa* x *O. glaberrima* progenies and three improved japonica check varieties, at two levels of input management.



Seedling vigor (1 = high, 9 = low).

Harvesting WARDA rice trials, M'bé

Using *Oryza glaberrima* in breeding for drought resistance in upland rice

M.P. Jones, A. Audebert (CIRAD), K.L. Sahrawat, B.H. Diandue and K. Aluko

Drought is a major constraint to increased upland rice production in West Africa because highly variable rainfall in the forest and savanna can induce water stress at any stage of crop development. WARDA's varietal evaluation for drought resistance makes use of field screening nurseries during the wet season at two sites in Côte d'Ivoire (M'bé and Korhogo), and differential boom-irrigation in the dry season at M'bé. Field screening nurseries with different representative locations and soil types, different planting dates, and controlled irrigation, are used to capture the different timings and intensities of drought stress encountered in West Africa. Dry or wet season rain-out shelter evaluations help screen rice lines for two distinctly different types of drought response, either prior to panicle initiation during the vegetative phase, or during the reproductive stage prior to flowering.

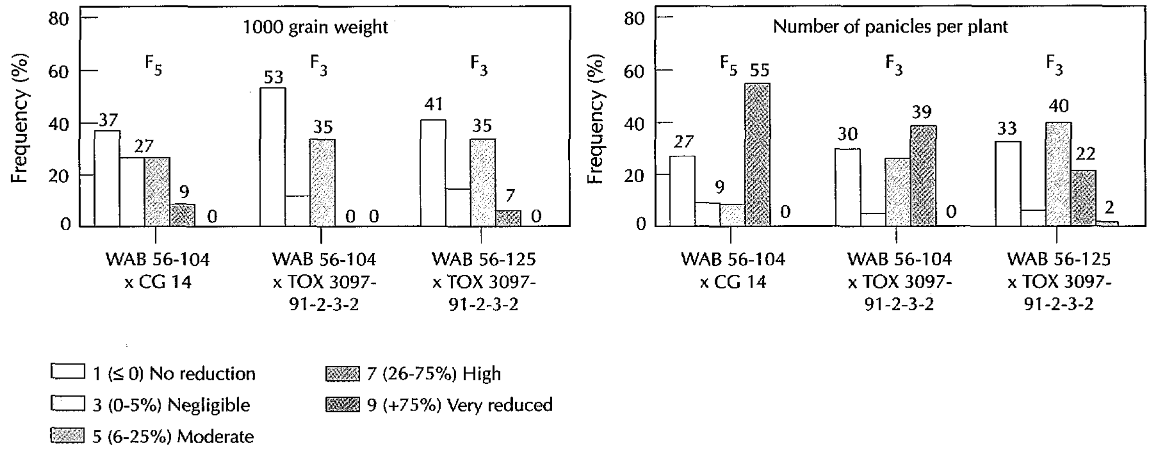
During the 1995 dry season we evaluated 26 *O. sativa*, 38 *O. glaberrima*, 58 sativa/glaberrima fixed progenies, and three segregating populations under differential irrigation causing drought at vegetative and reproductive stages. Considerable variation for seedling vigor, leaf tip burn, leaf rolling and unrolling ability, tillering, number of panicles per plant, and 1000 grain weight was observed among the fixed lines and within each of the three segregating populations (Figure 38). Generally, water stress delayed flowering and maturity. The most promising lines resistant at both vegetative and reproductive stages were four sativa/glaberrima newly fixed lines, WAB 450-1-B-P-20-HB, WAB 450-12-2-BL1-DV5, WAB 450-12-2-BL1-DR1 and WAB 480-34-2-BL1-DR1 and three *O. glaberrima* landraces, TOG 5505, TOG 5980 and TOG 5486. These lines remained green and continued to tiller during and after the imposition of drought stress. Several promising lines were also selected from the segregating populations, particularly from within the *O. glaberrima* population (WAB 56-104 x CG 14), that showed high tillering, good vegetative growth and low spikelet sterility.

In a separate field trial at M'bé, five cultivars: two *O. glaberrima*, CG 14 and CG 20; an improved japonica, IDSA 6; a traditional japonica, Moroberekan; and, an improved indica, Bouaké 189, were subjected to 0 (natural field drought stress), 15 mm and 30 mm sprinkler-irrigation at four-day intervals. Tiller number and dry matter production at harvest were highest in the *O. glaberrima* types under all moisture regimes. Moroberekan gave the highest and most stable 1000 grain weight but the lowest grain yield due to poor tillering. Drought stress significantly reduced yields in Bouaké 189 and Moroberekan. The *O. glaberrima* landraces and an improved tropical japonica, IDSA 6, had stable yields of about 3 t ha^{-1} across moisture regimes. However, it is

Materials and method

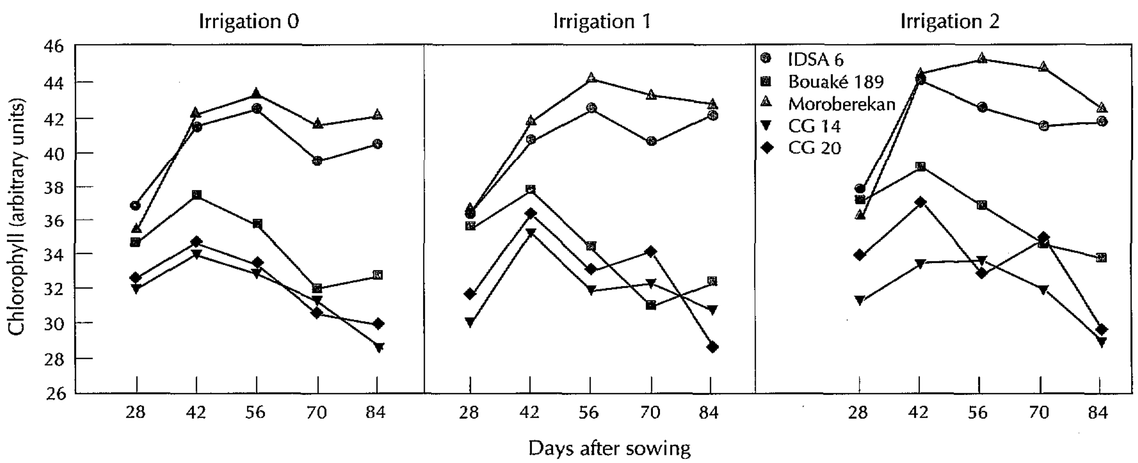
The different input/management levels are as follows. Low: 40 kg N ha^{-1} applied as 2 splits after manual weeding at two dates; soil preparation by hoe. High: 20-36-36 kg N-P-K ha^{-1}; chemical weeding with Ronstar pre-emergence herbicide and manual clean weeding througout the season; harrowing by tractor. All variety plots have a yield area of 12.5 m^2 and the RYT is replicated four times.

Figure 38: Distribution of reduction over control of 1000 grain weight and number of panicles per plant after 55 days of drought stress during the vegetative phase in three segregating populations.



interesting to note that the areal leaf chlorophyll content of the *O. glaberrima* and *O. sativa* indica entries decreased with time, particularly under stress conditions. But it remained high and constant after the maximum tillering stage in the japonica varieties (Figure 39). This may have reduced photosynthetic rates in the *O. glaberrima* and indica types, and actually resulted in lower dry matter production under drought (data not presented). This growth reduction did not affect yields of the *O. glaberrima*. The understanding of these stress responses, their heritability, and sensitivity to phenological timing of drought is extremely important when screening for drought resistance, and further studies will be conducted during 1996. In addition, we will continue to search for new and superior sources of drought resistance, particularly from *O. glaberrima,* for introgression into high yielding improved rice varieties.

Figure 39: Areal leaf chlorophyll content of five rice cultivars under drought stress, M'bé, Côte d'Ivoire.



Materials and method

In an upland field at M'bé during the 1995 dry season, three test plots were separately boom-irrigated: (1) throughout the crop cycle for the control plot, (2) for the first 15 days and after 50 days after sowing to induce drought stress during the vegetative stage and (3) for the first 45 days, and after 66 days to maturity to induce drought stresses during the reproductive phase. In all plots, 20-36-36 NPK ha^{-1} as basals and two splits of 40 kg N ha^{-1} as urea at 45 and 60 DAS were applied.

New acidity- and blast-resistant upland rices

M.P. Jones, K.L. Sahrawat and K. Aluko

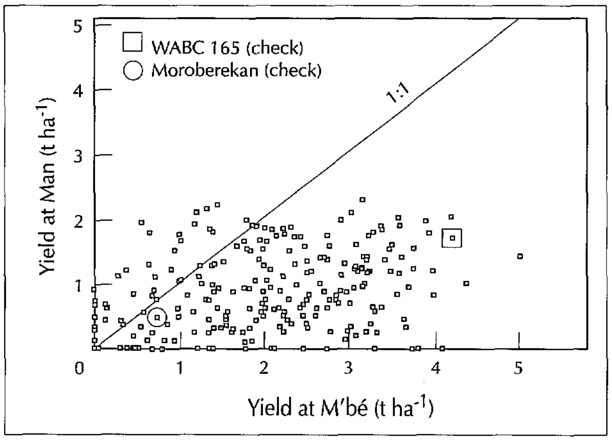
Acidity is the most widespread soil constraint in the humid forest zone, where 70% of upland rice is cultivated in West Africa. Upland rice is often grown on acid Alfisols, Ultisols and Oxisols which are extremely low in available phosphorus and frequently render rice plants susceptible to fungal diseases such as blast, sheath rot, and glume discoloration. Improving tolerance to acidity and associated problems would increase and stabilize upland rice yields of resource-poor farmers, who rarely use fertilizers or pesticides.

WARDA's strategy to improve rice production on acid uplands aims at making the most efficient use of available P, so that rice production can be sustained with minimal P application. A principal component of this strategy is the development of rice cultivars that are adapted to acid soils and associated disease problems. Differential responses of rice germplasm to acidity and leaf and neck blast were reported in 1994.

In 1995, the search for acidity-tolerant rice germplasm continued with the evaluation of 900 newly fixed lines in an observational nursery. A further 260 selections which were not originally bred for acid soils, but had shown promise in previous trials were evaluated in two observational and three replicated yield trials conducted on an acidic (pH 4.3) and P-deficient soil (ca. 3 mg P kg^{-1} Bray-1 P) at Man in western Côte d'Ivoire. A set of the observational and replicated yield trials were conducted at M'bé, a non-acidic site in the humid forest/savanna transition zone in central Côte d'Ivoire. Phenotypic evaluation based on a 1 to 9 scale (1 = excellent performance and 9 = dead plants) was used to assess each entry for acidity tolerance,and field resistance to blast, sheath rot, and glume discoloration, as well as phenotypic acceptability.

Grain yields at Man were reduced by acidity and leaf and neck blast. In the observational nursery, acidity scores ranged from 1 to 9 at Man, and 40 lines died within 60 days after emergence. On the basis of phenotypic acceptability; lodging resistance and plant height (intermediate stature, 90-120 cm); earliness (100-125 days); and, tolerance to acidity and resistance to blast, sheath rot and glume discoloration, 180 lines were selected for further evaluation in observational yield trials during 1996. In the 1995 observational yield trials, 38 cultivars outyielded the best standard check variety, WABC 165, by 15 to 80%. The best yielders were WAB 502-13-4-1, WAB 502-11-5-1, IR 5931-11-3-1, WAB 462-15-5-1, WAB 462-30-5-1, ITA 329 and B 5592-5-ST-31-1-1 (*see* Figure 40).

Figure 40: Performance of entries in observational yield trials blast/acidity resistant lines.



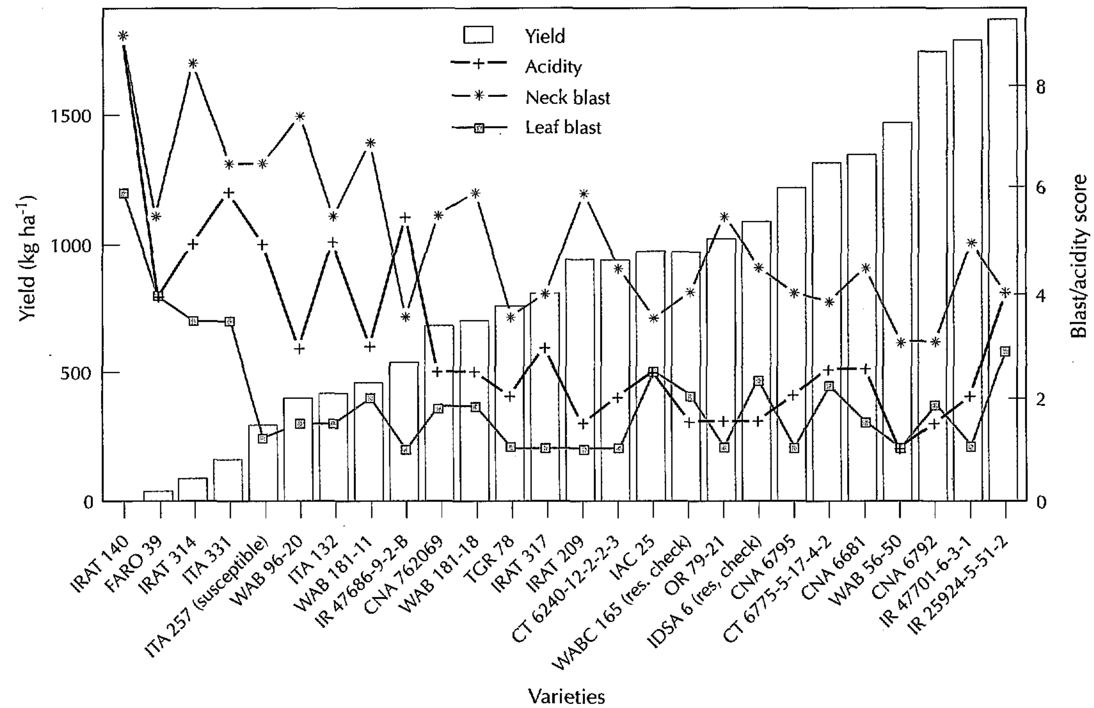
Based on grain yield and the traits mentioned above, a further 18 entries were selected for evaluation in replicated yield trials during 1996. In the 1995 replicated yield trials, cultivars tolerant to acidity and resistant to blast gave the highest grain yield at Man (Figure 41 *opposite*). Though yields were generally lower at Man, some varieties, such as WAB 181-44 and WAB 32-55, gave stable yields across locations.

Several promising new varieties with superior tolerance to soil acidity and high yield potential were selected for further characterization in 1996. In addition, promising *O. glaberrima* cultivars and new lines of *O. sativa* x *O. glaberrima* crosses will also be evaluated at Man for tolerance to soil acidity and P deficiency.

Materials and method

Observational nurseries: single 4 rows x 5 m long plots of test entries with check varieties repeated after every 20 test entries. Observational yield trials: modified augmented design with concurrent plots of a susceptible (IDSA 6) or a tolerant (WABC 165) check variety surrounded by eight test entries in a block. Plot size was 6 rows x 5 m long. Replicated yield trials: randomized complete block design with four replications. Plot size was 12 rows x 5 m long.

Figure 41: Performance of entries in a replicated yield trial on acid upland soil at Man, Côte d'Ivoire.



A procedure to generate fertile doubled-haploid lines derived from japonica x *Oryza glaberrima* F_2 populations

M.P. Jones, S. Mandé, H. Sehi and D. Macaire

O. glaberrima steud rice varieties are mainly cultivated under rainfed rice environments and possess desirable traits such as rapid vegetative growth and resistance to diseases and insect pests, as well as tolerance to acid soils, iron toxicity, drought, unfavorable temperatures and excess water. The transfer of these traits to high yielding upland rice varieties is a priority breeding goal for developing novel upland plant types adapted to resource-limited production environments, particularly in weed-prone upland fields.

We used anther culture to generate large populations of doubled haploids (DH) from japonica x *O. glaberrima* F_2 populations during 1994, and to overcome some general constraints to wide crosses such as: slow fixation of the lines; frequent partial sterility of the progenies; and, low recovery of useful recombinants. Also, as reported in 1994, japonica x *O. glaberrima* populations are generally less amenable to androgenesis than are intrajaponica crosses, producing more albino, haploid and partially sterile diploid plants. During 1995, we developed a modified anther culture methodology that enables the production of large populations of fully fertile doubled haploids generated from F_2 populations between tropical japonica and *O. glaberrima* varieties.

Anther culturability of four hybrids is given in Table 23 *overleaf*. The frequency of callusing anthers ranged from 29.2 to 47.6%, while the regenerating capacities of the microspore-derived calli varied from 1.2 to 22.4%. Calli that formed green plants ranged from 0.37 to 7.2%. The modified N6 medium resulted in production of large number of fast-growing, white, compact and lobed calli with fairly high regenerability. The japonica x *O. glaberrima* populations appeared to have lower anther culture response than the japonica x japonica and japonica x indica hybrids. The indica x japonica hybrids exhibited the poorest anther culture response suggesting a cytoplasmic incompatability.

The albino and green plant regenerating capacities of the microspore calli increased slightly at 5 and 6 weeks after inoculation of the anthers, respectively, then decreased gradually. Such a decline can be due to a depletion of the available nutrients in the unrenewed culture medium and/

Table 23: Anther culturability of *O. sativa* x *O. glaberrima* hybrids.

Hybrids	Type of cross[a]	Anther plated	Callusing anthers (%)		Calli regenerating green plants		Calli regenerating albino plants
			No.	(%)	No.	(%)	No.
WAB 450	ja. x gl.	3500	1666	47.6	37	2.2	56
WAB 515	ja. x in.	2200	893	40.6	48	5.4	65
WAB 585	ja. x ja.	500	161	32.2	36	22.4	53
WAB 668	in. x ja.	1900	555	29.2	07	1.2	23

[a] ja. = japonica; in. = indica and gl. = *O. glaberrima*. Number of green shoot forming-calli per 100 anthers inoculated.

Table 24: Frequency of spontaneous recovery of haploid, diploid and polyploid type anther culture plants.

Hybrids	Type of cross[a]	Survival after transfer to soil (%)	Total number of plants	Haploid plants		Diploid plants
				No.	%	No.
WAB 450	ja. x gl.	96	37	17	46	11
WAB 515	ja. x in.	96	48	22	45	10
WAB 585	ja. x ja.	95	36	9	25	27
WAB 668	in. x ja.	96	7	3	43	2
Mean					40	

[a] ja. = japonica; in. = indica and gl. = *O. glaberrima*.

or to a release of toxic compounds from the senescent anther walls. Spontaneous doubled haploid plants ranged from 21 to 75%, and averaged 40% (Table 24). Polyploid type plants, mainly tetraploids, represented approximately 21%, while semi-sterile diploid plants were found in some anther culture derived populations. This sterility appeared to be generally stable over successive selfing generations suggesting cross-chromosomal abnormality like aneuploidy, which is known to occur at 10% frequency in rice anther culture derived materials.

Our studies show that it is possible to generate from interspecific crosses large populations of recombinant doubled haploid lines that can be of value in rice breeding and genetics. Future studies will aim at limiting the problem of partial sterility.

Materials and method

Four F_2 populations of japonica x *O. glaberrima*, japonica x japonica, japonica x indica and indica x japonica were used in this study. Fifteen panicles of each population were collected at booting stage and sterilized. They were then cold treated for 13 days at 8-10°C. The panicles were then extracted from the boots. Anthers were dissected from the spikelets and plated in a jar containing 10 ml of semi-solid (solidified with 1.8 g l^{-1} of phytagel) or liquid N6 medium containing N6 salts, supplemented with 2.5 mg l^{-1} of 2,4-D, 0.5 mg l^{-1} of kinetin, 50 g l^{-1} of maltose and 150 ml l^{-1} of coconut milk, and incubated in the dark at 25 ± 1°C. Microspore calli of lengths between 1 and 2 mm that emerged from the anthers between the third and eighth week after plating were transferred for four more weeks into 100 mm jar containing 25 ml semi-solid MS medium (MS basal medium supplemented with 4 mg l^{-1} of kinetin, 1 mg l^{-1} of NAA and 30 g l^{-1} of sucrose) under light intensity of 2500 lux and photoperiod of 16 hours per day. The calli regenerating green plantlets were then transferred into test tubes containing a semi-solid rooting medium made up of half the MS salts supplemented with multi-effective triazole, a hardening chemical. After three to four weeks of growth in test tubes, plants with vigorous roots and canopy were transferred to grow in the soil until maturity.

Progress in breeding for iron toxicity tolerance

B.N. Singh, A. Efisue and K.L. Sahrawat

Iron toxicity is a major abiotic constraint to lowland rice production in the savanna and humid forest environments of West Africa. In the bottoms of inland valleys, where seepage water from adjoining upland areas provides for a steady influx of soluble iron, and where waterlogged conditions keep the iron in the reduced chemical state, iron toxicity leads to visible leaf discoloration, stunting, and yield reductions. Although water and soil fertility management methods are available to reduce the toxicity, varietal tolerance is the economically more attractive solution for the resource-poor farmer.

During the past five years, WARDA and the regional Lowland Rice Breeding Task Force have identified hotspot locations to screen for iron toxicity tolerant rices, and significant progress has been made in selecting such materials. Varietal screening is now routinely done at the following 16 hotspots: Niouli (Benin); Menchum Valley (Cameroon); Kwadaso and Fumesua (Ghana); Edozhigi, Gadza, Anfani, Ikot Obong and Mbiabet (Nigeria); Korhogo (Côte d'Ivoire); Longorolla (Mali); Brefet (the Gambia); Killisi and Bordo (Guinea); Djibelor (Senegal); and Kabala (Sierra Leone). Past selection for high-yielding, iron toxicity tolerant germplasm was handicapped by the absence of a high-yielding tolerant check. In 1994, it was decided to replace the traditional, low-yielding check Suakoko 8 with CK 4, one of the rare materials that combine high iron toxicity tolerance with a yield potential exceeding eight tons per hectare.

During 1995, 74 new single and double crosses were made to incorporate iron toxicity tolerance genes from donors, such as Matcandu, Suakoko 8, CK 4, CK 30, ITA 230 and Mahsuri, into agronomically superior materials. Forty-nine F_2 and 23 F_3 populations from previous crosses were grown at Edozhigi (hotspot with loamy sand, acid, low in carbon, N and P). At Ibadan, Nigeria, we evaluated 150 pedigree lines selected in previous years for their yield potential.

Lines that advance to the replicated yield trials and advanced yield trials are routinely tested regionally at hotspots by the Sahel Irrigated Rice or the Lowland Rice Breeding Task Forces, depending on the plant type. In 1995, the best-performing advanced selections under iron toxic conditions were BR 50-120-2, TOX 3881-7-2-3-1-3, TOX 3760-22-1-2-1-3-2, TOX 3717-47-2-2, WITA 3 (TOX 3100-32-2-1-3-5) and WITA 4 (TOX 3100-44-1-2-3-3).

On-farm trials in 1995 at iron-toxic locations demonstrated the importance of specifically selecting varieties for different levels of management, where iron toxicity may either occur as the single most important stress, or in combination with other major stresses. At the adverse site of Anfani in Nigeria, iron seeps from adjoining uplands into the lowlands. In addition to the inherent heterogeneity and poor water control of the site, severe African rice gall midge infestation confounded iron toxicity effects on the crop. Under these conditions, the traditional tolerant check Suakoko 8, which is also quite weed competitive and compensates for temporary growth reductions with a long duration, outyielded all other entries, including the improved check CK 4 (1.45 versus 0.65 t ha^{-1}). Two new lines tolerant to iron toxicity, TOX 3093-35-2-3-3 and WITA 1 (TOX 3118-6-E2-3-2), were inferior to Suakoko 8, but significantly outyielded CK 4. By contrast, in the favorable rainfed ecology of the Menchum site in Cameroon, on-farm yields averaged 3.1 t ha^{-1}. Under these conditions, TOX 3093-35-2-3-3 had significantly lower yields than CK 4, which was among the top yielders (4.3 t ha^{-1}). WITA 1, WITA 3 and WITA 4, which are WARDA's current "best bet" short duration materials for iron-toxic irrigated and favorable rainfed lowland environments, gave evidence of their good yield stability in farmers' fields, with yields between 3.8 and 4.1 t ha^{-1}.

In 1996, we will refine our varietal improvement strategy for iron toxic environments with different management levels and degree of interference of third stresses. In particular, we will seek to combine tolerance to iron toxicity (e.g. WITA 1, -3, -4) with resistance to rice yellow mottle virus (e.g. WITA 7, -8, -9).

Varietal improvement for irrigated lowlands

B.N. Singh, A. Efisue, K. Miezan , M.P. Jones and A.A. Sy

Compared with the upland and rainfed lowlands, the irrigated lowland ecology is a favorable rice-growing environment. Rice yields are highest under irrigation with proper management and appropriate varieties. In West Africa, between 560 000 and 600 000 ha of rice lands are irrigated, with an average yield of 2.8 t ha^{-1}.

Breeding research on irrigated lowland rice in 1995, as in previous years, emphasized early- and medium-maturing rice varieties having 105 ± 5 and 125 ± 5 days duration, respectively. The general objective is to combine resistance to major stresses with appropriate plant types having a high yield potential, and with slender, high-quality grains. The stresses explicitly addressed by breeding and varietal selection are: leaf and panicle blast, leaf scald, African rice gall midge (ARGM), rice yellow mottle virus (RYMV), stalk-eyed stem borer, bakanae, glume discoloration, brown spot, and iron toxicity. As blast is a major disease during the seedling stage, an initial screen for blast resistance was applied to all segregating generations and fixed lines. A mixture of five highly susceptible lines were used as infector rows, which were inoculated with mixed isolates from the field. Lines were screened using the IRRI-SES scale.

Twenty-five crosses were made to incorporate genes for long slender and aromatic grains from Pusa Basmati, DR 2, Basmati 217, Eguanzampa, IR 841-67-1-1, and Kilombero. Forty single and double crosses were made to incorporate into new materials, blast resistance from improved donors such as ITA 230, ITA 239, IR 46, ITA 416, TOX 3118-47-1-1-2-3, ITA 414 and TOX 3226-5-2-2-2. Fifty F_2 populations, 40 F_3 and 117 F_4 bulks were evaluated in the screenhouse for blast resistance. Only resistant plants (scores 1, 3, and 5) were transplanted. The populations were further bulked to advance the generations. In addition, 2614 pedigree lines from 111 crosses were evaluated, and further selections were made from 798 lines.

The 250 fixed lines selected from 1994 pedigree lines were further evaluated during 1995 in on-station initial evaluation trials. The trial was grown in augmented design with five checks randomized in each 10 entries. Selected lines will be evaluated regionally by the Lowland Rice Breeding Task Force in 1996.

In 1995, the Task Force conducted the following trials across the region: regional irrigated lowland observational nursery with 100 entries; replicated yield trial with 24 entries (Table 25); and, two advanced yield trials with 12 early- and 12-medium duration entries. Lines selected in previous years were evaluated in elite varietal trials in Chad, Cameroon and Côte d'Ivoire, or in coordinated rice evaluation trials in Nigeria. On-farm trials were conducted in Cameroon and Nigeria, based on materials with proven and durable adaptation to target environments. A Task Force regional quality

Table 25: Regional irrigated lowland replicated yield trial at Ibadan, Nigeria, 1995 wet season.

Entry	Grain yield (kg ha^{-1})	Plant age at flowering (days)	Height (cm)	Panicle no.	Phenotypic acceptability (SES scale)
RF 85 C-C1-1-37-1-2-2-3	3342 a	97	94	153	1
TOX 3792-10-1-2-1-1-3-1	3302 ab	97	109	191	1
TOX 3440-16-2-1-2-3	3244 abc	95	101	137	3
TOX 3809-33-2-3-3-2-1	3187 abcd	97	123	151	3
TOX 3717-25-2-1-2	3181 abcd	92	102	170	1
TOX 3118-47-1-1	3093 abcde	100	116	162	3
TOX 3784-20-2-2-2	3069 abcdef	90	98	181	3
TOX 3772-94-1-1-1	3023 abcdefg	91	96	181	3
TOX 3440-16-3-2-2-3	3001 abcdefg	94	94	152	3
TOX 3553-34-3-2-3-2-2	2961 abcdefgh	92	102	181	5
TOX 3369-11-1-2-2	2837 abcdefghi	91	98	143	3
TOX 3772-40-3-2-2	2793 bcdefghi	91	104	170	3
TOX 3440-16-1-2-1-2	2761 cdefghi	91	102	163	3
TOX 3558-73-3-2-1-3-1	2761 cdefghi	95	100	187	3
TOX 3109-73-4-5-4-1	2700 defghi	94	99	180	1
ITA 230	2635 efghij	87	97	160	3
TOX 3440-16-3-1-1-3	2627 efghij	93	97	144	5
TOX 3732-14-1-3-2	2541 fghij	88	98	140	5
TOX 3772-110-3-3-3	2527 ghij	90	94	165	5
ITA 306 (check)	2520 ghij	89	93	148	3
TOX 3162-11-1-3-1-1-1	2460 hij	91	99	161	5
TOX 3870-28-2-1-1	2332 ijk	91	101	187	3
TOX 3440-16-1-2-3-2	2104 jk	92	98	180	5
TOX 3441-123-2-2-1-2-3	1907 k	81	90	136	9
Overall mean	2788		92	100	163
Standard error	187.86	1.05	2.13	17.54	
LSD 5%	535		3	6	50
Probability of F-value	0.0001	0.0001	0.0002	0.5081	
Coefficient of variation (%)	11.67	1.98	3.69	18.59	
R^2	0.8253	0.8763	0.8620	0.3297	

Means with the same letter are not significant at 5%.

rice yield trial with 12 entries was also conducted to select speciality rices producing grain types with a high market value.

In the regional replicated yield trial at Ibadan, severe ARGM infestation was observed. Yields ranged between 1.9 t ha^{-1} and 3.3 t ha^{-1}, compared with a varietal yield potential that generally exceeded 6 t ha^{-1} (Table 25). Seven lines yielded significantly better than the local check, ITA 306. RF 85C-C1-1-37-1-2-2-3, a line developed through genetic male sterile facilitated recurrent selections, had the highest yields. In the same trial conducted at M'bé, however, only mild ARGM infestation was observed. Four entries yielded significantly better than the local check, Bouaké 189. TOX 3440-16-1-2-2-3 yielded a maximum of 7.7 t ha^{-1}, followed by TOX 3440-16-2-1-2-3 (7.1 t ha^{-1}), TOX 3440-16-3-2-2-3 (6.0 t ha^{-1}) and TOX 3118-47-1-1 (5.9 t ha^{-1}). In the same trial at Fanaye in Senegal, the yields were even higher as there was no disease or insect incidence, and solar radiation was non-limiting. TOX 3440-16-2-1 yielded a maximum of 12.8 t ha^{-1}, followed by TOX 3772-40-3-2 (11.2 t ha^{-1}), TOX 3792-10-1-2 (10.4 t ha^{-1}) and RF 85C-C1-37-1-2-2-3 (9.4 t ha^{-1}), thereby exceeding the recently released line BW 293-2 (Sahel 201, *see* 1994 Annual Report).

In the early-duration advanced yield trial at Ibadan, the incidence of ARGM was extremely high, resulting in an average tiller infestation of 62% at mid-season. The highest yield was 3.1 t ha^{-1} from FARO 44 (SIPI 692033), the regional check. Nine entries yielded higher than the local check, FARO 50 (2.5 t ha^{-1}). In the same trial conducted at M'bé, ARGM infestation was mild. TOX 3255-82-1-3-2 yielded a maximum of 8.5 t ha^{-1} and was significantly superior to the local check, Bouaké 189 (5.9 t ha^{-1}) and FARO 44, the regional check (6.3 t ha^{-1}).

In the medium-duration advanced yield trial at Ibadan, the incidence of ARGM (68%) was even higher than in the early-duration advanced yield trial. Again, the medium-duration check varieties had an edge over many of the new materials under ARGM pressure, but were clearly outyielded under low ARGM pressure at M'bé by TOX 3241-31-2-1-3-1, TOX 3440-16-3-3-2-3 and TOX 3073-17-1-3-3-3.

In elite varietal trials in Chad, lines selected in previous years were evaluated at Ambadane, Midekhine and Sagour. TOX 3440-18-1-2-2-1, TOX 3093-35-2-3-3 and TOX 3058-28-1-1 were among the highest yielders at at least two of three sites, confirming their consistent performance in previous trials across the region.

In summary, the range of stable and high yielding irrigated rice materials has been substantially broadened for the region, and many of the new lines consistently outyield local and regional checks. However, we do not yet have an answer to the ARGM problem, which is locally extremely severe. As opposed to RYMV, a disease of greater regional importance for which genetic donors for resistance have been identified and are being used, no such donors were available for ARGM in 1995. Durable solutions may ultimately have to be based on wide crosses with *O. glaberrima*, which is currently the only known reservoir of resistance genes. In 1996, we will expand WARDA's existing japonica x *O. glaberrima* hybridization program to include the more difficult indica x *O. glaberrima* crosses for lowland ecologies.

Materials and method

With the exception of the unreplicated observational nursery trials, all trials had a randomized complete block design (RCBD) with three replications. The individual plot size was 10 m^2 for RYT and 15 m^2 for AYT. At M'bé and Ibadan, 80-40-40 kg ha^{-1} NPK was applied, using a triple split for N. At Fanaye, the dose was 120-60-60 because climate permitted a higher yield potential.

Progress in varietal improvement for rainfed lowland ecosystems

B.N. Singh and O. Oladimeji

The inland valley bottoms and floodplains with no or partial water control are collectively called rainfed lowland systems. They may occupy up to 1.1 million hectares in West Africa, including about 0.6 million hectares of "classical" inland valley lowlands. This environment is extremely diverse, as it may be affected to varying degrees by drought, floods, iron toxicity, as well as a host of biotic stresses. Major biotic stresses associated with poor water control are weeds and blast disease. Input levels usually depend on hydrology and degree of water management, ranging from zero to input levels similar to those in irrigated systems. The cultivated area of rainfed lowlands are increasing dramatically in West Africa, thereby providing high potential returns to varietal improvement.

The plant type requirements for rainfed lowlands differ from those in irrigated systems. Tall plants with good seedling vigor are needed. They should also possess combined adaptations to pests and diseases, such as leaf and panicle blast, African rice gall midge, stalk-eyed stem borer, iron toxicity, leaf scald, bakanae, brown spot, rice yellow mottle virus, and grain discoloration. Yield stability is the major breeding objective for rainfed lowland rice.

During 1995, selections were made from previous years' crosses, and 110 new crosses were made to incorporate resistance to drought and blast into suitable plant types. Selections were made from 50 F_2, 36 F_3 and 116 F_4 populations, based on their resistance to leaf blast and drought at the seedling stage in the screenhouse. In addition, 15 900 pedigree lines from 67 indica x japonica crosses were evaluated, 303 uniform lines were bulked, and further selections were made from 458 segregating lines. For indica x indica crosses, 1374 selections were made from 3309 pedigree lines. From genetic-male-sterility-aided transfer of genes for blast, iron toxicity and drought resistance, we derived 1255 male fertile lines, which were then planted as random mating bulk populations.

In order to account for the hydrological diversity of rainfed lowlands, genetic materials were grouped at an early stage of selection into plant types suited to: drought prone, favorable, medium-deep flooded, and low-input rainfed lowlands. Plant types suited to irrigated conditions were transferred to the respective breeding activity. Varietal selection proceeded from on-station initial evaluation trials, via regional observational nurseries, replicated yield trials and advanced yield trials, to elite varietal trials.

In the regional replicated yield trials for drought-prone lowlands at Ibadan, 24 entries selected from the previous year's observational nurseries were evaluated (Table 26). Transplanting took advantage of rain water caught in the bunded fields. Thereafter, the soil remained non-flooded but hydromorphic (groundwater fluctuating between 35 and 60 cm

Table 26: Regional rainfed lowland drought-resistance replicated yield trial at Ibadan, Nigeria, 1995 wet season. Entries are tabulated in decreasing order of grain yield (kg ha^{-1}).

Entry	Grain yield (kg ha^{-1})	Plant age at flowering (days)	Height (cm)	Panicle no.	% ARGM infestation at 60 DAT	Phenotypic acceptability (SES scale)
TOX 4008-34-1-1-1-2	4629 a	102	114	146	71	3
TOX 3880-38-1-1-2	4386 a	107	132	170	67	1
TOX 4004-28-3-1-2-2	4325 a	97	115	154	72	3
TOX 3100-44-1-2-3-3 (WITA 4)	4185 a	101	109	174	62	1
TOX 3731-31-3-2	4061 abc	110	106	159	55	1
TOX 4004-8-1-2-3	3818 abcd	96	107	149	66	3
TOX 4008-34-1-1-2	3805 abcd	101	106	146	69	3
TOX 3154-17-1-3-2-2	3786 abcd	104	108	163	62	5
ITA 368	3674 abcde	104	102	153	81	3
ITA 324	3573 abcde	100	101	151	65	5
TOX 3440-47-5-3-2-2	3550 abcde	105	111	156	73	3
TOX 3566-6-1-2-2-1-1-2	3371 abcdef	104	117	129	69	5
TOX 4008-33-1-2-1	3249 abcdef	102	112	147	70	1
TOX 3580-71-3-2-2	2868 bcdefg	100	105	109	72	5
ITA 212 (check)	2839 bcdefg	95	97	137	80	5
TOX 3440-16-3-1-1-2	2663 cdefg	100	97	130	77	5
TOX 3732-34-1-3-2	2613 cdefg	99	95	130	78	9
TOX 3876-53-1-2-1-2-2	2592 defg	102	108	120	81	5
IR 54 2388	defg 98	83	122	62	7	
TOX 3109-73-4-4-2-5	2383 defg	101	86	112	82	7
TOX 3872-6-3-2-2	2274 efg	112	112	128	67	5
FARO 44	2041 fg	92	99	97	73	7
DJ 11-507-15	1602 g	86	97	94	72	7
TOX 3084-136-1-3-1-2	[a]	96	91	112	62	7
Overall mean	3255	101	105	137	70	
Standard error	505.32	0.99	4.42	15.42	4.62	
LSD 5%	1457	3	13	44	13.15	
Probability of F-value	0.0026	0.0001	0.0001	0.0173	0.0071	
Coefficient of variation (%)	26.89	1.70	7.31	19.49	11.38	
R^2	0.5814	0.9413	0.7490	0.5160	0.5511	

[a] Entry damaged by rats. Means with the same letter are not significantly different at 5%. ARGM = African rice gall midge. DAT = days after transplanting.

Table 27: Third regional rainfed lowland favorable advanced yield trial at Ibadan, Nigeria 1995 wet season. Entries are tabulated in decreasing order of grain yield (kg ha^{-1}).

Entry	Grain yield (kg ha^{-1})	Plant age at flowering (days)	Height (cm)	Panicle no.	% ARGM infestation at 60 DAT	Phenotypic acceptibility (SES scale)	Iron toxicity score
TOX 3880-38-1-1-2	4142 a	115	122	106	3	1	1
TOX 3440-47-5-3-1-1	4031 a	102	106	136	3	1	1
ITA 324	3945 ab	107	95	119	7	3	1
TOX 3967-17-1-1	3733 abc	115	106	121	3	3	5
TOX 3884-23-3-3-1	3360 abc	104	100	118	5	3	5
TOX 3956-24-2-1-2-2	3306 abcd	102	98	103	5	3	3
TOX 3399-64-2-2-1	3151 bcd	102	95	112	5	5	5
ITA 368	3083 cd	105	94	103	5	5	7
TOX 4004-8-1-2-2-3	3015 cd	103	115	100	3	3	1
TOX 3440-132-3-3-1	2939 cd	102	105	103	3	1	3
CISADANE	2888 cd	116	95	114	3	5	7
BG 90-2 (Check)	2805 d	104	84	113	3	5	7
Overall mean	3367	107	101	112			
Standard error	288.86	2.11	3.68	8.76			
LSD 5%	847	60	11	26			
Probability of F-value	0.0222	0.0001	0.0001	0.2397			
Coefficient of variation (%)	14.86	3.44	6.29	13.52			
R^2	0.6183	0.7775	0.7944	0.4643			

Means with the same letter are not significantly different at 5%. ARGM = African rice gall midge.

depth), resulting in moderate water stress during the vegetative and reproductive stages. Four entries yielded significantly higher than the local check, ITA 212. They were: TOX 4008-34-1-1-1-2, TOX 3880-38-1-1-2, TOX 4004-28-3-1-2-2 and WITA 4. The good and stable performance of WITA 4 was also confirmed in independent iron toxicity trials and in an elite varietal trial in Chad during the same year, confirming this line as one of the most broadly adapted lowland rice varieties available today in West Africa.

In the 1995 regional advanced yield trials for favorable rainfed lowlands at Ibadan, no moisture stress was observed, due to abundant seepage from adjoining upland areas. However, iron toxicicity symptoms occurred in many lines, particularly the regional check BG 90-2 and the partially gall midge resistant cultivar, Cisadane (Table 27). Four improved lines outyielded both, probably due to their superior tolerance to iron toxicity. The top yielder was TOX 3880-38-1-1-2. Also among the best performing lines was ITA 324, which also gave the highest yields in the elite varietal trial in Chad mentioned above.

In the 1995 low-input advanced yield trial at Ibadan, which was strongly affected by iron toxicity, only one entry stood out and significantly outyielded the checks and most of the other improved materials. This line, TOX 85C-C5-85-1, gave a yield of 3.8 t ha^{-1}, as compared to a mean of 2.1 t ha^{-1} for the 16 entries of this trial. Since low fertilizer application, iron toxicity and only one single weeding cycle created a multi-stress environment in this trial, follow-up studies are needed to show the specific adaptations of this line.

In 1996, we will continue rainfed lowland breeding activities along the sub-ecosystem-oriented itineraries. In addition, we will conduct in-depth studies on the traits that render some of the more recent progenies outstanding, in order to improve our screening tools and identify new genetic donors for multiple stress resistance.

Implementing an integrated strategy for the sustainable control of RYMV

B.N. Singh and C. Paul

Although no immune indica donors have been identified for resistance to rice yellow mottle virus (RYMV), resistant and moderately resistant varieties are available from tropical upland japonica and indica lines, and crosses have been made to transfer their resistance genes to improved indica varieties.

Seventy eight new single and double crosses were made in 1995 using resistant donors. Thirty six F_2 and eighty F_3 populations were grown in the screenhouse and inoculated. The resistant plants were harvested separately, and these will be advanced for continuous selection using the pedigree method in the screenhouse. Under the aegis of the Lowland Rice Breeding Task Force, 751 F_3 lines from 13 crosses were also evaluated at Rokupr, Sierra Leone, under field conditions.

Searching for new resistant donors, we screened 658 additional improved upland lines from germplasm collections using artificial inoculation. Their resistance was compared to that of ITA 306 and Moroberekan, the susceptible and resistant checks, respectively. Some 267 resistant plants were harvested individually, and will be re-evaluated in the 1996 dry season.

We received 327 upland japonica lines from the Centro Internacional de Agricultura Tropical (CIAT) and screened them for their RYMV resistance under inoculated conditions. Nineteen lines were observed as resistant or moderately resistant.

In collaboration with France's Centre de coopératation internationale en recherche agronomique pour le développement (CIRAD), we screened 184 doubled haploid lines, 103 single seed descent-derived lines, and 99 F_2-derived plants from six parent diallel crosses for their RYMV resistance under artificial inoculation. Resistant plants were harvested separately, and will be further evaluated during the 1996 dry season.

In past research, a number of immune lines have been found in *Oryza glaberrima*. In 1995, work to determine the genetics of resistance in five *O. glaberrima* lines (TOX 5675, TOG 7291, TOG 5681, TOG 7235, and TOG 5674) was undertaken. F_1 crosses between resistant and susceptible, and among different resistant lines were made. The number of genes and their allelic relationships will be studied in 1996, using generation mean analyses. The genetics of resistance in japonica and indica resistant lines will also be undertaken in 1996.

Sahel irrigated rice program

Irrigated rice in the Sahel is cultivated on about 200 000 ha, with a potential yield of 8-9 t ha^{-1}. Average farmers' yields are significantly lower (4-5 t ha^{-1}). This yield gap is due to poor crop and resource management, inappropriate varieties and a range of socio-economic constraints. The sustainability of irrigated systems in the Sahel is threatened by soil degradation (salinization and alkalinization) and a decline of soil fertility (if average nutrient outputs exceed nutrient inputs).

The Sahel irrigated rice program focuses on increased and sustainable production from irrigated rice-based systems in the Sahel, through:

- characterization of irrigated rice-based ecosystems;
- germplasm improvement; and,
- development of sustainable cropping systems.

"Double-cropped fields with drainage were less saline than single-cropped fields with or without drainage."

More than 4000 measurements of bulk soil conductivity in an irrigation scheme in the Senegal River Delta showed that salinity was strongly related to land use. Double-cropped fields with drainage were less saline than single-cropped fields with or without drainage. Results could be explained by differences in upward salt transport due to capillary rise from a shallow saline groundwater table. Studies on water movement in a dry, cracked heavy clay soil, revealed the importance of local swelling processes which has strong implications for water-solute transport in alkaline and saline soils. Soil puddling and subsequent surface drainage proved very effective for desalinization, but crop establishment in puddled soil was poor.

In our germplasm improvement program eight medium-duration and seven short-duration high yielding varieties adapted to the Sahelian climate were identified and will be screened for blast and rice yellow mottle virus (RYMV) resistance. The variety IR 13240, which was released in Senegal as Sahel 108, was released in Burkina Faso. A detailed physiological study to derive thermal constants, that are determinants for crop growth duration, from leaf appearance rate was started. Progress was also made in understanding physiological mechanisms responsible for varietal differences in resistance to salinity.

Promising first results were obtained in field tests with IRRI's stripper-harvester/ thresher-cleaner combination, which may be an alternative to combine harvesting in the Senegal River Basin. A regional trial on N, P, K use efficiency and productivity of irrigated rice was started at key sites in Senegal, Burkina Faso and Mali. First results from Senegal indicate a large diversity in fertilizer strategies among farmers and no relation between total fertilizer applied and yield, illustrating the potential for improvement of resource-use efficiency in irrigated rice-based systems. Field experiments to develop a decision tool for optimization of nitrogen fertilizer application were conducted at WARDA's research farms in Fanaye and Ndiaye and will be completed in 1996.

SAHEL CHARACTERIZATION RESEARCH

The Sahel is the transition zone from the Sahara desert to the Guinea savanna. This includes parts of Senegal, Gambia, Mauritania, Mali, Niger, Nigeria, Burkina Faso, Cameroon and Chad. A minor area is taken up by Guinea-Bissau, Guinea, Benin and the Central African Republic. Rainfall varies between 100 and 800 mm per year. Three issues are of great importance to irrigated agriculture (mainly rice) in the Sahel:

- an increase in production;
- an increase in resource use efficiency; and,
- prevention of environmental degradation.

In order to achieve these objectives, the Sahelian irrigated rice growing environments need to be characterized, with respect to the factors limiting production and its sustainability.

The area under rice cropping in the Sahel varies from year to year and from season to season. Remote sensing techniques may be used to estimate surfaces under rice cropping. In 1995, spectral responses of rice at different growth stages were determined, which will help to interpret satellite images.

During the last three years, emphasis in the Sahel characterization program has been on the effect of extreme temperatures on spikelet sterility, yield and crop growth duration. Accurate estimations of potential yield (limited by solar radiation and temperature only) can now be made for any sowing date and site in the Sahel, using the crop growth model ORYZA1S, provided adequate weather data are available. In 1995, research on thermal constants, which govern to a large extent growth duration, was further advanced.

The research focus of the characterization program shifted, however, to:

- determination of easily measurable soil indicators for regional characterization of environmental degradation, due to salinization and alkalinization; and,
- modeling of soil degradation processes.

An electromagnetic conductivity meter (EM38) was successfully used for rapid appraisal of salinity levels in rice fields. Good agreement was found between EM38 measurements and conventional laboratory salinity measurements. A detailed study was conducted on water flow mechanisms in a typical cracked, heavy clay soil. Cracks closed rapidly, starting from the soil surface, indicating the importance of local swelling processes on water and solute transport and modeling of such processes.

Deriving thermal constants from leaf appearance rates

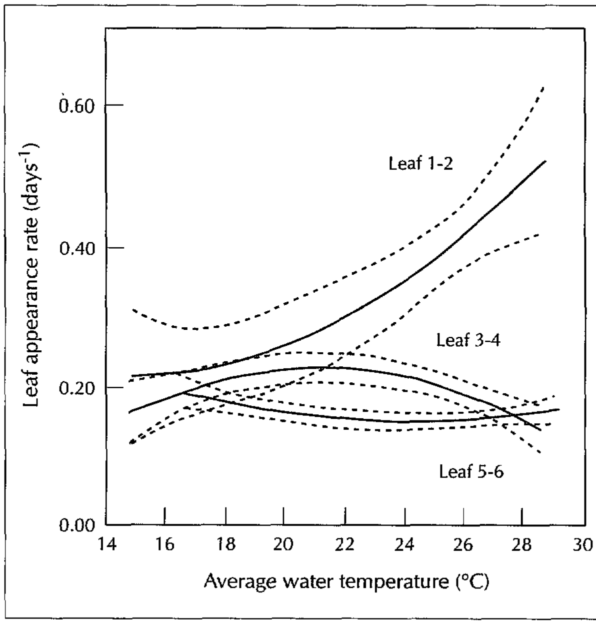
M. Sié, M. Dingkuhn, K. Miezan and M.C.S. Wopereis

Genotypic differences in thermal constants (T_{opt} and T_{base}) determine, to a large extent, varietal differences in the development rate from seed establishment to flowering. Such constants are usually determined from phytotron experiments, measuring the duration to flowering at different constant temperature regimes. We tested the possibility of deriving such constants in a cheaper and more direct way, by measuring leaf appearance rates of rice exposed to a wide range of temperatures in the field.

Three *Oryza sativa* indica rice varieties (Jaya, IKP, IR 64) were grown in the field at 15-day intervals (12 sowing dates) during the dry season of 1995 in Ndiaye, Senegal, under optimal irrigated growing conditions. Leaf appearance rates were monitored for every sowing date and regressed against average water temperature.

Average water temperature in the field experiment varied from 15-28°C. Leaf appearance rates were relatively insensitive to water temperature, with the exception of the first four leaves, whose leaf appearance rate changed with aver age water temperature (Figure 42). T_{opt} for the average leaf appearance rate calculated from leaf 1 to leaf 4 was 23°C for Jaya and IKP, and 24°C for IR 64. Estimation of T_{base} proved to be impossible due to the large errors involved in extrapolating regression lines to the average water temperature axis. Deriving thermal constants for the development from sowing to flowering from leaf appearance rates was, therefore, not straightforward. The total number of leaves between sowing and panicle initiation increased with decreasing water temperatures. Average leaf appearance rate for successive leaves increased with plant age. Leaf appearance rate was 0.22 $days^{-1}$ for the first three leaves and 0.15 $days^{-1}$ for leaves 9-12. Further analysis of the data will allow separation of the contribution of delays in leaf appearance, photoperiod and possible other effects of temperature on growth duration for the different varieties.

Figure 42: Development rates of rice variety IKP from leaf 1 to leaf 2, leaf 3 to leaf 4 and leaf 5 to leaf 6 ($days^{-1}$) versus average water temperature as determined for 12 planting dates in the dry season of 1995.



Materials and method

The field experiment (irrigated rice, 28 varieties, only results for three varieties are reported here) was conducted at WARDA's Sahel station at Ndiaye, Senegal and comprised 12 planting dates at 15-day intervals from 2 January to 16 June 1995. Pre-germinated seeds were direct seeded in 1 m^2 mini-plots (16 plants m^{-2}). Maximum and minimum water and air temperatures were monitored twice daily (8.00 am and 6.00 pm). Average leaf appearance rates (leaf 1 to leaf 2, leaf 3 to leaf 4, and leaf 5 to leaf 6) were regressed against average water temperature for all varieties and seeding dates to derive estimates for T_{opt} and T_{base} as a function of growth stage and variety.

Spectral reflectance of irrigated rice

M.C.S. Wopereis, J. Ceuppens (SAED) and D. Lambrechts (SAED)

The area under irrigated rice in the Senegal River Delta and Middle Valley has almost tripled over the last five years, largely due to the establishment of private irrigation schemes. However, the surface area under rice cropping varies greatly from season to season and from year to year. Interpretation of a satellite image taken near the end of the different growing seasons may quickly reveal surface areas under rice cropping. A first estimate of expected production levels may even be derived if a time series of satellite images is available for a given growing season. To detect rice fields and to estimate above ground biomass from satellite images, canopy reflectance of irrigated rice at different growth stages must be determined.

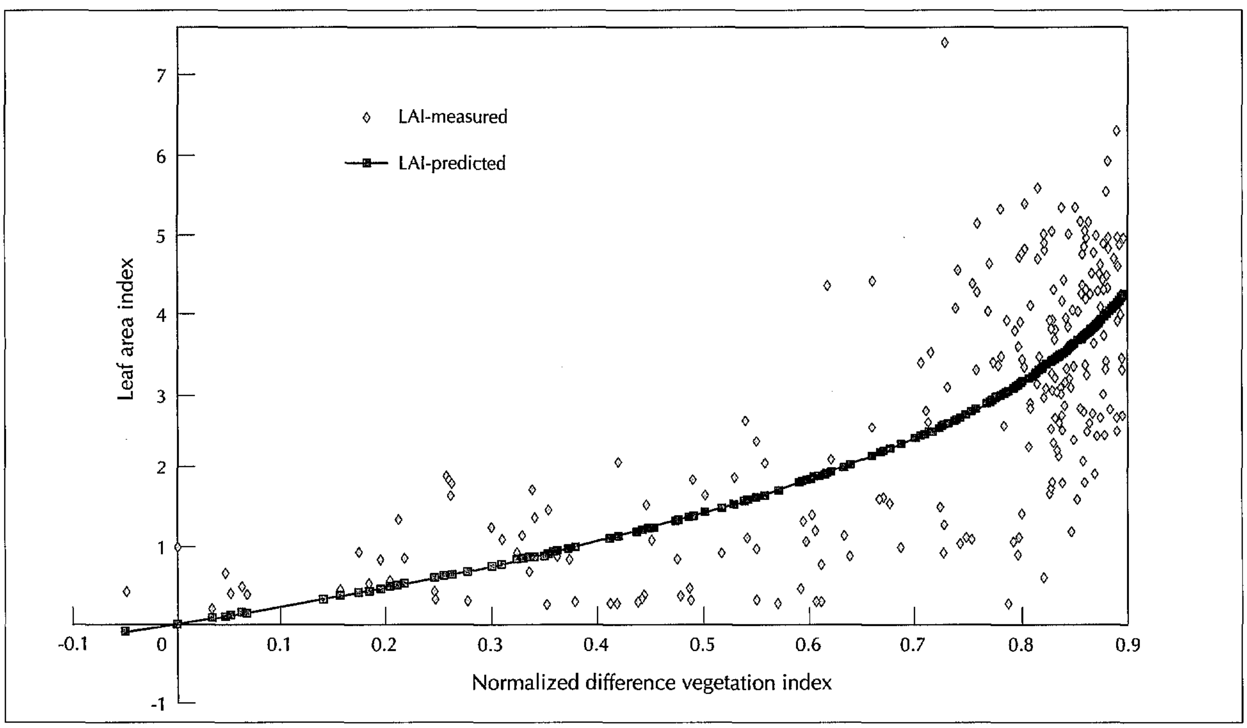
Canopy reflectance in eight different wavelengths of direct seeded and transplanted irrigated rice (Sahel 108 and Jaya) at 9 fertilizer application levels was determined throughout the wet season at WARDA's Sahel station at Ndiaye, using a portable reflectance meter. The objective of the study was to determine whether spectral reflectance can be used to estimate rice canopy leaf area index (LAI), chlorophyll content and above-ground dry matter accumulation for possible future use in satellite image interpretation.

Clear differences in reflectance patterns were observed as a function of growth stage and crop establishment method. Differences in spectral reflectance caused by a different fertilizer application and/or a different rice variety were found to be minor. Reflectance values were generally low in the blue (460 nm) and the red (600-700 nm) wavelengths and peaked in the near infrared (700-810 nm). The different spectral reflection curves showed a clear influence of the mixed soil-water background in the infrared bands. This influence decreased rapidly during the growing season due to canopy closure. A normalized difference vegetation index (NDVI) was calculated from (infrared reflectance - red reflectance)/(infrared reflectance + red reflectance). A clear relation between LAI and NDVI was found (Figure 43):

$$LAI = -1/0.47 * \ln(1 - NDVI/1.06);$$
$$r^2 = 0.73.$$

The experiments will be continued in the dry season of 1996 to investigate the importance and evolution of the influence of the mixed soil-water background; the influence of planting date on spectral reflectance of the canopy; and, the relation between chlorophyll content and reflection values.

Figure 43: Leaf area index (LAI) vs normalized difference vegetation index (NDVI) for transplanted and direct seeded irrigated rice at different growth stages (all data).



Materials and method

The fertilizer N use efficiency experiment at Ndiaye followed a CRB design with 3 replications and 9 treatments, including a non-fertilizer control and the most common farmers' practice (120 kg N ha^{-1} at the start of tillering and panicle initiation). Three different levels of N (120, 180, 240 kg ha^{-1}) were tested in four equal splits at the start of tillering, maximum tillering, panicle initiation and heading. For the remaining four treatments, the effect of timing of application was determined by omitting one of the four splits at a total N level of 120 kg ha^{-1} (i.e. 0-30-30-30 or 30-0-30-30, 30-30-0-30 and 30-30-30-0). Leaf Area Index (LAI) was determined non-destructively, weekly, using a portable LAI2000 meter. Total above ground dry matter was measured one day before fertilizer application and at maturity. Canopy reflectance was determined approximately every two weeks in 8 wavelengths (green, red and near-infrared) using a portable reflectance meter (CROPSCAN).

Electromagnetic soil salinity mapping of rice irrigation schemes in the Senegal River Delta

M.C.S. Wopereis, J. Ceuppens (SAED) and K. Miezan

Monitoring of salinity build-up in the Senegal River Delta is of great importance to avoid environmental degradation. Characterization of spatial and temporal variability of soil salinity in large rice irrigation schemes is, however, virtually impossible using conventional techniques, involving soil sampling at different depths and measurement of conductivity of soil extracts in the laboratory. We tested the use of an electromagnetic conductivity meter (EM38) to determine soil salinity levels. This method involves no sampling and measurements can be taken almost as fast as one can walk.

We conducted more than 4000 horizontal and vertical measurements of bulk soil conductivity using an EM38 in 40 rice fields in the irrigation scheme of Thiagar in the Senegal River Delta. The objectives of this study were to:

- derive simple conversion rules between electromagnetic measurement of salinity and conventional laboratory analyses of electrical conductivity of the saturation-extract at different depths;
- investigate the relative importance of cropping systems (single-cropping versus double-cropping), water management (drainage/non-drainage), soil type and positioning in irrigation/drainage line on salinity status of individual rice fields.

Average EM38 readings ranged between 40 and 800 mS m^{-1} per field. Thirty measurements per field were sufficient to estimate average field soil salinity status within a relative error of 20%. A multiple linear regression model based on vertical and horizontal electromagnetic readings explained 60-75% of the variability in electric conductivity measured in a 1:5 saturation extract at three depths (0-5, 10-15 and 30-35 cm). Inclusion of soil-water content slightly improved predictions (Table 28). Salinity was strongly related to land use and increased in the following order: double-cropping (i.e. two

Table 28: Regression models, with (equation 1) and without (equation 2) inclusion of moisture content.

Depth (cm)		A	B	C	D	r^2	n
	Equation 1: $Ln(EC_{lab}) = A*ln(H) + B*(ln(V) - ln(H)) + C*MC + D$						
0-5	Parameter	1.244	3.014	-3.160	-1.076	0.61	43
10-15	Parameter	0.920	2.821	0.004	-1.759	0.69	43
30-35	Parameter	1.125	2.564	0.833	-2.172	0.76	46
	Equation 2: $Ln(EC_{lab}) = A*ln(H) + B*(ln(V) - ln(H)) + C$						
0-5	Parameter	1.187	3.419	-1.535		0.57	43
10-15	Parameter	0.920	2.819	-1.757		0.69	43
30-35	Parameter	1.121	2.461	-1.881		0.75	46

MC = moisture content (volume %); V = vertical EM38 reading (dS m^{-1}); H = horizontal EM38 reading (dS m^{-1}); EC_{lab} = electrical conductivity of 1:5 soil extract (dS m^{-1}); n = sample size.

crops per year) with drainage, single-cropping (i.e. one rice crop per year) with drainage, single-cropping without any drainage, abandoned fields. Variability of the EM38 readings increased in the same order. Results illustrated the importance of differences in the magnitude of upward salt transport due to capillary rise from the shallow saline groundwater table in the Delta. Studies on the maximum surface that can be irrigated in the Delta (taking into account differences in percolation rate and capillary rise among major soil types) without risking contact between topsoil and the highly saline groundwater are urgently needed.

Materials and method

Two surveys were conducted in the rice perimeter of Thiagar (16°25'N, 15°70'W), Northern Senegal (900 ha). Four land use groups were defined: double cropping (until 1994) with drainage (DC-D), single cropping with drainage (SC-D), single cropping without drainage (SC-ND) and abandoned fields, for salinity reasons (A). Horizontal and vertical above-ground measurements were taken of soil electrical conductivity using a Geonics EM38 electromagnetic induction meter (Geonics Limited, Ontario). During the first survey, EM38 measurements were taken on a 6 x 6 m grid in four fields in all four land use categories. In the second survey, 30 EM38 measurements were taken per field, on the two diagonals of another 24 fields.

Water movement and soil swelling in a dry, cracked vertisol

M.C.S. Wopereis, P. Boivin (ORSTOM) and F. Favre (ORSTOM)

Vertisols are among the major soil types present in the Senegal River Valley and Delta and are widely used for irrigation. Irrigated vertisols in an arid climate have a natural tendency to accumulate salts. The percolation rate under flooded conditions is low and the strong evaporative demand of the air may result in a net upward movement of water, and salt accumulation in the topsoil. Poor water management may further aggravate salinity problems and may lead to sodification and alkalinization. When dry, vertisols shrink to form deep vertical cracks, while when saturated, swelling occurs due to the presence of expanding clay minerals.

Development of alternative water management techniques for salinity control require detailed studies on soil-water movement. In this study, dynamics of water movement and subsequent changes in macroporosity (crack closure) after irrigation were studied in-situ for a cracked vertisol.

Surface irrigation and simulated rainfall (intensity 90 mm hour^{-1}) on cracked subplots (crack width 0.02-0.04 m; crack depth 0.3 m) resulted in crack closure within 4.5 hours. Soil swelling was heterogenous, with a very rapid expansion of the 1-2 cm border zone of soil islands (soil masses distinctively separated by cracks). After 22 hours, some cracks were not yet fully closed in the subsoil, indicating that crack closure started at the soil surface. At the moment of crack closure, the relative contribution of the movement of the soil islands as a whole to crack closure was only 19%; the contribution of swelling of the crack border zone at the soil surface was 81%. After 22 hours, these percentages changed only slightly to 27% and 73% respectively, due to slow vertical and lateral redistribution of water in the soil matrix (Table 29). Average linear shrinkage of the soil island border zone at the soil surface calculated at crack closure ranged from 19% to 28%. Maximum bulk linear shrinkage determined at the field level was only 7%. Results indicate the importance of rapid, local, heterogenous swelling processes to water flow into cracked vertisols, which has important implications for modeling of water-solute transport in such soils.

Table 29: Contribution of soil island border expansion and soil island swelling (percentages) to crack closure in subplot B1.

Time (hours)	Soil island border expansion (%)	Soil island swelling (%)
4.5	81	19
24	73	27

Data are shown for measurements conducted 4.5 hours after the start of rainfall simulation (moment of crack closure) and after 22 hours (end of experiment). Data are average values of measurements conducted on 12 soil cracks.

Materials and method

Experiments were conducted in December 1994 and sited on a cracked non-cropped field near the rice perimeter of Nianga (16°33'N, 14°57'W), Northern Senegal. Average width of soil masses separated by cracks (*soil islands*) was about 0.6 m, crack depth about 0.3 m, crack width 0.02-0.04 m. Two small subplots of 2.25 m^2 of cracked soil (C1, C2) were selected. Subplots were hydrologically isolated from their surrounding areas with metal sheets. Water was applied using simulated rainfall with an intensity of 88 mm hr^{-1} (C1) and surface irrigation (C2). Soil pressure potential was measured using sets of ultra thin tensiometers. The movement of the soil islands as a whole was monitored with a simple 3:1 magnifying gauge. Relative contributions of (i) the movement of soil islands and (ii) swelling of the soil island border zone to crack closure were calculated for 12 separate soil cracks at crack closure and at the end of the experiment (after 24 hours).

GERMPLASM IMPROVEMENT RESEARCH

Sustainable irrigated rice production systems in the Sahel require varieties which enable farmers to have high returns from their investments using improved and sustainable crop and resource management practices while protecting the environment. Such varieties need to resist and/or tolerate climatic variations (particularly temperature) in terms of crop duration and panicle sterility, soil problems such as salinity and alkalinity, and major diseases such as blast and rice yellow mottle virus (RYMV). In addition, these varieties must meet requirements for grain quality as preferred by consumers in the region.

"More than 2800 introductions of rice breeding lines from Asia, Latin America and Africa have been evaluated in the Sahel to date."

Since 1991, WARDA's Sahel program has reorganized its germplasm improvement activities to address these issues through massive introduction and evaluation of breeding lines from Asia, Latin America and Africa, in order to exploit fully the genetic diversity of existing rice germplasm at the international level. An intensive hybridization program has been initiated to develop new phenotypes better adapted to irrigated conditions in the Sahel. Over 2800 introductions have been evaluated to date, among which about 150 are at advanced stages of evaluation in both wet and dry seasons. Some of these advanced lines have been released by national programs in Senegal, Mauritania, Mali and Burkina Faso, or are involved in multilocational and demonstration trials in national programs.

In 1995, more than 600 lines were evaluated in initial evaluation trials, observational nurseries and advanced yield trials. Advanced selections were also evaluated for their tolerance to salinity and characterized for their photothermal constants governing the variability of crop duration.

In addition, 60 F_5 families from crosses performed in 1992 were also evaluated. Only results from advanced yield nurseries are reported here. The trials were conducted at Ndiaye (a site nearer to the ocean with moderate temperature and a long cool season) and Fanaye (arid inland site with high temperature fluctuations). Both sites are located in the Senegal River Valley in Senegal.

In 1995 important advances were also made in understanding physiological mechanisms governing resistance to salinity of irrigated rice in the Sahel.

Identification of stable high-yielding varieties for the wet season

K. Miezan, M. Sié and S. Gaye

Fifteen breeding lines, composed of eight medium-duration and seven short-duration varieties, were evaluated for the second year in two advanced yield nurseries at Fanaye and Ndiaye. The checks used were Jaya and BW 293-2 for the medium duration, and, I Kong Pao and IR 13240-108-2-2-3 for the short duration.

The results showed significant differences in yield among the medium-duration entries (LSD 0.05 = 0.5) at Fanaye but not at Ndiaye. Bg 380-2, ITA 252, UPR 254-85-1-TCA3 and ITA 234 gave higher yields (7.2 t ha^{-1}, 7.0 t ha^{-1}, 6.0 t ha^{-1} and 5.9 t ha^{-1} respectively) than the checks Jaya (5.8 t ha^{-1}) and/or BW 293-2 (5.1 t ha^{-1}) at Fanaye, confirming their superiority, expressed in 1994 at the same site. Similar trends were observed at Ndiaye, although the differences were not significant.

In the short-duration group, the yield differences among the entries were significant at both sites. IR 32307-107-3-2-2 and IR 31851-96-2-3-2-1 confirmed their good performance of 1994 with 6.0 t ha^{-1} and 6.3 t ha^{-1} at Ndiaye (LSD 0.05 = 1.3) and 6.0 t ha^{-1} and 5.3 t ha^{-1} at Fanaye (LSD 0.05 = 0.3) in 1995 compared to the checks I Kong Pao and IR 13240-108-2-2-3 which gave 4.6 t ha^{-1} and 5.0 t ha^{-1} at Ndiaye and 5.6 and 5.8 t ha^{-1} at Fanaye.

The best medium-duration and short-duration varieties identified after two years of evaluation have been sent to the plant pathologist and the grain quality laboratory at WARDA's main research center at M'bé for assessment for disease resistance (blast, RYMV) and grain quality characteristics.

The results also confirm the possibility of identifying for the Sahel, short-duration varieties which can yield as much as medium-duration varieties under transplanting. The possibility for irrigation water saving and macro nutrient use efficiency of these varieties needs to be studied.

Materials and method

Plants were transplanted from a seedbed, generally 25 DAS, at a spacing of 20 x 20 cm. Each plot received 120 kg N ha^{-1} applied as urea in a triple split, 60 kg P ha^{-1} as superphosphate and 60 kg KCl ha^{-1}. Weeds were controlled by application of propanyl (10 liters ha^{-1}), followed by hand weeding at midseason where necessary. The trials at Ndiaye were covered with fishing nets to protect them from bird damage.

Sodium uptake to the rice plant restricted by a varietal root filter

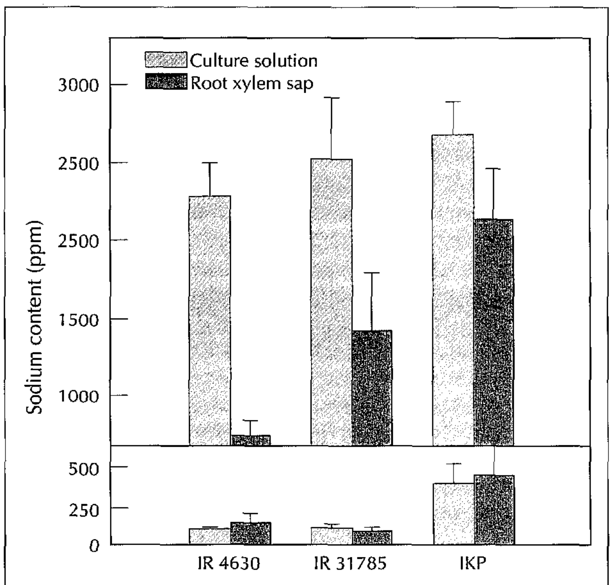
F. Asch, C. Wittstock and A. Audebert (CIRAD)

As a part of the development of screening tools for salt tolerance of irrigated rice, sodium uptake to the rice xylem was studied in three genotypes grown in screenhouse hydro culture at WARDA's research station at Ndiaye, Senegal. The genotypes in this study were:

(1) IR 4630-22-2, salt tolerant;
(2) I Kong Pao, salt tolerant, local check and well adapted to Sahelian conditions; and,
(3) IR 31785-58-1-2-3-3, WARDA's susceptibility check.

Root xylem sodium concentrations were compared with culture solution sodium concentrations (Figure 44). In freshwater controls, no differences were observed between root xylem and culture solution sodium concentrations in any of the genotypes. With 60 millimoles (mmol) NaCl, applied genotypes differed in their root xylem sodium content. Only 33% of the external sodium concentration was found in the root xylem of IR 4630-22-2, 60% in IR 31785-58-1-2-3-3, and 80% in I Kong Pao.

Figure 44: Root xylem sodium concentrations of three varieties in a screenhouse trial in the wet season 1995 after 24 hours of exposure to 60 mmol NaCl.



Lower part: control treatment; upper part: salinity treatment. Error bars = SE over 5 replications.

Our observation that the sodium concentration in the xylem sap can be significantly lower, but not higher, than that of the ambient solution (Figure 44), indicates that a "root filter" for sodium exists. This filter can be passive (exclusion) or active (e.g., excretion of absorbed Na at the root surface), and evidently represents an important avoidance component of rice salt-resistance. The filter appears to be most efficient in IR 4630-22-2 and least efficient in I Kong Pao. We included this result in the salt uptake model for irrigated rice by introducing an additional varietal constant for root sodium uptake.

Materials and method

In a completely randomized design individual 21-day-old plants were transferred from a seedbed to Styrofoam floats in water cooled buckets containing 4 liters of Yoshida nutrient solution. Plants were grown in solution for four weeks before they were subjected to the different treatments. Sodium was given as NaCl (p.a.). 5 plants per variety and treatment were subjected to two levels of salinity: 0 mmol NaCl (EC 0.8 mS cm^{-1}) and 60 mmol NaCl (6.5 mS cm^{-1}). After 24 hours root systems were cut off from the plant just below the stembase. The root was dried superficially on blotting paper. The entire root was inserted into a Scholander-type pressure bomb. Superficial water was removed by applying 0.2 MPa for 30 seconds. Xylem sap was sampled for 2 minutes at 1 MPa. Xylem sap was analyzed flamephotometrically for sodium and potassium content.

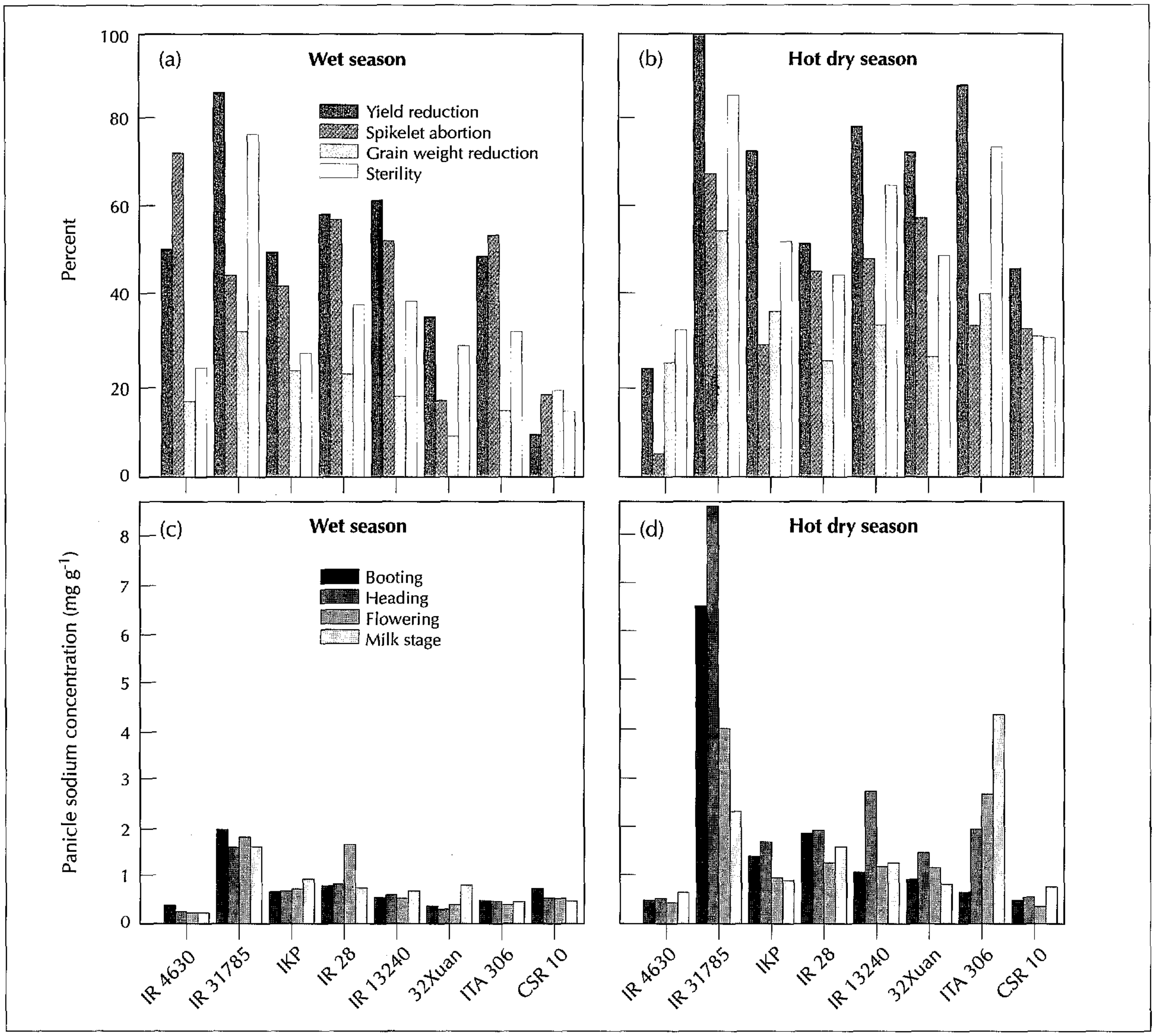
Effects of sodium uptake to the panicles on yield components of irrigated rice

F. Asch and C. Wittstock

Sodium is passively taken up to the plant via the transpiration stream. Thus, in a panicle that is still enveloped by the flag leaf and therefore does not transpire, sodium concentrations should be relatively low. After panicle exsertion until full expansion, the spikelets transpire and an increase in panicle sodium concentration can be expected. After pollination (or onset of grainfilling) carbohydrates are transported into, and water out of, the panicle, therefore sodium concentrations are likely to decrease.

Figure 45 c and d (*overleaf*) shows the sodium concentration of the panicle for the eight genotypes and both seasons. We found that, compared to all other tissues, i.e. roots, stems and leaves (*see* also WARDA Annual Report 1992), panicle sodium concentrations were generally five to ten times lower. Panicle sodium concentration in the wet season was similar for all genotypes except IR 31785-58-1-2-3-3 (WARDA's susceptible check) and IR 4630-22-2 (WARDA's tolerant check) which had the highest and the lowest concentration, respectively. In the hot dry season, panicle sodium concentrations were generally higher than in the wet season, and sodium uptake to the panicle was strongest in the suscep-

Figure 45: Panicle sodium concentration of four different panicle development stages and yield components of eight genotypes.



Data from WARDA's continuous salinity trial of wet and hot dry season 1994. Yield components are expressed as reductions compared to fresh water controls except for sterility. Genotype names are abbreviated.

tible genotypes IR 31785-58-1-2-3-3, IR 28, ITA 306 and IR 13240. Panicle transpiration alone did not explain the sodium uptake to the panicle in the respective stages, tolerant genotypes like IR 4630 and CSR 10 showed no increase in panicle sodium in both seasons.

Yield reduction and salinity influence on panicle yield components, however, varied strongly among the genotypes in both seasons (Figure 45 a and b). In the wet season spikelet abortion contributed most to the yield reduction, whereas in the hot dry season sterility in combination with poor grain filling was more important. In order to evaluate the importance of sodium concentration of the panicle on yield components, we calculated a correlation matrix over all genotypes for the changes in the yield components (as illustrated in Figure 45) and the increase in panicle sodium concentration (compared to freshwater controls) in the respective stages. In the wet season, grain weight reduction at all stages and sterility in the early stages were correlated with an increase of sodium in the panicles, but spikelet abortion was not. In the hot dry season, grain weight reduction, spikelet abortion and sterility were correlated with increasing panicle sodium concentration but only in the early stages until flowering.

We conclude that panicle sodium concentration is an important factor in yield reduction in genotypes that are sensitive to salt. In tolerant genotypes like IR 4630, which are known to control their transpiration, panicle sodium concentration does not increase under salinity. Strong increases in sodium concentration in the immature panicle, however, can affect the development of the spikelets and, therefore, decrease yield.

Materials and method

Plants were grown in WARDA's salinity trial at Ndiaye with 3 replications and either irrigation with fresh water or a constant electric conductivity of 3.5 mS cm^{-1} in the floodwater. Fertilizer application was 120-60-60 kg ha^{-1} N-P-K in two splits. The experiment was conducted in the wet and hot dry season 1994. Five panicles per season, panicle development stage, variety, treatment and replication were sampled, oven-dried and analyzed for sodium and potassium content after 48 hours of acid extraction. Yield and yield components were determined from a 12 hill sample at maturity. All yield related result were corrected to 14% grain moisture content.

Air humidity effects on transpiration among rice varieties subjected to salt stress

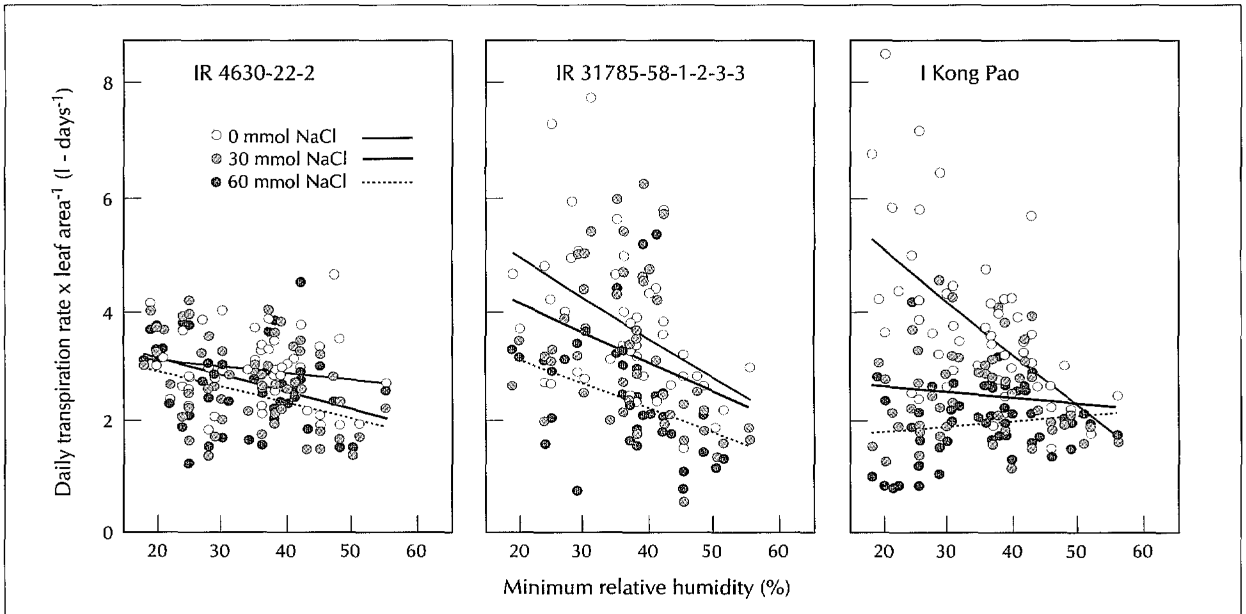
F. Asch

Salt (sodium chloride) is passively taken up to the shoot via the transpiration stream. If sodium is not excluded from the plant at the root level, sodium accumulation in stems and leaves is directly proportional to the transpiration history. The higher the evaporative demand of the atmosphere, the more water that passes through the plant and the more sodium that accumulates in the tissues, if transpiration is not controlled. Stomatal closure under salinity is a possibility to control transpiration and thus salt influx.

In order to determine air humidity x salinity effects on transpiration, daily transpiration rates and leaf area were measured over an entire season for the three varieties grown in culture solution. Transpiration rates were expressed on a leaf area basis (*see* Figure 46).

Transpiration rates of IR 4630-22-2 were generally low (1.5 to 4 kg m^{-2} $days^{-1}$), and were not influenced by air humidity or salt treatment. Since a decrease in air humidity is associated with an increase in evaporative demand, results indicate that IR 4630-22-2 stomata must have responded to air humidity under both saline and control conditions. In I Kong

Figure 46: Air humidity influence on daily transpiration per leaf area of three varieties subjected to different levels of salinity in a hydro-culture screenhouse trial at WARDA's research station in Ndiaye, Senegal.



Humidity is expressed as minimum between 0800 and 2000 hours.

Pao, transpiration rates markedly increased with decreasing air humidity under non-saline conditions, but did not respond under salinity. For IR 31785-58-1-2-3-3, transpiration rates increased with decreasing air humidity under both saline and control treatments, although transpiration rates were generally lower under salinity. It appears, therefore, that the tolerant check IR 4630 controlled its transpiration under both saline and control treatments, I Kong Pao controlled its transpiration specifically under salinity depending on the salt concentration, and the susceptible check IR 31785-58-1-2-3-3 controlled its transpiration least.

The results presented in Figure 46 reflected well the salt susceptibility of the three test varieties observed in the field. Tolerant IR 4630-22-2 strongly regulated transpiration, susceptible IR 31785-58-1-2-3-3 did not. I Kong Pao, which is also tolerant, but does not exclude sodium particularly well (*see* "Sodium uptake to the rice plant restricted by a varietal root filter", page 95), regulated its transpiration strongly only when salinity and low air humidity occurred together.

Among the many factors that determine the varietal resistance to saline environments, air humidity- and/or salinity-dependent regulation of transpiration plays a major role in the Sahel, in contrast to monsoonal Asia, where the relative humidity is higher throughout the year and thus, rice water consumption lower.

Materials and method

In a randomized complete block design three 21-day-old plants each were transferred to Styrofoam floats in buckets containing 8 liters of Yoshida nutrient solution. Buckets were cooled in a concrete waterbath using water circulated from an adjacent underground reservoir. Plants were grown in solution for 7 days before 18 plants per variety, treatment and replication (3) they were continuously subjected to three levels of salinity (NaCl): 0 mmol NaCl (EC 0.8 mS cm^{-1}), 30 mmol NaCl (EC 3.5 mS cm^{-1}) and 60 mmol NaCl (6.5 mS cm^{-1}). Daily transpiration rate was measured by difference weighing and leaf area (destructive with Li 3000; Li-Cor, Lincoln, Nebraska) was determined in 10 day intervals on a one-hill basis. Temperature and relative humidity were recorded with a thermohygrograph (Cole Parmer, Illinois, 7 day revolution). Nutrient solution was changed weekly.

Influence of potassium nutrition on rice yields under salt stress

F. Asch and C. Wittstock

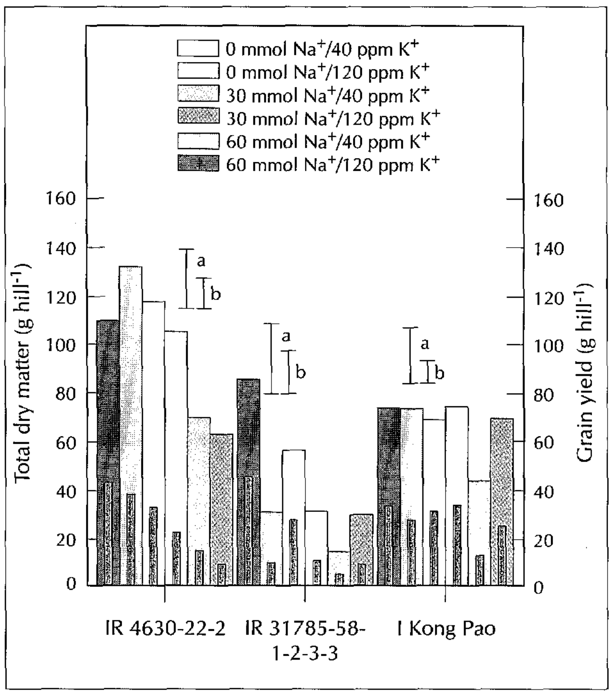
Potassium fertilization on saline fields improves the K/Na ratio of the soil solution and may mitigate salinity effects. We studied the effects of increased potassium concentrations in the nutrient solution on dry matter production and grain yield in three varieties. Test varieties in this trial were:

(1) IR 4630-22-2, salt tolerant;
(2) I Kong Pao, salt tolerant, local check and well adapted to Sahelian conditions; and,
(3) IR 31785-58-1-2-3-3, WARDA's susceptibility check.

In IR 31785-58-1-2-3-3, dry matter and grain yield were reduced by 30% and 90%, respectively, in the two salinity treatments. IR 31785 was negatively affected by additional potassium under non-saline and moderately saline conditions. Under high salinity, however, dry matter production and grain yield doubled with potassium treatment compared to normal potassium conditions.

Up to concentrations of 30 millimoles NaCl (which resulted in electric conductivity values of approximately 3.5 mS cm^{-1}) no reduction in dry matter or grain yield was observed in the two tolerant varieties independent of the potassium treatment. Additional potassium had no effect on IR 4630-22-2. Salinity effects seemed to be slightly enhanced by potassium, but the differences were not significant. Significantly positive effects ($p < 0.05$) of potassium nutrition were observed only in I Kong Pao under high salinity (Figure 47).

Figure 47: Grain yield and total dry matter of three rice varieties under salt stress and different potassium fertilization in a screenhouse trial in the wet season 1995 at WARDA's research station in Ndiaye, Senegal.



Thin and uniformly shaded bars = grain yield. Error bars = LSD at $p < 0.05$ for (a) total dry matter and (b) grain yield.

These results indicate strong differences among varieties in the effectiveness of potassium fertilization under saline and non-saline conditions. Varieties like IR 4630-22-2, that keep a high endogenous potassium level even under adverse conditions, did not seem to profit from potassium fertilization. Varieties like I Kong Pao, that keep a high potassium level under non-saline conditions, profit from additional potassium fertilization under saline conditions. Salt-susceptible genotypes such as IR 31785-58-1-2-3-3 seem to suffer additional salt stress from high potassium doses. Potassium had a positive effect only in highly saline environments, probably because it creates an osmotic stress which is not toxic to the plant.

WARDA's research will continue in this direction in 1996 in collaboration with the University of Hamburg, Germany.

Materials and method

The trial was conducted in the wet season 1995 in WARDA's screenhouses in Ndiaye, Senegal. In a randomized block design, individual 21-day-old plants were transferred to Styrofoam floats in water cooled buckets containing 4 l of Yoshida nutrient solution. 72 h after transplanting the plants were subjected to six different treatments:
(1) control,
(2) + 30 mmol NaCl,
(3) + 60 mmol NaCl,
(4) + 120 ppm K^+,
(5) + 80 ppm K^+ + 30 mmol NaCl,
(6) + 80 ppm K^+ + 60 mmol NaCl.
Solution was changed weekly and pH was adjusted to 5 every two days. At maturity total dry matter and grain yield was determined. Samples were oven dried for 72 h, grain moisture content corrected to 14%.

DEVELOPMENT OF SUSTAINABLE CROPPING SYSTEMS

The demand for rice in the Sahel is increasing and rapidly outgrowing domestic supply. However, farmers in irrigated rice-based systems are facing both short-term and long-term constraints. Resource-use efficiency (especially nutrient management) is far from optimal, due to a range of agronomic and socio-economic constraints, contributing yields well below their economic potential. Long-term problems include land degradation (salinization, alkalinization) due to poor fits between soil type and cropping system, and inadequate plot and scheme level water management. Stagnant yields and mining of soil fertility, reported in Asia, may also occur in irrigated rice-based systems in West Africa if nutrient outputs consistently exceed nutrient inputs.

Double-cropping (growing two crops per year on the same site) requires careful planning in the Sahel due to extreme temperatures in the hot dry and wet seasons. In the Senegal River Basin, harvest is frequently delayed because combine harvesters breakdown or are delayed. Good results were obtained with the International Rice Research Institute's (IRRI) stripper-harvester and thresher-cleaner combination, which may be a cheap, easy-to-maintain and manufacture alternative to combine harvesting.

> "First results indicate a large diversity in fertilizer application strategies and no relation between yields and applied fertilizer nitrogen."

We started yield gap surveys in three key irrigation schemes (Office du Niger, Mali; Kou valley, Burkina Faso; and, Thiagar irrigation scheme, Senegal) in 1995. First results indicate a large diversity in fertilizer application strategies and no relation between yields and applied fertilizer nitrogen. An experiment on optimization of nitrogen application was conducted during the inter-season and wet season of 1995 at WARDA's research farms in Ndiaye and Fanaye, Senegal. The experiments will be continued in the dry season in 1996. Results will be used to develop a decision tool for nitrogen management.

Soil puddling and subsequent surface drainage was five times as effective as conventional tillage and drainage in removing salt from a highly saline soil. Plant establishment in puddled soil was, however, poor. A survey in Thiagar revealed the importance of water management and cropping system on soil salinity in the Senegal River Delta.

IRRI's stripper-harvester/thresher-cleaner tested in the Sahel

M.C.S. Wopereis, M. Ndiaye, S. Diack, B. Douthwaite (IRRI), S. Kanté (ISRA) and A. Mane (SAED)

The only mechanical harvesting option available to farmers in the Senegal River Basin is large imported combine harvesters (4.5 m harvest width, US$80 000 new). These machines are inappropriate for the region because of high initial investment costs, difficulty in maintenance, and the inability to work in soft field conditions. Frequent breakdowns lead to excessive harvest delays.

An alternative to the combine harvester, the stripper-gatherer/thresher-cleaner (SG-TC) system developed by the International Rice Research Institute (IRRI), was discussed during a four-day seminar organized by WARDA's Sahel Program in Ndiaye, Senegal in late November 1995. The SG-TC system has been adopted by farmers in the Philippines, where it costs US$3000 and can harvest about one hectare per day with eight workers. The system was tested in Senegalese farmers' fields after the seminar under the guidance of Dr. B. Douthwaite from IRRI.

Results of the field tests in the Senegal River Delta (Photograph, Table 30) confirmed that harvesting one hectare in a day using the Stripper-Gatherer and four operators (two drivers and two carriers for the containers) is possible. The performance of the Thresher-Cleaner was excellent for Stripper-Gatherer-harvested paddy, but less good in the case of manual harvesting. A second test focused on differences between manual harvesting and SG-TC harvesting. Losses were 7.3% and 1.4%, respectively. The overall conclusion was that the equipment had a lot of potential but local adaptation was needed, in particular, making the machines stronger.

A memorandum of agreement was signed among WARDA, the Institut sénégalais de recherches agricoles (ISRA) and the Société nationale d'aménagement et d'exploitation des terres du delta du fleuve Sénégal (SAED) on 5 December 1995, stating the responsibilities of each organization in research and evaluation of the technology. Further field tests with SG-TC prototypes, manufactured locally, will be conducted in 1996. It is hoped that ultimate commercialization of the technology can help Senegalese farmers harvest on time and thus reduce very high post-production losses.

Table 30: Field test results for the SG800-TC600 harvesting system, Senegal River Delta, Senegal (wet season, 1995).

	Stripper-Gatherer	**Thresher-Cleaner**
Performance:	6 hours 45 minutes ha^{-1}	(manual harvest): 430 kg hour^{-1} (SG harvest): 1.1 t hour^{-1}
Fuel:	325 cc hour^{-1}	350 cc hour^{-1}
Speed:	1.1 km hour^{-1}	–
Losses:	102 kg ha^{-1}1 (< 2%)	negligible
Operators:	four	four

Site: Thiagar; surface field: 3000 m^2; variety: Sahel 108, direct seeded; yield: 6 t ha^{-1}; field conditions: muddy.

Materials and method

A field test was conducted using two Philippine-manufactured SG-TC systems (Mark I version) in a farmer's field in the Senegal River Delta during December 1995.

Testing the IRRI designed SG800 stripper-harvester in the Senegal River Delta, Senegal

Effects of puddling on soil desalinization and rice growth

S. Häfele, M.C.S. Wopereis, J.P. Ndiaye (ISRA) and M. Ndiaye

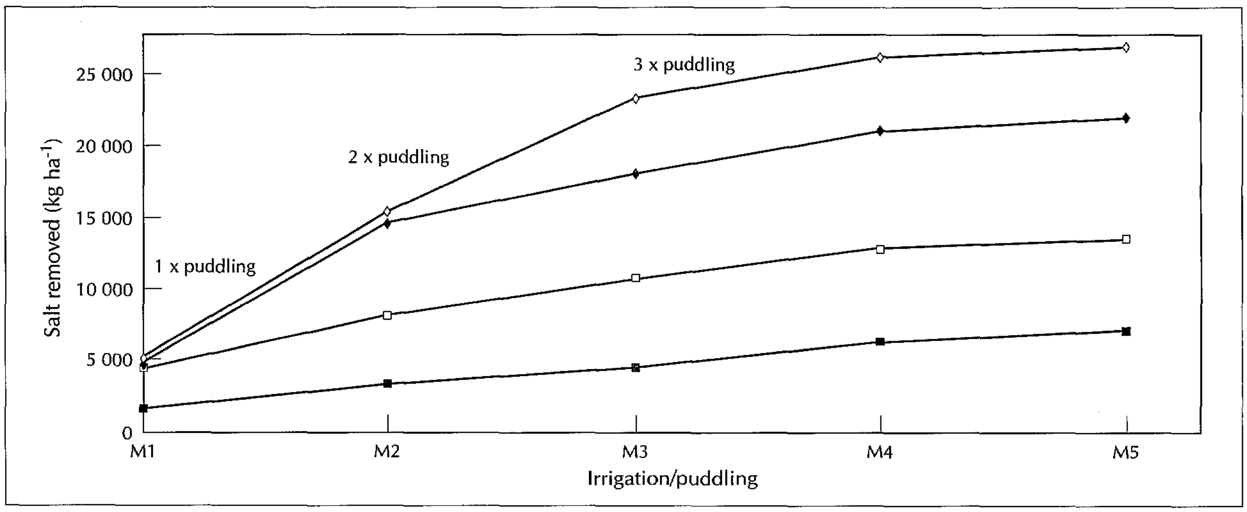
Soil salinity is a common problem in arid and semi-arid environments. In the Senegal River Delta, rice fields without adequate surface water drainage facilities are often abandoned after a few years because of a buildup of salt in the root zone. Rehabilitation of these abandoned soils is usually not undertaken because of excessive water needs. The efficiency of surface water flushings might be improved by the introduction of soil puddling (plowing and harrowing of soil under water-saturated soil conditions). In contrast to Asia, this tillage technique is not widely practised in Sahelian West Africa.

The potential of soil puddling using an IRRI hydro-tiller as a means of rehabilitating saline soils was tested at an extremely saline site in the Senegal River Delta.

Repetitive puddling and surface water drainage in an extremely saline field was very effective in removing salt from the soil profile (Figure 48). Puddling, followed by surface drainage removed about 5 t salt ha^{-1}, as opposed to approximately 1 t salt ha^{-1} per flushing in the dry tilled plots. Flushings following drainage after the last puddling in treatments T2, T3 and T4 did not remove more salt than the irrigation/drainage cycles in the non-puddled fields (Figure 48). Depth of the puddled layer increased after each puddling, and new salt from the subsoil was, therefore, brought in solution. Average depth for T2, T3 and T4 was 12, 22 and 31 cm, respectively. Most salt was removed in case of three puddlings with the hydrotiller. However, the establishment of rice seedlings was poor in the plots with two and three puddlings (data not shown). The best establishment was achieved in the plots without puddling and with only one puddling.

Results can be explained by the destruction of the soil structure through puddling, which brought essentially all soluble salts in the topsoil in solution. In the non-puddled plots, diffusion of salt from the saline soil aggregates to the soil solution was relatively slow. An increased number of irrigation and drainage cycles after puddling will reduce salinity levels in the soil solution to a level that can be tolerated by the rice plant. Another possibility may be to start rice cropping after re-establishment of the soil structure only (i.e. after drying of the topsoil).

Figure 48: Amount of salt drained from experimental plots, Ndiol, Senegal.



Materials and method

The field experiment was conducted in Ndiol, a coastal arid village in the Senegal River Delta (16°14'N, 16°14'W). The study site has been abandoned for rice cropping for salinity reasons. Topography is flat. Soil type is salic fluvisol (FAO soil classification; local name Hollaldé). Twelve subplots of 5 x 10 m were constructed in three rows of four plots, separated by bunds.

Salt removal using conventional dry soil-tillage and five irrigation and drainage cycles was compared with wet tillage (1, 2 or 3 times puddling) using an IRRI-designed HT-1 hydro-tiller and five irrigation and drainage cycles. A complete salt and water balance was established for each plot. To test the effect of the different treatments on plant growth, two rice cultivars (IR 28 and IKP) were grown in each plot under both transplanted and direct-seeded conditions.

Farmers' fertilizer strategies and corresponding yields: an example from the Senegal River Delta

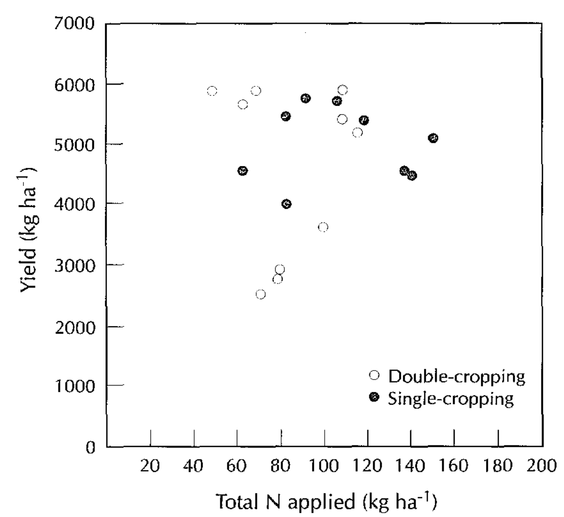
M.C.S. Wopereis, S. Diack and J.B. Sène

The blanket fertilizer recommendation for rice in Senegal is 120 kg N, 60 kg K, and 60 kg P ha^{-1}, regardless of growing season, soil type, and rice variety grown. More specific recommendations, tailored to local biophysical and socio-economic settings, are likely to increase fertilizer input use efficiency and yields.

A survey was conducted to see if farmers stick to the blanket recommendation, to find out if there was a relation between yield and total amount of fertilizer applied in farmers' fields, and to determine the yield gap between potential yield and farmers' yields, due to poor soil nutrient management. The study was conducted in a formerly parastatal irrigation scheme in the Senegal River Delta, where farmers now work in cooperatives. In each farmers' field, a small 10 x 10 m area was separated from the main field by bunds. Farmers were asked not to apply fertilizers in these mini-plots (T0). Crop growth and nutrient uptake (N, P, K) were measured in each mini-plot (T0) and main field (TP).

T0 yields were in the range of 2-3.5 t ha^{-1}. TP yields varied from 3-5 t ha^{-1}. Almost none of the 22 farmers included in this study applied fertilizer in the same way. No relation was found between yield and total amount of N fertilizer input (Figure 49), clearly illustrating the need for improved soil nutrient management. An adjacent, researcher-managed, controlled experiment yielded 8.4 t ha^{-1}, indicating a yield gap varying from 3-5 t ha^{-1}. In 1996, analysis of nutrient uptake by the rice plants sampled at maturity will give an insight into the magnitude and variability of fertilizer recovery and soil nutrient supplying capacity. Socio-economic constraints to crop and resource management practices of farmers will be analyzed as well. Similar trials are on-going in Mali (Office du Niger) and Burkina Faso (Kou Valley). They are expected to give insight in how fertilizer use efficiency in irrigated rice-based systems in the Sahel can be improved.

Figure 49: Yields versus total N applied in farmers' fields.



Materials and method

The study was conducted in the irrigation scheme of Thiagar in the Senegal River Delta in the 1995 wet season. A distinction was made between farmers who cultivate one rice crop per year (single-cropping site) and farmers who cultivate two rice crops per year (double-cropping site). In each farmer's field, a 10 x 10 m area at the irrigation canal side was separated from the main field by bunds. Farmers were asked not to apply fertilizer in these mini-plots (T0). Crop growth and nutrient uptake were measured in each mini-plot (T0) and main field (TP).

A researcher-managed field trial was conducted at both single- and double-cropping sites using two varieties (Sahel 108 and Jaya), and varying strategies of fertilizer application (highest total N application: 180 kg ha^{-1}).

Rice science training and communications

A. Youdeowei

Highlights of WARDA's training and communications activities in 1995 were: completing the United Nations Development Programme (UNDP)-supported communications and training project RAF/89/055; initiating integration of some training activities with core research activities; and, publicizing WARDA's advances in research.

In February, the UNDP organized an end-of-project mission to WARDA and selected WARDA member countries to evaluate the communications and training project it had supported since 1990. Following a positive evaluation, a tripartite review was hosted by the UNDP at its regional office in Abidjan to consider the report and to make recommendations for a new project, and for a donors meeting to support the new project. Residual project activities, mainly the preparation and publication of training manuals and guides, were continued.

Integrating training with core research activities was initiated through intensive consultations between the WARDA training and communications division and the research Task Forces. These consultations have resulted in a consolidated list of group training courses aimed at developing capacities of our national program partners in rice research and technology transfer. WARDA's future group training program will be developed from this list of courses.

In collaboration with the Food and Agriculture Organization of the United Nations (FAO) and the Ministries of Agriculture of Ghana, Côte d'Ivoire and Burkina Faso, the division contributed to a pilot FAO technical cooperation program project on season-long farmer participatory rice integrated pest management (IPM) training program in Ghana. With technical and financial assistance from the FAO, the objective of this project was to introduce the highly successful farmer participatory IPM training methodology developed by the FAO inter-country program for rice IPM in southeast Asia into Africa and to make rice farmers IPM experts. Season-long training of selected agricultural extension agents in training of trainers (TOT) training, and rice farmers in farmers' field schools (FFS) was successfully conducted at the Dawhenya irrigated rice scheme near Tema, Ghana.

The success of the Dawhenya training showed that the farmer participatory training methodology was applicable to West African rice farming systems and could be accepted and adopted by rice farmers. It also provided an opportunity for WARDA's training and research staff to work directly with national agricultural extension workers and rice farmers in the field.

We also concluded arrangements for similar TOT and FFS training at Sakassou in Côte d'Ivoire and at the Vallée du Kou in Burkina Faso, starting in 1996.

A major public awareness program of activities to publicize WARDA's research was launched through the production of a series of popular publications and articles targeted to WARDA's donors and the general public. This was supplemented with WARDA's active participation in CGIAR public awareness activities, and in international, regional and national exhibitions and fairs.

The division continued to play a significant role in the Consultative Group on International Agricultural Research (CGIAR) inter-center training program initiative. In addition to consolidating our efforts in organizing group training courses with other CGIAR centers, we hosted the i -center training group meeting in November 1995.

Our library and documentation center provided up-to-date rice science literature to researchers, fulfilling its mandate as a technical research support service. Requests for document delivery and literature search services increased dramatically during the year. With support from the Technical Centre for Agricultural and Rural Cooperation (CTA), which has its headquarters in the Netherlands, we intensified training for national agricultural research systems (NARS) librarians and documentalists, in order to build capacities in providing literature services to NARS researchers. The library and documentation center is now recognized as the major rice science literature service center in sub-Saharan Africa.

Training in agricultural information management

A. Diallo and A. Youdeowei

There are many constraints to effective agricultural information dissemination in WARDA member countries that continue to impede rapid progress in agricultural and rural development in the region.

Information services (libraries, and documentation centers and services) are inadequately staffed, funded, and managed, and access to international databases and current literature severely limited. Librarians and documentalists need to be trained in the basic elements of and procedures for agricultural information management. In many cases, modern information management and dissemination systems using new technologies have either not been introduced, or introduced in spite of a shortage of trained computer-literate and specialized personnel. Another serious problem is the absence of an enabling environment within which effective agricultural information systems can be built and sustained.

It is within this framework that WARDA established in 1991 an integrated West Africa Rice Information System (WARIS). Since WARIS became operational, demand for information from scientists as well as requests for training of national agricultural research system (NARS) librarians and documentalists has increased beyond expectations.

The establishment and strengthening of WARIS at WARDA has been supported by the Technical Centre for Agricultural and Rural Cooperation (CTA) based in the Netherlands, and the International Development Research Centre (IDRC) in Canada.

Since WARIS became operational, demand for information services has expanded well beyond projections in terms of:

- the number of scientists making requests for information services;
- the diversity of information demands covering all aspects of agricultural research; and,
- increasing requests from all over sub-Saharan Africa for training at WARDA of NARS librarians and documentalists on agricultural information management.

With the development of modern agricultural information facilities at WARDA's library and documentation center, considerable potential exists for WARDA to design, organize and manage individual and regional group training in agricultural information management and the use of new information technologies.

WARDA has, in the past, organized such regional training courses and is offering an increasing number of short-term on-the-job training programs to upgrade the skills of NARS information staff.

WARDA's training program in rice science information management

The global objective of WARDA's training program in rice science information management is to strengthen the capacity of staff in charge of NARS rice information services to manage more effectively agricultural, particularly rice, information.

The specific objectives of the training program are:

- to build national capacities in procedures for the organization and management of agricultural information;
- to facilitate access to and dissemination of agricultural technologies through strengthening the capabilities of NARS information personnel in managing agricultural information services;
- to develop the "computer and new technologies culture" of NARS agricultural information personnel; and,
- to promote the dissemination of agricultural information in West Africa through the organization of group training courses focusing on the use of new information technologies.

The ultimate goal of this training is to increase the flow of relevant rice information in member countries through good control and efficient management of locally generated information, access to international literature, and effective participation in international agricultural information networks.

The training subjects covered are:

- organization and management of a rice/agricultural library/documentation center;
- design and management of bibliographic and factual databases;
- bibliographic and factual database management software programs with emphasis on Mini-Micro CDS/ISIS et Heurisko;
- information retrieval: principles and software programs;
- design of reference materials: bibliographies, directories, operations manuals, guides; and,

- setting-up and configuring an information-processing dedicated computer workstation (CD-ROM drives, software programs, other peripheral devices).

Individual training

Individual training addresses the specific needs of NARS staff working in rice information services in order to upgrade their skills and enhance their familiarity with modern information management methods and technologies.

Individual training is organized upon request in the following formats:

- from one week up to two months on-the-job training program; and,
- follow-up missions and on-the-spot training for former trainees.

The purpose of the follow-up missions to the institutions of staff trained at WARDA headquarters is to help solve any problems encountered after the training program has taken place; to design, adopt or adapt more efficient library management and organization procedures; and, to install hardware and software for database management and CD-ROM stations.

For scientists in general, and more particularly for those enrolled in a Master or PhD program, there exists an initiation to information retrieval; use of databases and personal bibliographic software such as Pro-Cite and EndNote Plus to organize references and build bibliographies; and, orientation to information sources and services.

Group technical training

In order to respond to the increasing demand for training from both NARS and regional organizations, WARDA, working in close collaboration with CTA, has started the design of short-term group training courses in agricultural information management for librarians and documentalists in West Africa as well as sub-Saharan Africa.

Regional group training courses are organized jointly by WARDA and CTA at WARDA's library and documentation center at M'bé, near Bouaké, Côte d'Ivoire, and at other locations within the region. On request, in-country specific training courses can also be organized.

Lectures on information, database and bibliographical references management are also delivered and practicals organized for inclusion in other WARDA group training courses.

Prospects for future training in agricultural information management

The objective of WARDA's library and documentation center is to ensure that rice science researchers can gain access to up-to-date information relevant to their work, by means of appropriate retrieval and dissemination services. Adequate facilities need to be put in place and mechanisms developed in the short- and medium-term at WARDA and at NARS so that relevant information on rice is easily available to rice scientists in West Africa. This will be achieved when all the links of the information processing and dissemination chain are managed by highly skilled staff. Gradually, WARDA's role will shift from being an agricultural information management provider, to being a facilitator and coordinator. The WARDA library and documentation center is preparing for this shift by putting more emphasis, and most of its resources, into capacity-building through training both at WARDA and in WARDA member states, and through follow-up, consultative and advisory missions. These activities will be undertaken in collaboration with other regional organizations and within the context of the CGIAR inter-center training program (ICTP).

CTA and the Economic Community of West African States (ECOWAS) have established a project to study the agricultural information needs of the countries of West Africa and to create an integrated information program for agricultural development in West Africa.

WARDA has been identified as the leading institution ECOWAS will rely upon to coordinate and implement its integrated information program for agricultural development in West Africa. The project has been submitted for funding to the European Union. WARDA is also in charge of Project 1: Training of researchers in agricultural communication, and Project 4: Establishment of an integrated agricultural information program. Project 1 aims at promoting the effective communication of agricultural research results and the dissemination of new technologies in order to promote agricultural development. Project 4 was identified to enhance the local production, processing and dissemination of information, and the development of information management capacities.

The strategy to be adopted for the implementation of Project 1 will involve individual training in special techniques, group training, and thematic seminars to increase the communication capabilities of national agricultural research systems. It is expected that about 750 scientists and technicians will be trained over five years.

Project 4 is an attempt to establish and maintain an integrated information system for agricultural research, training, and extension for West Africa. Capacity-building through training and retraining will constitute one of its pillars.

Rice science training and communications activities

A. Youdeowei, A. Diallo and C. Diop

The last UNDP-supported group training course on Sahel irrigated rice production was organized at WARDA's Sahel irrigated rice program in St-Louis, Senegal. Other group training courses organized during the year were collaborative group training activities involving other CGIAR centers and CTA.

Evaluation of the WARDA communications and training project RAF/89/055 In February 1995, UNDP consultants completed an in-depth end-of-project evaluation of the Communications and Training project which WARDA had been implementing since 1990. The review report commended WARDA for outstanding achievements in the implementation of the project, noting that all the objectives were met and expected results obtained, even surpassed, in spite of changes in the project environment.

There were measurable improvements in the performance of scientists and technicians, as acknowledged by the trainees themselves, as well as their superiors. The institutional impact was observed in NARS through improvement in scientific outputs, as well as stronger documentation and information services.

The evaluation mission also cited the positive impact of the training on women, especially in Nigeria and Benin. In Ghana, the success of the training had a multiplying effect, encouraging the transfer of acquired knowledge and skills to the target group, smallholder rice farmers who are women.

The mission made 14 recommendations, including the need for the UNDP to support a new project and for a roundtable discussion with potential donors to fund the new project.

Group training courses for 1995

Sahel irrigated rice production Working with WARDA scientists in the Sahel irrigated rice program, the detailed curriculum for this course was designed in 1994. It focused attention on the descriptions of the major biotic and socio-economic constraints in irrigated rice production in the Sahelian environment and their methods of management.The use of systems analysis and simulation modeling to facilitate the characterization of climatic constraints, cropping calendars, and rice yields in the Sahel was also covered.

The 25 training participants came from Senegal, Cameroon, Mali, Mauritania, Burkina Faso, Chad, Niger, Nigeria, Ghana and the Gambia. Resource persons included WARDA research scientists in the Sahel as well as specialists from the Institut sénégalais de recherches agricoles (ISRA) and the Société nationale d'aménagement et d'exploitation des terres du delta du fleuve Sénégal et des vallées du fleuve Sénégal et de la Falémé (SAED) who are working in the Sahel. Birane Kane of SAED served as the technical coordinator. The course was delivered in French and English.

Writing and production of agricultural extension materials Agricultural extension materials are useful instruments for the transfer of technology from research to farmers. The expert panel which met in Ouagadougou, Burkina Faso in 1991 to design a program for strengthening agricultural communication in West Africa, developed details for a group training course in the writing and production of agricultural extension materials. In collaboration with and with support from CTA, and the agricultural extension services of the Ministry of Food and Agriculture in Ghana, this course was held at the Sasakawa Center in the University of Cape Coast, Ghana, in October 1995.

"The course fine-tuned my skills and knowledge on writing and production of agricultural extension materials. The knowledge and skills I have acquired will be used to improve the production of simple and meaningful extension materials for frontline staff and farmers to enhance their performance."
Nancy Amponsah Mensah, Ghana

The participants, 15 in all, were selected from the national agricultural extension services of the Gambia, Ghana, Nigeria, and Sierra Leone. Resource persons were: Joseph Kwarteng, Director of the Sasakawa Center, Ghana; Tunji Arokoyo, Institute of Agricultural Research, Ahmadu Bello University, Nigeria; Edward Ntifo-Siaw and Joseph Amarteh, University of Cape Coast, Ghana; Joy Mukanyange, CTA, the Netherlands; and, Anthony Youdeowei, WARDA, Côte d'Ivoire. Marcus Hakutangwi, of the Zimbabwean Ministry of Agriculture's extension service, also participated, in order to initiate planning for a similar course in Zimbabwe in 1996.

The course featured extensive practical exercises to produce a variety of extension materials such as leaflets, posters, flipcharts, simple folders and a newsletter. Before finalizing these materials trainees field-tested them with field extension agents and farmers for acceptability.

Trainees from the "Writing and production of agricultural extension materials" course evaluating an extension folder with a local farmer, Cape Coast, Ghana

Trainees practised how to brief and work with artists, and how to take and process photographs. The participants' course evaluation recommended that similar courses should be organized to include participants from all over Africa.

Scientific writing for agricultural research scientists In the context of the on-going collaboration between CTA and the CGIAR centers ICRAF and IPGRI, two group training courses in scientific writing for agricultural research scientists were organized in 1995.

The first course was organized by ICRAF in the context of their SALWA network, in Bamako, Mali. It was held in French. WARDA provided resource persons Blanche Kiniffo and Alassane Diallo. The 12 participants came from Burkina Faso, Mali, Niger and Senegal.

"The "do's" and "don'ts" in every section of a scientific paper were well demonstrated."
James Kombiok, Ghana

The second course, given in English to 18 participants from Ghana, the Gambia, Nigeria, Sierra Leone and Côte d'Ivoire, was held at the École nationale supérieure agronomique (ENSA) in Yamoussoukro, Côte d'Ivoire. Financial support for this course was provided by CTA and by the CGIAR. Resource persons were Anthony Youdeowei, Alassane Diallo and Abdoulaye Adam from WARDA; Paul Stapleton from IPGRI, Rome; and, Helen van Houten from ICRAF, Nairobi.

"During this course,I was able to learn many things which, I am convinced, are going to improve my ability to write and edit scientific papers. I believe that this course has given me more confidence and increased my interest to write papers for publication."
Peter T. J. Alpha, Sierra Leone

Trainees stated their expectations from the course as follows:

- to gain and improve skills in scientific writing for publication;
- to learn how to write research grant proposals effectively; and,
- to improve skills in the oral communication of research findings.

The course was strongly interactive, and included detailed review and critiques of draft manuscripts by trainees, critiques of published papers, planning and production of scientific posters, and video-recordings of oral presentations of research results for participants to self-evaluate.

Selective Dissemination of Information (SDI) service Working with CTA, a 3-week group training course on SDI service was organized at WARDA's Training Center at M'bé in Côte d'Ivoire. This course is part of the WARDA/CTA joint program for strengthening documentation services in the NARS of sub-Saharan Africa. The 13 participants came from Benin, Gabon, Guinea, Niger, Senegal, Chad, Togo and Côte d'Ivoire. The resource persons were Marie Jose-Gehl from CTA; Aline Vidal-Lisette, a consultant from Côte d'Ivoire; Alassane Diallo, the WARDA documentalist; and, Alioune Thioune, head of computing services at the central library of the Cheikh Anta Diop University in Senegal.

Trainees interacted with rice research scientists selected from WARDA and from the Institut des Savanes (IDESSA), Côte d'Ivoire, to develop their research information profiles.

Farmer participatory rice integrated pest management (IPM) training In 1995, the FAO approved three national projects on farmer participatory season-long rice IPM training for Ghana, Côte d'Ivoire and Burkina Faso. The main objective of this project is to introduce the farmer participatory season-long rice IPM training methodology, which was successfully developed and promoted by the FAO Inter-country IPM program in southeast Asia, into Africa, in order to empower African smallholder rice farmers to become IPM experts. With technical and financial support from the FAO this program was started in Ghana from June to October 1995 at the Dawhenya irrigated rice scheme where training of trainers (TOT) and farmers' field schools (FFS) were established. WARDA provided technical support by six WARDA scientists who visited the site, while the training unit was assigned the task of documenting the training process, preparing rice IPM field guides relevant to West Africa, as well as developing a training of trainers manual. WARDA collaborated closely with the FAO and the Ghanaian Ministry of Food and Agriculture's agricultural extension services. Twenty-eight extension workers participated in the TOT training while 75 smallholder rice farmers were involved in the FFS training.

The Dawhenya training was highly successful and demonstrated that the season-long rice IPM training methodology is applicable and acceptable to West African rice farmers. The net returns in rice yields from farmer field schools were 32% higher in IPM practice plots than from farmer practice plots. This FAO/WARDA national collaborative effort provided WARDA an excellent opportunity to work with national agricultural extension systems and with rice farmers.

Training of trainers participants at the rice integrated pest management (IPM) course, Dawhenya, Ghana

Inter-Center Training Group activities

Agricultural research management training course The second in the series of collaborative training courses in agricultural research management for NARS scientists was held at the ICRISAT Sahelian Center Training and Visitors Center in Niamey, Niger, in November 1995. This follows a previous collaborative group training course program, initiated in 1994 with a course held at the Agricultural and Rural Management Institute (ARMTI) in Ilorin, Nigeria. The second course was a collaborative effort organized in the context of the CGIAR system-wide Inter-Center Training Group activity involving WARDA, ISNAR, IITA and ICRISAT. Seventeen participants from Benin, Cameroon, Mali, Niger, Chad, Togo, Zaire, as well as one from WARDA took this course, which was taught in French. Its main objectives were to improve the ability of participants to plan and organize agricultural research programs; to develop, motivate and lead research activities; to monitor and evaluate research; to manage human and financial resources for research; to develop and use linkages which ensure that research results benefit the end users; and, to manage up-to-date information technology.

The third in the series of courses, scheduled for November 1996, will be co-hosted by WARDA and IDESSA at WARDA's Training Center at M'bé, near Bouaké, Côte d'Ivoire.

Inter-Center Training Group meeting WARDA hosted the 1995 annual meeting of the Inter-Center Training Group in November. Fifteen participants representing ten CGIAR centers attended, as well as — for the first time — four representatives from the NARS of Kenya, Nigeria, Zambia and Côte d'Ivoire. The group reviewed progress in the following activities assigned to centers in 1994. These included:

- training needs assessment;
- training database for sub-Saharan Africa;
- database on training materials;
- devolution of training; and,
- survey of training capacities in NARS.

The group also discussed the major elements of an inter-center collaborative training proposal being prepared for submission to the European Union for funding, and planned activities for 1996 and 1997. WARDA was appointed the co-ordinating center for ICTG activities for 1996.

COMMUNICATIONS ACTIVITIES

Publications

Because our publications unit facilities remain weak, we continued to rely on contracting freelance science editors and designers for production of our publications.

The publications which were produced and distributed during the year are given below.

WARDA Annual Report 1994

Advances in Rice Research: Crossing African and Asian Rice varieties

WARDA Reprints Series numbers 15-19

Current Contents at WARDA (monthly)

Integrated pest management posters:

- Training of Trainers for rice integrated pest management
- Farmers' Field Schools for rice integrated pest management

WARDA in Perspective

WARDA training guides:

1. Sampling and preservation of rice insects
2. The rice plant and its environment
3. Survey and development of uplands for rice production
4. Survey and development of lowlands for rice production

Development of Training Materials in Agriculture

Scientific writing for agricultural research scientists: A training reference manual

Partners in Development:
- WARDA and Japan
- WARDA and CTA

Translation and interpretation services

The dramatic increase in research program activities at WARDA has resulted in greater demand for translation and interpretation services. A wider variety of documents were translated, including reports on research activities of the research Task Forces, reports for the Inland Valley Consortium and the Health Consortium project. There has also been a corresponding increase in the volume of technical meetings and, therefore, demand for simultaneous interpretation services.

During the year we strengthened our capacity through the purchase of dictaphones and portable public address systems for interpretation during field visits, and a dual-deck recording system for meetings.

Public awareness

A major public awareness effort to publicize WARDA's work was initiated during the year, through the production and widescale distribution of popular publications on WARDA's work, and through participation in regional and international meetings where WARDA mounted exhibits on its research, training and communications activities. Publications, pictures and specimens of rice varieties developed at WARDA were exhibited at the CGIAR Lucerne meeting in Switzerland; at the FAO 50th anniversary in Quebec, Canada; and, at the Rice Festival in Montpellier, France. The brochure *WARDA in Perspective* was widely distributed at the African Agricultural Festival held in Accra, Ghana.

These efforts gave considerable regional and international publicity to WARDA and to CGIAR contributions to agricultural development in the sub-region.

Library and documentation center

The implementation of the West Africa Rice Information System (WARIS) project has resulted in upgraded rice library and documentation collections, and improved and expanded information services for the benefit of WARDA and its NARS scientists. During the year, WARDA library and documentation staff responded to increasing requests for literature and information from the rice scientists community.

New literature — 631 books, 431 annual reports, 729 catalogs and pamphlets, 1510 reprints and photocopies, and 1380 miscellaneous and grey literature — was added to the collections. The library subscribed to Current Contents on CD-ROM (agriculture, biology and environmental sciences with abstracts), updated weekly, with one CD-ROM for the previous year.

Due to the growing interest expressed by rice researchers in WARDA member states, distribution of the Current Contents at WARDA increased from 200 copies in January to 220 copies in August, generating a demand for 53 476 photocopied pages of articles and book chapters.

Development and updating of bibliographical databases was vigorously pursued and the main database WARBI now holds 14 400 records. A new database covering rice terminology, VOCAB, was designed and established, mainly for translation purposes and the publication of a new edition of the bilingual (English and French) Rice Vocabulary, first published by WARDA in 1975. Assistance was provided in January to the Compagnie ivoirienne pour le développement des fibres textiles (CIDT), Bouaké, Côte d'Ivoire to computerize its documentation center. Individualized on-the-job training program on the use of CD-ROM databases was offered in October to a staff member from the FAO regional office in Abidjan, Côte d'Ivoire.

West Africa Rice Development Association

Statement of financial position for the year ended December 31, 1995 (in US dollars)

ASSETS	1995	1994
Current assets		
Cash and cash equivalents	930 792	1 073 994
Accounts receivable:		
Donors	1 592 487	1 756 558
Employees	255 741	279 490
Others	1 282 079	746 041
Inventories	602 772	684 391
Prepaid expenses	198 166	216 418
Other current assets	324 359	—
Total current assets	5 186 396	4 756 892
Fixed assets		
Property, plant and equipment	15 753 441	14 509 084
Less accumulated depreciation	(2 905 083)	(2 283 224)
Total fixed assets – net	12 848 358	12 225 860
TOTAL ASSETS	**18 034 754**	**16 982 752**
LIABILITIES		
Current liabilities		
Accounts payable:		
Donors	1 873 144	2 516 744
Employees	115 109	66 243
Others	2 159 574	2 034 827
Accruals and provisions	556 634	462 967
Total current liabilities	4 704 461	5 080 781
Long-term liabilities	—	—
TOTAL LIABILITIES	**4 704 461**	**5 080 781**
NET ASSETS		
Captial invested in fixed assets:		
Centre owned	12 848 358	12 225 860
In custody	—	—
Capital fund	(68 187)	(1 636 637)
Operating funds	550 122	1 312 748
Total net assets	13 330 293	11 901 971
TOTAL LIABILITIES AND NET ASSETS	**18 034 754**	**16 982 752**

West Africa Rice Development Association

Statement of activities by funding for the year ended 31 December 1995 (in US dollars)

	Unrestriced research agenda	Restricted research agenda	Complementary agenda	Total 1995	Total 1994
Revenue					
Grants	4 434 419	3 137 970	889 783	8 462 172	6 760 240
Member state contributions	—	—	—	—	64 045
Other revenues	93 677	—	—	93 677	36 541
Total revenue	**4 528 096**	**3 137 970**	**889 783**	**8 555 849**	**6 860 826**
Operating expenses					
Research programs	2 386 523	2 666 578	834 442	5 887 543	4 518 209
Training and communications	589 051	236 308	—	825 359	1 047 523
Administration and general operations	1 874 819	—	—	1 874 819	1 437 608
Depreciation	621 859	—	—	621 859	535 180
Gross operating expenses	5 472 252	2 902 886	834 442	9 209 580	7 538 520
Recovery of indirect charges	(181 530)	—	—	(181 530)	(205 847)
Net operating expenses	5 290 722	2 902 886	834 442	9 028 050	7 332 673
Excess/(deficit) of revenue over expenses	(762 626)	235 084	55 341	(472 201)	(471 847)
Allocated as follows:					
Operating fund	762 626	—	—	762 626	471 847
Capital fund	—	(235 084)	(55 341)	(290 425)	—

	Unrestriced research agenda	Restricted research agenda	Complementary agenda	Total 1995	Total 1994
Operating expenses by natural classification					
Personnel costs	2 899 626	1 277 377	408 838	4 585 841	3 372 537
Supplies and services	1 575 729	1 343 416	355 216	3 274 361	3 132 135
Travel	375 038	282 093	70 387	727 518	498 668
Depreciation	621 859	—	—	621 859	535 180
Total	**5 472 252**	**2 902 886**	**834 441**	**9 209 579**	**7 538 520**

West Africa Rice Development Association

Grants and contributions for the year ended 31 December 1995 (in US dollars)

Unrestricted research agenda	**1995**	**1994**
Canada (CIDA)	485 317	507 246
France	72 883	195 960
Germany (BMZ/GTZ)	417 797	367 102
Japan	1 179 033	1 416 328
Korea	50 000	50 000
The Netherlands	312 110	270 438
Norway	201 518	—
Spain	25 000	—
Sweden	505 393	467 221
United Kingdom (ODA)	175 368	172 057
United States (USAID)	200 000	50 000
World Bank	810 000	—
Subtotal	4 434 419	3 496 353
Restricted research agenda		
African Development Bank (Institutional support)	757 606	838 072
African Development Bank (Integrated pest management)		126 051
Canada (IDRC) Small grants project	18 207	44 850
Canada (IDRC) (West Africa Rice Information System project)		112 313
European Union (Crop and resource management)	614 639	562 001
France (Agro-physiology project)	94 106	12 134
Germany (BMZ/GTZ) (temperature, stress project)	545 162	282 655
Germany (BMZ/GTZ) (salinity project)	69 886	73 323
Japan (Grain quality studies)	63 080	36 178
Rockefeller Foundation (Anther culture project)	62 210	31 980
UNDP (Training and communications)	236 308	445 204
United Kingdom (ODA/NRI) Weeds project	50 946	35 108
United Kingdom (ODA) INGER project	166 805	55 197
United States (USAID) Rice network project	459 016	366 315
Subtotal	3 137 970	3 021 381
Total research agenda grants	**7 572 389**	**6 517 734**
Complementary		
Norway (Vector-borne diseases project)	21 599	—
Denmark (Vector-borne diseases project)	37 183	—
Canada (IDRC) (Vector-borne diseases project)	151 090	22 129
The Netherlands (Inland Valley Consortium project)	537 145	173 556
France (Inland Valley Consortium project)	13 342	—
Germany (GTZ) (Pesticides project)	16 469	—
Germany (GTZ) (Soil nitrogen project)	41 748	—
United Kingdom (ODA/NRI) Nematology project	34 743	7 807
United Kingdom (ODA/NRI) Weed/insect interaction project	11 105	17 667
United Kingdom (ODA/CABI) Rice gall midge project	25 359	21 347
Total complementary grants	**889 783**	**242 506**

WARDA 1995 Board of Trustees

WARDA senior staff and associates

(All positions located at Headquarters and Main Research Center in M'bé near Bouaké, Côte d'Ivoire, unless otherwise noted.)

Director General	Eugene R. Terry
Head of Finance and Personnel Services	Kwame Akuffo-Akoto
Head of Administration and Support Services	Robert Lemp
Head of Farm Management and Engineering Services	Chitti Babu Buyyala
Internal Auditor	Clement Babalola
Director of Research	Peter Matlon
Continuum program leader	Michael Dingkuhn
Agricultural economist	Akin Adesina (left in 1995)
Agronomist	Mathias Becker
Entomologist	Elvis Heinrichs
Hydrologist	Nick van de Giesen
INGER-Africa coordinator	Robert Guei
Lowland rice breeder (Ibadan, Nigeria)	B.N. Singh
Pathologist	Abdoul Aziz Sy
Policy economist	Thomas Randolph
Soil scientist	Kanwar Sahrawat
Statistician	Abdoulaye Adam
Upland rice breeder	Monty Jones
Sahel irrigated rice progam leader (St-Louis, Senegal)	Kouamé Miezan
Agronomist (St-Louis, Senegal)	Marco Wopereis
Collaborating and project scientists	
Entomologist (Ibadan, Nigeria)	Charles Williams (CABI-IIBC)
Human health project coordinator	Thomas Teuscher
Inland Valley Consortium coordinator	Jean-Yves Jamin (CIRAD)
Inland Valley Consortium research coordinator	Pieter Windmeijer (SC-DLO)
Nematologist	Danny Coyne (NRI)
Physiologist	Alain Audebert (CIRAD)
Weed Scientist	David Johnson (NRI)
Director of Training and Communications	Anthony Youdeowei
Documentalist	Alassane Diallo

African Development Bank research fellows in 1995

Country and name; Degree; Institution; Discipline; Supervisor(s); and Research topic

Burkina Faso

Moussa Sié — PhD, University of Montpellier, France; Plant breeding/Physiology; K.Miezan, M.C.S. Wopereis and Michael Dingkuhn; *The use of thermal constants as selection criteria for rice varieties adapted to irragated rice cultivation in the Sahel*

Séré Yacouba — PhD, University of Paris X (Orsay), France; Pathology; A.A. Sy; *The bio-ecology of vectors of rice blast in Burkina Faso*

Cameroon

Georges Dimithe — Michigan State University, USA; Economics; A. Adesina and T.F. Randolph; *An economic analysis of rice production competitiveness: the case of lowland rice in Mali*

Chad

Koupeur Tarhondé — Doctorat 3e cycle, University of Abidjan, Côte d'Ivoire; Plant Genetics; M.P. Jones; *The response of improved rainfed rice varieties to different levels of management inputs*

Côte d'Ivoire

Namizata Fofana — Doctorat 3e cycle, University of Abidjan, Côte d'Ivoire; Agro-economics; A. Adesina; *The role of women in intensified rice production in Côte d'Ivoire*

Dobo Macaire — Doctorat 3e cycle, University of Abidjan, Côte d'Ivoire; Plant Genetics; M.P. Jones; *Determining the ecosystems that promote anther culturability in various rice varieties*

Anne-Marie Ouassa — PhD, National University of Côte d'Ivoire; Medical Entomology; E.A. Heinrichs and T. Teuscher; *The impact of different agricultural systems and methods of larval control on the production of* Anopheles gambiae *larvae in irrigated rice*

N'Guessan Placide — PhD, University of Montpellier, France; Pathology; A.A. Sy; *The epidemiology and variability of the rice yellow mottle virus*

Jean-Philippe Tré — Purdue University, USA; Economics; A. Adesina; *The rates of return to mangrove rice research in Sierra Leone*

Ghana

J.V.K. Afun — PhD, Wye College, University of London, UK; Crop Protection; D.E. Johnson; *Weeds and weed management in the natural control of upland rice insect pests in Côte d'Ivoire*

L.T. Narteh — PhD, University of Ghana, Legon, Ghana; Soil Science; K.L. Sahrawat; *Iron toxicity in West African soils: the role of other nutrients*

Joseph Owusu Nipah — M.Phil., UST, Kumasi, Ghana; Plant breeding; M.P. Jones and B.N. Singh; *Varietal screening and genetic analysis for iron toxicity tolerance in rice*

Nigeria

M.E. Abo — PhD, Ahmadu Bello University, Zaria, Nigeria; Pathology; A.A. Sy; *The transmission of rice yellow mottle virus*

A.O. Joda — PhD, University of Ibadan, Nigeria; Entomology; B.N. Singh; *The bio-ecology and control of* Aspavia armigera *on rice in Nigeria*

Adesola O. Olaleye — PhD, University of Ibadan, Nigeria; Agronomy; B.N. Singh; *Suitability evaluation, characterization and rice yields in selected iron toxic soils of Nigeria*

Adebayo Amos Omoloye — PhD, University of Ibadan, Nigeria; Entomology; B.N. Singh; *Mechanisms of resistance in rice cultivars to the African rice gall midge*

Senegal

Abdrahmane Diallo — PhD, University Cheikh Anta Diop de Dakar, Senegal; Anthropology; T.F. Randolph; *The role of women in irrigated rice production systems*

Sitapha Diatta — PhD, University Henri Poincaré Nancy I, France; Soil Science; K.L. Sahrawat; *Soil and hydrology in two topographical sequences in Côte d'Ivoire*

Togo

Bidjokazo Fofana — PhD, University of Giessen, Germany; Weed Science; D.E. Johnson; *Differential competitive ability of upland rice cultivars with weeds*

Other trainees and interns, 1995

Name; Institution; Discipline; and Supervisor(s)

Allarangaye Dastre — Agricultural Research and Technology Department, Chad; Weed Science; D.E. Johnson

Niamien Affoué Joëlle — Chamber of Commerce and Industry of Côte d'Ivoire; Computer Science; R. Guei

O. Kane — Ecole nationale des Cadres Ruraux de Bambey (ENCR), Senegal; Physiology; F. Asch

Doffonsou Richard — Ecole nationale supérieure de statistique et d'économie appliquée (ENSEA), Côte d'Ivoire; Statistics; A. Adam

Hervé Lohoues — Ecole nationale supérieure de statistique et d'économie appliquée (ENSEA), Côte d'Ivoire; Statistics/Economics; T.F. Randolph

Mamadou Ganame — Institut d'économie rurale (IER), Mali; Pathology; A.A. Sy

Menidiou Dolo — Institut d'économie rurale (IER), Mali; Pathology; A.A. Sy

Bouma Thio — Institut d'études et de recherches agricoles (INERA), Burkina Faso; Nematology; M. Dingkuhn and D. Coyne

Chano Mahamane Moussa — Institut national des recherches agronomiques du Niger (INRAN), Niger; Weed Science; D.E. Johnson

C. Allain — Institut Supérieure Technique d'Outre Mer (ISTOM), France; Economics; M.C.S. Wopereis and F. Belières

U. Boundil — Institut Supérieure Technique d'Outre Mer (ISTOM), France; Varietal Improvement; K. Miezan and M. Sié

Anne-Gaelle Mellouette — Institut Supérieure Technique d'Outre Mer (ISTOM), France; Physiology; M. Becker and A. Audebert

Guillame de Salvert — Institut Supérieure Technique d'Outre Mer (ISTOM), France; Agronomy; M. Becker

Lassina Ouatara — University of Abidjan, Côte d'Ivoire; Soil Science; K.L. Sahrawat

R. Samba — University Cheikh Anta Diop de Dakar, Senegal; Soil Science; K.L. Sahrawat

Cecilia Ortiz Vinueza — Utah State University, USA; Economics; T.F. Randolph

Jeroen Roovers — Wageningen Agricultural University, the Netherlands; Forestry; P.N. Windmeijer

Jacinta Vigelandzoon — Wageningen Agricultural University, the Netherlands; Agronomy; N. van de Giesen and M. Becker

Publications by WARDA staff and students in 1995

Adesina, A.A., and Baidu-Forson, J. 1995. Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso and Guinea, West Africa. *Agricultural Economics.* 13: 1-9.

Adesina, A.A., and Sirajo, S. 1995. Farmers' perceptions and adoption of new agricultural technology: analysis of modern mangrove rice varieties in Guinea-Bissau. *Quarterly Journal of International Agriculture.* Vol. 34: No. 4: 358-371.

Adesina, A.A., and Ouattara, A.D. 1995. Cropping patterns in the savanna of West Africa: risk programming analysis in Côte d'Ivoire. In: Kang, B.T., Akobundu, I.O., Manyong, V.M., Carsky, R.J., Sanginga, N., and Kueneman, E.A. (eds). *Moist savannas of Africa. Potentials and constraints for crop production. Proceedings of an IITA/FAO workshop.* International Institute of Tropical Agriculture, Ibadan, Nigeria. September 19-23, 1994. pp. 225-248.

Adesina, A.A., and Ouattara, A.D. 1995. Risks, rainfed rice technologies, and farm-level ex-ante adoption patterns in a marginal environment: Savanna agro-ecological zone of Côte d'Ivoire. In: *Fragile lives in fragile ecosystems. Proceedings of the International Rice Research Conference.* International Rice Research Institute, Manila, Philippines. February 13-17, 1995. ISBN 971-22-0073-6. pp. 111-125.

Afun, J.K., Heinrichs, E.A., Johnson, D.E., and Russell-Smith, A. 1995. The influence of weeds in the natural control of upland rice insects pests in Côte d'Ivoire. In: *Proceedings of the 1995 Brighton Crop Protection Conference — Weeds.* Brighton, UK pp. 181-186.

Asch, F., Doerffling, K., and Dingkuhn, M. 1995. Response of rice varieties to soil salinity and air humidity: a possible involvement of root-borne ABA. *Plant and Soil.* 177: 11-19.

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Becker, M., Ladha, J.K., and Ali, M. 1995. Green manure technology: potential, usage, and limitations. A case study for lowland rice. In: Ladha, J.K., and Peoples, M.B. (eds). *Management of biological nitrogen fixation for the development of more productive and sustainable agricultural systems.* Kluwer Academic Publishers, Dordrecht, the Netherlands. pp. 181-193.

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Abbreviations and acronyms

ADB	African Development Bank
ADRAO	Association pour le développement de la riziculture en Afrique de l'Ouest (WARDA's french acronym and name)
AET	actual evapotranspiration
ARGM	African rice gall midge
BMZ	Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung (German Federal Ministry for Economic Cooperation and Development)
CABI	Centre for Agriculture and Biosciences International (United Kingdom)
CFA franc	Communauté Financière Africaine franc, the currency used by Benin, Burkina Faso, Côte d'Ivoire, Mali, Niger, Senegal and Togo
CGIAR	Consultative Group on International Agricultural Research
CIDA	Canadian International Development Agency
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement (France)
CNRS	Centre national de recherche scientifique (France)
CORAF	Conférence des responsables de la recherche agronomique africaine
CRET	coordinated replicated evaluation trials
CTA	Technical Centre for Agricultural and Rural Cooperation (the Netherlands)
DANIDA	Danish International Development Agency
DAE	days after emergence
DAS	days after sowing
DAT	days after transplanting
DRC	Domestic Resource Cost
ECA	Economic Commission for Africa
ENSA	Ecole nationale supérieure d'agriculture (Côte d'Ivoire)
FAO	Food and Agriculture Organization of the United Nations
FCFA	CFA franc, see above
FFS	farmers' field school
GIS	geographic information systems
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (Germany)
ha	hectare
ICTG	Inter-Center Training Group (CGIAR)
IDESSA	Institut des savanes (Côte d'Ivoire)
IDRC	International Development Research Centre (Canada)
IIBC	International Institute for Biological Control (United Kingdom)
INGER	International Network for Genetic Evaluation of Rice
IPM	integrated pest management
ISRA	Institut sénégalais de recherches agricoles (Senegal)
IVC	Inland Valley Consortium
K	potassium
kg	kilogram
kg ha^{-1}	kilograms per hectare
LAI	leaf area index
M&M	materials and method (of experiments)
MET	maximum evapotranspiration
Mg	megagram
mmol	millimole
N	nitrogen
NARS	national agricultural research systems
NDVI	normalized difference vegetation index
NPC	Nominal Protection Coefficient
N-P-K	nitrogen-phosphorus-potassium

NRI	Natural Resources Institute (United Kingdom)
ODA	Overseas Development Administration (United Kingdom)
ORSTOM	Institut français de recherche scientifique pour le développement en coopération (France)
P	phosphorus
PAM	Policy Analysis Matrix
PET	potential evapotranspiration
RADORT	Research on Accelerated Diffusion of Rice Technology project
RYMV	rice yellow mottle virus
SAED	Société nationale d'aménagement et d'exploitation des terres du delta du fleuve Sénégal et des vallées du fleuve Sénégal et de la Falémé
SC-DLO	Winand-Staring Centre for Integrated Land, Soil and Water Resources (the Netherlands)
SLA	specific leaf area
t	metric ton
$t\ ha^{-1}$	(metric) tons per hectare
TOT	training of trainers
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
WARIS	West Africa Rice Information System
WAU	Wageningen Agricultural University (the Netherlands)

About the Consultative Group on International Agricultural Research (CGIAR)

The CGIAR is a voluntary consortium of some 45 public and private sector donors that provides funding for 16 international agricultural research centers, including WARDA. Scientists at these centers conduct research with the aim of contributing to the alleviation of poverty and hunger in developing countries in ways that protect and enhance the environment.

Founded in 1971, the CGIAR is cosponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP) and the World Bank. However, the CGIAR remains an informal association based on consultation and consensus, guided by the highest quality independent scientific advice.

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Through international research and related activities, and in partnership with national research systems, to contribute to sustainable improvements in the productivity of agriculture, forestry, and fisheries in developing countries in ways that enhance nutrition and well-being, especially among low-income people.

CGIAR Centers

CIAT	Centro Internacional de Agricultura Tropical
CIFOR	Center for International Forestry Research
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo
CIP	Centro Internacional de la Papa
ICARDA	International Center for Agricultural Research in the Dry Areas
ICLARM	International Center for Living Aquatic Resources Management
ICRAF	International Centre for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IIMI	International Irrigation Management Institute
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IPGRI	International Plant Genetic Resources Institute
IRRI	International Rice Research Institute
ISNAR	International Service for National Agricultural Research
WARDA	West Africa Rice Development Association

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About the West Africa Rice Development Association (WARDA)

The West Africa Rice Development Association is an autonomous intergovernmental research association with a mission to strengthen West Africa's capability in rice production science, technology and socio-economics through research, training and communications activities.

In collaboration with the national agricultural research systems of member states, academic institutions, international donors and other organizations, the work of WARDA ultimately benefits West African farmers — mostly small-scale producers — who cultivate rice, as well as the millions of African families who eat rice as a staple food.

WARDA was formed in 1971 by 11 countries with the assistance of the United Nations Development Programme (UNDP), the Food and Agriculture Organization of the United Nations (FAO) and the Economic Commission for Africa (ECA). It now comprises 17 member states: Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, the Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo.

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